NONRESIDENT
TRAINING
COURSE

Engineman 3rd Class

NAVEDTRA 14331

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PREFACE

By enrolling in this self-study course, you have demonstrated a desire to improve yourself and the Navy. Remember, however, this self-study course is only one part of the total Navy training program. Practical experience, schools, selected reading, and your desire to succeed are also necessary to successfully round out a fully meaningful training program.

COURSE OVERVIEW: In completing this nonresident training course, you will demonstrate a knowledge of the subject matter by correctly answering questions on the following: the construction, design, principles of operation, and basic maintenance of diesel engines, reduction gears, and related auxiliary equipment and support systems; the design, construction, principles of operation, application, and basic maintenance of mechanical components such as pumps, valves, and control devices; the design, principles of operation, and basic maintenance of marine auxiliary equipment, specifically compressed air systems, distilling plants, evaporators, refrigeration and air-conditioning systems, deck machinery, steering gear, and laundry and galley equipment.

THE COURSE: This self-study course is organized into subject matter areas, each containing learning objectives to help you determine what you should learn along with text and illustrations to help you understand the information. The subject matter reflects day-to-day requirements and experiences of personnel in the rating or skill area. It also reflects guidance provided by Enlisted Community Managers (ECMs) and other senior personnel, technical references, instructions, etc., and the occupational standards, which are listed in the *Manual of Navy Enlisted Manpower Personnel Classifications and Occupational Standards*, NAVPERS 18068 found on line at https://buperscd.technology.navy.mil/bup_updt/upd_CD/BUPERS/enlistedManOpen.htm.

VALUE: In completing this course, you will improve your military and professional knowledge. Importantly, it can also help you study for the Navy-wide advancement in rate examination. If you are studying and discover a reference in the text to another publication for further information, look it up.

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CHAPTER 1

INTRODUCTION TO THE ENGINEMAN RATING

This nonresident training course is designed to help you increase your knowledge in the various aspects of the Engineman rating and to help you advance in rating to EN3. Your contribution to the Navy depends on your willingness and ability to accept increasing responsibilities as you advance in rate. When you assume the duties of an Engineman, you begin to accept certain responsibilities for the work of others. As you advance in your career, you will accept responsibilities in military matters as well as in the occupational requirements of the Engineman rating.

ENGINEMAN RATING

The Engineman rating is a general rating; that is, it covers a broad occupational field of related duties and functions.

Enginemen are assigned to all types of ships. On diesel engine propelled ships, most Enginemen are assigned to M division, where they operate and maintain ship propulsion machinery and associated equipment such as pumps, distilling plants, compressors, valves, oil purifiers, heat exchangers, governors, reduction gears, shafts, and shaft bearings.

Enginemen on ships propelled by gas turbines or steam machinery are usually assigned to A division, where they maintain and repair machinery such as steering engines, anchor windlasses, cranes, winches, elevators, laundry equipment, galley equipment, and air-conditioning and refrigeration equipment.

The nature of an Engineman's duties depends largely on the type of ship or station to which the Engineman is assigned. Repair ships and tenders furnish other ships with spare parts, repairs, and other services that are beyond the facilities of the ship's crew. The duties of an Engineman assigned to a repair ship or tender may consist mainly of repairs and other services to ships assigned to the tender or repair ship.

This manual is organized to give you a systematic understanding of your job. The occupational standards used in preparing the text are contained in the *Manual of Navy Enlisted Manpower and Personnel Classifications and Occupational Standards,* NAVPERS 18068 can be found on line at https://buperscd.technology.navy.mil/bup_updt/upd_CD/BUPERS/enlistedmanopen.htm. We recommend that you study the Engineman section of NAVPERS 18068 to gain an understanding of the skills required of an Engineman. Then, study the subject matter in this nonresident training course very carefully. The knowledge you gain will enable you to become a more proficient operator and mechanic, and the Navy will profit from your skills.

As you advance to EN3, your responsibilities for military leadership will be the same as those of petty officers in other ratings, since every petty officer has military as well as technical duties. Your responsibilities for technical leadership will be unique to your rating and directly related to your work as an Engineman. Operating and maintaining a ship's engineering plant and associated equipment requires teamwork along with a special kind of leadership that can be developed only by personnel who have a high degree of technical competence and a deep sense of personal responsibility. You should strive to improve your leadership and technical knowledge through study, observation, and practical application.

Leadership in a technical field involves more than just giving orders. In fact, you can demonstrate some of the most important aspects of technical leadership even if you are not required to tell anyone else what to do. As an EN3, you demonstrate technical leadership when you follow orders exactly, when you observe safety precautions, when you accept responsibility, when you continue to increase your knowledge, and when you perform every detail of your work with integrity and reliability.

Integrity of work is really a key factor in technical leadership, and all other factors relate to it in some way. Integrity of work is demonstrated in big ways and little ways—the way you stand a messenger watch, the way you maintain your tools and equipment, the way you deal with machinery failures and casualties, and the way you wipe up deck plates. When you perform every job just as well as you can, and when you constantly work to increase your knowledge, you demonstrate integrity of work in a concrete, practical, everyday sort of way. When your work has integrity, you are demonstrating technical leadership.

NAVY ENLISTED CLASSIFICATION CODES

The Engineman rating is a source of a number of Navy enlisted classification (NEC) codes. The NECs reflect special knowledges and skills in certain ratings. The NEC coding system is a form of management control over enlisted skills. It identifies skills and training required for specific types of operations or equipment. The Chief of Naval Personnel details skilled personnel to those ships that require these skills. There are a number of NECs that you may earn at certain grade levels by satisfactorily completing an applicable course of instruction at a Navy school. Your personnel office will have complete information on NECs and qualification procedures. The *Manual of Navy Enlisted Manpower and Personnel Classifications and Occupational Standards,* NAVPERS 18068 can be seen on line at https://buperscd.technology.navy.mil/bup_updt/upd_CD/BUPERS/enlistedmanopen.htm.

STANDARDS

The Navy has established certain standards to help you obtain the best results from your training program. These standards provide a step-by-step procedure for you to follow in order to gain the maximum knowledge available as you progress in your rating.

OCCUPATIONAL STANDARDS

Occupational standards are the minimum task requirements that are directly related to the work of each rating, and they are divided into subject matter groups.

In the *Manual of Navy Enlisted Manpower and Personnel Classifications and Occupational Standards,* NAVPERS 18068, Section I contains the occupational standards for advancement to each paygrade in each enlisted rating. Section 11 contains the NECs.

The occupational standards addressed in this NRTC were those included in NAVPERS 18068E and were the current occupational standards for EN3 at the time of the writing of this manual. These standards are covered in the information in this text; however, the text may not be considered current in areas that may be affected by later changes in the occupational standards. Your educational services officer should have a current edition of the occupational standards that apply to your rating at this time, or the current version can be found on line.

PERSONNEL QUALIFICATION STANDARDS (PQSs)

A Personnel Qualification Standard (PQS) is a written list of knowledges and skills. These skills are required for you to qualify for a specific equipment or system, or to perform as a team member within an assigned unit. The PQS program is a method for qualifying you to perform your assigned duties.

PQS listings can be found at the PQS Development Group Web Site at https://wwwcfs.cnet.navy.mil/pqs.

Personnel Qualifications Standards are divided into four sections: Theory, Systems, Watchstations, and a Qualification Card. The Theory section contains the facts, principles, and fundamentals concerning the subject for which you are qualifying. The Systems section deals with the major working parts of the installation, with the organization, or with the equipment with which the PQS is concerned. The Watchstation section defines the actual duties, assignments, and responsibilities you must perform to obtain your qualification. Finally, the Qualification Card contains questions that match those in the Watchstation section and provides a space for your supervisor's or qualifying officer's signature to show that you have met these qualifications.

If you have any questions regarding PQS in general or specifically, see your supervisor or training petty officer.

SOURCES OF INFORMATION

One of the most useful things you can learn about a subject is how to find out more about it. No single publication can give you all the information you will need to perform the duties of your rating. You should learn where to look for accurate, authoritative, up-to-date information on all subjects related to the naval requirements for advancement and the occupational standards of your rating.

In this section, we will discuss most of the publications you will use for detailed information, for advancement, and for everyday work. Some are changed or revised from time to time, so meat regular intervals, others as the need arises. Be sure that you have the latest edition. Check on line for publications available there. When using any publication that is kept current by means of changes, be sure you have a copy

in which all official changes have been made. Canceled or obsolete information will not help you do your work or advance in rate. At best, it is a waste of time; at worst, it is likely to be dangerously misleading.

NAVEDTRA PUBLICATIONS

The Naval Education and Training Command and its field activities come directly under the command of the Commander, Naval Education and Training Command. Training materials published by the Naval Education and Training Command are designated as NAVEDTRA. NAVTRA and NAVPERS designators on publications will remain as originally assigned. The designators of publications printed hereafter will be changed to NAVEDTRA as each publication is revised.

The naval training publications described here include some that are absolutely essential for anyone seeking advancement and some that are not essential, but extremely helpful.

Bibliography for Advancement Study

Bibliography for Advancement Study (Bibs), (https://www.advancement.cnet.navy.mil) lists recommended nonresident training courses and other reference materials that should be used by enlisted personnel who are working toward advancement.

Bibliography for Advancement Study is revised and maintained by the Naval Education and Training Professional Development and Technology Center (NETPDTC).

The recommended references are listed by exam date and paygrade in *Bibliography for Advancement Study.* Since you are working for advancement to third class, study the material that is listed for third class.

Besides nonresident training courses, the *Bibliography for Advancement Study* lists official publications on which you may be examined. You should not only study the sections required, but also become as familiar as possible with all publications you use.

Advancement Handbook

The purpose of the Advancement Handbook is to help you focus your preparation for the Navywide advancement-in-rating examinations. The Bibs together with the handbook form a comprehensive examination study package. The EN handbook provides skill and knowledge components for each paygrade of the EN rating, so working with Part 1, for EN3, will help you concentrate your study on those areas that may be tested. This will help you get the most out of your study time.

The Advancement Handbook may be found on line at https://www.advancement.cnet.navy.mil.

Nonresident Training Courses (NRTCs)

There are two general types of NRTCs: RATING manuals (such as this one) are prepared for most enlisted ratings. A rating manual gives information that is directly related to the occupational standards on one rating; SUBJECT MATTER manuals or BASIC manuals give information that applies to more than one rating. (Example: *Tools and Their Uses,* NAVEDTRA 14256.)

NRTCs have major revisions from time to time to keep them up to date technically, and as they are printed on demand and available in CD and on line, minor revisions and corrections are made constantly.

Each time an NRTC is revised, it is brought into conformance with the official publications and directives on which it is based. However, during the life of any edition of an NRTC, changes will be made to the official sources, and discrepancies will arise. You should always refer to the appropriate official publication or directive.

NRTCs are designed to help you prepare for advancement. The following suggestions may help you make the best use of this manual and other Navy training publications when you prepare for advancement.

1. Study the occupational standards for your rating before you study the training manual, and refer to the standards frequently as you study. Remember, you are studying the manual primarily to meet these standards.
2. Set up a regular study plan. It will probably be easier for you to stick to a schedule if you can study at the same time each day. Try to schedule your studying for a time of day when you will not have too many interruptions or distractions.
3. Before you study any part of the manual intensively, become familiar with the entire book. Read the preface and the table of contents. Check through the index. Thumb through the book without any particular plan. Look at the illustrations and read bits here and there as you see things that interest you. Review the glossary,

which provides definitions that apply to words or terms as they are used within the engineering field and within the text. There are many words with more than one meaning. Do not assume that you know the meaning of a word. Look it up in the glossary.

4. Look at the NRTC in more detail to see how it is organized. Look at the table of contents again. Then, chapter-by-chapter, read the introduction, the headings, and the subheadings. This will give you a pretty clear picture of the scope and content of the book. As you look through the book, ask yourself some questions:

   What do I need to learn about this?

   What do I already know about this?

   How is this information related to information given in other chapters?

   How is this information related to the occupational standards?

5. When you have a general idea of what is in the NRTC and how it is organized, fill in the details by intensive study. Try to cover a complete unit in each study period—it may be a chapter, a section of a chapter, or a subsection. The amount of material that you can cover at one time will depend on how well you know the subject.

6. In studying any one unit—chapter, section, or subsection—write down questions as they occur to you. You may find it helpful to make a written outline of the unit, or, at least, to write down the most important ideas.

7. As you study, relate the information in the NRTC to the knowledge you already have. When you read about a process, a skill, or a situation, try to see how this information ties in with your own past experience.

8. When you have finished studying a unit, take time out to see what you have learned. Look back over your notes and questions. Maybe some of your questions have been answered, but perhaps you still have some that are not answered. Without looking at the NRTC, write down the main ideas that you have gotten from studying this unit. Do not just quote the book. If you cannot give these ideas in your own words, the chances are that you have not really mastered the information.

9. Think of your future as you study NRTCs. You are working for advancement to third class right now, but you will soon be working toward higher rates. Anything extra that you can learn now will also help you later.

NAVSEA PUBLICATIONS

The publications issued by the Naval Sea Systems Command are of particular importance to engineering department personnel. Although you do not need to know everything in these publications, you should have a general idea of where to find the information in them.

Naval Ships' Technical Manual

The *Naval Ships' Technical Manual* is the basic engineering doctrine publication of the Naval Sea Systems Command. The manual is kept up to date by means of quarterly changes. As new chapters are issued, they are designated by a new chapter numbering system.

The following chapters of the *Naval Ships' Technical Manual* are of particular importance to the Engineman. For your convenience, both the new and old numbers for each chapter are listed.

NEW	OLD	CHAPTER
078	(9950)	Gaskets and Packing
079 (3)	(9880, Sec. III)	Engineering Casualty Control
080	(9001	Publications and Drawings
220	(9560, Vol. I)	Boiler Water/Feedwater
220	(9560, Vol. II)	Water Chemistry Test and Treatment
233	(9412)	Diesel Engines
241	(9420)	Reduction Gears
244	(943 1)	Bearings
262	(9450)	Lubricating Oils, Greases, and Hydraulic Fluids and Lubricating Systems
503	(9470)	Pumps
505	(9480)	Piping Systems
510	(9380)	Ventilating Heating, and Air Conditioning
516	(9590)	Refrigeration Systems
531	(9580)	Distilling Plants
541	(9550)	Fuel Oil Stowage and Equipment
551	(9490)	Compressed Air Plants
556	((210)	Hydraulic Equipment
562	(9220)	Surface Ship Steering Systems
593	(None)	Pollution Control

Deckplate

The *Deckplate* is a monthly publication that contains interesting and useful articles on all aspects of shipboard engineering. This magazine is particularly useful because it presents information that supplements and clarifies information contained in the *Naval Ships' Technical Manual.* It also presents information on new developments in naval engineering.

Manufacturers' Technical Manuals

The manufacturers' technical manuals furnished with most machinery units and many items of equipment are valuable sources of information on construction, operation, maintenance, and repair. The manufacturers' technical manuals that are furnished with most shipboard engineering equipment are given NAVSEA numbers.

Drawings

As an Engineman, you will read and work from mechanical drawings. You will find information on how to read and interpret drawings in *Blueprint Reading and Sketching,* NAVEDTRA 14040.

You must also know how to locate applicable drawings. For some purposes, the drawings included in the manufacturers' technical manuals for the machinery or equipment may give you the information you need. In many cases, however, you will find it necessary to consult the onboard drawings. These are sometimes referred to as ship's plans or ship's blueprints, and they are listed in an index called the ship's drawing index (SDI). The SDI lists all working drawings that have a NAVSEA drawing number, all manufacturers' drawings designated as certification data sheets, equipment drawing lists, and assembly drawings that list detail drawings.

For detailed information on drawings, and procedures for locating drawings, refer to *Naval Ships' Technical Manual,* chapter 080, Publications and Drawings.

SHIPS' MAINTENANCE AND MATERIAL MANAGEMENT (3-M) SYSTEMS

The primary objective of the Ship's 3-M Systems is to manage maintenance and maintenance support in a way that will ensure maximum equipment operational readiness. There are basically two systems that make up the 3-M Systems. They are the Planned Maintenance System (PMS) and the Maintenance Data System (MDS). We will discuss both of these systems in the next few sections of this chapter.

PLANNED MAINTENANCE SYSTEM (PMS)

The Planned Maintenance System (PMS) is an overall management tool that provides a simple and efficient way in which basic maintenance on all equipment can be planned, scheduled, controlled, and performed. The information in this section is intended to provide you with an overview in terms of the purposes, benefits, and limitations of the PMS.

Purposes of PMS

The PMS was established for several purposes:

1. To reduce complex maintenance to simplified procedures that are easily identified and managed at all levels
2. To define the minimum planned maintenance required to schedule and control PMS performances
3. To describe the methods and tools to be used
4. To provide for the detection and prevention of impending casualties
5. To forecast and plan manpower and material requirements
6. To plan and schedule maintenance tasks
7. To estimate and evaluate material readiness
8. To detect areas requiring additional or improved personnel training and improved maintenance techniques or attention
9. To provide increased readiness of the ship

Benefits of PMS

As mentioned before, the Planned Maintenance System is a management tool. By using PMS, the commanding officer can readily determine whether his ship is being properly maintained. Reliability is intensified. Preventive maintenance reduces the need for major corrective maintenance, increases economy, and saves the cost of repairs.

The Planned Maintenance System assures better records since it provides additional useful data to the

shipboard maintenance manager. The flexibility of the system allows for the programming of inevitable changes in employment schedules. This advantage helps the shipboard maintenance manager plan preventive maintenance more effectively.

Better leadership and management can be realized if a manager can reduce frustrating breakdowns and irregular hours of work. Consequently, PMS offers a means of improving morale and thus enhances the effectiveness of all hands.

Limitations of PMS

The PMS is not self-starting. It does not automatically produce good results; considerable professional guidance is required. Continuous direction at each level must be maintained. One individual must be assigned both the authority and the responsibility at each level of the system's operation.

Training in the maintenance steps as well asin the system is necessary. No system is a substitute for the actual, technical ability required of the petty officers who direct and perform the upkeep of the equipment.

MAINTENANCE DATA SYSTEM (MDS)

The Maintenance Data System (MDS) is exactly what it implies. The system works to collect maintenance data and to store it for future use. From the MDS comes the current ship's maintenance project (CSMP), automated work request, pre-INSURV deficiency, and a means for the fleet to report configuration changes to equipment.

As a third class petty officer, you will be required to learn how to prepare various MDS forms. In the following sections of this chapter, we will discuss two of the MDS reports with which you will come into contact. These reports are (1) the Ship's Maintenance Action Form (OPNAV 4790/2K), and (2) the Current Ship's Maintenance Project.

Ship's Maintenance Action Form

The Ship's Maintenance Action Form, OPNAV 4790/2K, is used by maintenance personnel to report deferred maintenance actions and completed maintenance actions (including those previously deferred). This form also allows the entry of screening and planning information for management and control of intermediate maintenance activity workloads.

The OPNAV 4790/2K is originated in the work center. It is screened by the division officer and engineer officer for accuracy and legibility. It is then initialed by the division officer and engineer officer before being forwarded to the3-M coordinator. When the form is used to defer maintenance, the 3-M coordinator will send two copies of it back to the originating work center to hold on file. When the deferred maintenance is completed, one of the copies is used to document the completion of the maintenance.

Current Ship's Maintenance Project

The standard CSMP is a computer-produced report. It lists deferred maintenance and alterations which have been identified through Maintenance Data Collection System (MDCS) reporting. Copies of the CSMP should be received monthly. The engineer officer gets a copy for each of the engineering department work centers. Each work center gets a copy with its own deferred maintenance only.

The purpose of the CSMP is to provide shipboard maintenance managers with a consolidated listing of deferred corrective maintenance so they can manage and control its accomplishment. The work center supervisor is responsible for ensuring the CSMP accurately describes the material condition of his work center.

Each month when a new CSMP is received, verified, and updated, the old CSMP may be destroyed.

The current Ships' *Maintenance and Material Management (3-M) Manual,* OPNAVINST 4790.4, contains complete instructions and procedures for the completion and routing of all 3-M Systems forms.

HEALTH PROGRAMS

There are two health programs with which you will be directly involved in day-to-day operations in the engine room: heat stress and hearing conservation.

HEAT STRESS

Heat stress is caused by high heat and humidity. This can be controlled somewhat by ensuring that all lagging and insulation is in its proper place, that steam and hot water leaks are corrected as soon as possible, and that all the ventilation systems are operating as designed. There are other measures that you can take to help reduce heat stress. You can ensure that readings are taken and recorded at each watch or work station every hour and at any other time that the temperature

exceeds 100°F dry-bulb temperature. You can ensure that they are reported to the engineering officer of the watch (EOOW) so that a heat survey can be conducted and corrective action can be taken.

HEARING CONSERVATION

The loud, high-pitched noise produced by an operating propulsion plant can cause hearing loss. A hearing loss can seldom be restored. For this reason, ear protection must be worn in all areas where the sound level is 84 dB or greater. In these places, warning signs must be posted cautioning about noise hazards that may cause loss of hearing.

For further information on health programs, refer to the *Naval Occupational Safety and Health Program Manual,* OPNAVINST 5100.19.

SUMMARY

In this chapter, we have discussed the Engineman rating and the different methods you can use to obtain the knowledge you must have to perform your job aboard ship. Remember, information is usually available when you need it. You just have to know where to look. This chapter will, we hope, serve as a guide to help you locate and use the information that you will require.

CHAPTER 2

RECIPROCATING INTERNAL-COMBUSTION ENGINE

The engines with which you will be working will convert heat energy into work by burning fuel in a confined chamber within the engine; thus the term INTERNAL COMBUSTION. Because they have pistons that employ a back-and-forth motion, diesel and gasoline engines are also classified as RECIPROCATING engines. The occupational standards for advancement in the Engineman rating require you to know a great deal about reciprocating internal-combustion engines. Some of the required knowledge has been introduced and explained in the training manual, *Fireman,* NAVEDTRA 14104. This chapter provides additional information to help you to understand the differences between the various types of engines and the principles by which an internal-combustion engine operates.

CYCLES OF OPERATION

The operation of an internal-combustion engine involves the admission of fuel and air into a combustion space and the compression and ignition of the charge. The combustion process releases gases and increases the temperature within the space. As temperature increases, pressure increases, and the expansion of gases forces the piston to move. The movement is transmitted through specially designed parts to a shaft. The resulting rotary motion of the shaft is used for work. Thus, the expansion of the gases within the cylinder is transformed into rotary mechanical energy. In order for the process to be continuous, the expanded gases must be removed from the combustion space, a new charge must be admitted, and combustion must be repeated.

In the process of engine operation, beginning with the admission of air and fuel and following through to the removal of the expanded gases, a series of events or phases takes place. The term *cycle* identifies the sequence of events that takes place in the cylinder of an engine for each power impulse transmitted to the crankshaft. These events always occur in the same order each time the cycle is repeated. The number of events occurring in a cycle of operation depends upon whether the engine is diesel or gasoline. Table 2-1 shows the events and their sequence in one cycle of operation of each of these types of engines.

The principal difference, as shown in the table, in the cycles of operation for diesel and gasoline engines involves the admission of fuel and air to the cylinder. While this takes place as one event in a gasoline engine, it involves two events in a diesel engine. Consequently, there are six main events that take place in the cycle of operation of the diesel engine and five main events that take place in the cycle of the gasoline engine. The number of events that take place is NOT identical to the number of piston strokes that occur during a cycle of operation. Even though the events of a cycle are closely related to piston position and movement, ALL of the events will take place during a cycle regardless of the number of piston strokes involved. We will discuss the

Table 2-1.—Sequence of Events in a Cycle of Operation in a Diesel and Gasoline Engine

DIESEL ENGINE	GASOLINE ENGINE
Intake of air.	Intake of fuel and air
Compression of air . . .	Compression of fuel-air mixture
Injection of fuel	
Ignition and combustion of charge	Ignition and combustion of charge
Expansion of gases . . .	Expansion of gases
Removal of waste . . .	Removal of waste

relationship of events and piston strokes later in this chapter.

A cycle of operation in either a diesel or gasoline engine involves two basic factors—heat and mechanics. The means by which heat energy is transformed into mechanical energy involves many terms such as matter, molecules, energy,heat, temperature, the mechanical equivalent of heat, force, pressure, volume, work, and power. (If you need to review these terms, see the appropriate sections in *Fireman,* NAVEDTRA 14104.)

The method by which an engine operates is referred to as the MECHANICAL, or operating, CYCLE of an engine. The heat process that produces the forces that move engine parts is referred to as the COMBUSTION CYCLE. Both mechanical and combustion cycles are included in a cycle of operation of an engine.

MECHANICAL CYCLES

We have talked about the events taking place in a cycle of engine operation, but we have said very little about piston strokes except that a complete sequence of events will occur during a cycle regardless of the number of strokes made by the piston. The number of piston strokes occurring during any one cycle of events is limited to either two or four, depending on the design of the engine. Thus, we have a 4-stroke cycle and a 2-stroke cycle. These cycles are known as the mechanical cycles of operation.

From your study of *Fireman,* NAVEDTRA 14104, you should recall that the terms *4-stroke* and *2-stroke* identify the number of strokes the piston makes during a cycle of events. You should also recall that both types of mechanical cycles, 4-stroke and 2-stroke, are used in both diesel and gasoline reciprocating engines. Most gasoline engines in Navy service operate on the 4-stroke cycle. Most diesels operate on the 2-stroke cycle. You may be required to operate and maintain engines that operate on either of these mechanical cycles. Therefore, you should be familiar with the principal differences in these cycles. The relationship between the events and piston strokes occurring in a cycle of operation involves some of these differences. A thorough understanding of the relationship will aid you in carrying out your duties in connection with engine operation and maintenance.

Relationship of Events and Strokes in a Cycle

A piston stroke is the distance a piston moves between limits of travel. The cycle of operation in an engine that operates on the 4-stroke cycle involves four piston strokes—INTAKE, COMPRESSION, POWER, and EXHAUST. In the 2-stroke cycle, only two strokes are involved—POWER and COMPRESSION. The strokes are named to correspond with the events. However, since six events are listed for diesel engines, more than one event must take place during some of the strokes, especially in the 2-stroke cycle. Even so, it is common practice to identify some of the events as strokes of the piston. This is because such events as intake, compression, power, and exhaust in a 4-stroke cycle involve at least a major portion of a stroke and, in some cases, more than one stroke. The same is true of power and compression events and strokes in a 2-stroke cycle. In associating the events with strokes, you should not overlook other events taking place during a cycle of operation. You will have to consider all events in the operation of an engine when you begin to deal with maintenance problems involving the timing of fuel injection systems.

4-Stroke Cycle Diesel Engine

To help you understand the relationship between events and strokes, we will discuss the number of events that occur during a specific stroke. We will also discuss the duration of an event with respect to a piston stroke and the cases where one event overlaps another. We can demonstrate the relationship of events to strokes by showing the changing situation in a cylinder during a cycle of operation. Figure 2-1 illustrates these changes for a 4-stroke cycle diesel engine.

The relationship of events to strokes is more readily understood if the movements of a piston and its crankshaft are considered first. In figure 2-1, each view showing piston travel is reflected on the graph and illustrates the approximate piston position and valve action. Top center and bottom center identify points where changes in direction of motion take place. In other words, when the piston is at top center, upward motion has stopped and downward motion is ready to begin. With respect to motion, the piston is "dead." Likewise, when the piston is at bottom center, downward motion has stopped

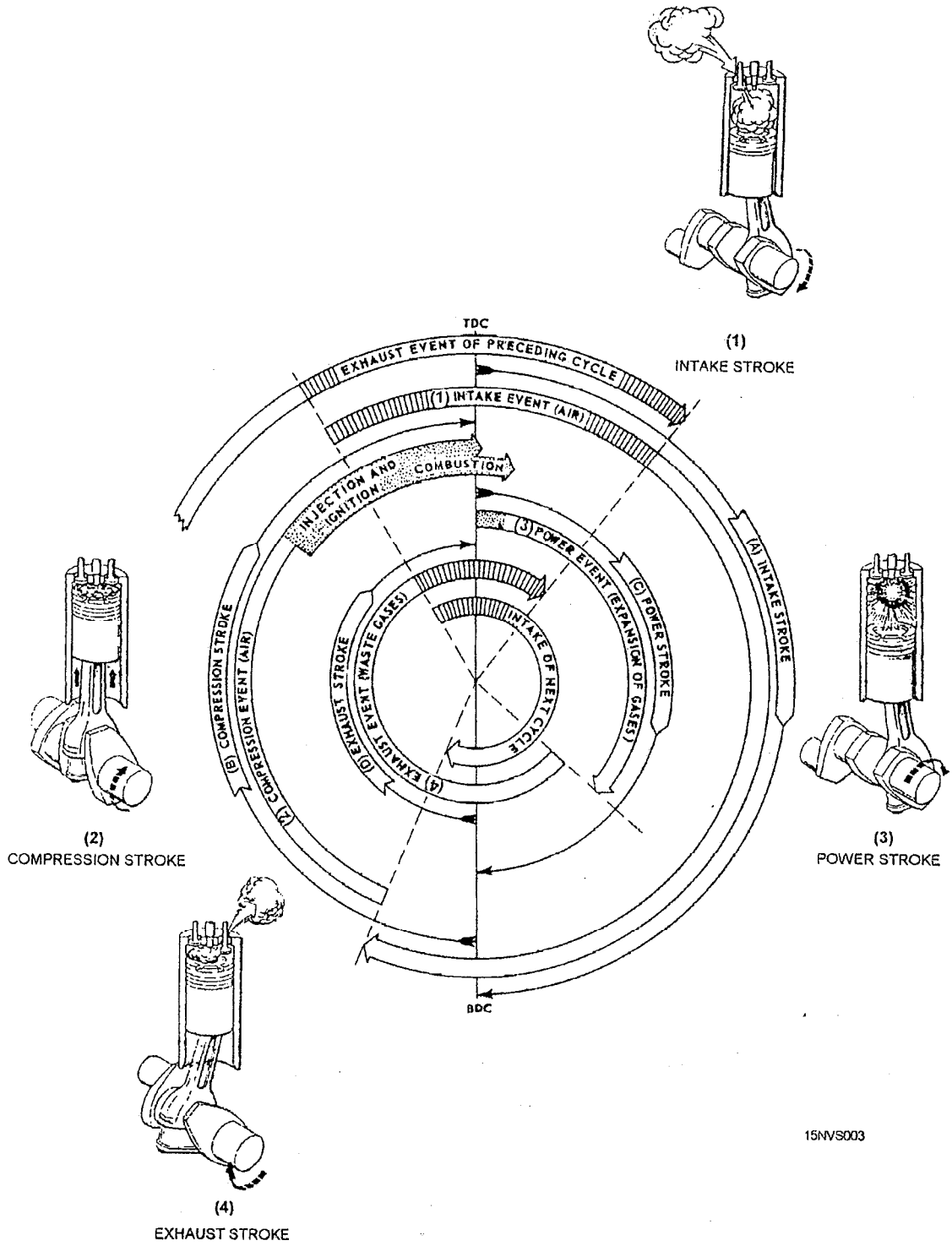


Figure 2-1.—Strokes and events in a 4-stroke cycle diesel engine.

and upward motion is ready to begin and the piston is said to be at bottom "dead" center. The points which designate changes in direction of motion for a piston and crank are frequently called TOP DEAD CENTER (TDC) and BOTTOM DEAD CENTER (BDC). You should keep TDC and BDC in mind since they identify the start and end of a STROKE (180 degrees of crankshaft rotation) and since they are the points from which the start and end of EVENTS are established.

Let's pick up the action of the piston of a 4-stroke cycle engine as it moves up the cylinder towards TDC. Refer to figure 2-1 and locate the top arrow labeled EXHAUST EVENT OF PRECEDING CYCLE. This arrow indicates that the exhaust valve or valves at the top of the cylinder are open as the piston reaches TDC. And, several degrees after TDC, the dashed line indicates that the exhaust valves are closed. Now, locate the arrow labeled INTAKE EVENT (AIR). Notice that this arrow starts at the same point in the cycle as the exhaust event for the preceding cycle. The shaded parts of the two top arrows indicate that during this part of the cycle, both the intake and exhaust valves will be open. This is necessary because the incoming air must be allowed to flow through the cylinder to "sweep out" or scavenge any exhaust gases remaining from the preceding combustion event. The remainder of the arrow labeled INTAKE EVENT (AIR) shows that the intake valves remain open as the piston moves toward BDC and slightly past BDC. The dashed line just past BDC indicates when the intake valves are closed, and the compression stroke begins. Now, the piston continues moving up to compress the air trapped in the cylinder, because during this event, both the intake and exhaust valves are closed. The action of the pistons in compressing the air rapidly increases the pressure within the cylinder. This action, in turn, results in a rapid increase in temperature. The increase in temperature occurs because the molecules of air are being squeezed into a smaller and smaller space. Just before the piston reaches TDC, fuel is injected into the cylinder as a spray of finely atomized droplets (very tiny drops). As some of the molecules of the hydrocarbon fuel come into contact with hot molecules of oxygen, the combustion process begins. The rapid burning of the fuel as it mixes with the oxygen results in a drastic increase in temperature and pressure as the gases released by the combustion process expand. Since the piston is free to move, the rapidly expanding gases force the piston to begin its downward stroke, which is indicated by the arrow labeled POWER EVENT (EXPANSION OF GASES). The power stroke continues to the point indicated by the dashed line, at which time the exhaust valves open. The arrow labeled EXHAUST EVENT (WASTE GASES) shows that the exhaust valves are open as the piston moves towards BDC . . . past BDC . . . and up towards TDC, at which point the cycle of events repeats.

In summary, during the 4-stroke cycle, the piston moves up and down within the cylinder, and the crankshaft makes two complete revolutions, for a total travel of 720 degrees. In other words, 4-stroke cycle engines have only one power event per cylinder during 720 degrees of crankshaft rotation.

2-Stroke Cycle Diesel Engine

Now let's analyze the sequence of events for a 2-stroke cycle engine. Refer to Figure 2-2. First of all, you should be aware of one you should be aware of one of the primary physical differences between 4-stroke and 2-stroke cycle engines: 2-stroke engines do *not* use intake valves. To work properly, a 2-stroke engine must have some means of forcing air into the cylinder for the scavenging event. Two-stroke diesel engines may use an external blower or turbocharger (or both) to perform this function. Finally, notice the location of the ports in the cylinder through which air must flow. They are located near the *bottom* of the cylinder.

Now, let's take a look at the 2-stroke cycle of events. Locate the engine labeled SCAVENGING (view 1 and the corresponding arrow in the circle). The scavenging event (which is very similar to the air intake event of a 4-stroke cycle engine) begins almost 45 degrees BEFORE the piston reaches BDC. During this time, the exhaust valve or valves are open. As the piston moves down to BDC, it uncovers the ports near the bottom of the cylinder. (This arrangement serves the same function as the intake valves in a 4-stroke cycle engine). The blower on the side of the engine forces air to flow into the bottom of the cylinder and out through the exhaust valves at the top of the cylinder. This action serves to scavenge any exhaust gases that might remain in the cylinder and to fill the cylinder with a fresh "charge" of air. The first dashed line to the left of BDC shows that the exhaust valves are shut at this point. The piston continues to move up and the next dashed

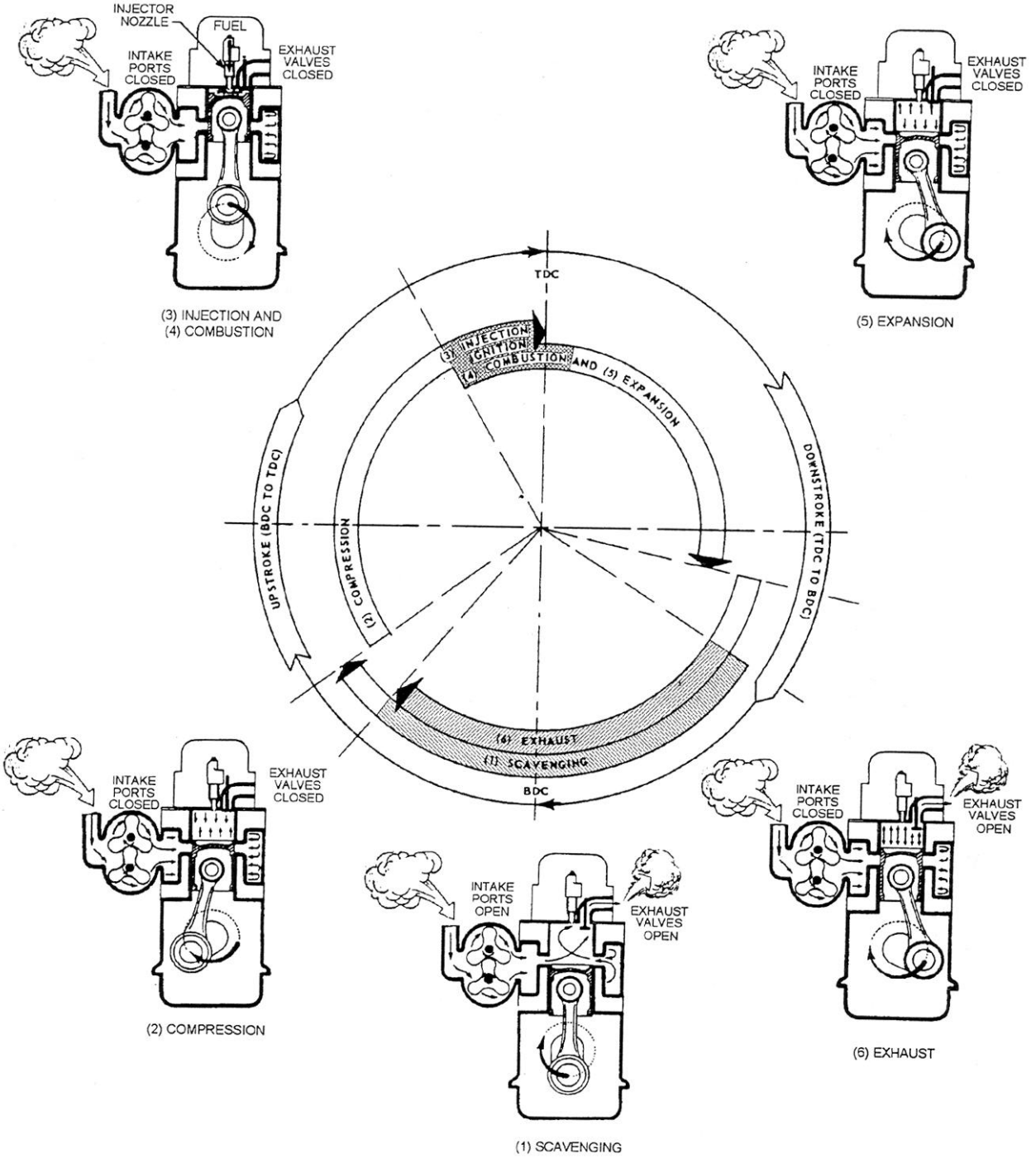


Figure 2-2.—Strokes and events in a 2-stroke cycle diesel engine cylinder.

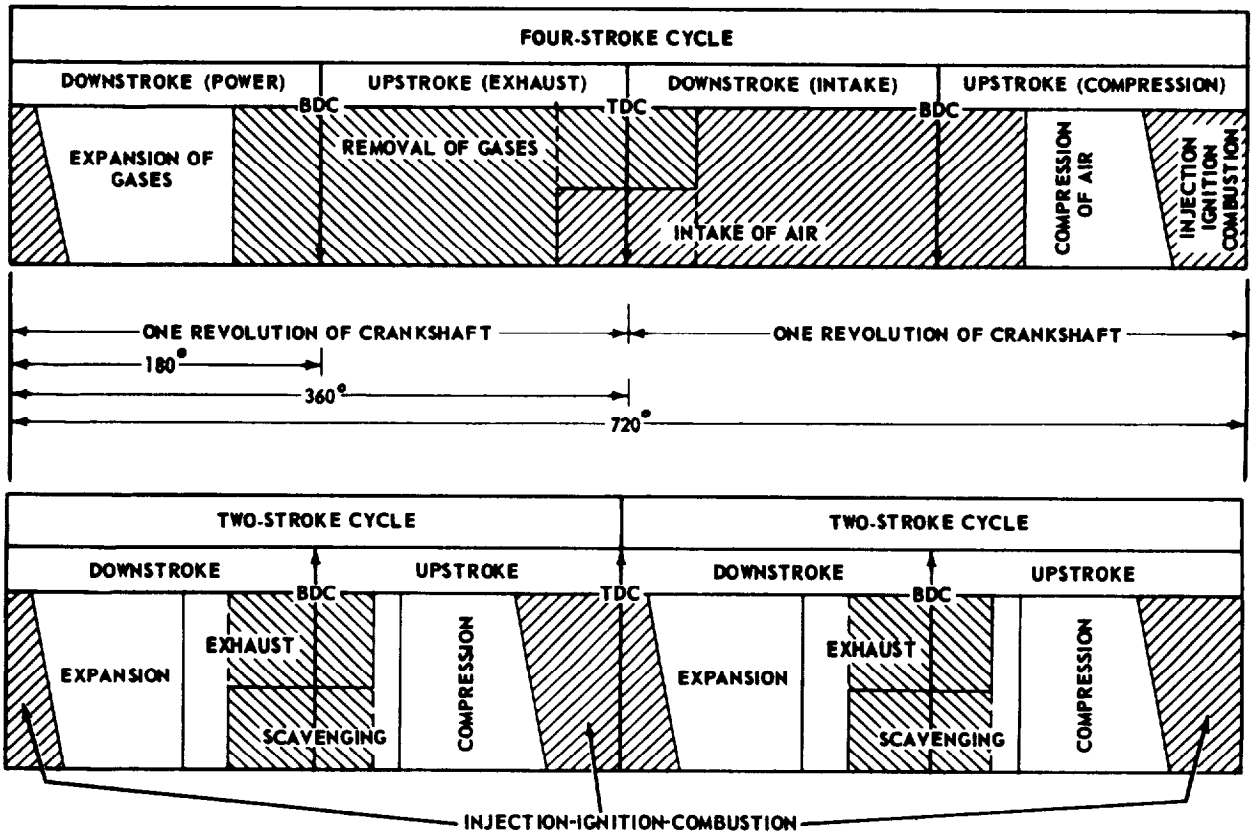
line shows the point at which the intake ports are blocked by the piston (view 2). At this point, the compression stroke begins. The piston compresses the air within the cylinder, causing its pressure and temperature to increase rapidly. At a point several degrees before the piston reaches TDC, fuel is injected into the cylinder. The heat of the compressed air ignites the fuel and the process of combustion causes a drastic increase in temperature and pressure within the cylinder (view 3/4). The rapid expansion of combustion gases forces the piston to move down for the power stroke (view 5). The power stroke continues until the exhaust valves are open (view 6). This part of the cycle indicates the beginning of the exhaust event.

In summary, a 2-stroke engine cycle will have one power event per cylinder for every 360 degrees of rotation of the crankshaft.

Comparison of 2-Stroke and 4-Stroke Cycle Diesel Engines

Figure 2-3 shows a comparison of the events that occur during the same length of time for both 2-stroke and 4-stroke cycle engines. The graph shows that, during the same amount of time, a 2-stroke engine will have two power events while a 4-stroke engine will have only one. This might lead you to believe that 2-stroke cycle engines are more efficient than 4-stroke engines; however, that is not the case. In order to work properly, a 2-stroke engine must have some method of forcing air into and through the cylinders. And, since this air pump (blower) is driven by the engine, it robs some of the horsepower that would otherwise be available to drive the load. Also, the combustion process in a 2-stroke engine is not as complete as it is in a 4-stroke cycle engine. Since each type of engine has certain advantages over the other, the Navy uses both 2-stroke and 4-stroke cycle engines for main propulsion and electrical generating service.

The illustrations we have used to represent the cycles of operation are for demonstration purposes only. The exact number of degrees before or after TDC or BDC at which an event starts and ends will vary among engines. You can



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Figure 2-3.—Comparison of the 2- and 4-stroke cycles.

find information on such details in the appropriate technical manuals dealing with the specific engine in question.

Gasoline Engines

Diagrams that show the mechanical cycles of operation in gasoline engines are somewhat similar to those described in this chapter for diesel engines, except that there would be one less event taking place during the gasoline engine cycle. Since air and fuel are admitted to the cylinder of a gasoline engine as a mixture during the intake event, the injection event does not apply.

COMBUSTION CYCLES

Up to this point, we have given greater consideration to the stroke of a piston and the related events taking place during a cycle of operation than we have to the heat process involved in the cycle. However, we cannot discuss the mechanics of engine operation without dealing with heat. Such terms as ignition, combustion, and expansion of gases indicate that heat is essential to a cycle of engine operation.

So far, the only difference we have pointed out between diesel and gasoline engines is the number of events that occur during the cycle of operation. We have told you that either the 2- or the 4-stroke cycle may apply to both a diesel and a gasoline engine. Then, one of the principal differences between these types of engines must involve the heat processes that produce the forces that make the engine operate. The heat processes are sometimes called COMBUSTION or HEAT CYCLES.

The two most common combustion cycles associated with reciprocating internal-combustion engines are the OTTO cycle (gasoline engines) and the DIESEL cycle (diesel engines). Each of these combustion cycles will be discussed.

In talking about combustion cycles, we must bring up another important difference between gasoline and diesel engines—the difference in COMPRESSION PRESSURE. Compression pressure is directly related to the combustion process in an engine. Diesel engines have a much higher compression pressure than gasoline engines. The higher compression pressure in diesels explains the difference in the methods of ignition used in gasoline and diesel engines.

Methods of Ignition

When the gases within a cylinder are compressed, the temperature of the confined gases rises. As the compression increases, the temperature rises. In a gasoline engine, the compression temperature is always lower than the point at which the fuel will ignite spontaneously. Thus, the heat required to ignite the fuel must come from an external source (spark plug). This method is referred to as SPARK IGNITION. On the other hand, the compression temperature in a diesel engine is far above the ignition point of the fuel oil. Therefore, ignition of the fuel takes place as a result of heat generated by compression of the air within the cylinder, an action referred to as COMPRESSION IGNITION.

The difference in the methods of ignition indicates that there is a basic difference in the combustion cycles upon which diesel and gasoline engines operate. The difference involves the behavior of the combustion gases under varying conditions of pressure, temperature, and volume. Since this is so, you should be familiar with the relationship of these factors before considering the combustion cycles individually. (The basic laws and processes involved in a volume, temperature, and pressure relationship are discussed under the properties of gases in *Fireman*, NAVEDTRA 14104.) *You should also be aware that compression ratio (clearance volume) refers to the comparison between the volume above the piston at BDC to the volume above the piston at TDC.*

Relationship of Temperature, Pressure, and Volume

The relationship of temperature, pressure, and volume as found in an engine can be illustrated by a description of what takes place in a cylinder that is fitted with a reciprocating piston. Follow

views A through D in figure 2-4. Note the instruments that indicate the pressure within the cylinder and that the temperature both inside and outside the cylinder is approximately 70°F. Assume the cylinder is an airtight container, as it is in our example. Now compare views A and B of figure 2-4. If a force pushes the piston toward the top of the cylinder, the entrapped charge is compressed. In views B and C, the compression progresses. The VOLUME of the air DECREASES, the PRESSURE INCREASES, and the TEMPERATURE RISES. These changing conditions continue as the piston moves. When the piston nears TDC in view D, there has been a marked decrease in volume. Also, both pressure and temperature are much greater than at the beginning of compression. Notice that the pressure has gone from 0 psi to 470 psi and

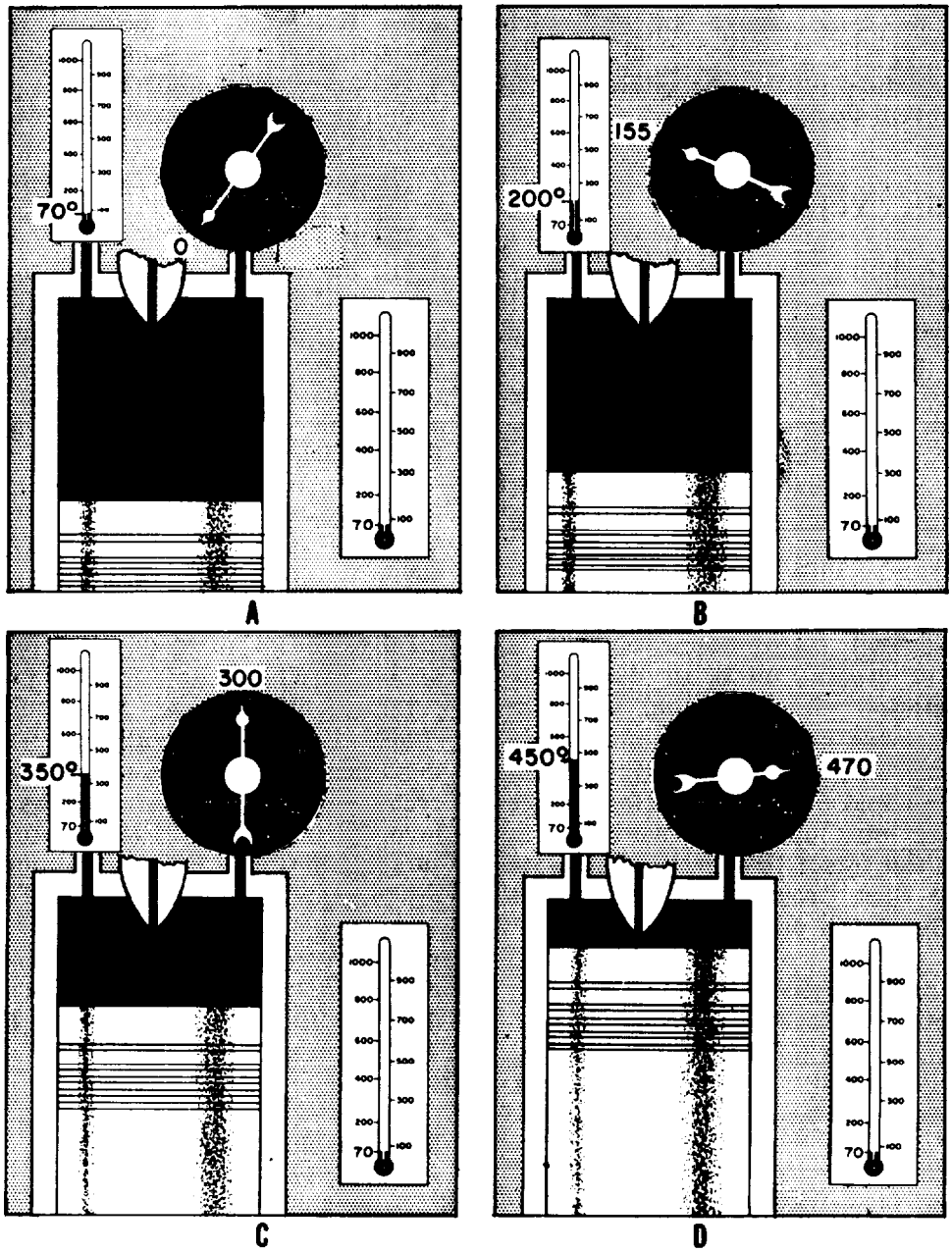


Figure 2-4.—Volume, temperature, and pressure relationships in a cylinder.

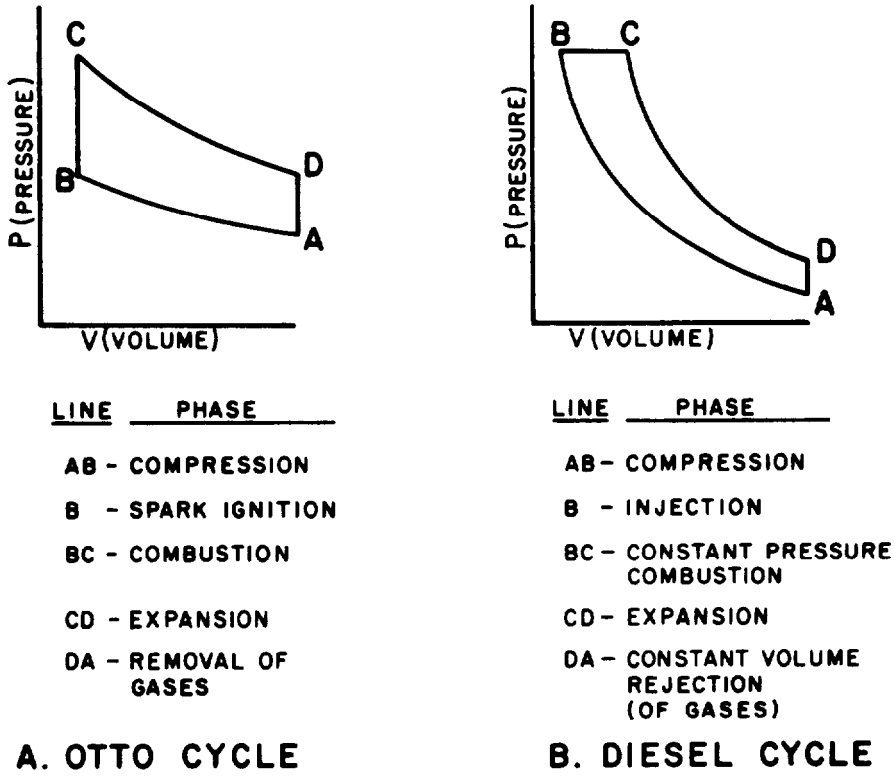
the temperature has increased from 70°F to approximately 450°F. These changing conditions indicate that mechanical energy, in the form of force applied to the piston, has been transformed into heat energy in the compressed air. The temperature of the air has been raised sufficiently to cause ignition of the fuel that is injected into the cylinder.

Further changes take place after ignition. Since ignition occurs shortly before TDC, there is little change in volume until the piston passes TDC. However, there is a sharp increase in both pressure and temperature shortly after ignition takes place. The increased pressure forces the piston downward. As the piston moves downward, the gases expand (increase in volume), and pressure and temperature decrease rapidly. These changes in volume, pressure, and temperature are representative of the changing conditions in the cylinder of a diesel engine.

In comparison with the requirement of a diesel engine, a gasoline engine needs a lower compression ratio and lower combustion chamber temperatures. The reason for this is that the heat of compression of a diesel engine would ignite a gasoline and air mixture before the piston could approach the top of its stroke. This pre-ignition would tend to drive the piston back down the cylinder and place an excessive, damaging strain on the engine. As a rule, gasoline engines use compression ratios under 10:1. It is the electric spark that causes ignition of the fuel to occur.

The changes in volume and pressure in an engine cylinder can be illustrated by diagrams similar to those shown in figure 2-5. Such diagrams are made by devices that measure and record the pressures at various piston positions during a cycle of engine operation. Diagrams, such as these, that show the relationship between pressures and corresponding piston positions are called PRESSURE-VOLUME DIAGRAMS or INDICATOR CARDS.

On diagrams that provide a graphic representation of cylinder pressure as related to volume, the vertical line P on the diagram represents pressure and the horizontal line V represents volume. (Refer to fig. 2-5.) When a diagram is used as an indicator card, the pressure line is marked off in inches. Thus, the volume line can be used to show the length of the piston stroke



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Figure 2-5.—Pressure-volume diagrams for theoretical combustion cycles.

that is proportional to volume. The distance between adjacent letters on each of the diagrams (views A and B of fig. 2-5) represents an event of a combustion cycle. A combustion cycle includes compression of air, burning of the charge, expansion of gases, and removal of gases.

The diagrams shown in figure 2-5 provide a means by which the Otto and diesel combustion cycles can be compared. Referring to the diagrams as we discuss these combustion cycles will help you to identify the principal differences between these cycles. The diagrams shown are theoretical pressure-volume diagrams. Diagrams representing conditions in operating engines will be given later.

Otto (Constant-Volume) Cycle

In theory, the Otto combustion cycle is one in which combustion, caused by an electric spark, occurs at constant volume. The Otto cycle and its principles serve as the basis for modern gasoline engine design.

In the Otto cycle (view A of fig. 2-5), compression of the charge in the cylinder occurs at line AB. Spark ignition occurs at point B. Because of the volatility of the mixture, combustion practically amounts to an explosion. Combustion, represented by line BC, occurs (theoretically) just as the piston reaches TDC. During combustion, there is almost no piston travel. Thus, there is no change in the volume of the gas in the cylinder. This lack of change in volume accounts for the descriptive term, CONSTANT VOLUME. During combustion, there is a rapid rise in temperature followed by a pressure increase. The pressure increase performs the work during the expansion phase, as represented by line CD in the figure. The removal of gases, represented by line DA in the figure, is at CONSTANT VOLUME.

Theoretical Diesel (Constant-Pressure) Cycle

When discussing diesel engines, we must point out that there is a difference between the theoretical, or "true," diesel cycle and the "actual" diesel cycle, that really occurs in an operating diesel engine.

The true diesel cycle may be defined as one in which combustion, induced by compression ignition, theoretically occurs at a constant pressure. (See view B of fig. 2-5.) Compression of the air (line AB) increases its temperature to a point that ignition occurs automatically when the fuel is injected. Fuel injection and combustion are controlled to give constant pressure combustion (line BC). This phase is followed by expansion (line CD) and CONSTANT-VOLUME REJECTION of the gases (line DA).

In the true diesel cycle, the burning of the mixture of fuel and compressed air is a relatively slow process when compared with the quick, explosive type of combustion process of the Otto cycle. In the true diesel cycle, the injected fuel penetrates the compressed air, some of the fuel ignites, then the rest of the charge bums. The expansion of the gases keeps pace with the change in volume caused by piston travel. Thus, combustion is said to occur at CONSTANT PRESSURE (line BC).

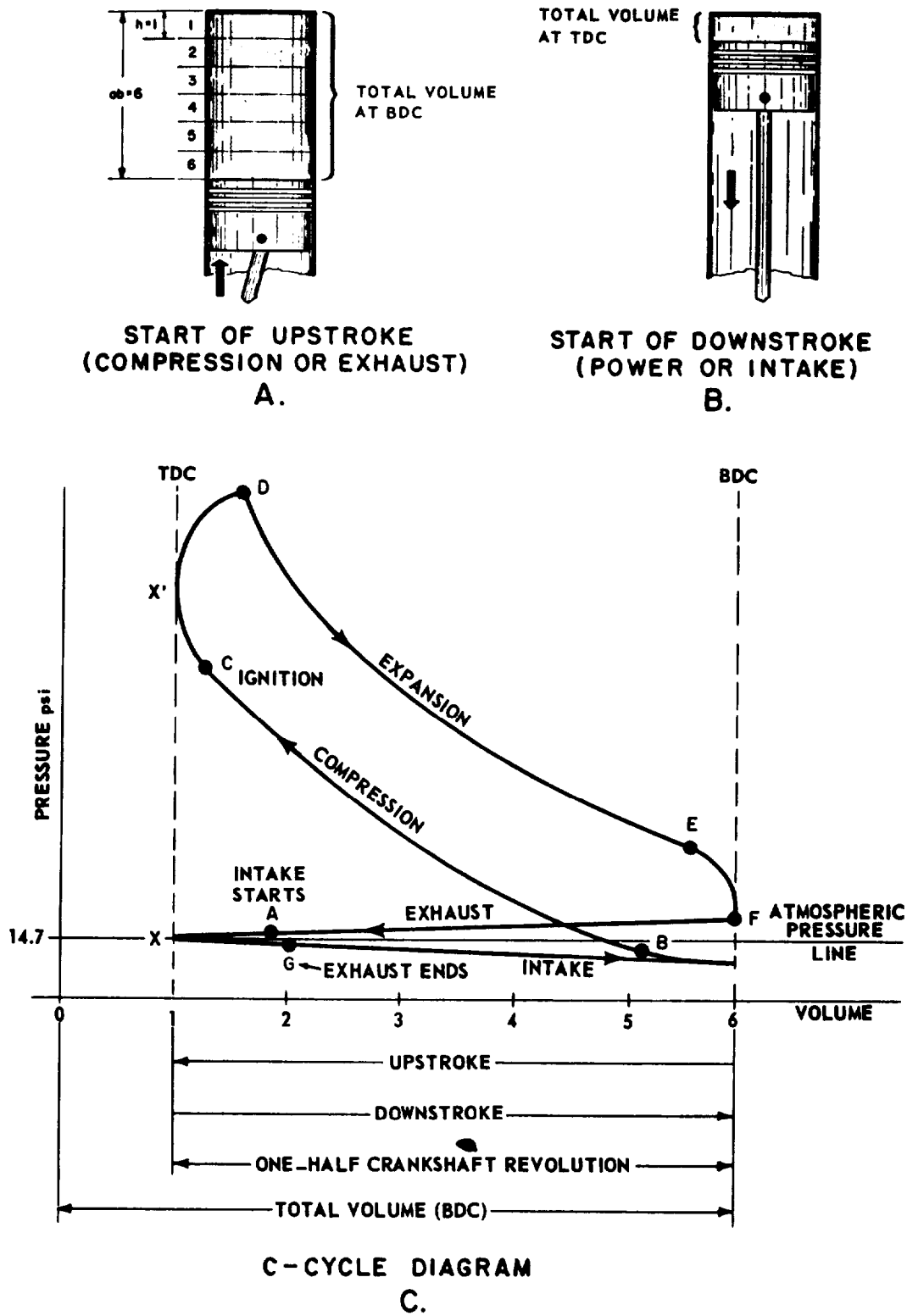
Actual Combustion Cycles

The preceding discussion covered the theoretical (true) combustion cycles which serve as the basis for modern engines. In actual operation, modern engines operate on modifications of the theoretical cycles. However, some characteristics of the true cycles are incorporated in the actual cycles of modern engines, as you will see in the following discussion of examples representing the actual cycles of operation in gasoline and diesel engines.

The examples we will use are based on the 4-stroke mechanical cycle so that you may compare the cycles found in both gasoline and diesel engines. (The majority of gasoline engines use this 4-stroke mechanical cycle.) We will also point out differences existing in diesel engines operating on the 2-stroke cycle.

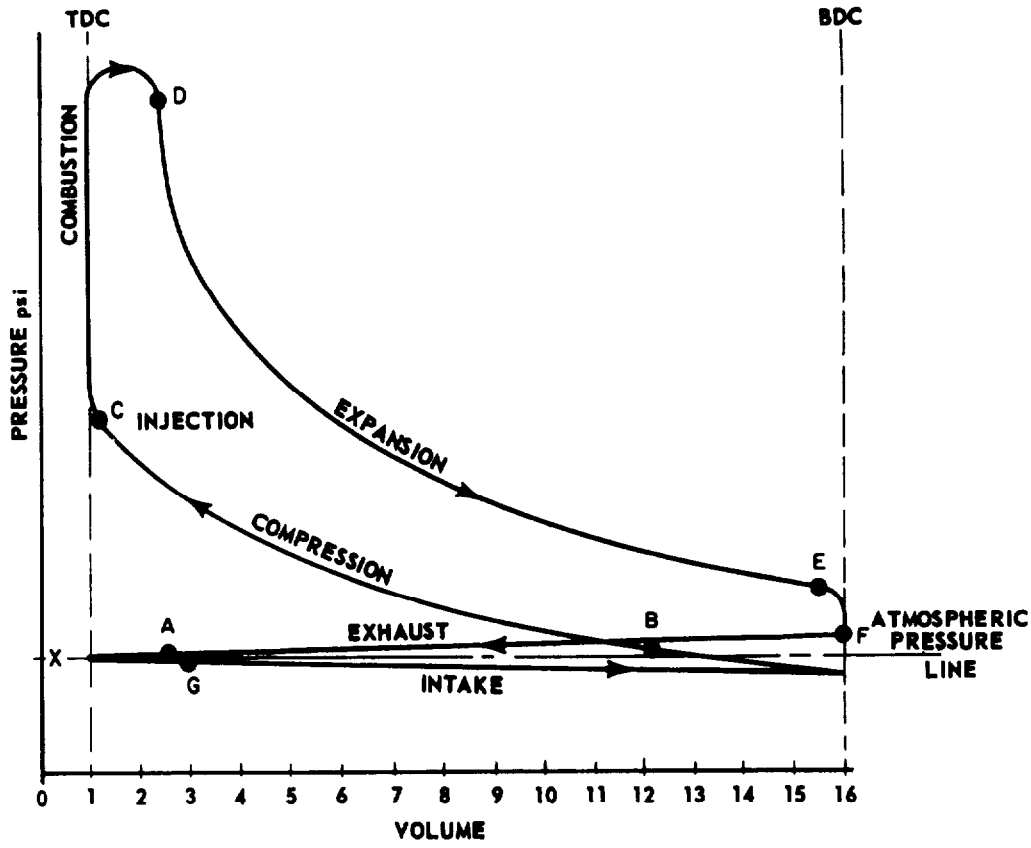
The diagrams in figures 2-6 and 2-7 are representative of the changing conditions in a gasoline and a diesel cylinder during actual engine operation. Some of the events are exaggerated to show more clearly the changes that take place and, at the same time, to show how the theoretical and actual cycles differ.

The compression ratio situation and a pressure-volume diagram for a 4-stroke Otto cycle are shown in figure 2-6. View A shows the



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Figure 2-6.—Pressure-volume diagram for an Otto (gasoline) 4-stroke cycle.



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Figure 2-7.—Pressure-volume diagram for a diesel 4-stroke cycle.

piston on BDC at the start of an upstroke. (In a 4-stroke cycle engine, this stroke could be identified as either the compression stroke or the exhaust stroke.) Study views A and B of figure 2-6. Notice that in moving from BDC to TDC (view B), the piston travels five-sixths of the total distance AB. In other words, the VOLUME has been decreased to one-sixth of the volume when the piston was BDC. Thus, the compression ratio is 6:l.

View C of figure 2-6 shows the changes in volume and pressure during one complete 4-stroke cycle. Notice that lines representing the COMBUSTION and EXHAUST phases are not as straight as they were in the theoretical diagram. The vertical line at the left represents cylinder pressure in pounds per square inch (psi). Atmospheric pressure is represented by a horizontal line called the ATMOSPHERIC PRESSURE LINE. Pressures below this line are less than atmospheric pressure, while pressures above the line are more than atmospheric. The bottom horizontal line represents cylinder volume and piston movement. The volume line is divided into six parts that correspond to the divisions of volume shown in view A. Since piston movement and volume are proportional, the distance between 0 and 6 indicates the volume when the piston was at BDC, and the distance from 0 to 1 indicates the volume with the piston at TDC. Thus, the distance from 1 to 6 corresponds to total piston travel with the numbers in between identifying changes in volume that result from the reciprocating motion of the piston. The curved lines in view C of figure 2-6 represent the changes of both pressure and volume that take place during the four piston strokes of the cycle.

To make it easier for you to compare the discussion on the relationship of strokes and events in the diesel 4-stroke cycle (fig. 2-1) with the discussion on the Otto 4-stroke cycle (fig. 2-6), we will begin the cycle of operation at the INTAKE. (Refer to fig. 2-6.) In the Otto cycle, the INTAKE event includes the admission of fuel and

air. As indicated earlier, the INTAKE event starts before TDC, or at point A in view C of figure 2-6. Note that pressure is decreasing and that after the piston reaches TDC and starts down, a vacuum is created that facilitates the flow of the fuel-air mixture into the cylinder. The INTAKE event continues a few degrees past BDC and ends at point B. Since the piston is now on an upstroke, COMPRESSION takes place and continues until the piston reaches TDC. Notice the increase in pressure (X to X') and the decrease in volume (F to X). Spark IGNITION at point C starts COMBUSTION, which takes place very rapidly. There is some change in volume since the COMBUSTION phase starts before TDC and ends after TDC.

Pressure increases sharply during the COMBUSTION phase (curve CD). The increase in pressure provides the force necessary to drive the piston down again. The gases continue to expand as the piston moves toward BDC. The pressure decreases as the volume increases, from D to E. The EXHAUST event starts at point E, a few degrees before BDC. The pressure drops rapidly until the piston reaches BDC. As the piston moves toward TDC, there is a slight drop in pressure as the waste gases are discharged. The EXHAUST event continues a few degrees past TDC to point G so that the incoming charge aids in removing the remaining waste gases.

The actual diesel combustion cycle (fig. 2-7) is one in which the COMBUSTION phase, induced by COMPRESSION/IGNITION, begins on a constant-volume basis and ends on a constant-pressure basis. In other words, the *ACTUAL CYCLE is a combination of features found in both the Otto and the theoretical diesel cycles.* The actual cycle is used as the basis for the design of practically all modern diesel engines and is referred to as a MODIFIED DIESEL CYCLE.

An example of a pressure-volume diagram for a modified 4-stroke diesel engine is shown in figure 2-7. Notice that the volume line (bottom of figure) is divided into 16 units. These units indicate a 16:l compression ratio. The higher compression ratio accounts for the increased temperature necessary for ignition of the charge. Fuel is injected at point C and COMBUSTION is represented by line CD. While combustion in the Otto cycle is at constant-volume practically throughout the phase, combustion in the actual diesel cycle takes place with volume that is practically constant for a short period of time. During this period of time, there is a sharp increase in pressure until the piston reaches a point slightly past TDC. Then, combustion continues at a relatively constant pressure which drops slightly as combustion ends at point D.

Pressure-volume diagrams for gasoline and diesel engines that operate on the 2-stroke cycle are similar to those just discussed. The only difference is that separate exhaust and intake curves do not exist. They do not exist because intake and exhaust occur during a relatively short interval of time near BDC and do not involve full strokes of the piston as in the 4-stroke cycle. Thus, a pressure-volume diagram for a 2-stroke modified diesel cycle will be similar to the diagram formed by the F-B-C-D-E-F cycle illustrated in figure 2-7. The exhaust and intake phases will take place between E and B with some overlap of the events. (Refer again to fig. 2-2.)

The preceding discussion has pointed out some of the main differences between engines that operate on the Otto cycle and those that operate on the diesel cycle. In brief, these differences involve

- the mixing of fuel and air,
- the compression ratio,
- the method of ignition, and
- the combustion process.

In regard to differences in engines, there is another variation you may find in the engines you operate and maintain. *Sometimes, the manner in which the pressure of combustion gases acts upon the piston is used as a method of classifying engines.* This method of classification is discussed in the information that follows.

CLASSIFICATION OF ENGINES ACCORDING TO THE ACTION OF PRESSURE ON PISTONS

Engines are classified in many ways. You are already familiar with some classifications, such as those based on

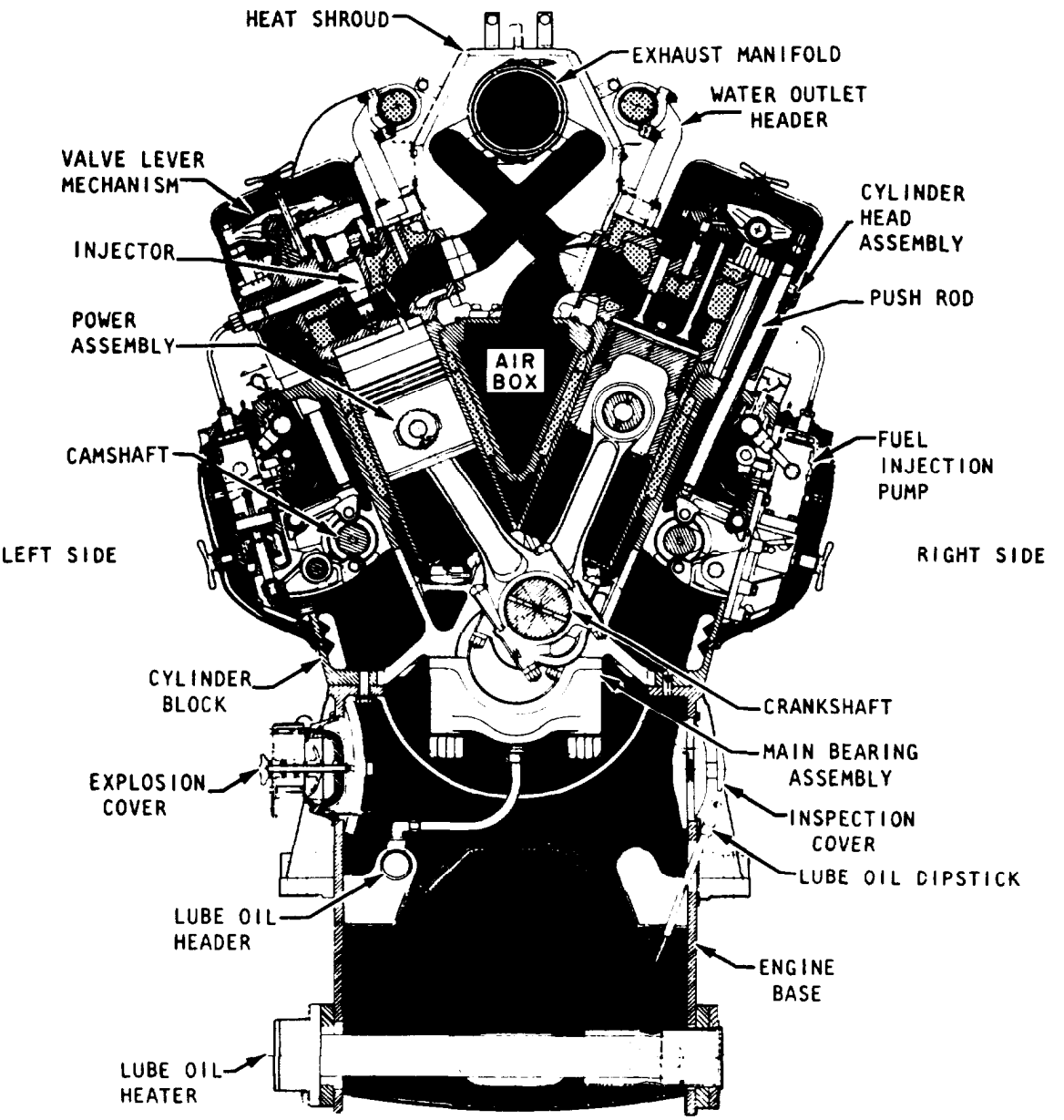
1. the fuels used (diesel fuel and gasoline),
2. the ignition methods (spark and compression),
3. the combustion cycles (Otto and diesel), and
4. the mechanical cycles (2-stroke and 4-stroke).

Additional information will be given in subsequent chapters of this manual on some of the factors related to the above classifications as well as to other types of classifications, such as those based on

5. the cylinder arrangements (V, in-line, opposed),
6. the cooling media (liquid and air), and
7. the way air enters the cylinder and the exhaust leaves the cylinder (port-scavenging and valve scavenging).

Classification of internal combustion engines according to combustion-gas action is based on whether the pressure created by the combustion gases acts upon one surface of a single piston or against single surfaces of two separate and opposed pistons. The two types of engine under this classification are commonly referred to as SINGLE-ACTING and OPPOSED-PISTON engines.

You should understand that the opposed-piston engine is actually a form of a single-acting engine since pressure is applied to only one surface



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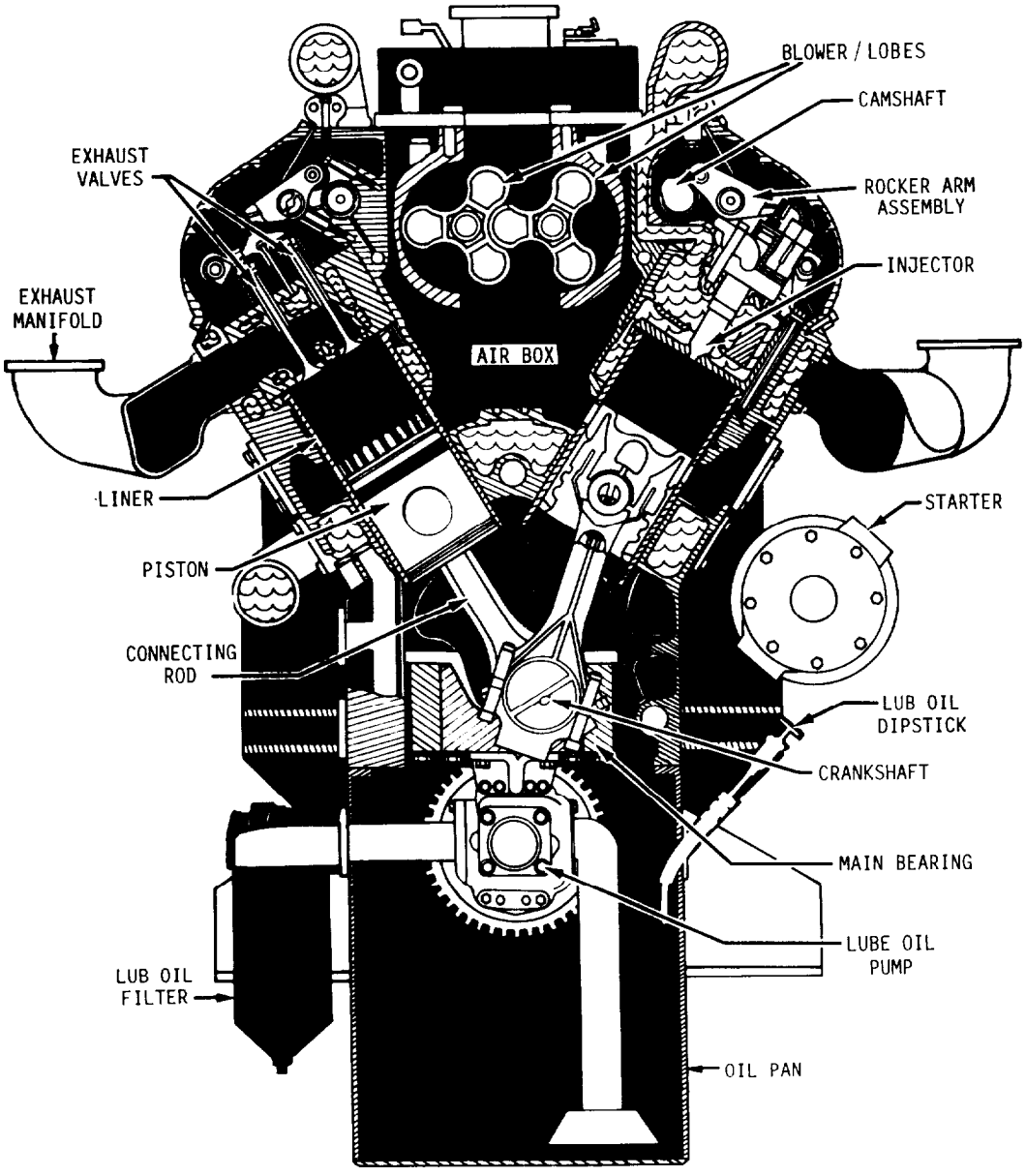
Figure 2-8.—Cross section of an Alto 251C 16-cylinder, 4-stroke cycle, single-acting engine.

of the pistons. For the purpose of this rate training manual, we will provide separate discussions on the single-acting (one piston per cylinder) and opposed-piston (two pistons per cylinder) engines.

SINGLE-ACTING ENGINES

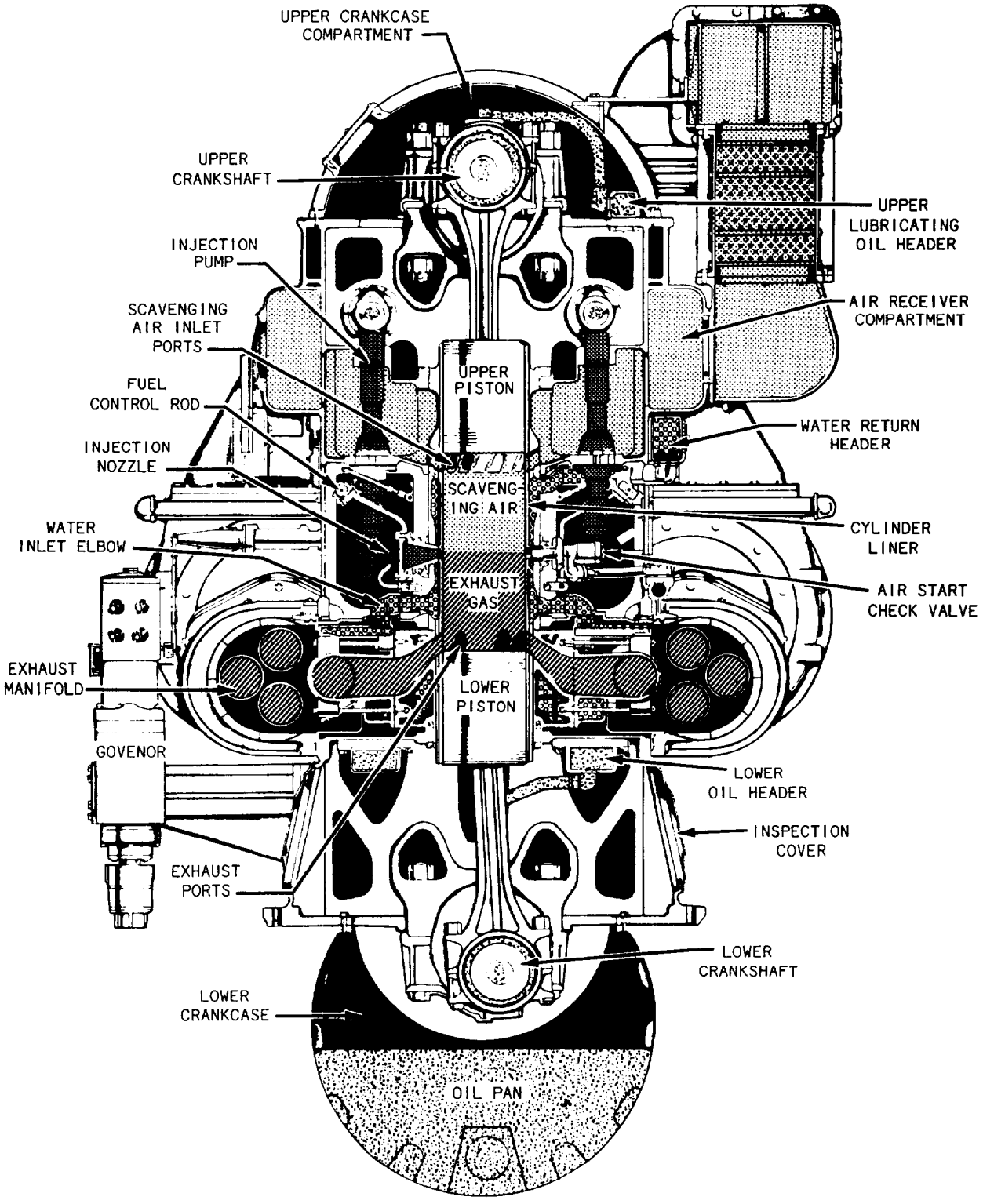
Engines of the single-acting type have ONE PISTON per cylinder, with the pressure of combustion gases acting on only one surface of the piston. This is a feature of design rather than of principle, because the basic principles of operation apply whether an engine is single-acting or opposed-piston.

The pistons in most single-acting diesel engines are of the trunk type (length greater than diameter). The barrel or wall of a piston of this type has one end closed (crown) and one end open (skirt). Only the piston crown serves as part of the combustion space surface. Therefore, the pressure of combustion can act only against the crown. Thus, with respect to the surfaces of a piston, pressure is single acting. All 4-stroke cycle engines (fig. 2-8) and most 2-stroke cycle engines (fig. 2-9) are single acting.



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Figure 2-9.—End cross section of a General Motors series 149 2-stroke cycle, single-acting diesel engine.



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Figure 2-10.—Cross section of a Fairbanks-Morse 2-stroke cycle, opposed-piston diesel engine.

OPPOSED-PISTON ENGINES

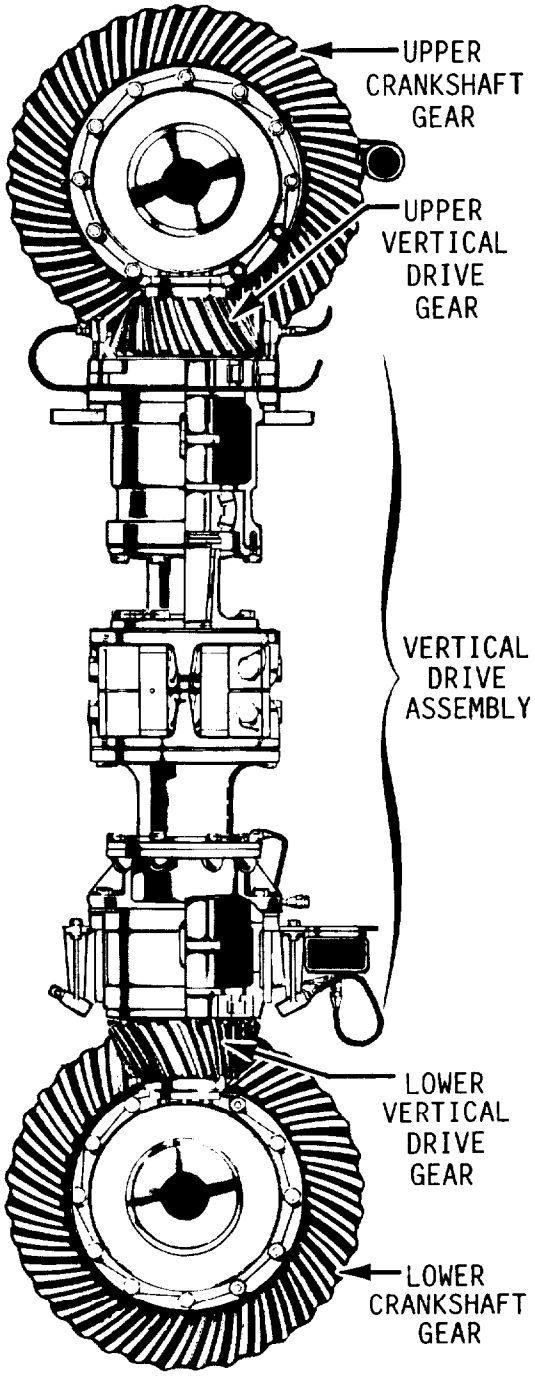
With respect to the combustion-gas action, the term OPPOSED-PISTON identifies those engines that have TWO PISTONS and ONE COMBUSTION SPACE in each cylinder. (Refer to fig. 2-10.) The pistons are arranged in opposed positions; that is, crown to crown, with the combustion space in between. When combustion takes place, the gases act against the crowns of both pistons, driving them in opposite directions. Thus, the term *opposed* not only signifies that the gases act in opposite directions (with respect to pressure and piston surfaces), but also classifies piston arrangement within the cylinder.

In engines that have the opposed-piston arrangement, two crankshafts (upper and lower) are required for transmission of power. Both shafts contribute to the power output of the engine. In opposed-piston engines that are common to Navy service, the crankshafts are connected by a vertical gear drive which provides the power developed by the upper crankshaft. This power is delivered through the vertical drive shaft to the lower crankshaft. Large roller bearings and thrust bearings support and guide the vertical drive shaft. (See fig. 2-11.)

The cylinders of opposed-piston engines do not have valves. Instead, they employ scavenging air ports located near the top of the cylinder. (Refer to fig. 2-10.) These ports are opened and closed by the upper piston. Exhaust ports, located near the bottom of the cylinder, are closed and opened by the lower piston.

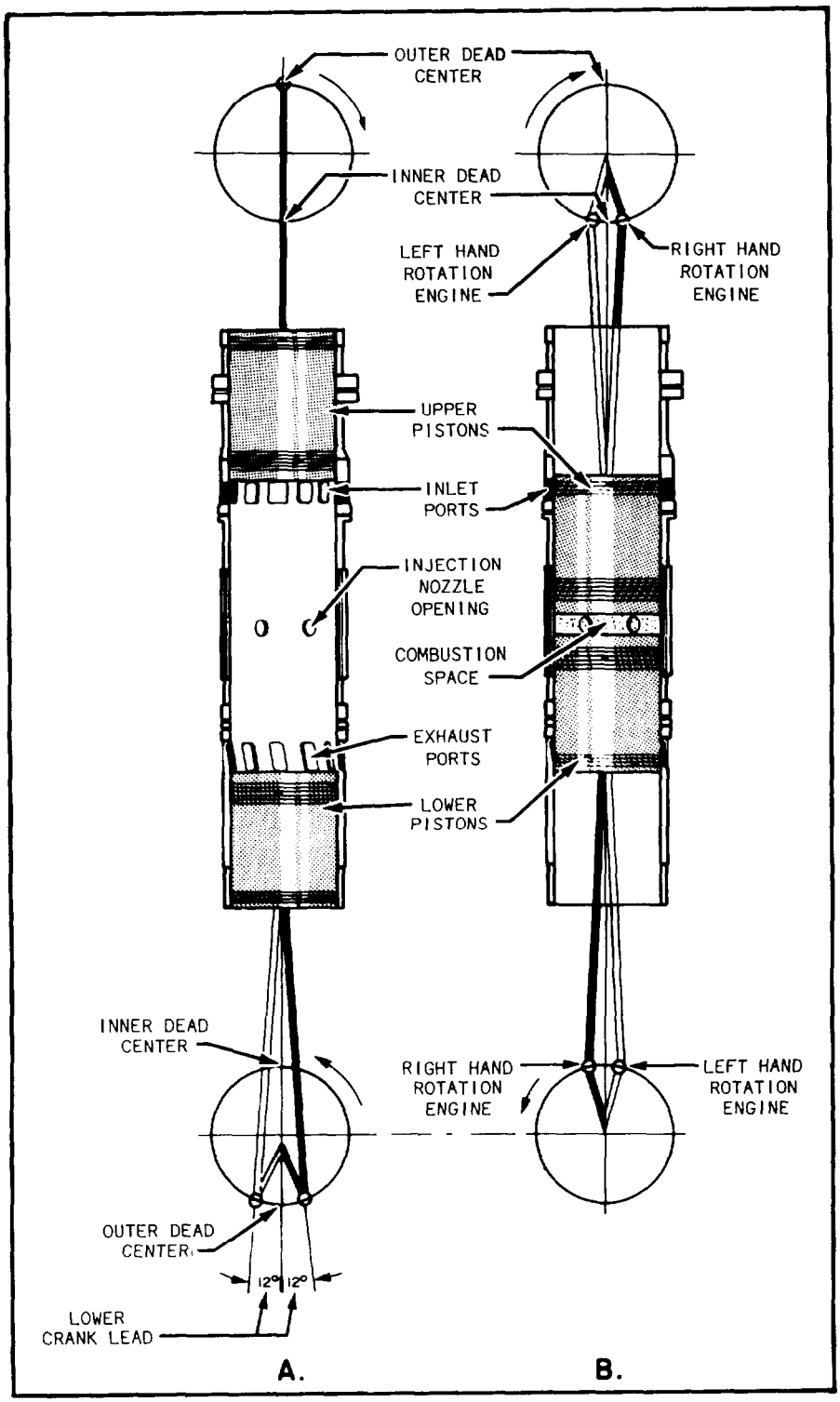
Movement of the opposed pistons is such that the crowns are closest together near the center of the cylinder. When in this position, the pistons are not at the true piston dead centers. This is because the lower crankshaft operates a few degrees in advance of the upper shaft. The number of degrees that a crank on the lower shaft travels in advance of the corresponding crank of the upper shaft is called LOWER CRANK LEAD. (Refer to fig. 2-12.)

Note in view A of figure 2-12 that the lower crankshaft is 12 degrees *past* outer dead center (ODC), when the upper piston is ON outer dead center. In other words, the lower shaft leads the upper shaft by 12 degrees of rotation. Outer dead center (ODC) and inner dead center (IDC) of an opposed piston engine correspond, respectively, to BDC and TDC of single-acting engines.



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Figure 2-11.—Vertical drive assembly in a Fairbanks-Morse opposed-piston engine.



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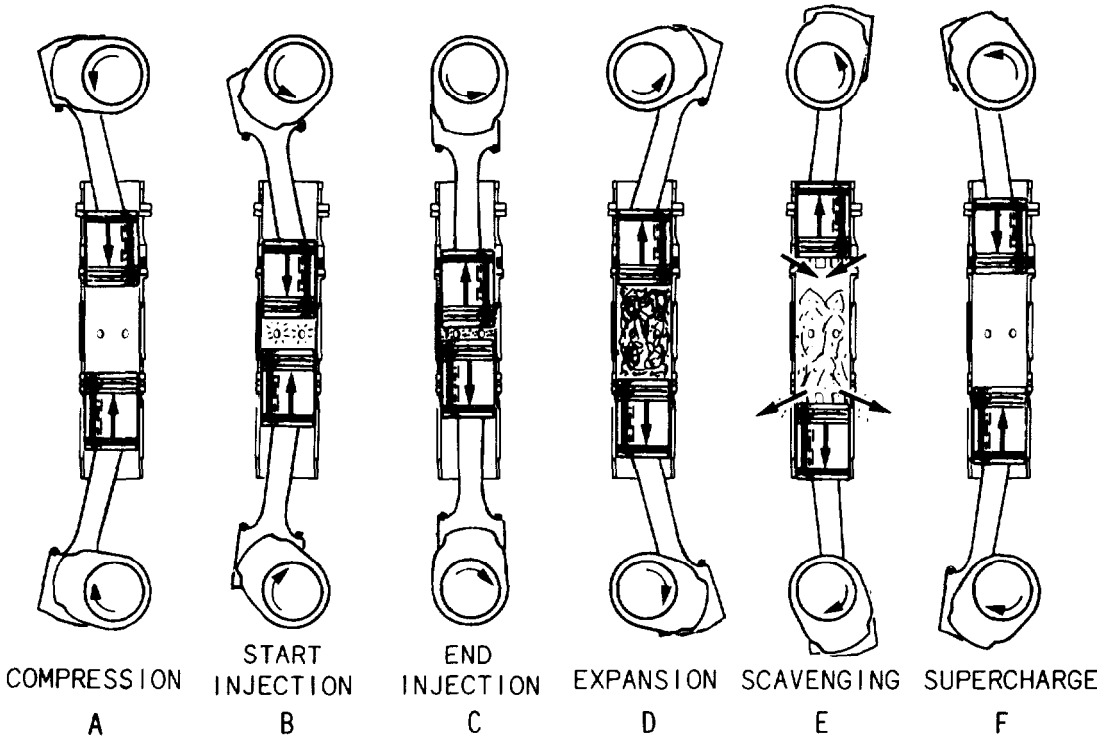
Figure 2-12.—Lower crank lead in an opposed-piston engine.

In view B of figure 2-12, the lower shaft is shown a few degrees *past* IDC and the upper shaft the same number of degrees *before* IDC. (Keep in mind that the upper and lower shafts rotate in opposite directions.) With the shafts at these positions, the pistons are closest together and are sometimes referred to as being at COMBUSTION DEAD CENTER. Note that the midpoint between the shaft positions is piston dead center.

Opposed-piston engines used by the Navy operate on the 2-stroke cycle. In engines of the opposed-piston type, as in 2-stroke cycle single-acting engines, there is an overlap of the various events occurring during a cycle of operation. INJECTION and the burning of the fuel start during the latter part of the COMPRESSION event and extend into the POWER phase. There is also an overlap of the EXHAUST and SCAVENGING periods. The events in the cycle of operation of an opposed-piston, 2-stroke, diesel engine cycle are shown in figure 2-13.

In view A of figure 2-13, the cylinder is charged with air and the pistons are moving toward IDC. Since the scavenging air ports are covered by the upper piston and the exhaust ports are covered by the lower piston, COMPRESSION is taking place. A few degrees before the lower piston reaches IDC, fuel is injected, as represented in view B of the figure, and COMBUSTION occurs. Injection is completed, as indicated in view C, slightly before the pistons reach combustion dead center, where compression is highest. The combustion of the fuel almost doubles the pressure shortly after this point in the cycle. As the gases expand, as indicated in view D, the pistons are driven in opposite directions toward the ODCs, and power is transmitted to both crankshafts. As each of the pistons approaches ODC, the lower piston uncovers the exhaust ports to allow the waste gases to escape from the combustion space. Then, the upper piston uncovers the scavenging air ports, as in view E. The flow of scavenging air forces the remaining gases out of the cylinder. Next, the lower piston covers the exhaust ports, as indicated in view F, and air continues to fill the cylinder until the upper piston covers the scavenging air ports. Thus, the cycle is completed.

In the cycle of operation just described, the exhaust ports are uncovered (view E) and covered (view F) slightly before the intake ports are opened and closed because of the lower crankshaft lead.



75.10

Figure 2-13.—Events in an operating cycle of an opposed-piston engine.

Lower crank lead influences scavenging as well as power output.

Since the intake ports are open for a brief interval after the exhaust ports close, air can be forced into the cylinder at a pressure above that of the atmosphere. (In other words, the cylinder can be supercharged.) This feature results in the development of more power than would be possible if pressure were normal.

Crank lead also results in less power being delivered to the upper shaft than to the lower shaft. The amount of power transmitted to each crankshaft differs because, by the time the upper piston reaches IDC after INJECTION and COMBUSTION, the lower piston has already entered the POWER phase of the cycle. The lower piston, therefore, receives the greater part of the force created by COMBUSTION. In other words, by the time the upper piston reaches IDC and begins to transmit power, the volume of the gases has already begun to increase. Therefore, the pressure acting on the upper piston is less than the pressure that was acting on the lower piston when it began to deliver power.

The amount of power delivered by the lower crankshaft varies with the engine model. In some engines, from 70 to 80 percent of the total power output is delivered by the lower crankshaft. The power available from the upper shaft is already less than that from the lower shaft power because of lower crank lead. The power from the upper shaft is further reduced insofar as engine output is concerned, by the load of the engine accessories which the upper shaft generally drives.

Modern engines of the opposed-piston design have several advantages over single-acting engines of comparable rating. Some of these advantages are

- less weight per horsepower developed,
- lack of cylinder heads and valve mechanisms (and the cooling and lubricating problems associated with them), and
- fewer moving parts.

Single-acting engines have their own advantages, such as not requiring blowers, if they are of the 4-stroke cycle design. These engines are more efficient if they are supercharged with a turbocharger, which is driven by the otherwise wasted energy of exhaust gases. Certain repairs are easier on a single-acting engine since the combustion space can be entered without the removal of an engine crankshaft and piston assembly.

SUMMARY

In this chapter, we have covered the principles of operation associated with 2- and 4-stroke cycle engines and opposed-piston engines. It is essential that you fully understand the principles of operation of these engines. To do so, you must know the meaning and significance of such terms as OTTO CYCLE, THEORETICAL DIESEL CYCLE, ACTUAL DIESEL CYCLE, POWER STROKE, COMPRESSION STROKE, SCAVENGING, and SUPERCHARGING. This chapter has provided you with basic information associated with these terms. As you progress through this nonresident training course, subsequent chapters will provide you with additional information that will clarify and supplement the information you have just read. It may also help you to refer to figures 2-8, 2-9, and 2-10 as you study the information in the following chapters.

CHAPTER 3

PRINCIPAL STATIONARY PARTS OF AN ENGINE

Most internal-combustion engines of the reciprocating type are constructed in the same general pattern. Although engines are not exactly alike, there are certain features common to all of them and the main parts of most engines are similarly arranged. Gasoline engines and diesel engines have the same basic structure; therefore, the descriptions of the engine parts and systems in this rate training manual will apply generally to both types of engines. However, differences do exist and we will point these out wherever they occur. The main differences in diesel and gasoline engines exist in the fuel systems and the methods of ignition.

The main parts of an engine, excluding accessories and systems, may be divided into two principal groups: (1) those parts that do not involve motion, such as the structural frame and its components and related parts; and (2) those parts that involve motion. This chapter deals with the main stationary parts of an engine. Information about the moving parts of an engine will be given in the chapters that follow. After reading this chapter, you should be able to identify the principal stationary parts of an engine in terms of basic design, location, and function.

The stationary parts of an engine maintain the moving parts in their proper relative position so that the gas pressure produced by combustion can "push" the pistons and rotate the crankshaft. The prime requirements for the stationary parts of Navy diesel engines are

- ample strength,
- low weight,
- minimum size, and
- simplicity of design.

Ample strength is necessary if the parts are to withstand the extreme forces that are developed within the engine. Space limitations aboard ship make minimum weight and size essential. Simplicity of design is of great importance when maintenance and overhaul procedures are performed.

ENGINE FRAMES

The term *frame* is sometimes used to identify a single part of an engine. It is also used to identify several stationary parts that are fastened together. These stationary parts support most of the moving engine parts and engine accessories. When we talk about the frame, we will use the latter meaning in our discussion. As the load-carrying part of the engine, the frame may include such parts as the cylinder block, base, sump or oil pan, and end plates.

CYLINDER BLOCKS

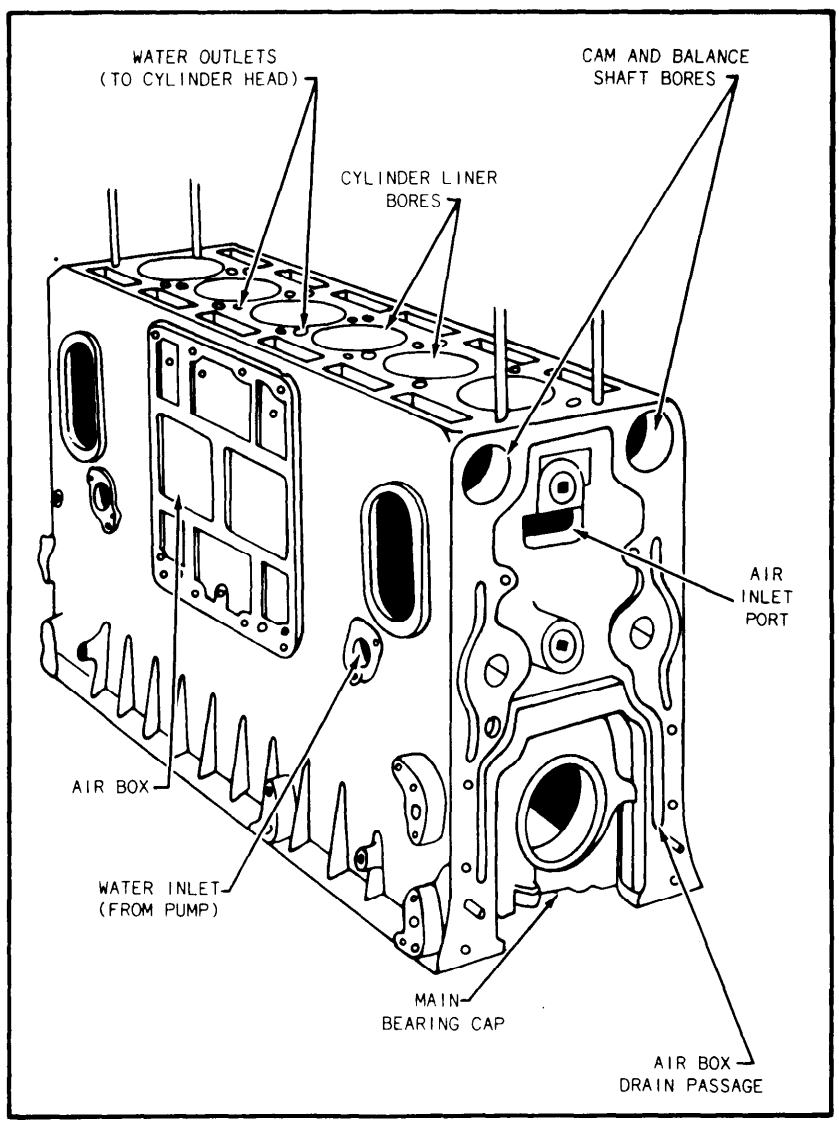
A cylinder block is the part of the engine frame that supports the engine's cylinder liners, head (or heads), and crankshaft. (In modern engines, the term *crankcase* identifies the location of the crankshaft, and not a separate component of the frame.) The blocks for most large engines are of welded-steel construction. In this type of construction, the block is made of steel forgings and plates that are welded horizontally and vertically for strength and rigidity. These plates are located where loads occur. Deck plates are generally fashioned to house and hold the cylinder liners. The uprights and other members are welded with the deck plates into one rigid unit. Blocks of small high-speed engines are often of cast iron en bloc (in one piece) construction.

A cylinder block may contain passages to allow circulation of cooling water around the liners for cooling of the cylinder. However, if the liner is constructed with integral cooling passages, the cylinder block generally will not have cooling passages. Many blocks have drilled lube oil passages. Most 2-stroke cycle engines have air passages in the block.

In other words, a passage that is an integral part of an engine block may serve as a part of the cooling, lubricating, or air system. Generally, we think of one cylinder block in connection with all cylinders of an engine. Some engines, however, may have a separate block for each group of cylinders. Examples of cylinder blocks common to Navy service are shown in figures 3-1, 3-2, 3-3, and 3-4. Figure 3-l shows an example of an in-line, 6-cylinder block; and figure 3-2 shows the same block in a cutaway view.

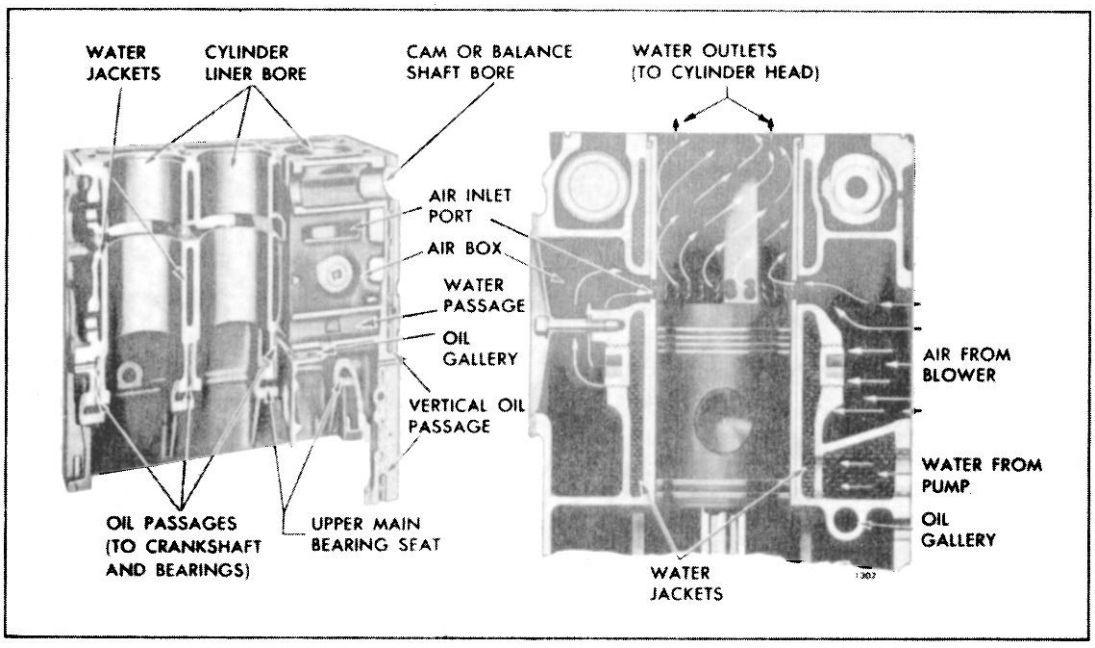
In figure 3-1, the entire unit is a one-piece casting of alloy cast iron. Transverse members provide rigidity and strength, ensuring alignment of the bores and bearings under all loads. The block is bored to receive the cylinder liners. Note the air inlet ports in the cylinder bores and the water jackets which extend to the full length of the bores. Air space surrounds the water jackets. Through this space, commonly called the air box, air is conducted from the blower to the inlet ports of the cylinder liner. Other parts, which are cast integral with this type of block, are the upper halves of the main bearing seats, handholes, bore for the cam or balance shaft, lubricating oil passages, and coolant passages.

The cylinder block shown in figure 3-3 is made up of two 8-cylinder alloy cast iron sections. The front and rear block sections are bolted together to form a rigid self-supporting, 16-cylinder,



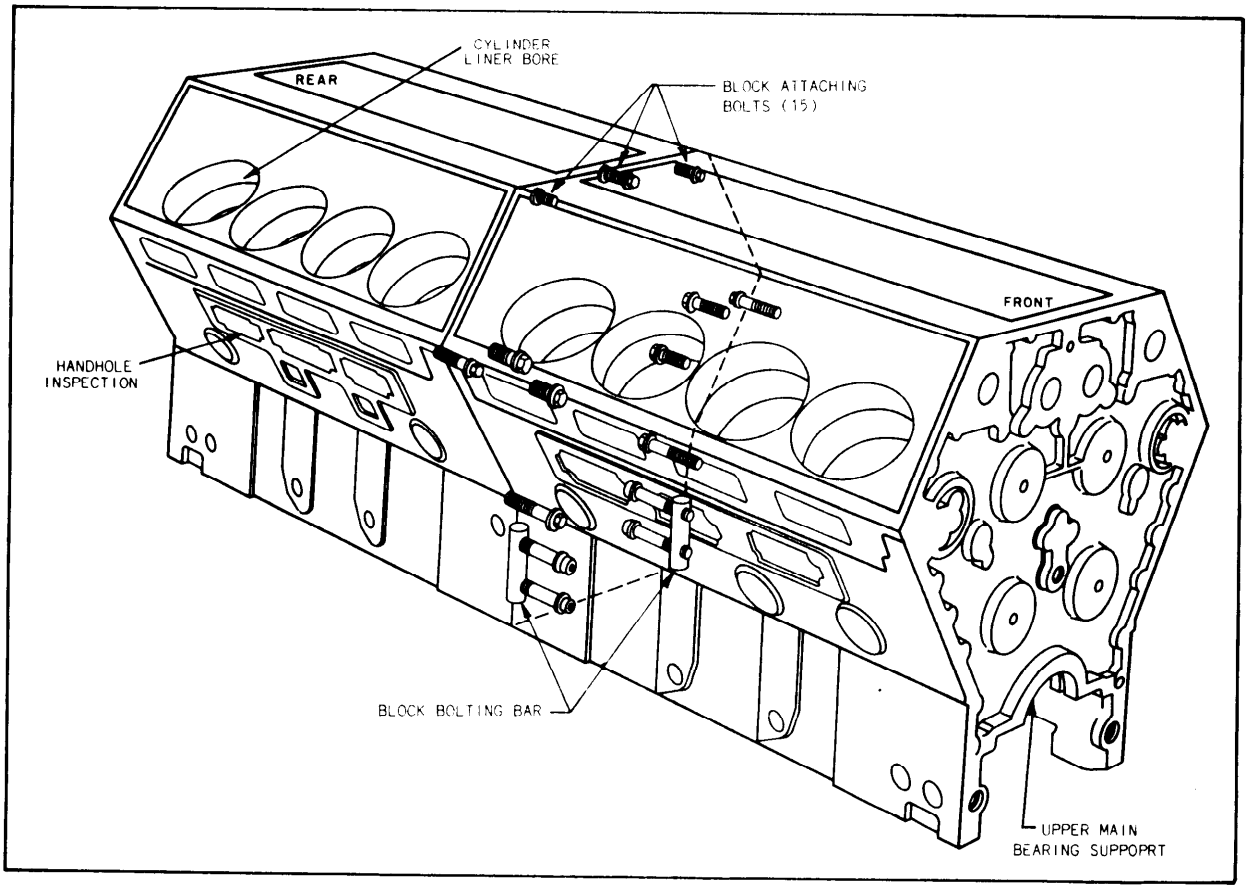
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Figure 3-1.—A General Motors in-line, 6-cylinder block.



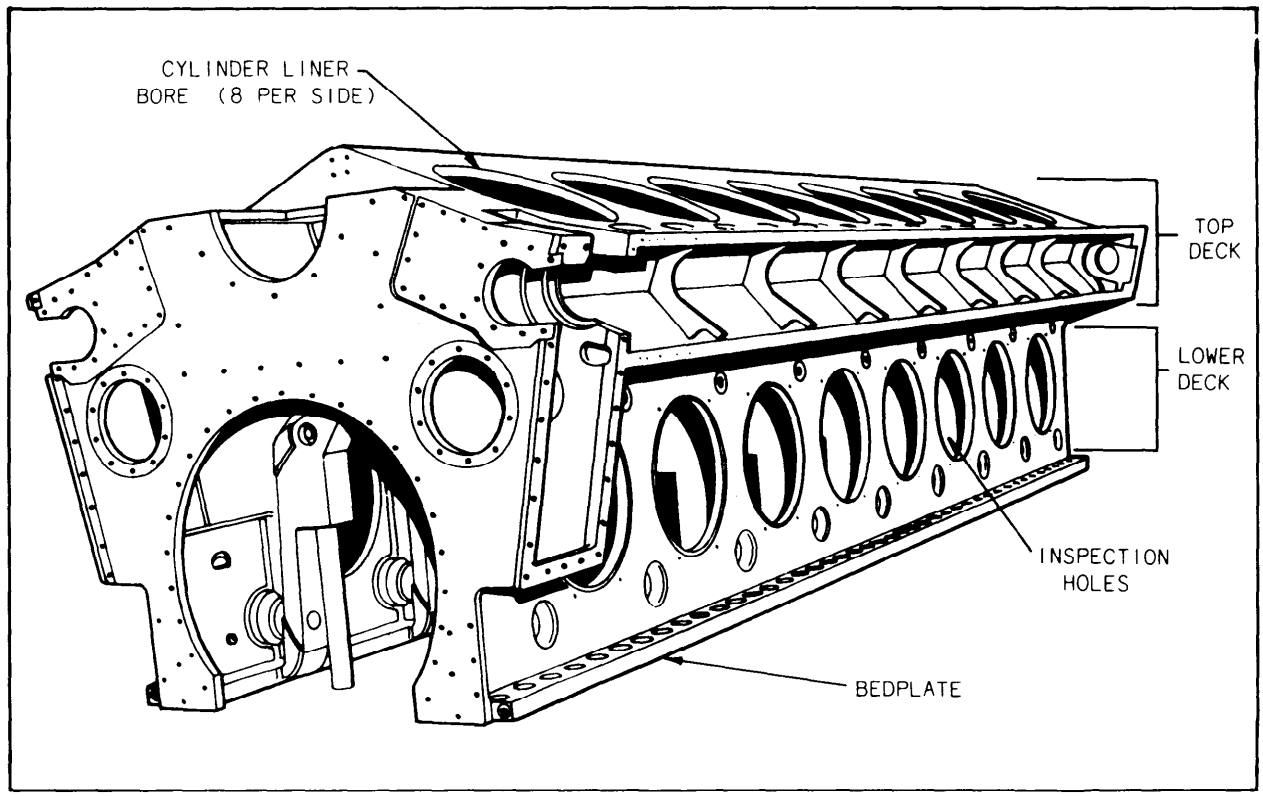
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Figure 3-2.—Cutaway view of a cylinder block showing air and water passages.



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Figure 3-3.—A 16-cylinder, 2-piece block (16 V series 149).



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Figure 3-4.—A Colt-Pielstick PC 2.5 16-cylinder block.

V-type arrangement which accommodates the cylinder assemblies, crankshaft, and engine-mounted components. Water passages are cast in the block to provide coolant to the cylinder liners and the cylinder heads. Main oil galleries are drilled in the block to direct lubricating oil to the crankshaft main bearings and related parts. The front and rear block sections are not interchangeable.

A cylinder block for a large diesel engine that consists of steel plates and forgings is shown in figure 3-4. The steel plates and forgings are welded together to provide the structural support for the stationary and moving components. The upper deck contains the cylinder assemblies and related gear. The lower deck, which forms the crankcase, is mounted with an oil pan to the bedplates. (The oil pan is not shown in fig. 3-4.)

END PLATES

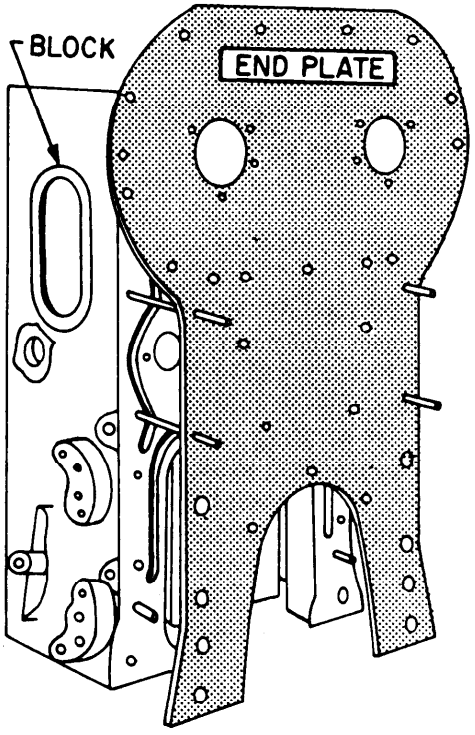
Some engines have flat steel plates attached to each end of the cylinder block. End plates add rigidity to the block and provide a mounting surface for parts such as gears, blowers, pumps, and generators. The type of plate that would attach to the cylinder block shown in figure 3-l is shown in figure 3-5.

BASES

In the majority of large engines, a base is used to support the cylinder block. The base shown in figure 3-6 is a welded-steel structure. Not only does the base support the cylinder block but it also provides a mounting surface for accessories to the engine and serves as a reservoir for the lubricating oil used by the engine. Many of the smaller engines do not have a separate base. Instead, they have an oil pan, which is secured directly to the bottom of the block. The block shown in figure 3-l uses such a pan. Usually, the oil pan serves only as the lower portion of the crankshaft housing and as an oil reservoir that collects and holds the oil.

SUMPS AND OIL PANS

A reservoir that is used for the collecting and holding of lubricating oil is a necessary part of



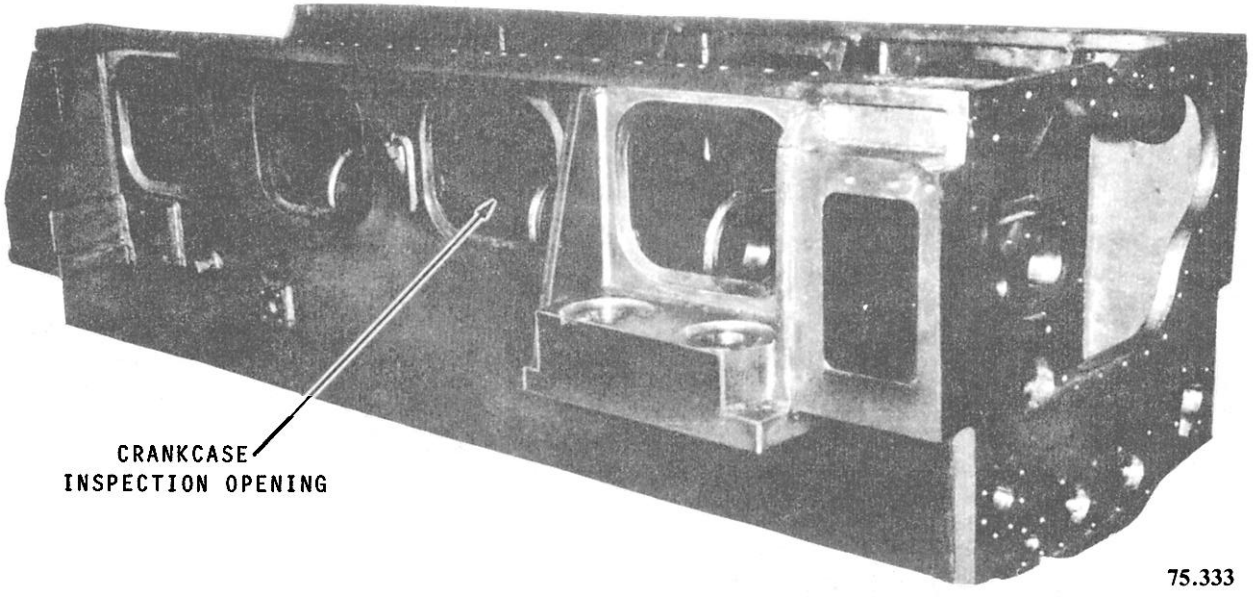
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Figure 3-5.—Front end plate on a cylinder block.

the structure of an engine. The reservoir may be called a sump or an oil pan, depending on the design of the engine. In most engines, the reservoir is usually attached directly to the engine. In dry sump engines, however, the oil pan merely catches the lubricating oil as the oil drains through the engine. As the lubricating oil reaches the oil pan, it immediately drains by gravity flow from the oil pan to a reservoir (that is located apart from the engine) where the lube oil for the engine is collected so it can be cooled and filtered. It is from this reservoir that the engine is supplied with lubricating oil and not from the oil pan. Thus, in dry sump engines, the oil pan remains essentially dry. Regardless of the design of the engine, the oil reservoir serves the same purpose wherever it is located.

ACCESS OPENINGS AND COVERS

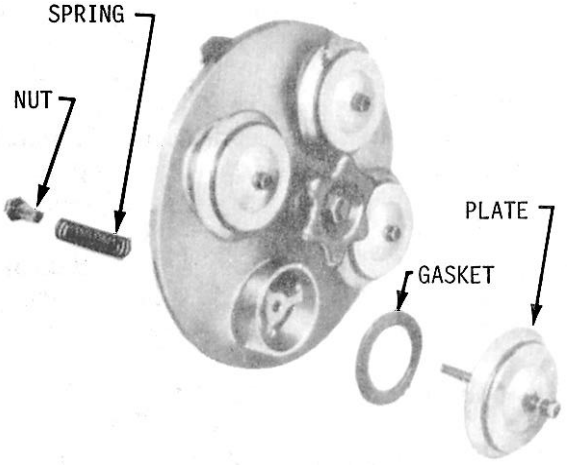
Many engines, especially the larger ones, have openings in some part of the engine frame. (See figs. 3-4 and 3-6.) These openings permit access to the cylinder liners, main and connecting rod bearings, injector control shafts, and various other internal engine parts. Access doors are usually secured with handwheel or nut-operated clamps and are fitted with gaskets to keep dirt and foreign material out of the interior of the engine. On some engines, the covers (sometimes called



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Figure 3-6.—A 251-C Alco cylinder base.

doors or plates) for access openings are constructed to serve as safety devices. A safety cover is a cover that is equipped with a spring-loaded pressure plate. (See fig. 3-7.) The spring maintains a pressure that keeps the plate sealed under normal operating conditions. In the event of a crankcase explosion or extreme pressure within the crankcase, the excess pressure overcomes the spring tension, and the plate in the safety cover acts as a vent to allow combustible gases to escape to the atmosphere. This release of excess pressure serves to minimize damage to the engine.



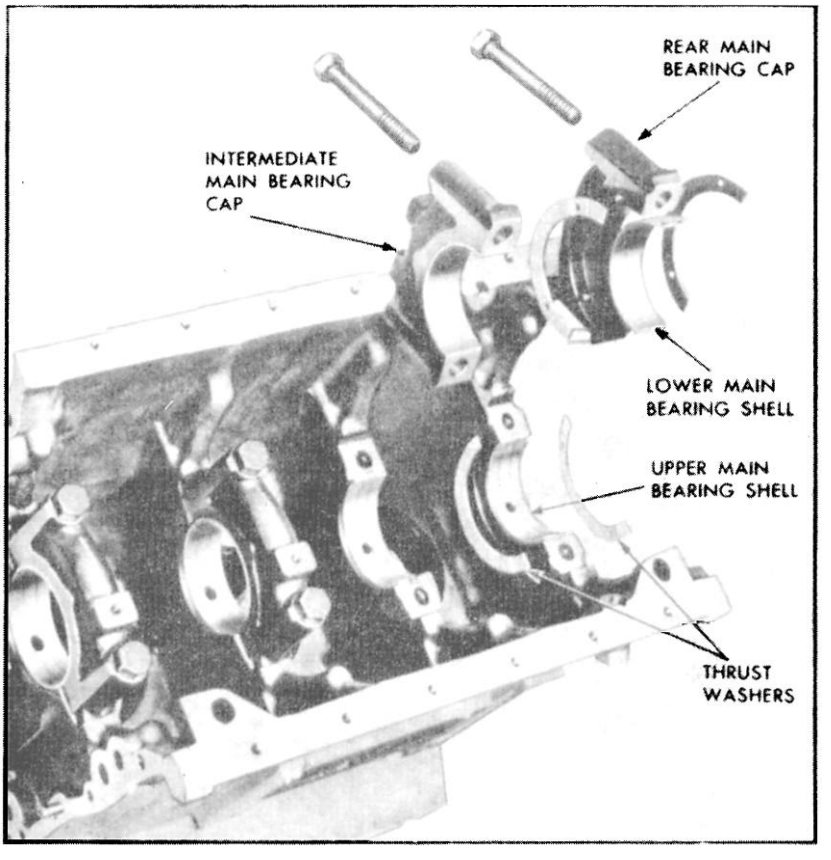
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Figure 3-7.—A safety handhole cover.

BEARINGS

The bearings of an engine make up an important group of parts. Some bearings remain stationary in performing their functions, while others move. The primary function of bearings is to support rotating shafts and other moving parts, and to transmit loads from one engine part to another. To accomplish this function in a practical manner, bearings must (1) reduce the friction between the moving surfaces by separating them with a film of lubricant, and (2) carry away the heat produced by unavoidable friction.

One group of stationary bearings serves to support the crankshaft. These bearings are



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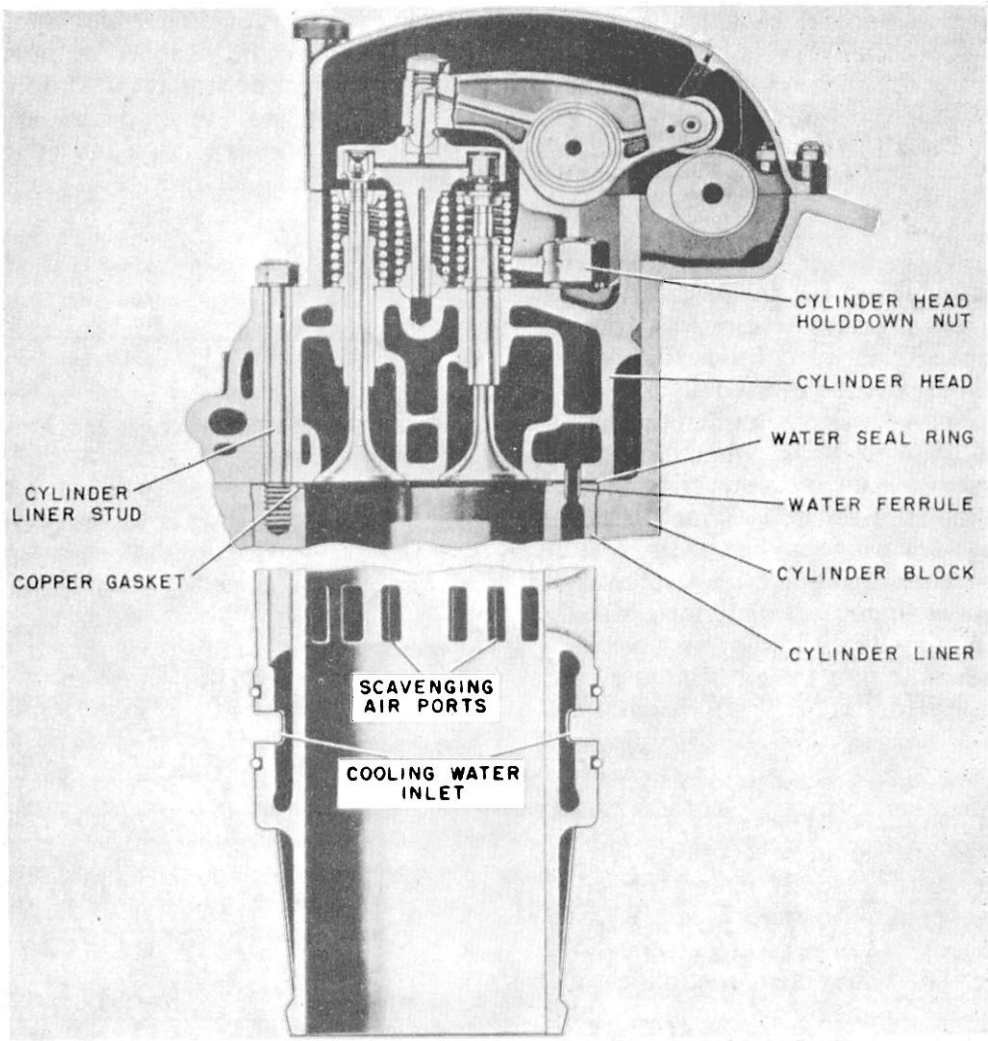
Figure 3-8.— Upper and lower main bearing shells, bearing caps, and rear main bearing thrust washers.

generally called main bearings. (See fig. 3-8.) The main bearings consist of an upper bearing (shell) ‘seated in the cylinder block main bearing support and a lower bearing (shell) seated in the main ‘bearing cap. The thrust washers shown in figure 3-8 are used to take up the axial (back and forth) movement of the crankshaft. Additional information on bearings is given in chapter 4 of this rate training manual.

CYLINDER ASSEMBLIES

The cylinder assembly completes the structural framework of an engine. As one of the main stationary parts of an engine, the cylinder assembly, along with various related working parts, serves as the area where combustion takes place. For purposes of our discussion, a cylinder assembly consists of the head, which covers the top of the cylinder, the cylinder liner, the gasket that forms a seal between the block (or frame) and the head, and the fasteners (usually studs with nuts) that hold the assembly together (fig. 3-9). The other engine parts shown in figure 3-9, many of which involve motion, are discussed later in this manual.

The design of the parts of the cylinder assembly varies considerably from one type of engine to another. Regardless of differences in design, however, the basic components of all cylinder assemblies function, along with related moving parts, to provide a gastight and liquid-tight space. Differences other than those in design can be found in various cylinder assemblies. For example, a gasket is necessary between the head



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Figure 3-9.—Principal stationary parts of a cylinder assembly.

and the block of most cylinder assemblies. However, such gaskets are not used on all engines. When a gasket is not a part of the assembly, the mating surfaces of the head and the block are accurately machined to form a seal between the two parts. Other differences are pointed out in the discussion that follows.

CYLINDER LINERS

The barrel or bore in which an engine piston moves back and forth may be an integral part of the cylinder block, or it may be a separate sleeve or liner. The first type, common in gasoline engines, has the disadvantage of not being replaceable. When excessive wear occurs in a block of this type, the cylinder must be rebored or honed. Reconditioning of this type cannot be repeated indefinitely and, in time, the entire block must be replaced. Another disadvantage is the inconvenience, especially in large engines, of having to remove the entire cylinder block from a ship in order to recondition the cylinders. For these reasons, diesel engines are constructed with replaceable cylinder liners. The cylinder liners we will discuss are representative of those used in diesel engines.

The material of a liner must withstand the extreme heat and pressure developed within the combustion space at the top of the cylinder and, at the same time, must permit the piston and its sealing rings to move with a minimum of friction. Close-grained cast iron is the material most commonly used for liner construction. (Steel, however, is sometimes used.) Some liners are plated on the wearing surface with porous chromium, because chromium has greater wear-resistant qualities than other materials. Also the pores in the plating tend to hold the lubricating oil and aid in maintaining the lubrication oil film that is necessary for reduction of friction and wear.

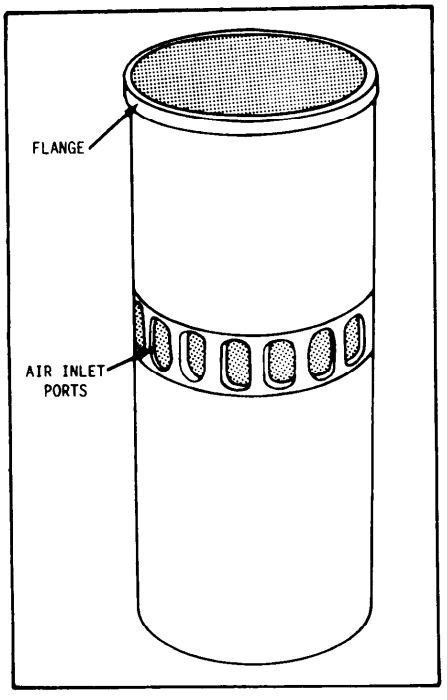
Cylinder liners may be divided into two general classifications or types—dry or wet. The dry liner does not come in contact with the coolant. Instead, it fits closely against the wall of the cooling jacket in the cylinder block. With the wet liner, the coolant comes in direct contact with the liner. Wet liners may have a cooling water space between the engine block and liner, or they may have integral cooling passages. Liners with integral cooling passages are sometimes referred to as water-jacket liners.

Dry Liners

Dry liners have relatively thin walls compared with wet liners (fig. 3-10). The cross section of a dry liner can be seen in the right-hand view of figure 3-2. Note that the coolant circulates through passages in the block and does not come in contact with the liner.

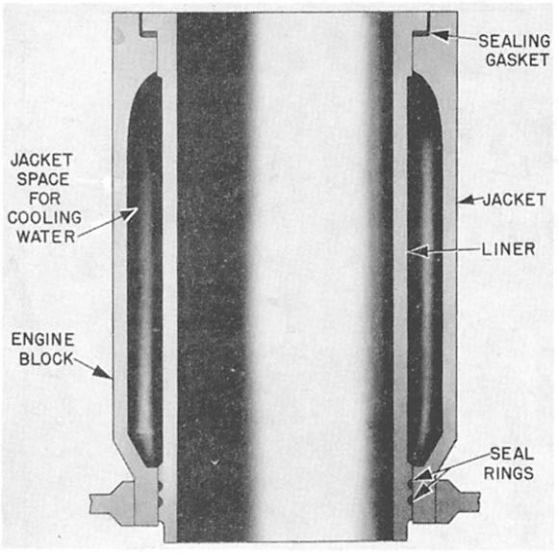
Wet Liners

In wet liners that do not have integral cooling passages, the water jacket is formed by the liner and a separate jacket which is a part of the block. (See fig. 3-11.) A static seal must be provided at both the combustion and crankshaft ends of the cylinders to prevent the leakage of coolant into the oil pan sump, or combustion space. Generally, the seal at the combustion end of a liner consists of either a gasket under a flange or a machined fit. Rubber or neoprene rings generally form the seal at the crankshaft end of the liner. Liners of this type are constructed to permit lengthwise expansion and contraction. The walls of a wet liner must be strong enough to withstand the full working pressure of the combustion gases.



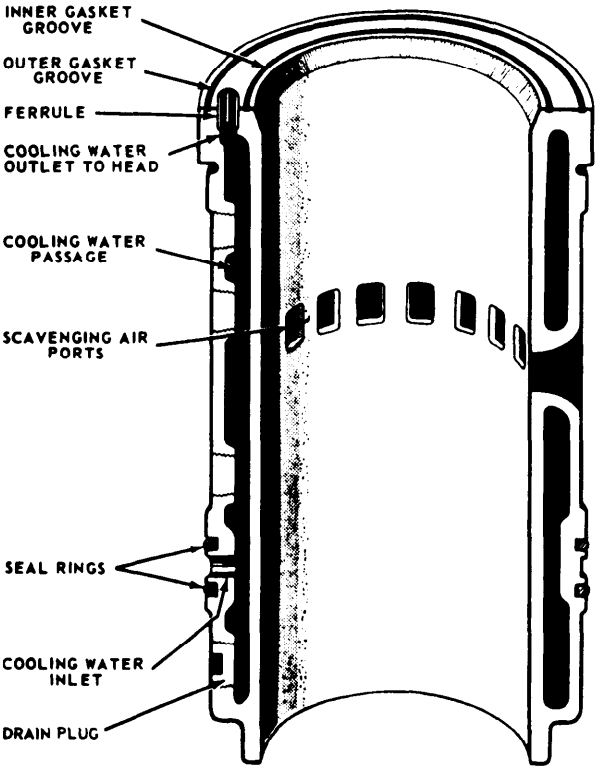
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Figure 3-10.—A dry cylinder liner (General Motors 71 series).



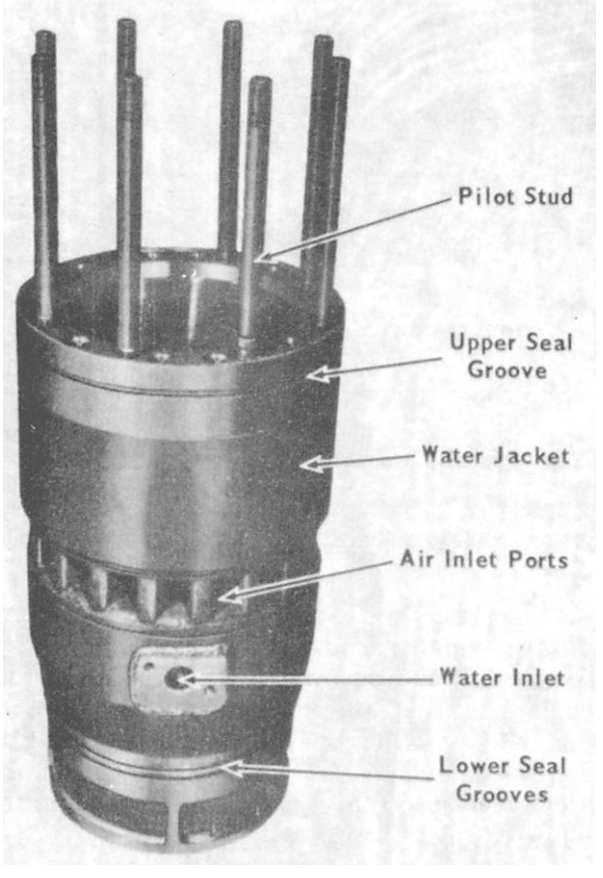
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Figure 3-11.—Cross section of a wet cylinder liner.



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Figure 3-13.—Cross section of a cast-on water-jacket cylinder liner with air ports.



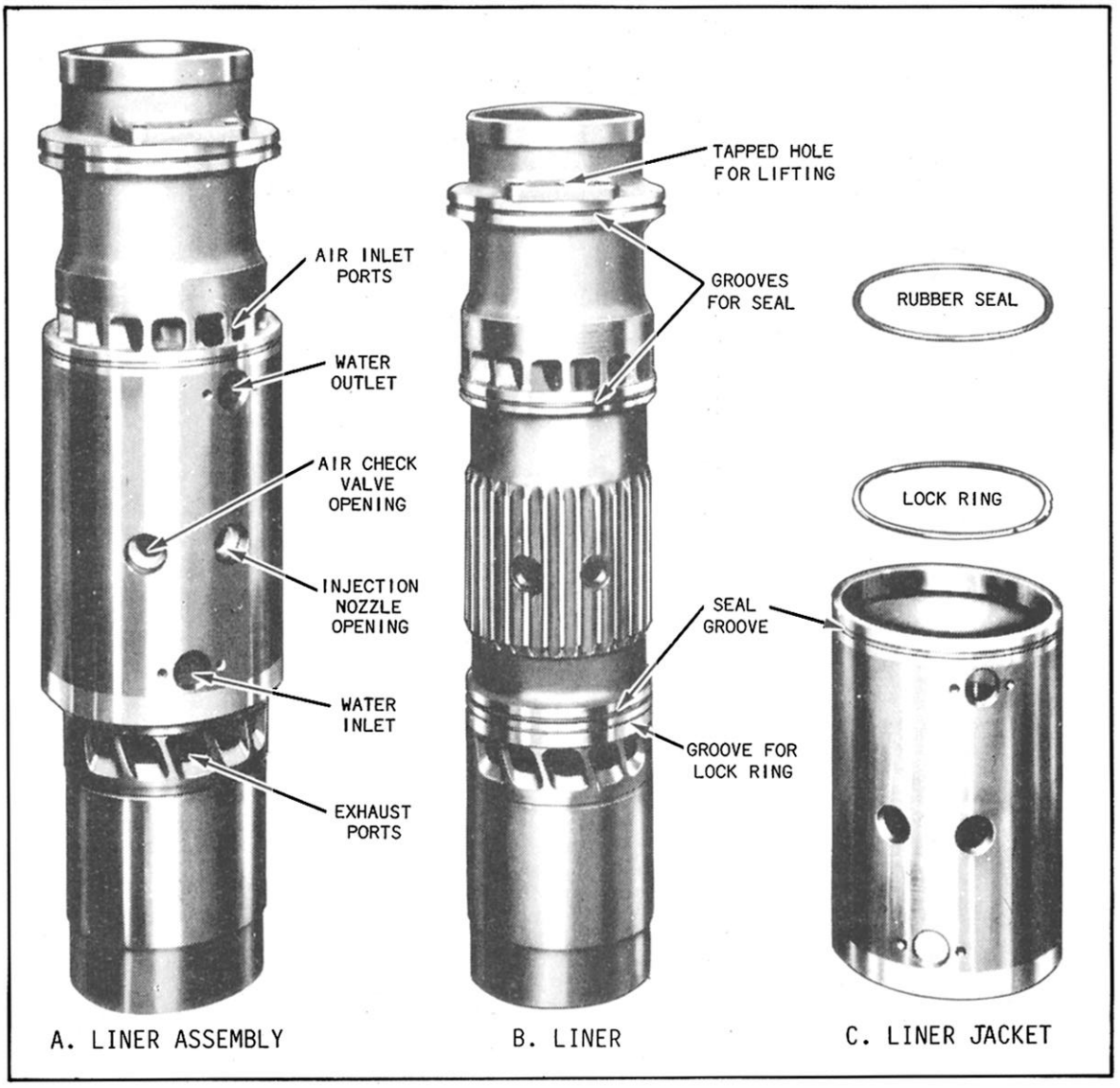
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Figure 3-12.—A brazed-on water-jacket cylinder liner (General Motors EMD 645E5).

Water-Jacket Liners

A cylinder sleeve of the water-jacket type has its own coolant jacket as an integral part of the liner assembly. The jacket may be brazed on (fig. 3-12), cast on (fig. 3-13), shrunk on, or sealed on (fig. 3-14) the liner. The liner shown in figure 3-12 is a brazed-on jacket type with a separate water jacket brazed onto the cylinder liner. In this type of liner, the inlet water circulates around the bottom of the liner. The water then progresses upward and discharges through drilled passages at the top of the liner into the cylinder head. Seals are placed around each drilled water passage so that the water passages will be watertight when the cylinder head is installed.

The water-jacket liner shown in figure 3-13 is of the cast-on jacket type. The water jacket is formed by the inner and outer walls of the liner. Ports divide the water space into lower and upper spaces, which are connected by vertical passages between the ports. The flow path for cooling in this liner is basically the same as in the brazed type of liner.



75.28

Figure 3-14.—A water-jacket cylinder liner assembly with a sealed-on jacket.

The water-jacket liner shown in figure 3-14 (view A) is of the sealed-on jacket type. This assembly consists of two components, the liner (view B) and the liner jacket (view C). The cylinder liner is sealed within the liner jacket by upper and lower O-rings. The liner (view B) is constructed with vertical ribs in the middle, between the inlet and exhaust ports. These ribs direct the water travel upward, absorbing heat from this part of the cylinder. Midway up the liner, openings are provided for the two injection nozzles, an air start check valve, and a cylinder relief valve. Additional information on liners can be found in *Naval Ships' Technical Manual,* chapter 233.

CYLINDER HEADS

The liners or bores of an internal-combustion engine must be sealed tightly to form the combustion chambers. In Navy engines, except for engines of the opposed-piston type, the space at the combustion end of a cylinder is formed and sealed by a cylinder head that is a separate unit from the block or liner.

A number of engine parts that are essential to engine operation may be found in or attached to the cylinder head. The cylinder head for a 4-stroke cycle engine will house intake and exhaust valves, valve guides, and valve seats; whereas for

a 2-stroke cycle engine, the head will carry many of the same parts with the exception of the intake valves. Rocker arm assemblies are frequently attached to the cylinder head. The fuel injection valve is almost always in the cylinder head or heads of a diesel engine, while the spark plugs are always in the cylinder head of gasoline engines. Cylinder heads of a diesel engine may also be fitted with air starting valves, indicator cocks, and safety valves.

The design and material of a cylinder head must be such that it can withstand the rapid changes of temperature and pressure that take place in the combustion space and the mechanical stress that results from the head being bolted securely to the block. Cylinder heads are made of heat-resistant alloy cast iron or aluminum alloy.

The number of cylinder heads found on diesel engines varies considerably. Small engines of the in-line cylinder arrangement use one head for all cylinders. A single head may cover all the cylinders in each bank in some V-type engines. Large diesel engines generally have one cylinder head for each cylinder, although some engines use one head for each pair of cylinders.

A cylinder head of the type used to seal all cylinders of one bank of a V-type block is shown in figure 3-15. The cylinder head, over each bank

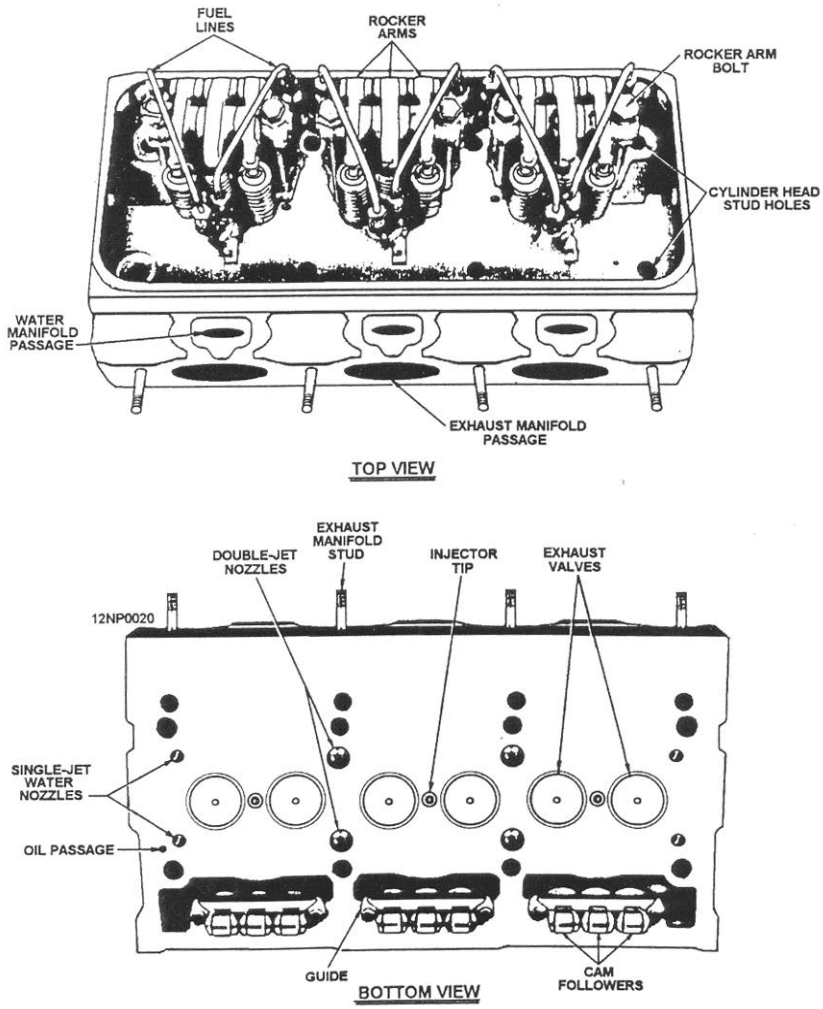


Figure 3-15.—A multiple cylinder head for a V-type engine.

of cylinders, is a one-piece casting which can be removed from the engine as an assembly containing such moving parts as the cam followers and guides, push rods, rocker arms, exhaust valves, and fuel injectors. The cylinder head shown in views A, B, and C of figure 3-16 is used when one cylinder head is required for each cylinder. The cylinder head is made of high-strength, cast-iron alloy with specially designed cast passages for water and exhaust gases. Drilled holes (view C) at the bottom of the cylinder head match the water discharge holes in the liner. Other passages in the cylinder head line up with mating elbows in the cylinder block to conduct exhaust gases through the water manifold to the exhaust manifold. Another opening located in the center of the cylinder head (view A) is where the fuel injector is installed.

Another cylinder head of the type used to seal one cylinder of a block is shown in figure 3-17. This cylinder head is different in construction compared to the heads we have discussed. The cylinder heads shown in figures 3-15 and 3-16 must be removed from the block before the exhaust valves can be serviced. The cylinder head in figure 3-17, however, features a caged design that allows for replacement of the exhaust valves and seats in minimal time without removal of the secured cylinder head. When the intake valves require servicing, the cylinder head must be removed from the block. Additional information on valves is contained in chapter 4 of this manual.

CYLINDER HEAD STUDS AND GASKETS

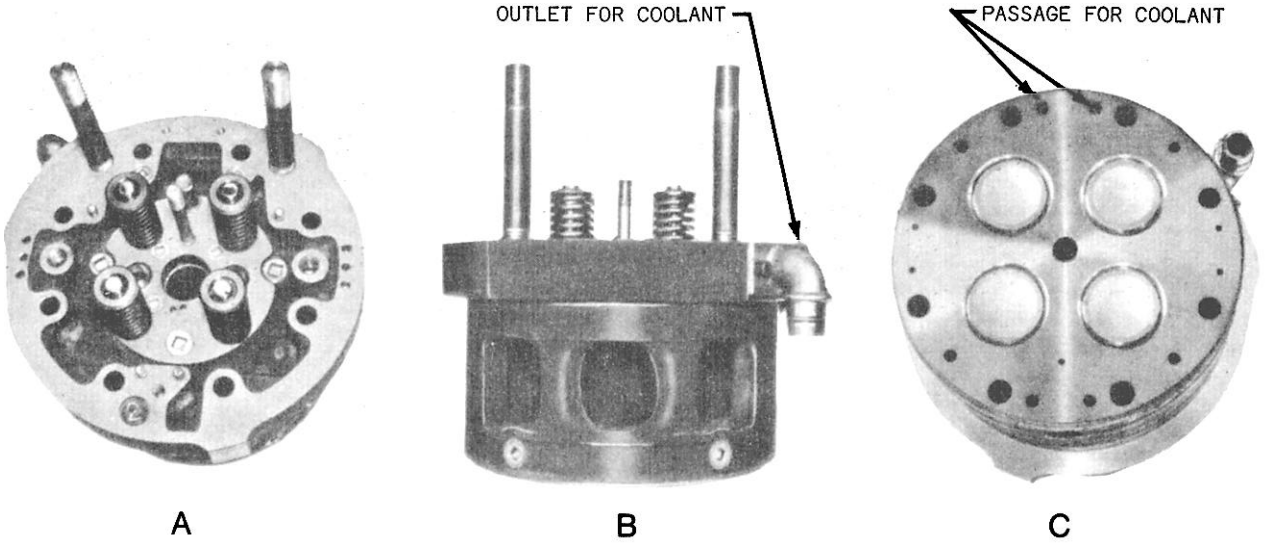
In many engines, the seal between the cylinder head and the block depends principally upon the integrity or smoothness of the metal surfaces, the gaskets, and the tightness of the fasteners.

Studs

Cylinder head studs are manufactured from round rod, generally of alloy steel. Threads are cut on both ends. The threads that screw into the block are generally made with finer threads than those on the nut end. This design allows for a tighter fit in the block, which keeps the stud from loosening when the stud nut is removed.

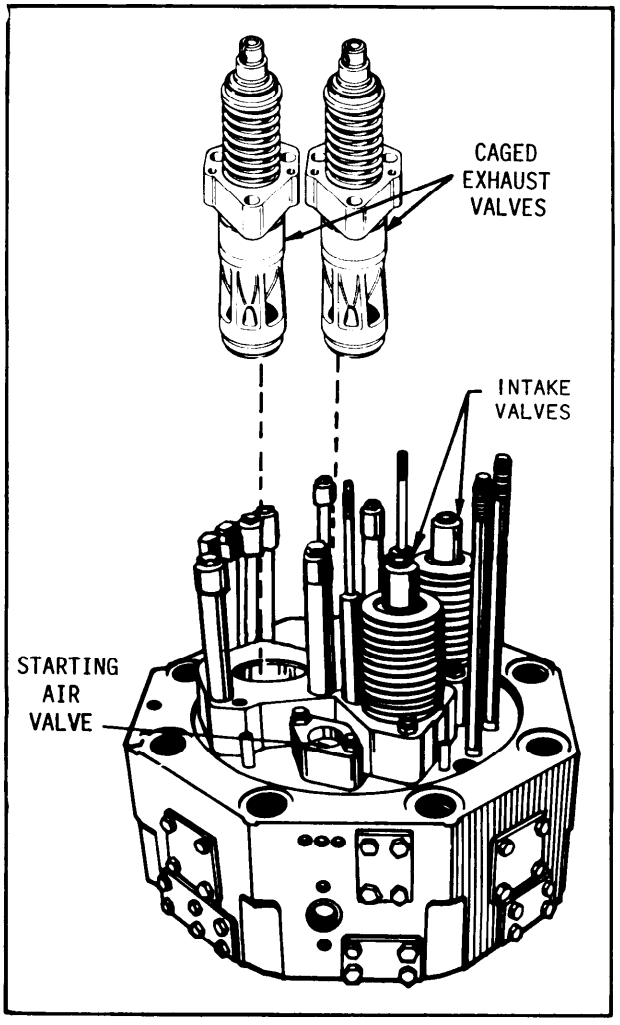
Figure 3-18 illustrates a sequence for the tightening of fasteners for two types of cylinder heads. This sequence is not a hard and fast rule but can be followed in the absence of more specific information. Fasteners are generally tightened sufficiently to seat the cylinder head lightly (finger tight). At least two or three rounds of tightening should be made before all fasteners are brought up to the specified torque for the studs being used.

When installing studs and nuts, you should carefully clean the threads of the studs and the nuts by wire-brushing and applying an approved solvent. Do not forget to inspect the blind holes and threads in the block. Cleaning will minimize



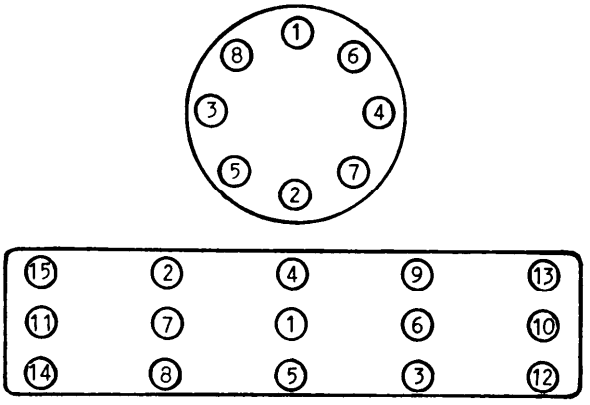
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Figure 3-16.—A General Motors EMD 645E5 cylinder bead.



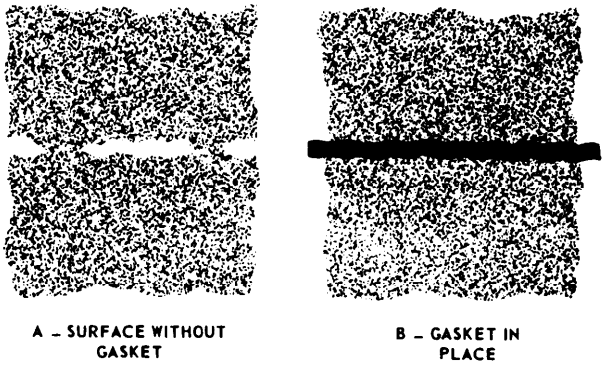
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Figure 3-17.—A Colt-Pielstick cylinder head with valves.



75.40

Figure 3-18.—Sequence for tightening cylinder head studs (fasteners).



75.41

Figure 3-19.—The principle of a gasket.

wear and distortion of threads resulting from dirt. It will also increase the accuracy of the torque wrench readings. (It should be obvious that a higher torque wrench reading will be necessary to reach required tension when the threads are dirty than when they are clean.) Caution: Torque specifications are normally for clean, dry threaded fasteners. Torque specifications for lubricated fasteners are not the same as those for dry fasteners.

All stud nuts should be tightened equally and according to specifications given in the manufacturer's technical manual. Overtightening is as undesirable as undertightening. Sometimes studs that are relatively inaccessible are neglected during the periodic checks for tightness. Such an oversight may result in studs coming loose and failing.

Gaskets

Even though gasket design is quite varied, all gaskets have compressibility as a common property. The principle by which this property is put to use in forming a seal between mating parts is illustrated in figure 3-19.

The mating surfaces of a cylinder block and head may appear to be quite smooth; however, if these surfaces are highly magnified, existing irregularities can be seen. Irregularities such as those illustrated in view A of figure 3-19 are sufficient to allow leakage of the combustion gases, oil, or coolant unless some compressible material is used between the mating surfaces (view B).

Materials used in the manufacture of gaskets vary as widely as does gasket design. Gaskets can be made from copper and other relatively soft metals, such as laminated steel sheets, fiber, cork, rubber, and synthetic rubber, and a combination of materials, such as copper and asbestos. Combinations of gaskets, seal rings, and grommets or similar devices (fig. 3-20) may be used in cylinder assemblies. These combinations serve to prevent the leakage of oil, water, and combustion gases between the cylinder block and the head. For additional information on gaskets, refer to *Naval Ships' Technical Manual*, chapter 078.

ENGINE MOUNTINGS

The devices, such as mountings, in an engine that serve to secure the engine in place are not an actual part of the engine. However, a discussion of these devices is included in this chapter since they are obviously essential for installation purposes and play an important part in reducing the possibility of damage to the engine and to the machinery driven by the engine.

Different terms are used in identification of the devices that secure an engine to a ship. Terms such as base, subbase, bed, frame, rails, mountings, and securing devices appear in various engine technical manuals. To avoid confusion with our discussion on the engine base, we will use the word *subbase* to refer to the supporting and connecting pedestal between an engine and the hull structure of a ship. We will also describe two devices used to attach the subbase for a diesel engine to the hull of a ship.

SUBBASE

The size and design of the subbase depends on the engine involved and its use. In many installations, the engine and the mechanism that it drives are mounted on a common subbase. One advantage of mounting both units on a common subbase is that misalignment is less likely to occur than when the units are mounted separately. Diesel-driven, electrical generator sets are usually secured to a common subbase.

A different type of mounting or subbase involves the use of handfitted chocks, or blocks, between the engine and the supporting structure of the ship. Bolts are the devices used to secure the engine rigidly in place and to maintain alignment.

SECURING DEVICES

The securing devices that are used to fasten a subbase to the structure of a ship may be classified, in general, as rigid or flexible. Propulsion engines are secured rigidly so that misalignment will not occur between the engine, reduction gear (or other driven mechanisms), and the propeller shaft. Engines that drive auxiliary equipment such as fire pumps or generators may be secured by either rigid or flexible devices.

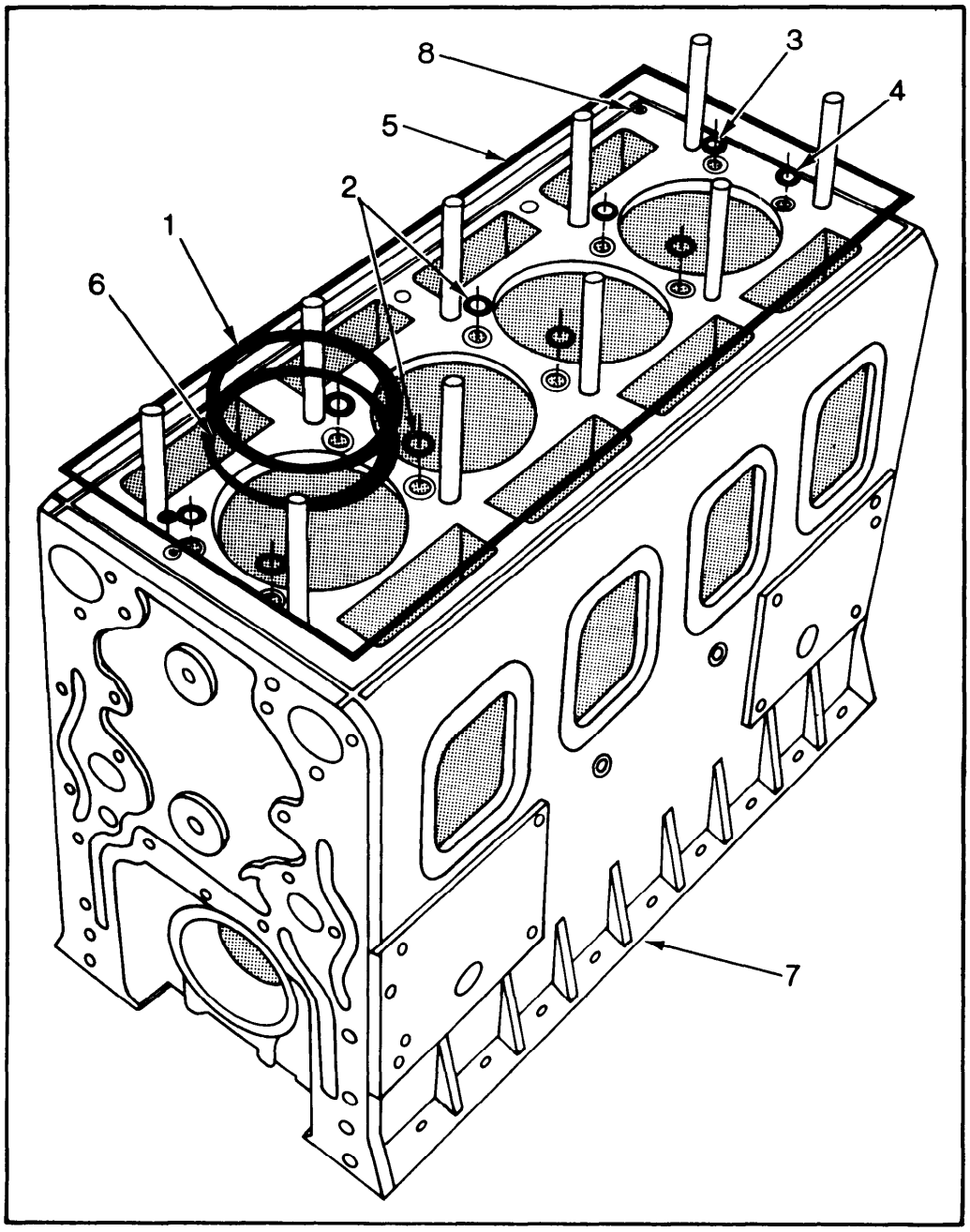
In installations where rigidity is of prime importance, bolts are used as the securing devices. Flexible securing devices are generally used between the subbase of a generator set and the structure of the ship. Flexible devices may also be placed between the engine and the subbase. Although flexible devices are not necessary for every type of generator set, they are desirable for generator sets that are mounted near the side of the hull. In this case, flexible devices will serve to reduce vibration. Flexible devices also aid in the prevention of damage from shock loads imposed by external forces.

Flexible securing devices are of two general types: vibration isolators and shock absorbers. Both types may be incorporated in a single securing device.

Vibration Isolators

Vibration isolators are designed to absorb the forces of relatively minor vibrations that are common to operating diesel engines. Such vibrations are referred to as high-frequency, low-amplitude vibrations, and they result from an unbalanced condition created by the motion of operating engine parts.

Isolators can be equipped with coil springs or flexible pads to absorb the energy of engine vibrations. An isolator reacts in the same manner, whether it is of the spring type or the flexible pad type. Examples of both types



1. Gasket—cylinder liner compression
2. Seal ring—water hole
3. Seal ring—water hole end
4. Seal ring—water and oil hole
5. Seal—cylinder head oil
6. Insert—cylinder liner
7. Block—cylinder
8. Plug—cylinder head oil seal cover

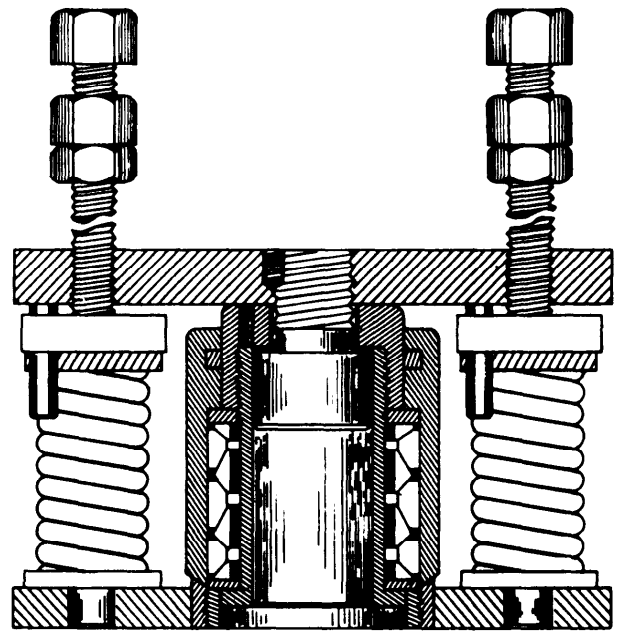
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Figure 3-20.—Cylinder head gaskets and oil and water seals.

of isolators are shown in figure 3-21 (views A and B). Four or more spring-type isolators, shown in view A of figure 3-21, are used to support a generator set. The flexible pad or "rubber sandwich" type of isolator, shown in view B, is used for the mounting of small Navy engines. The rubber block in the isolator shown in view B is bonded to steel plates that are fitted for attachment to the engine and the subbase.

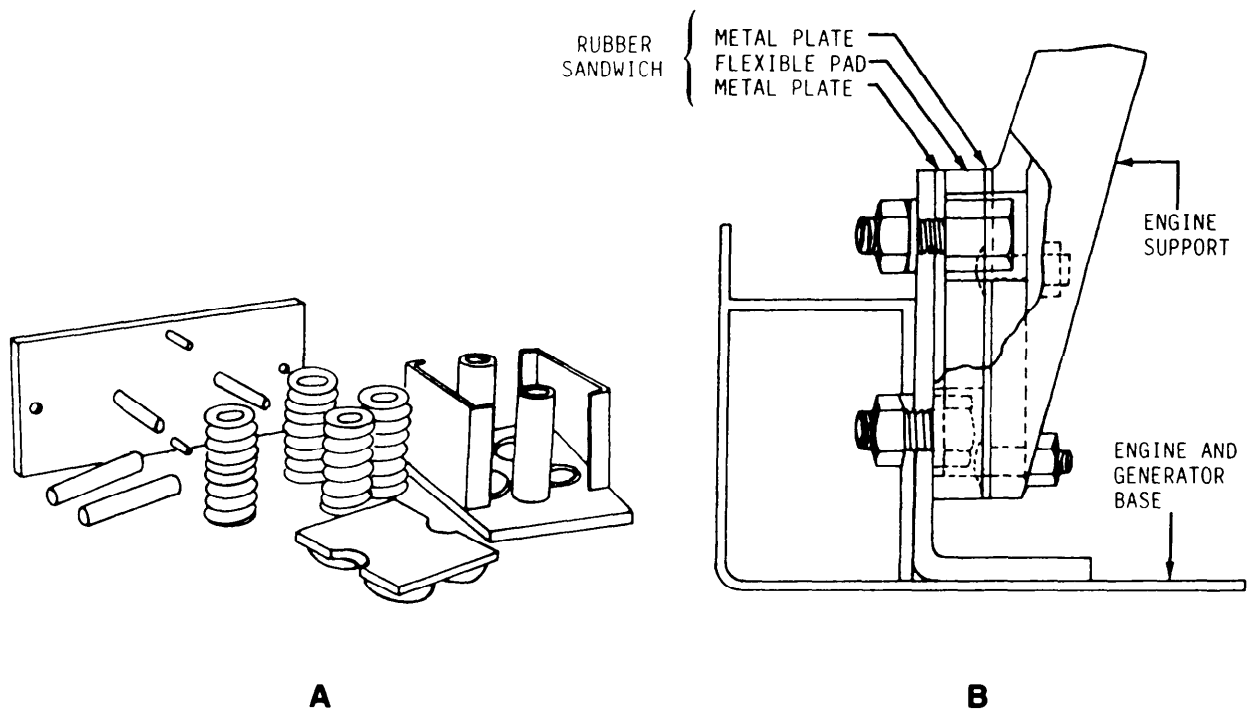
Shock Absorbers

Shock absorbers are used to absorb vibration forces that are greater than those originating in the engine. Such forces, or shock loads, may be induced by the detonation of depth charges, torpedoes, bombs, and other devices. The shock absorber operates on the same principle as the vibration isolator but provides additional support to protect the engine against severe shock loads. A type of shock absorber in use in the Navy is illustrated in figure 3-22.



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Figure 3-22.—Shock absorber.



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Figure 3-21.—Vibration isolators.

SUMMARY

An understanding of the function or purpose of each part of a diesel engine is fundamental to safe operation and effective engine maintenance. This chapter has provided a description of the principal stationary parts and how these parts function as a group to maintain the major moving parts of the engine in their proper relative positions. The stationary parts include items such as the subbase, block or frame, oil pan, bearings, end plates, and cylinder assemblies. Except for the cylinder assemblies and bearings, these parts, as a group, are sometimes referred to as the frame, which is the load-carrying part of the engine. Cylinder assemblies complete the structural framework of an engine. In addition to forming the combustion space, parts of a cylinder assembly serve as a mounting place for other engine parts that are essential to engine operation.

You should be familiar with the differences in design of these parts, as well as with the function of each part and how each part is related to the other parts of the engine. If your knowledge is weak in any of these areas, go back and review the information in this chapter before proceeding to chapter 4.

CHAPTER 4

PRINCIPAL MOVING AND RELATED COMPONENTS

Many of the principal parts that are within the main structure of an engine are moving parts. These moving parts convert the thermal energy released by combustion in the cylinder to mechanical energy, which is then available for useful work at the crankshaft.

In this chapter we will discuss the moving and related parts that seal and compress gases in the cylinder and transmit the power developed in the cylinder to the crankshaft. Other parts that serve to develop and transmit power, such as timing gears and gear trains, are discussed in later chapters of this manual. After reading the information in this chapter, you should be able to recognize and describe the basic types, functions, and characteristics of valves, valve-actuating mechanisms, piston and rod assemblies, crankshafts, flywheels, and jacking gears.

VALVE-ACTUATING MECHANISMS

Valve mechanisms may vary considerably in construction and design, even though the function remains the same. The basic types of valve mechanisms are described briefly in *Fireman,* NAVEDTRA 14104. We will go into more detail in the following paragraphs.

ACTUATING MECHANISM, as used in this chapter, is that combination of parts that receives power from the drive mechanism and transmits the power to the engine valves. In order for the intake and exhaust valves, fuel injection, and air start to operate, there must be a change in the type of motion. The rotary motion of the camshaft must be changed to a reciprocating motion. The group of parts that, by changing the type of motion, causes the valves of an engine to operate is generally referred to as the VALVE-ACTUATING MECHANISM. A valve-actuating mechanism may include the camshaft, cam followers, pushrods, rocker arms, and valve springs. In some engines, the camshaft is so located that pushrods are not needed. In such engines, the cam follower is a part of the rocker arm.

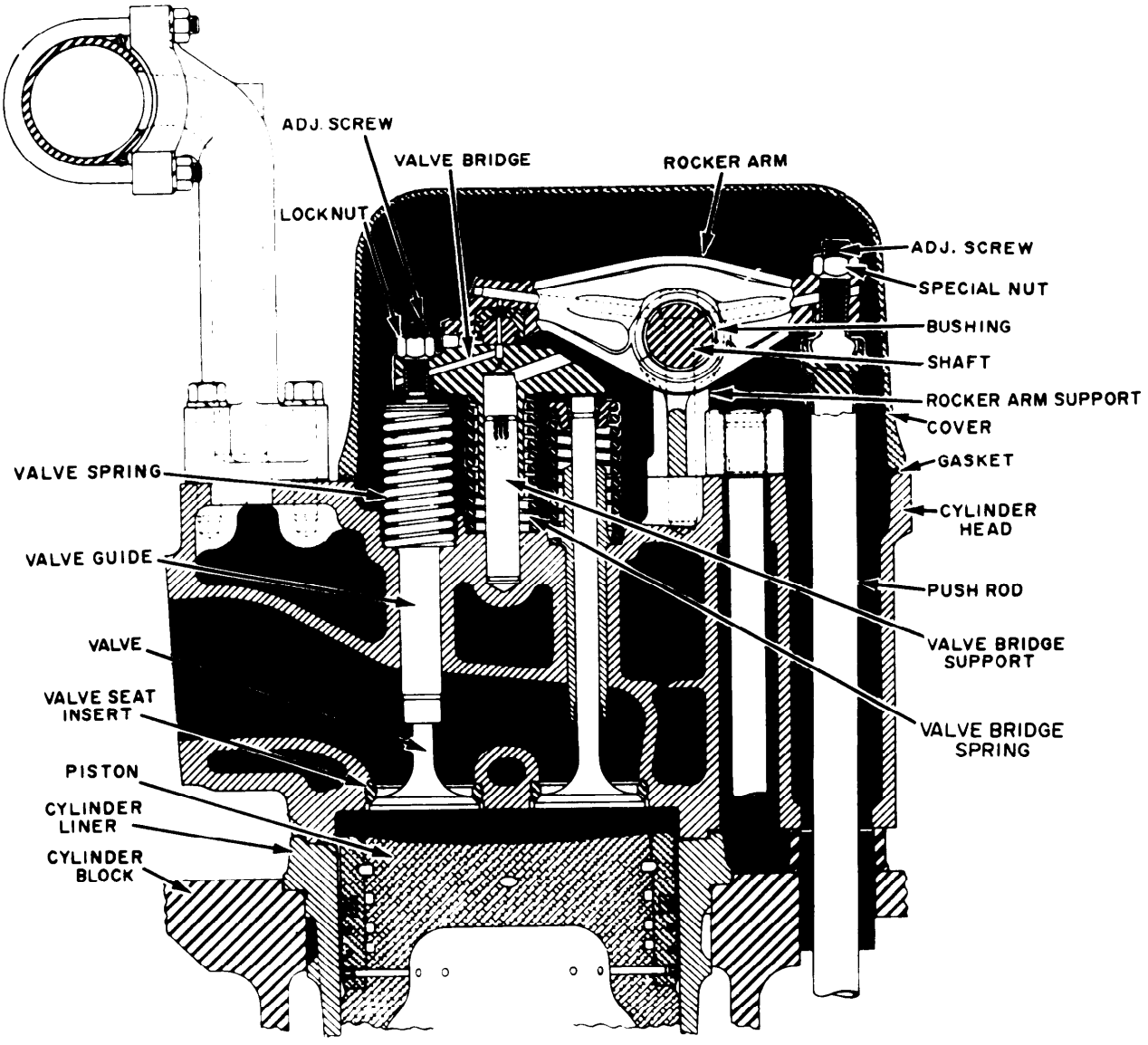
VALVES

The intake and exhaust valves used in internal-combustion engines are of the poppet type. Poppet valves have heads with cone-shaped or beveled edges and beveled seats, which give the valves a self-centering action. (See figs. 4-1 and 4-2.)

Exhaust valves are usually made of silicon-chromium steel or steel alloys. Usually, there is a high content of nickel and chromium included in the steel or alloy so that the valves can resist corrosion caused by high-temperature gases. A hard alloy, such as Stellite, is often welded to the seating surface of the valve face and to the tip of the valve stem. The hard alloy increases the wearing qualities of the surfaces, which make contact when the valve closes. Low-alloy steels are generally used for intake valves because these valves are not exposed to the corrosive action of the hot exhaust gases. Consequently, intake valves are capable of longer periods of trouble-free operation.

In some exhaust valves, sodium is used as an agent for cooling the valves. Sodium-filled poppet valves are provided with a chamber that is formed by the hollow stem that extends well up into the valve head. At operating temperatures, the sodium becomes a liquid and splashes up and down inside the hollow valve stem. The sodium is an effective agent that serves to transfer the heat from the hot exhaust valve head through the stem and valve guides and to the engine cooling system. Although sodium-filled exhaust valves are effective, they are not commonly used.

Valve seat inserts (fig. 4-1) are provided in most diesel engine cylinder heads so that valve seat life is extended. Valve seat inserts also have the advantage of being replaceable. Several different types of materials are used in the manufacture of valve seat inserts. Intake valve seats are



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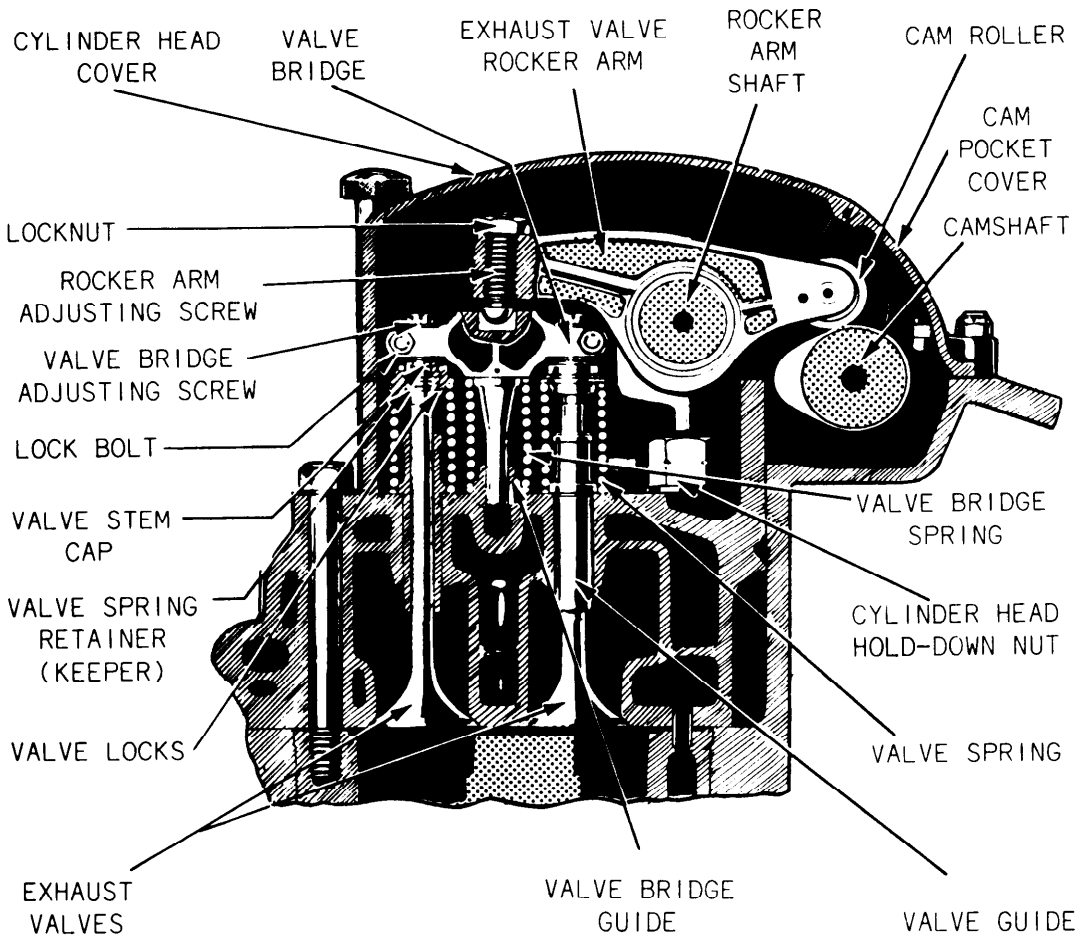
Figure 4-1.—Valve operating mechanism (Alco 251-C).

manufactured from special alloys of cast iron. Exhaust valve seats are made from stellite and hardened chrome vanadium steel. Valve seat inserts are installed with an interference fit.

Replaceable valve guides (fig. 4-1) are provided for most diesel engines. Replaceable valve guides are made of a cast iron alloy that has a superior wearability and is more corrosion resistant than the alloy that is used in the cylinder head. Replaceable valve guides not only provide a guide and bearing for each valve stem but also aid in conducting heat from each valve stem to the water jacket that surrounds the guide.

Valve Springs

Valve springs are mechanisms that serve to close the valves. Valve springs are made of highly tempered round steel wire that is wound in a spiral coil. Only a small percentage of the spring force is required to keep the valve tight on the valve seat of the head. The majority of the spring force is used to keep the pushrod (fig. 4-1) or the rocker arm (fig. 4-2) in contact with the cam while the valve is being opened and closed. This force of the valve spring prevents the bouncing or fluttering of the valve that would otherwise



75.24.1

Figure 4-2.—Valve operating mechanism with valve bridge (General Motors 16-278A).

occur from the rapid motion of the opening and closing of the valve at high speeds. So that the spring can have sufficient force, it is always compressed when it is installed. (It is further compressed, of course, whenever the valve is opened.)

Valve Spring Retainers

Valve springs are mounted between supports. These supports, commonly referred to as SPRING SEATS, are located at the ends of the spring. The LOWER SPRING SEAT may be simply a recess in the top of the cylinder head, or a steel washer that rests on top of the cylinder head, and is shaped to fit the bottom coil of the spring. The UPPER SPRING SEAT, called the SPRING RETAINER, is a steel washer that is shaped to fit the top of the spring. The upper spring seat is attached to the top of the valve stem by removable fastenings commonly known as valve keepers.

Valve Keepers

A widely used type of valve spring retainer is provided with a conical recess in the upper seat. The valve stem is locked in the recess by means of a conical split collar, called a LOCK or KEEPER. This collar fits around the stem and into one or more grooves turned in the valve stem (fig. 4-2).

Valve Rotators

On some engines that are subjected to long periods of idle or light loads, valve rotators may be used to keep the valves from sticking due to combustion deposits (carbon) forming on the valves. Valve rotators also serve to extend the life of the valves and valve seats by ensuring an even

distribution of wear on the valve stem and valve guide. Without rotation, the combustion deposits that form on the valve stem, face, and seat would be cleaned off on one side only. Standard valve spring seats allow rotation but do not assure it. With controlled rotation, carbon deposits are cleaned off all around the valve stem, face, and seat. Valve rotators may be installed below or above the valve spring according to design requirements.

CAMSHAFTS

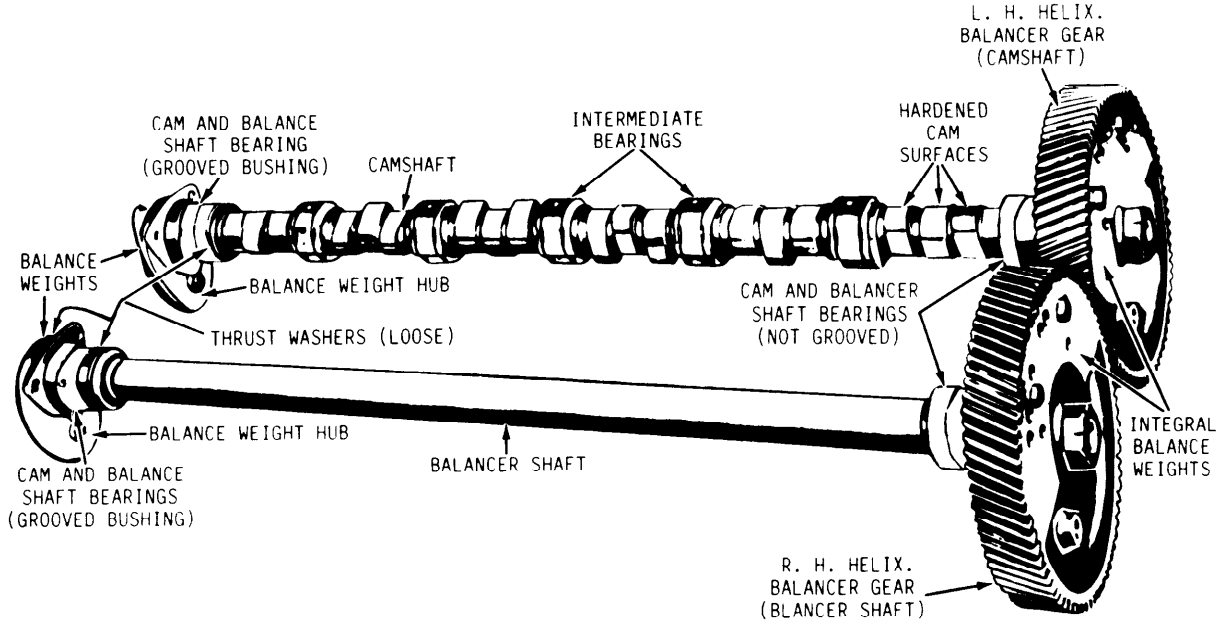
A camshaft is a shaft with eccentric projections called cams. The camshaft of an engine is designed to control the operation of the valves and fuel injection pump usually through various intermediate parts. On some engines, a balance shaft is used to counterbalance the rotation of the weighted camshaft and to stabilize the oscillatory impulses developed within the engine. (See fig. 4-3 for the location of the balance shaft and weights in the General Motors 6-71.)

The camshaft may be constructed in several ways. It can be forged in one piece (fig. 4-3) in which the cams themselves are integral to the shaft. (This is the most common design in small to medium engines.) A camshaft of a large engine may consist of a shaft with separate forged steel or cast iron cams keyed and shrunk on the camshaft. Another construction used on larger engines is a camshaft that is made from sections which are bolted together. Some engines have two camshafts and others have only one, depending on the design of the engine.

To reduce wear and to withstand repeated shock action, camshafts are made of low-carbon alloy steel with the cam and journal surfaces carburized (case-hardened) before the final grinding is done.

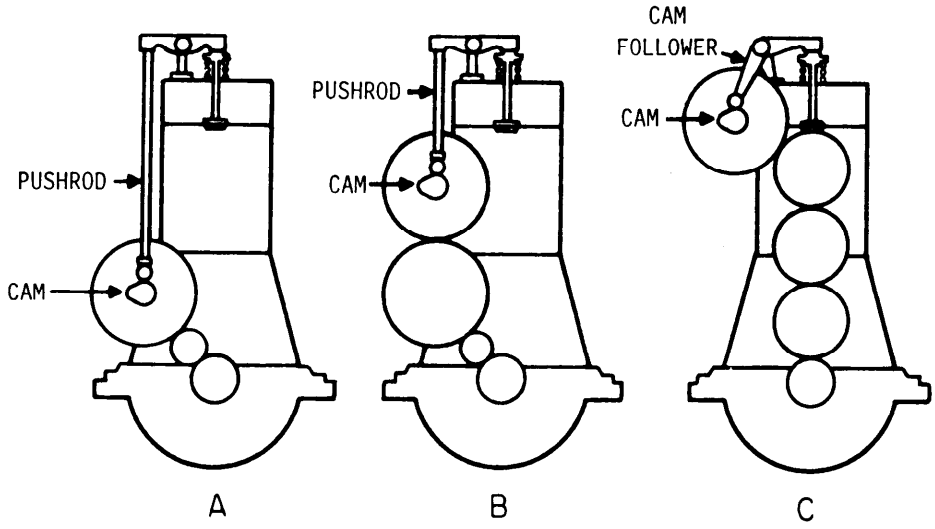
The cams are arranged on the shaft so that the proper firing order of the cylinders served can take place. If one cylinder is properly timed, the remaining cylinders are automatically in time. All cylinders will be affected if there is a change in timing. The shape of the cam determines the point of opening and closing, the speed of opening and closing, and the amount of the valve lift.

The camshaft in a 4-stroke cycle diesel engine carries the cams for actuating the intake and exhaust valves. In addition, the camshaft may carry cams for fuel injection equipment or air starting valves. In a 2-stroke cycle diesel engine there is no requirement for an intake cam due to the use of intake ports.



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Figure 4-3.—Cam and balancer shaft assemblies (General Motors 6-71).



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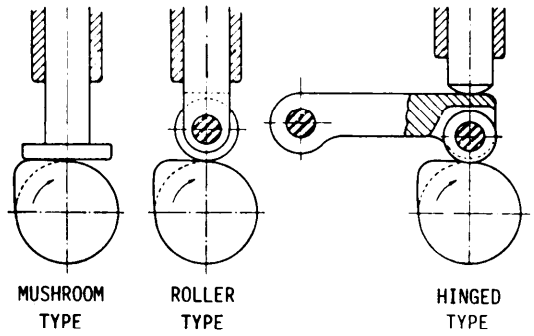
Figure 4-4.—Various camshaft locations.

The location of the camshaft differs in various engines. The camshaft may be located low (near the crankshaft) and may use long pushrods (fig. 4-1), or the camshaft may be located at the cylinder head level without pushrods (fig. 4-2). Variations of camshaft location are shown in figure 4-4.

Cam Followers and Lash Adjusters

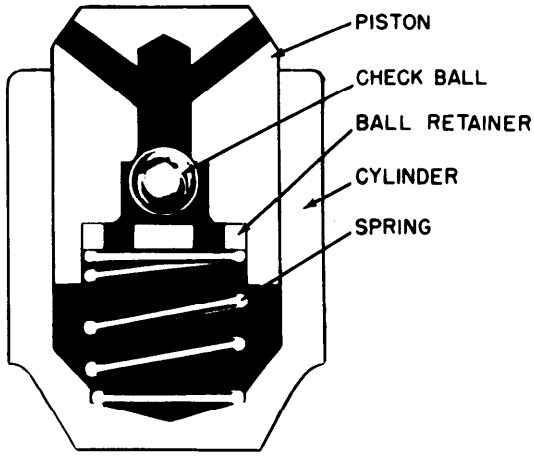
In the valve-actuating mechanism, cam followers change the rotary motion of the camshaft to reciprocating motion. This action opens the valves. Cam followers ride the flat of the cam and are raised, as the cam rotates, by the high side of the cam and lowered by tension from the valve spring. Three types of cam followers that are used in internal-combustion engines are shown in figure 4-5.

Hydraulic valve lifters (lash adjusters) are used on some engines to avoid the necessity of a clearance otherwise needed in the valve gear to allow for expansion resulting from temperature changes. Hydraulic valve lifters also eliminate the need for manual adjustment to take care of the wear at various points of the valve gear. They may be installed on the rocker arms, valve bridge, or cam follower. Figure 4-6 shows a larger sectional



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Figure 4-5.—Cam followers.



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Figure 4-6.—Hydraulic lash adjuster.

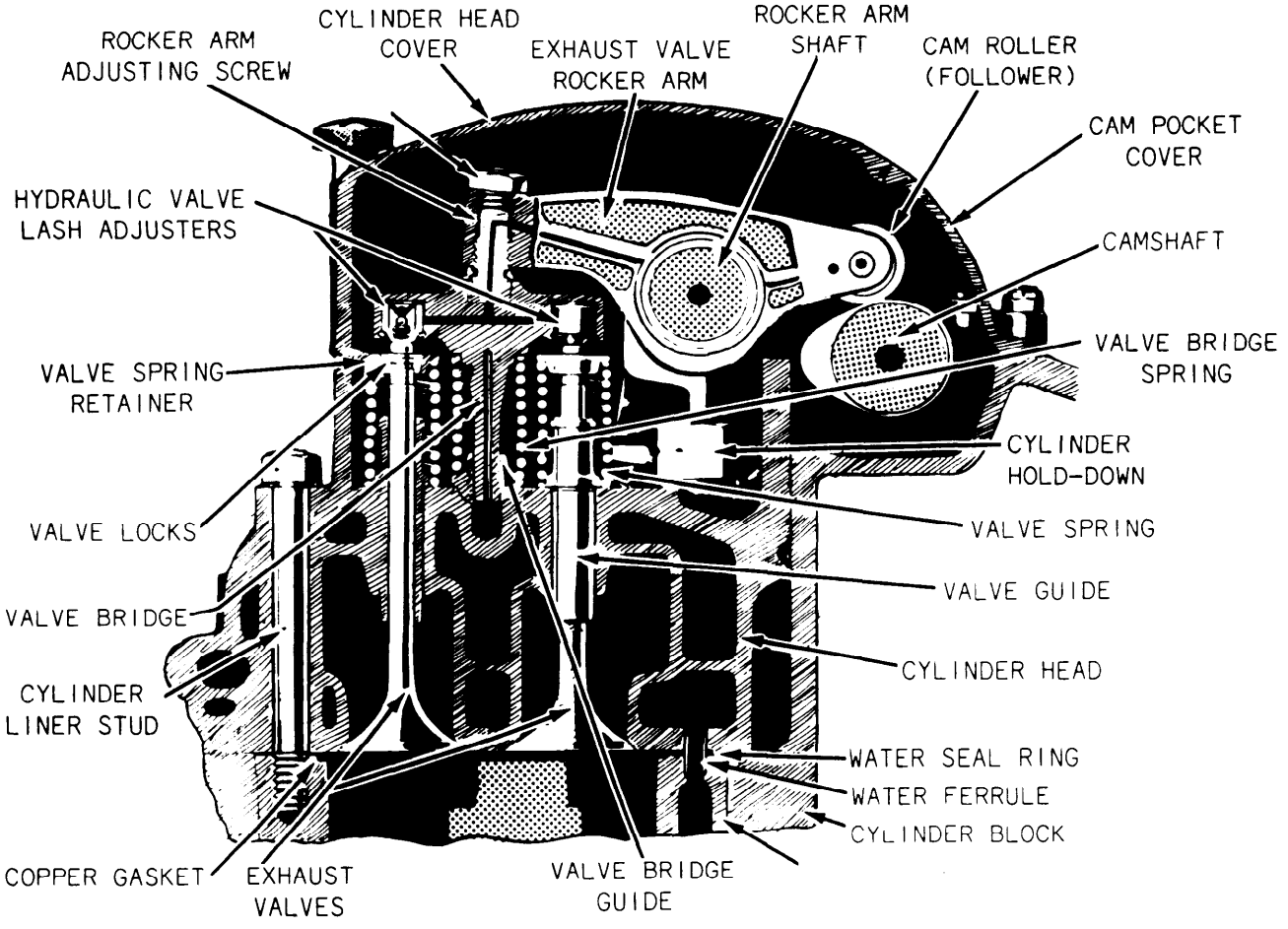
view of the hydraulic lash adjuster that is shown in figure 4-7.

Hydraulic lash adjusters may vary in design but generally consist of such basic parts as a cylinder, a piston or plunger, a ball check valve, and a spring. As precision parts, hydraulic valve lifters or adjusters require special care in handling and must be kept exceptionally clean. Abrasive materials must not be allowed to enter a hydraulic lash adjuster if the lash adjuster is to perform its function satisfactorily.

Rocker Arms and Pushrods

Rocker arms (levers) are part of the valve-actuating mechanism. A rocker arm is designed to pivot on a pivot pin or shaft that is secured to a bracket. The bracket is mounted on the cylinder head. One end of a rocker arm is in contact with the top of the valve stem, and the other end is actuated by the camshaft.

In some installations where the camshaft is located near the cylinder head, the rocker arm may be actuated from the cam by the use of cam followers. Figure 4-7 illustrates a design of this type in which a cylinder head of the GM 16-278A is fitted with three rocker arms or levers. (Fig. 4-7 is a cutaway view with one rocker arm shown.) The two outer arms operate the exhaust valves, and the inner arm operates the fuel injector. Since there are four exhaust valves per cylinder, each exhaust rocker arm must operate a pair of valves through a valve bridge. The valve bridge enables the rocker arm to operate two valves simultaneously. The valve bridge in this engine is made of forged steel and has a hardened ball socket into which the ball end of the rocker arm adjusting screw fits. The valve bridge has two arms, each of which fits over an exhaust valve. The valve bridge spring keeps valve bridge tension off the valve stems until the bridge is actuated by the rocker arm. When the valve end

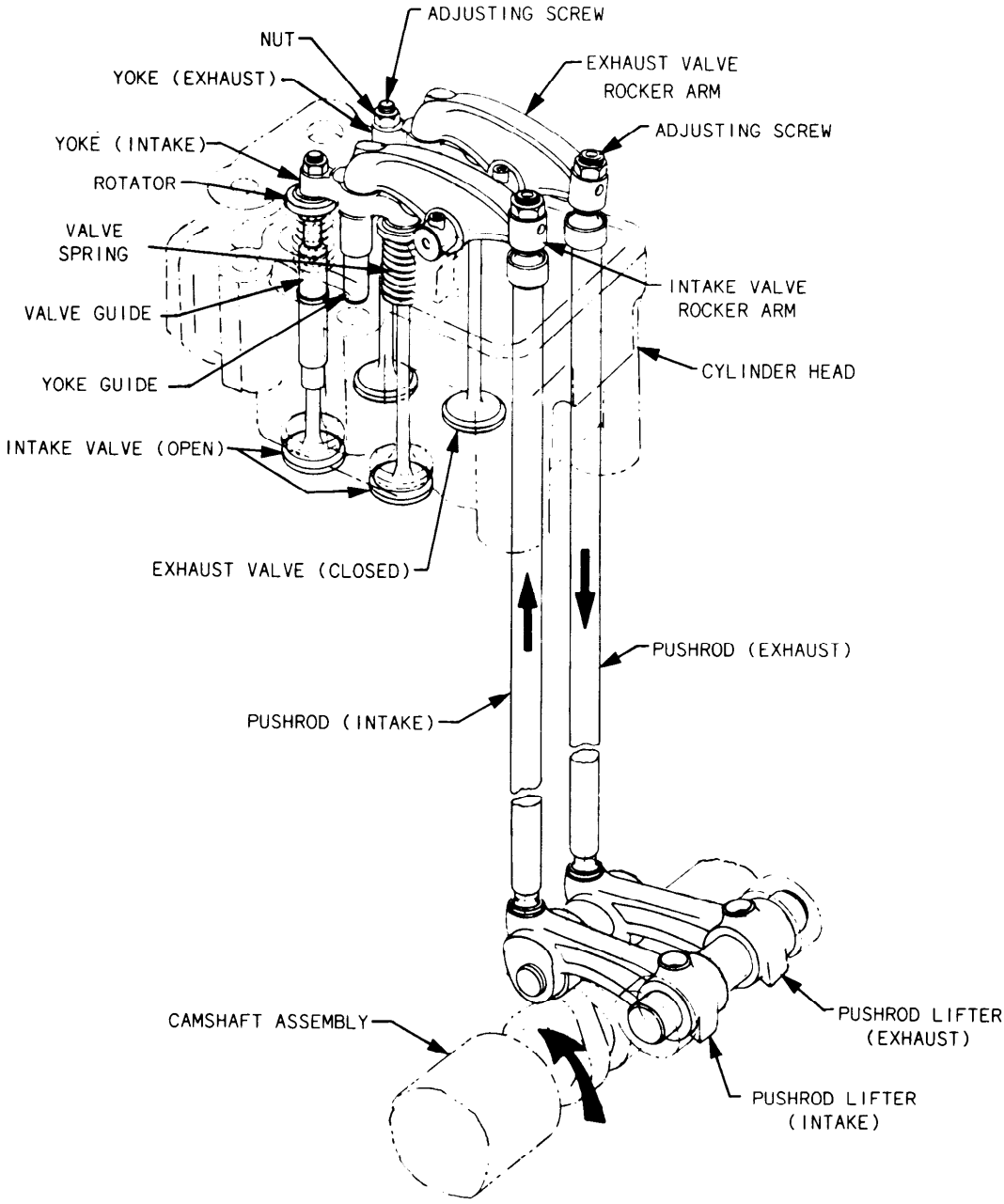


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Figure 4-7.—Valve gear (General Motors 16-278A).

of the rocker arm is forced down by the cam action, the valve bridge moves down, compressing the valve springs and opening the valves. By the time the action of the cam lobe has ceased, the valve springs will have closed the valves. The valve operating mechanism shown in figure 4-7 is representative of those in which the location of the camshaft eliminates the need for pushrods. (Note that the lobes of the cam come in direct contact with the rocker arm cam rollers.)

In installations where the camshaft is located below the cylinder head, the rocker arms are actuated by pushrods. (See fig. 4-8.) The lifters (cam followers) have rollers which are forced by the valve springs to follow the profiles of the cams. The pushrod transmits the motion from the



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Figure 4-8.—Valve rocker arm operation (ALCO).

roller type of lifter for intake and exhaust valve operation and are activated by their respective intake and exhaust lobes of the camshaft. The intake and exhaust valves in figure 4-8 are operated by mechanisms similar to those represented in figure 4-7 with two exceptions. The unit in figure 4-8 has no design requirement for an injector rocker arm because of the type of fuel system used. Also, the unit in figure 4-8 is a 4-stroke cycle unit and requires both an intake valve rocker arm and an exhaust valve rocker arm. (You should note, however, that pushrods can be used in both 2- and 4-stroke cycle engines.)

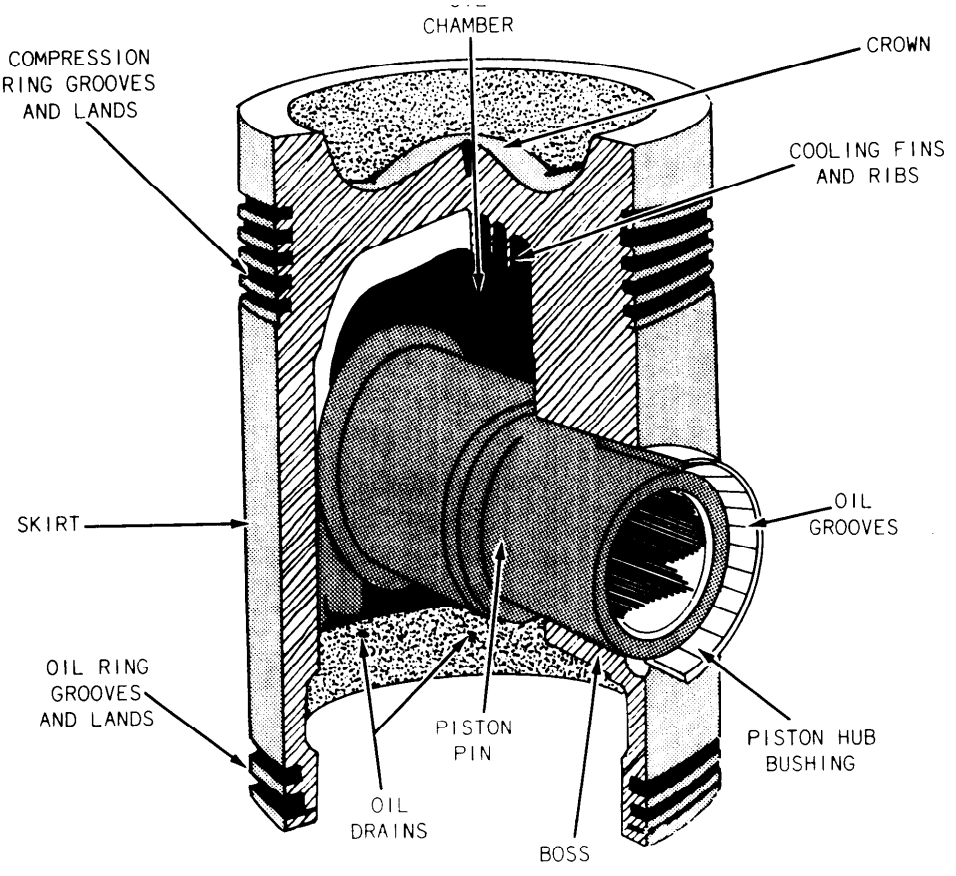
Other parts that transfer the rotary motion of the crankshaft to operate the valve-actuating mechanism as well as accessories are referred to as ENGINE DRIVE MECHANISMS. These parts will be discussed in chapter 5 of this rate training manual.

PRINCIPAL MOVING COMPONENTS

In this chapter, the PRINCIPAL MOVING COMPONENTS refer to the parts that convert the thermal energy released by combustion in the cylinder to mechanical energy. Mechanical energy then becomes available for useful work. The principal moving parts of an engine consist of the piston and connecting rod assemblies, crankshaft, bearings, and flywheel. Piston and connecting rod assemblies of an engine will include the piston, piston rings, piston pin, and connecting rod. These units and their functions in engine operation are discussed separately in the following sections.

PISTONS

As one of the major moving parts in the power-transmitting assembly, the piston must be so designed that it can withstand the extreme heat



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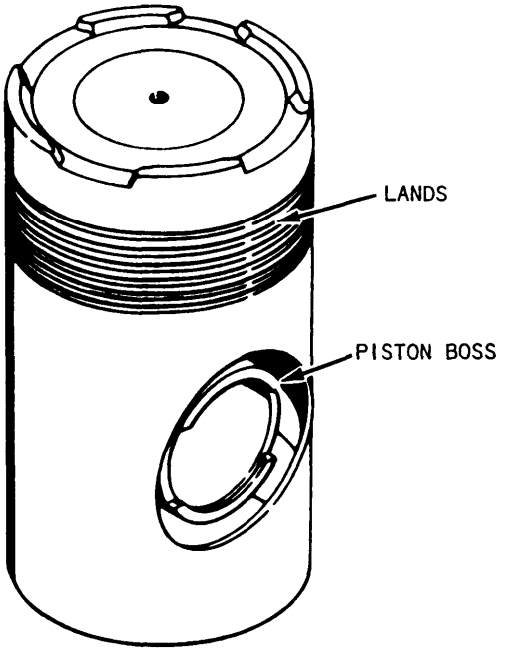
Figure 4-9.—Piston nomenclature for a trunk-type piston.

and pressure of combustion. Pistons must also be light enough to keep inertial loads on related parts to a minimum. The piston aids in sealing the cylinder to prevent the escape of combustion gases. It also transmits some of the heat through the piston rings to the cylinder wall.

Pistons have been constructed of a variety of metals—cast iron, nickel-coated cast iron, steel alloy, and aluminum alloy. Pistons of cast iron and aluminum are most commonly used at the present time. Cast iron gives longer service with little wear; it can be fitted to closer clearances, because it expands less with high temperatures, and it distorts less than aluminum. Lighter weight and higher conductivity are the principal advantages of aluminum pistons.

Cast iron is generally associated with the pistons of slow-speed engines, but it is also used for the pistons of some high-speed engines. In these pistons, the piston walls are of very thin construction, requiring additional cooling.

Pistons perform a number of functions. A piston, in addition to transmitting the force of combustion to the connecting rod and conducting the heat of combustion to the cylinder wall, may serve as a valve in opening and closing the ports of a 2-stroke cycle engine.



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Figure 4-10.—Piston (Colt-Pielstick PC 2.5).

Trunk-Type Pistons

There are two distinct types of pistons: the trunk type and the crosshead type. Variations in the design of trunk-type pistons can be seen in figures 4-9 and 4-10.

The CROWN, or head, of a piston acts as the moving surface that changes the volume of the content of the cylinder (compression), removes gases from the cylinder (exhaust), and transmits the energy of combustion (power). Generally, the crown end of a piston is slightly smaller in diameter than the skirt end. The resulting slight taper allows for expansion of the metal at the combustion end. Even though slight, the taper is sufficient so that, at normal operating temperatures, the diameter of the piston is the same throughout.

Manufacturers have produced a variety of crown designs—truncated, cone, recessed, dome or convex, concave or cup, and flat. Piston crowns of concave design are common in marine engines used by the Navy; however, other types may be encountered. An advantage of the concave shape is that it assists in creating air turbulence, which mixes the fuel with air during the last part of compression in diesel engines. Some concave types of pistons have recesses in the crown to allow room for the parts that protrude into the combustion space. Examples of such parts are the exhaust and intake valves, the air starting valve, and the injection nozzle. In some 2-stroke cycle engines, piston crowns are shaped with irregular surfaces which deflect and direct the flow of gases.

The SKIRT of a trunk-type piston receives the side thrust created by the movement of the crank and connecting rod. In turn, the piston transmits the thrust to the cylinder wall. In addition to receiving thrust, the skirt aids in keeping the piston in proper alignment within the cylinder. Some pistons are plated with a protective coating of tin which permits close fitting, reduces scuffings, and prolongs piston life. Still other pistons may be given a phosphate treatment to aid skirt lubrication. This process etches the surface and provides a nonmetallic, oil-absorbent, antifriction coating that promotes rapid break-in and reduces subsequent wear.

Most trunk-type pistons are of one-piece construction. Some trunk pistons are made of two parts and two metals; the trunk or skirt is made of cast iron or an aluminum alloy, and the crown or head is made of steel. In some pistons of this type of construction, the crown is fitted to the

trunk with a ground joint, while in others the parts are welded together.

Without GROOVES and LANDS, the piston rings cannot be properly spaced or held in position. The number of grooves and lands on a piston will vary considerably, depending on such factors as the size and the type of the piston. (See figs. 4-9 and 4-10.)

Some pistons have OIL DRAINS (small holes) in the bottom of some of the grooves (fig. 4-9); some pistons have oil drains in the skirt of the piston or in the land. These holes serve as oil returns, permitting lubricating oil from the cylinder wall to pass through the piston into the crankcase.

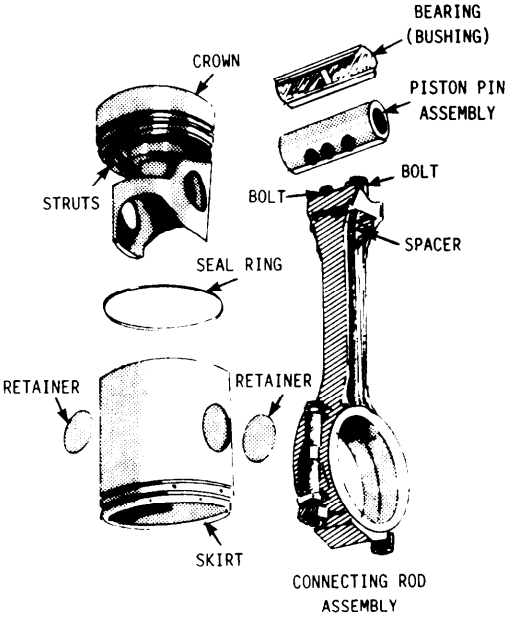
Generally, the BOSSES (hubs) of a piston are heavily reinforced openings in the piston skirt. (See fig. 4-10.) Some bosses are a part of an insert which is secured to the inside of the piston. The principal function of the bosses is to serve as mounting places for the bushings or bearings which support the piston pin. The bosses provide a means of attaching the connecting rod to the piston. Generally, the diameter of the piston at the bosses is slightly less than the diameter of the rest of the piston. This difference serves to compensate for the expansion of the extra metal in the bosses.

Because of the intense heat generated in the combustion chamber, adequate cooling must be provided. The heat transmitted through the rings (approximately 30 percent of the heat absorbed by the piston) to the cylinder wall is not sufficient in many engines to keep the unit cooled within operating limits. Most pistons have fins or ribs and struts as internal parts. (See fig. 4-9.) The additional surfaces of these parts help to dissipate heat; much of the heat is carried away by oil which may be pump-forced, sprayed, splashed, or thrown by centrifugal force onto the underside of the piston assembly. A different approach to cooling the piston head is with the use of drilled passages from the connecting rod through the piston pin to the piston bosses. Drilled passages in the piston direct the oil to cavities in the piston crown. Oil discharged from these cavities is controlled so a sizeable amount is retained at all times to cool the crown by "cocktail shaker" action as the piston moves up and down in the cylinder. (A cutaway view of this type of design is shown in figure 4-17.) Oil is the principal means of cooling for most piston assemblies. Intake air is also used in the cooling of hot engine parts. In order to exhaust or scavenge a cylinder of burned gases and cool the engine parts, the intake and exhaust valves or ports are so timed that both are open for a short time at the end of the exhaust stroke. This action allows the intake air to enter the cylinder, clean out the hot gases, and, at the same time, cool the parts.

Crosshead Pistons

A type of crosshead piston is currently being used in some engines (fig. 4-11). The crosshead piston is a two-piece unit with a crown that can withstand the high heat and pressure of a turbocharged engine and a skirt specifically designed to absorb side thrust.

The crown and skirt are held together by the piston pin. The downward load on the crown pushes directly on the pin through a large slipper bearing (bushing). The separate skirt has less thermal distortion than the crown piece and is free of downward thrust loads. It specifically guides the piston in the cylinder, takes up side thrust, and carries the oil scraper rings. The crown carries the compression rings. Since the crown is



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Figure 4-11.—Typical crosshead piston and connecting rod components.

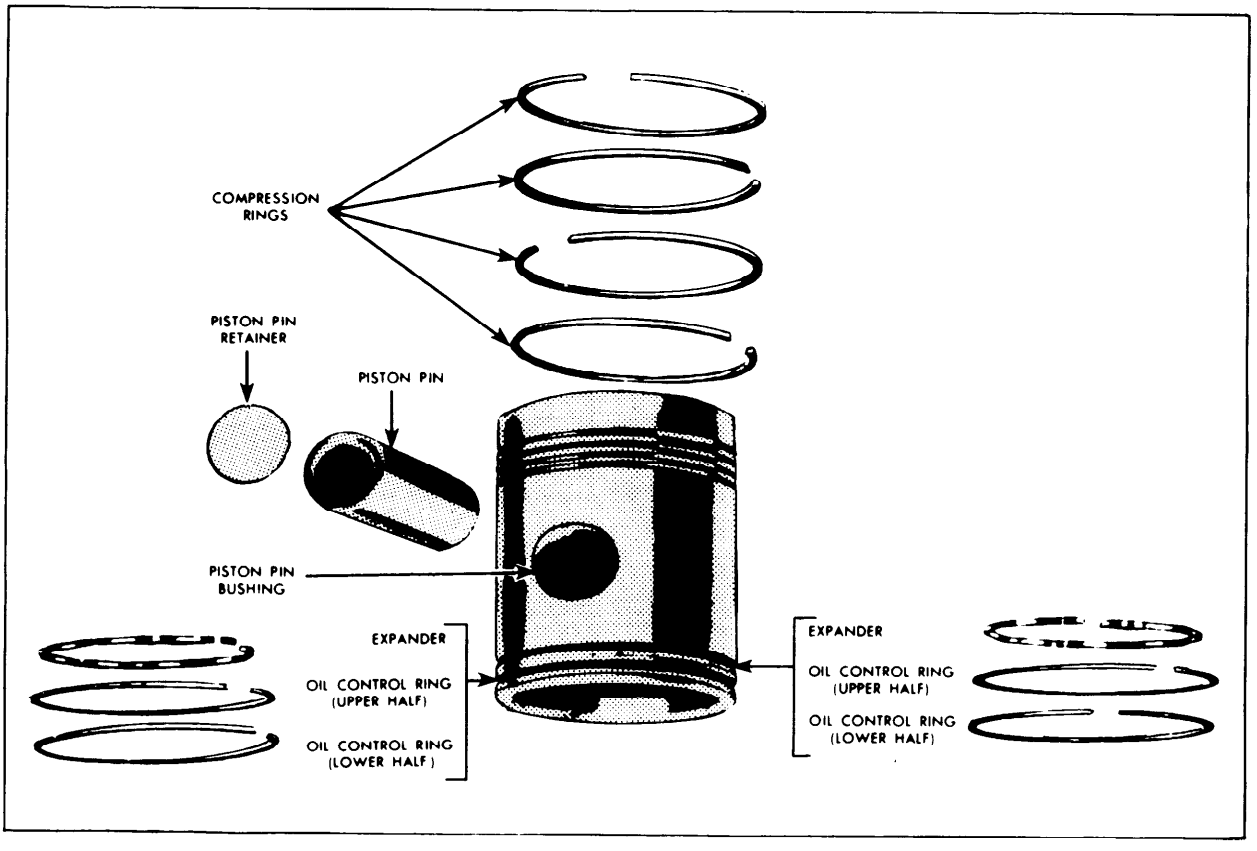
separate, it takes only a slight amount of side thrust and is not forced to slide sideways under the compression rings when they are pressed hard against the bottoms of their grooves by combustion gas pressure. Lubricating oil is fed upward by pressure to cool the piston pins and piston crown.

PISTON RINGS

Piston rings are particularly vital to engine operation in that they must effectively perform three functions: seal the cylinder, distribute and control lubricating oil on the cylinder wall, and transfer heat from the piston to the cylinder wall. All rings on a piston perform the latter function, but two general types of rings—compression and oil—are required to perform the first two functions.

The number of rings and their location will also vary considerably with the type and size of the piston. Refer to figures 4-9, 4-10, and 4-12. In these figures, the compression rings are located toward the crown or combustion end of the piston. The ring closest to the crown is sometimes referred to as the FIRING ring. Two different examples of piston ring location are shown in figures 4-10 and 4-12. In figure 4-10, both compression and oil rings are located toward the crown above the pin bosses. In figure 4-12, the compression rings are located above the bosses and the oil rings are located below the bosses.

The terms *above* and *below* adequately identify ring location when the crown of the piston is at the top, as it is in the in-line and V-type engines. These terms may lead to confusion, however, when reference is made to ring location on the upper pistons of opposed-piston engines. Piston ring location can be more accurately identified by reference to the crown or combustion end and to the skirt or crankshaft end of the piston. There are many variations in the design



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Figure 4-12.—Typical piston, piston rings, pin, and relative location of parts.

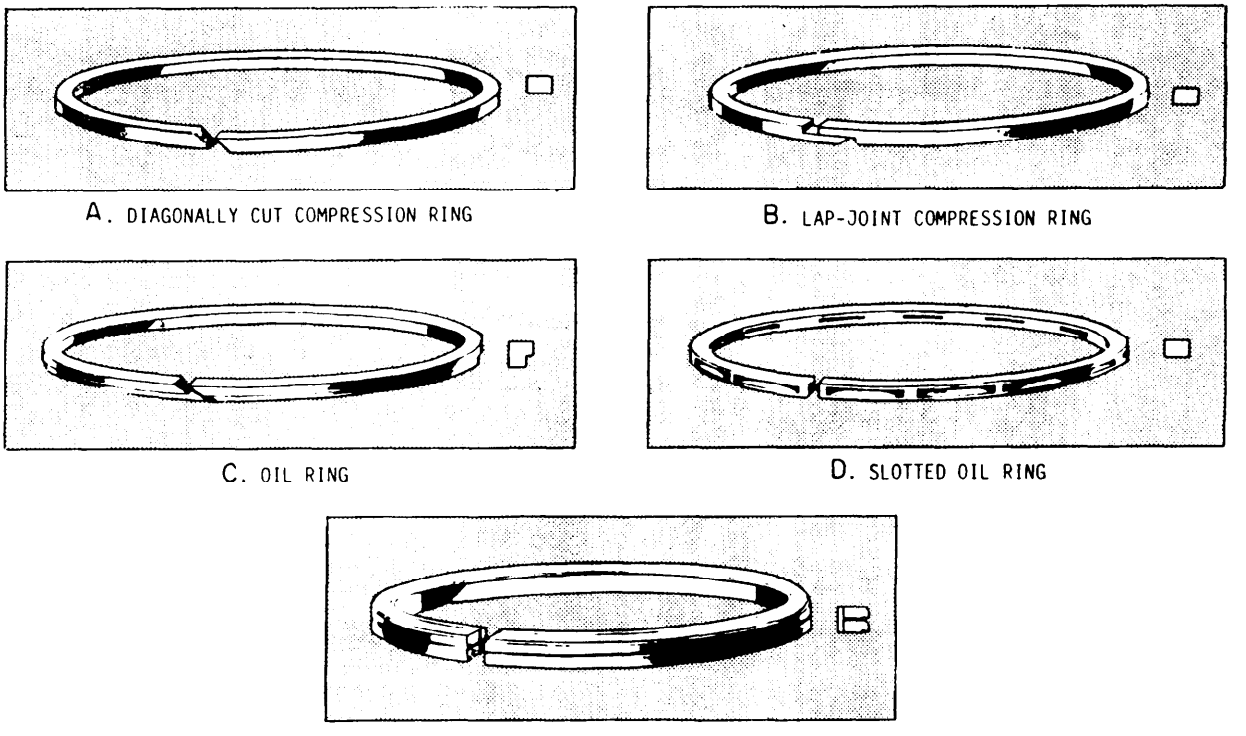
of compression and oil rings. Some common variations are illustrated in figure 4-13.

Compression Rings

The principal function of compression rings is to seal the cylinder and combustion space so that the gases within the space cannot escape until they have performed their function. Some oil is carried with the compression rings as they travel up and down the cylinder for lubrication.

Most compression rings are made of gray cast iron. Some types of compression rings, however, have special facings, such as bronze (inserted in a slot cut in the circumference of the ring) or a specially treated surface. Rings with the bronze inserts are sometimes called GOLD SEAL rings, while those with special facings are referred to as BIMETAL rings. The bimetal ring is composed of two layers of metal bonded together, the inner layer being steel and the outer layer being cast iron.

Compression rings come with a variety of cross sections; however, the rectangular cross section is the most common. Since piston rings contribute as much as any other one thing toward maintaining pressure in a cylinder, they must possess sufficient elasticity to press uniformly against the cylinder walls. The diameter of the ring, before installation, is slightly larger than the cylinder bore. Because of the joint, the ring can be compressed to enter the cylinder. The tension that is created when the ring is compressed and placed in a cylinder causes the ring to expand and produce a pressure against the cylinder wall. The pressure exerted by rings closest to the combustion space is increased by the action of the confined gases during compression and combustion. The gases enter behind the top ring, through the clearance between the ring and groove, and force the ring out against the cylinder and down against the bottom of the groove. The gas pressure on the second ring and each successive compression ring is progressively lessened since the gas that reaches these rings is limited to that passing through the gap of each preceding ring.



75.51

Figure 4-13.—Types of piston rings.

When a piston assembly is disassembled, you can look at the compression rings and tell whether they have been functioning properly. If a ring has been working properly, the face (surface bearing against the cylinder wall) and the bottom of the ring will be bright and shiny because of contact with the cylinder wall and the groove. The top and back (inside surface) of the ring will be black, since they are exposed to the hot combustion gases. Black areas on sealing surfaces indicate that hot gases have been escaping.

Under normal operating conditions, with engine parts functioning properly, there will be very little leakage of gas because of the excellent sealing of the piston rings. The oil that prevents metal-to-metal contact between the rings and cylinder wall also helps, to a degree, in making the seal. When a proper seal is established, the only point at which gas can leak is through the piston ring gap. The gap of a piston ring is so small, compared to the total circumference of the ring, that the amount of leakage is negligible when rings are functioning properly.

Oil Rings

Although oil rings come in a large variety of designs, they must all do two things: (1) distribute enough oil to the cylinder wall to prevent metal-to-metal contact, and (2) control the amount of oil distributed.

Without an adequate oil film between the rings and the cylinder, undue friction occurs, resulting in excessive wear of the rings and the cylinder wall. On the other hand, too much oil is as undesirable as not enough oil. If too much oil is distributed by the rings, the oil may reach the combustion space and burn, wasting oil and causing smoky exhaust and excessive carbon deposits in the cylinder. Such carbon deposits may cause the rings to stick in their grooves. Sticking rings lead to a poor gas seal. Thus, oil rings provide an important function in proper control and distribution of the lubricating oil. Some types of oil rings are shown in views C, D, and E of figure 4-13.

Different manufacturers use a variety of terms in their technical manuals to identify the oil rings of an engine—such terms as oil control, oil scraper, oil wiper, oil cutter, oil drain, and oil regulating. Regardless of the identifying terms used, all such rings are used to limit the oil film on the cylinder walls and to provide adequate lubrication to the compression rings.

Most oil control rings use some type of expander to force them against the cylinder wall. This aids in wiping the excess oil from the cylinder wall. For example, a General Motors 6-71 piston has two sets of oil control rings placed on the skirt below the piston pin. Both sets are identical, each consisting of three pieces (two rings and an expander). (See fig. 4-12.) The ring illustrated in view E of figure 4-13 is also a three-piece oil ring. In rings of this type, the two "scraping" pieces have very narrow faces bearing on the cylinder wall, which permit the ring assembly to conform rapidly to the shape of the cylinder wall. Since the ring tension is concentrated on a small area, the rings will cut through the oil film easily and remove the excess oil. The bevel on the upper edge of each ring face causes the ring to ride over the oil film as the piston moves toward top dead center (TDC), but as the piston moves downward for intake and power, the sharp, hook-like lower edge of each ring scrapes or wipes the oil from the cylinder wall.

Another example of differences in terminology and location is found in the Fairbanks-Morse (FM) 38D8 1/8. A piston in this type of engine has three oil rings all located on the skirt end. The two nearest the crankshaft end of the piston are called oil drain rings, while the ring nearest the pin bosses is referred to as the scraper. The drain rings are slotted to permit oil to pass through the ring and to continue on through the holes drilled in the ring grooves. View D of figure 4-13 shows one type of slotted oil ring. Additional information concerning pistons and piston rings can be found in *Naval Ships' Technical Manual,* chapter 233.

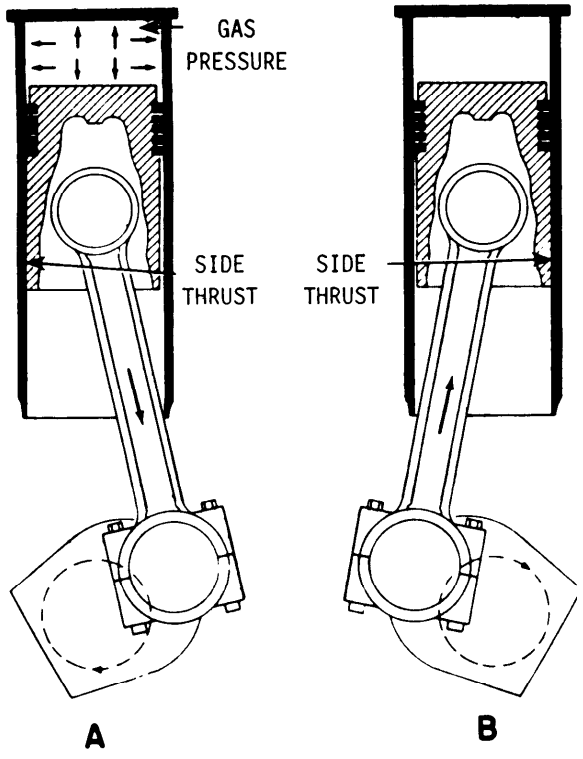
PISTON PINS AND PISTON BEARINGS

In trunk-type piston assemblies, the only connection between the piston and the connecting rod is the pin (sometimes referred to as the wrist pin) and its bearings. These parts must be of especially strong construction because the power developed in the cylinder is transmitted from the piston through the pin to the connecting rod. The pin is the pivot point where the straight-line, or reciprocating, motion of the piston changes to the reciprocating and rotating motion of the connecting rod. Thus, the pin is subjected to two principal forces—the forces created by combustion and the side thrust created by the change in direction of motion. Before discussing the pin further, let us consider the side thrust

which occurs in a single-acting engine equipped with trunk-type pistons. (Refer to fig. 4-14.)

Side thrust is exerted at all points during a stroke of a trunk-type piston, except at top dead center (TDC) and bottom dead center (BDC). The side thrust is absorbed by the cylinder wall. Thrust occurs first on one side of the cylinder and then on the other, depending on the position of the piston and the connecting rod and the direction of rotation of the crankshaft. In view A of figure 4-14, gas pressure is forcing the piston downward (power). Since the crankshaft is rotating clockwise, the force of combustion and the resistance of the driven parts tend to push the piston to the left. The resulting side thrust is exerted on the cylinder wall. If the crankshaft were rotating counterclockwise, the situation would be reversed.

In view B of figure 4-14, the piston is being pushed upward (compression) by the crankshaft and connecting rod. This causes the side thrust to be exerted on the opposite side of the cylinder. Thus, the side thrust alternates from side to side as the piston moves up and down. Side thrust in an engine cylinder makes proper lubrication and correct clearance essential. Without an oil film between the piston and the cylinder wall, metal-to-metal contact occurs and results in excessive wear. If the clearance between the piston and cylinder wall is excessive, a pounding noise, called PISTON SLAP, will occur as the thrust alternates from side to side.

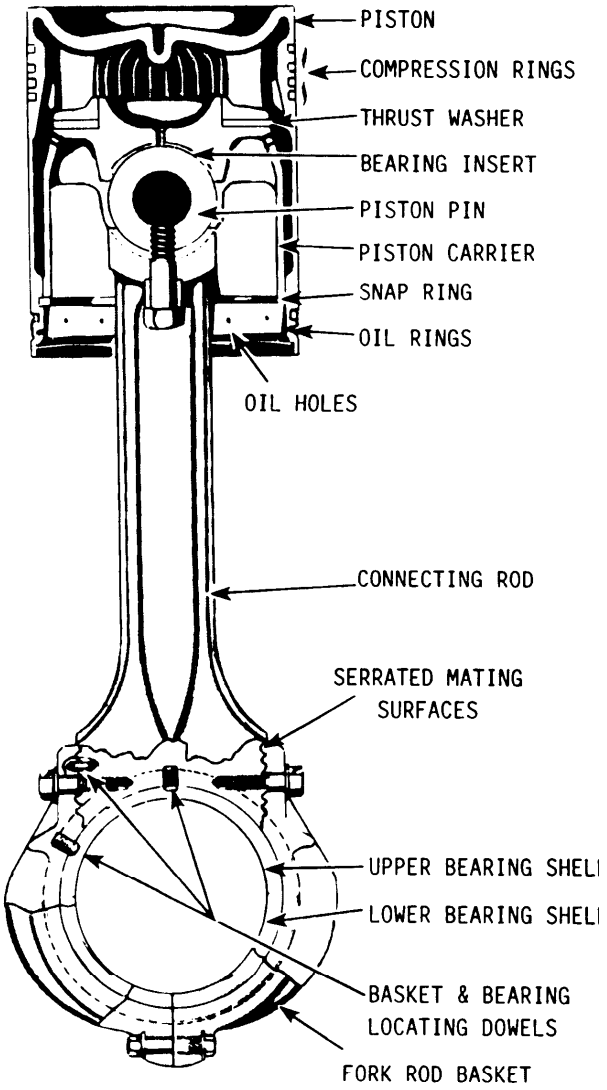


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Figure 4-14.—Trunk-type piston in a single-action engine showing side thrust.

Types of Piston Pins

Pins are usually hollow and made of alloy steel, machined, hardened, and precision-ground to fit the bearings. Their construction provides maximum strength with minimum weight. Some pins are chromium-plated to increase the wearing



75.358

Figure 4-15.—Cross section of a semifloating piston and connecting rod assembly.

qualities. The pins are lubricated by splash from the crankcase, by oil forced through drilled passages in the connecting rods, or by the use of piston oil spray nozzles.

Piston pins must be secured in position so that they do not protrude beyond the surface of the piston or have excessive end-to-end motion. Otherwise, the pin will tend to damage the cylinder wall. Piston pins may be secured in the connecting rod assembly in one of three ways: (1) rigidly fastened into the piston bosses, (2) clamped to the end of the rod, or (3) free to rotate in both piston and rod. When piston pins are secured by these methods, the pins are identified as (1) stationary (fixed), (2) semifloating, and (3) full-floating, respectively.

The STATIONARY pin is secured to the piston at the bosses, and the connecting rod oscillates on the pin. Since all movement is by the connecting rod, uneven wear may occur on the contacting surfaces in this type of installation. For this reason, use of this type of pin is not typical in Navy diesel engines.

SEMIFLOATING pins are secured in the middle to the connecting rod (fig. 4-15). The ends of the pin are free to move in the piston pin bearings in the bosses.

FULL-FLOATING pins are not secured to either the piston or the connecting rod. Pins of this type may be held in place by caps, plugs, and snap rings, or spring clips which are fitted in the bosses. (See fig. 4-12.) The securing devices for a full-floating pin permit the pin to rotate in both the rod and piston pin bosses. Of the three types of piston pins, the full-floating piston pin is the most common.

Types of Piston Pin Bearings

The bearings used in connection with most piston pins are of the sleeve bearing or bushing type. These bearings may be further identified according to location—the piston boss piston pin bearings and the connecting rod piston bearings.

The bearings or bushings are made of bronze or similar material. Since the bushing material is a relatively hard-bearing metal, surface-hardened piston pins are required. The bore of the bushing is accurately ground in line for the close fit of the piston pin. Most bushings have a number of small grooves cut in their bore for lubrication purposes (fig. 4-16). Some sleeve bushings have a press fit, while others are "cold shrunk" into the bosses.

Bearings of the sleeve bushing type for both the bosses and the connecting rod are shown in figure 4-16. Note that the bosses are a part of an insert.

If the piston pin is secured in the bosses of the piston (stationary) or if it floats (full-floating) in both the connecting rod and piston, the piston end

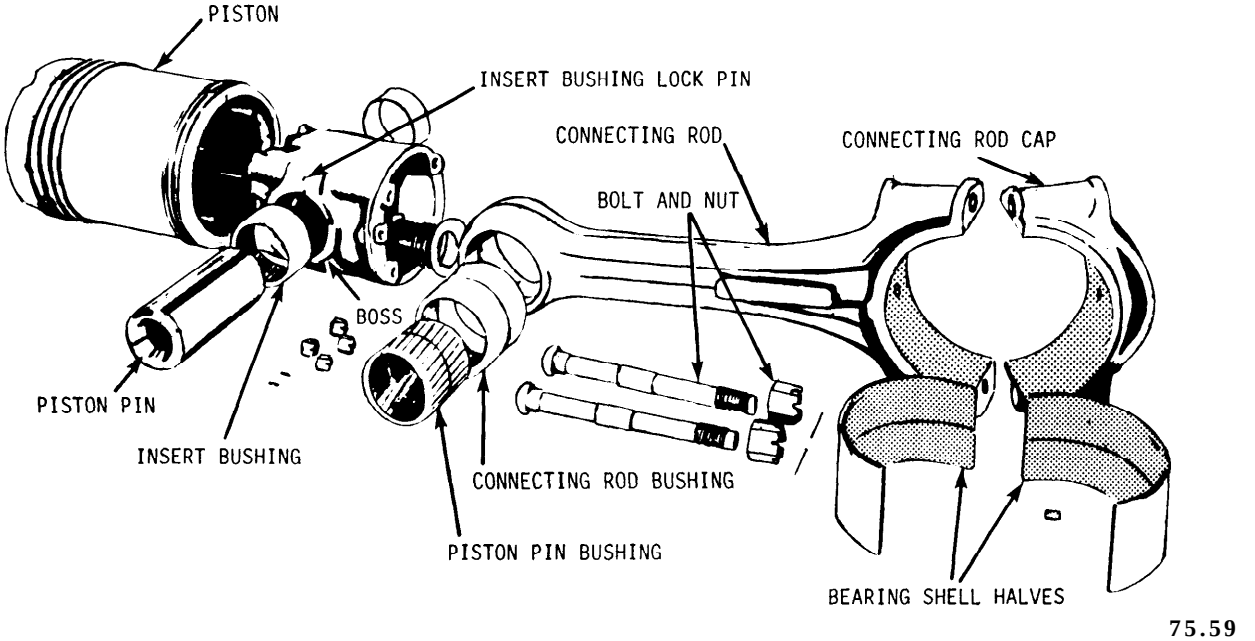


Figure 4-16.—Piston and connecting rod (Fairbanks-Morse).

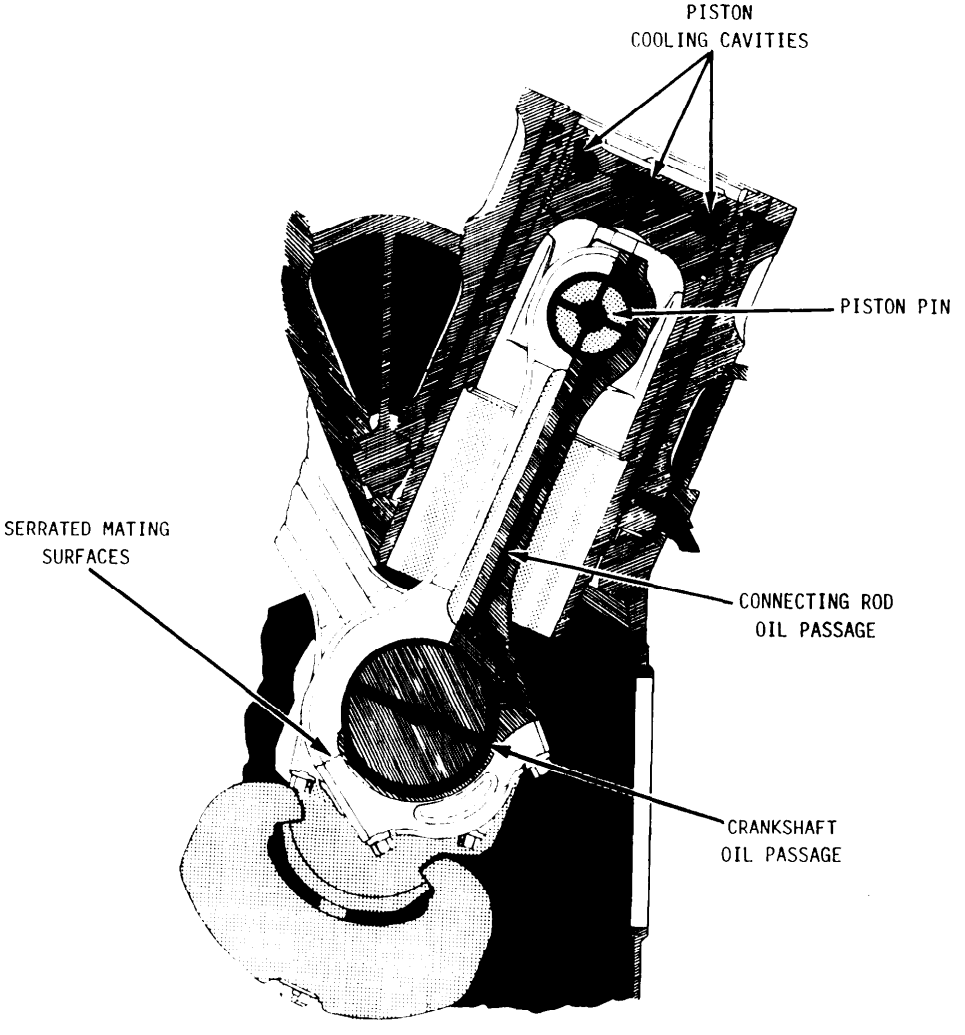
of the rod must be fitted with a sleeve bushing. Pistons fitted with semifloating pins (fig. 4-15) require no bearing at the rod end.

Sleeve bushings used in the piston end of connecting rods are similar in design to those used in piston bosses. Generally, bronze makes up the bearing surface. Some bearing surfaces are backed with a case-hardened steel sleeve, and the bushing has a shrink fit in the rod bore. In other bushings, the bushing fit is such that a gradual rotation (creep) takes place in the eye of the connecting rod. In another variation of the sleeve-type bushing, a cast bronze lining is pressed into a steel bushing in the connecting rod.

CONNECTING RODS

The connecting rod is the connecting link between the piston and the crankshaft. It is one of the most highly stressed parts of an engine in that the connecting rod transmits the forces of combustion to the crankshaft.

In general, the type of connecting rod used in an engine depends on the cylinder arrangement and the type of engine. Several types of connecting rods have been designed. Only two, however, the conventional rod and the fork and blade rod, are those likely to be found in marine engines used by the Navy and are the ones discussed here.



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Figure 4-17.—Cutaway view of a connecting rod showing oil passages (Colt-Pielstick).

Conventional Rods

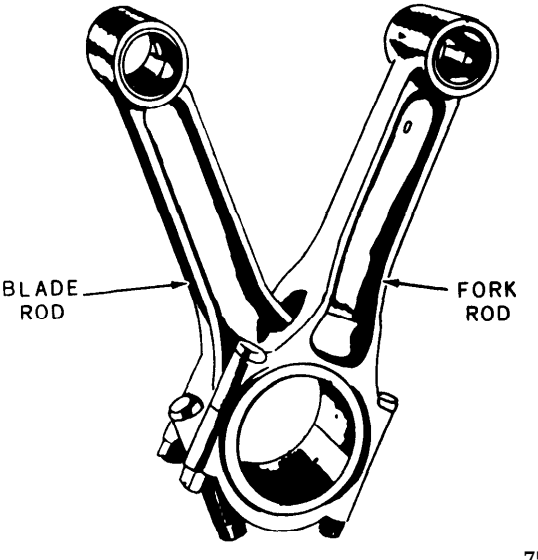
The conventional rod is sometimes referred to as the normal or standard rod because of its extensive use by many manufacturers. The rod illustrated in figure 4-16 is typical of those used in many in-line and V-type engines. When used in V-type engines, two rods are mounted on a single crankpin. The two cylinders served are offset so that the rods can be operated side by side.

Rods are generally made of drop-forged, heat-treated carbon steel (alloy steel forging). Most rods have an I- or H-shaped cross section which provides maximum strength with minimum weight. The bore (hub, eye) at the piston end of the rod is generally forged as an integral part of the rod (fig. 4-16); however, the use of semifloating piston pins eliminates the need for the bore. (See figs. 4-11 and 4-15.) The bore at the crankshaft end is formed by two parts, one an integral part of the rod and the other a removable cap. (See fig. 4-16.) Rods are generally drilled or bored to provide an oil passage from the crankshaft to the piston end of the rod.

The bore of the crankshaft end of a conventional rod is fitted with a precision bearing of the shell type. (See fig. 4-16.) In design and materials, rod bearings are similar to the main journal bearings, which are discussed in connection with crankshafts later in this chapter. Connecting rod bearings of most engines are pressure-lubricated by oil from adjacent main bearings, through drilled passages. The oil is evenly distributed over the bearing surfaces by oil grooves in the shells. Bearing shells have drilled holes which line up with an oil groove in the rod bearing seat. Oil from this groove is forced to the piston pin through the drilled passage in the rod. Figure 4-17 illustrates a drilled type of connecting rod, which in this example is used in conjunction with a "cocktail shaker" type of piston.

Fork and Blade (Plain) Connecting Rods

While two conventional rods are used to serve two cylinders in some V-type engines, a single assembly consisting of two rods is used in other engines of this type. As the name implies, one rod is fork-shaped at the crankshaft end to receive the blade rod. In general, fork and blade rods are similar to conventional rods in material and construction. However, design at the crankpin end (fig. 4-18) obviously differs from that of the conventional rods.



75.66

Figure 4-18.—Fork and blade connecting rod.

The bearings of fork and blade rods are similar to those already discussed, except that the upper shell must have a bearing surface on the outer surface to accommodate the blade rod.

Connecting Rod Bolts

Connecting rod bolts are the securing link between the piston assembly and the crankshaft. The rod bolts, because of the need for great strength, are generally made of heat-treated ahoy steel. Fine threads with close pitch are used to give maximum strength and to permit secure tighting. The majority of rod bolts used are machined to provide high fatique resistance by having a large portion of the body of the bolt turned to a diameter of less than the root diameter of the thread. Thus, all the body, except the ends and the center portion (which acts as a dowel), is machined to the smaller diameter. (Refer to the bolts in fig. 4-16.) As an additional precaution in some connecting rods, the mating surfaces between the foot of the rod and the connecting rod cap are serrated to help the bolts resist side forces. (Refer to figs. 4-15 and 4-17.)

CRANKSHAFT

As one of the largest moving parts in an engine, the crankshaft changes the movement of the piston and the connecting rod into the rotating

motion that is needed to drive such items as reduction gears, propeller shafts, generators, and pumps.

As the name implies, the crankshaft consists of a series of cranks (throws) formed as offsets in a shaft. The crankshaft is subjected to all the forces developed in an engine. Because of this, the shaft must be of especially strong construction. It is usually machined from forged alloy or high-carbon steel. The shafts of some engines are made of cast-iron alloy. Forged crankshafts are nitrided (heat-treated) to increase the strength of the shafts and to minimize wear.

While crankshafts of a few larger engines are of the built-up type (forged in separate sections and flanged together), the crankshafts of most modern engines are of one-piece construction (fig. 4-19).

CRANKSHAFT TERMINOLOGY

The parts of a crankshaft may be identified by various words. However, the terms in figure 4-19 are the ones that are most commonly used in the NAVSEA technical manuals for the engines used by the Navy.

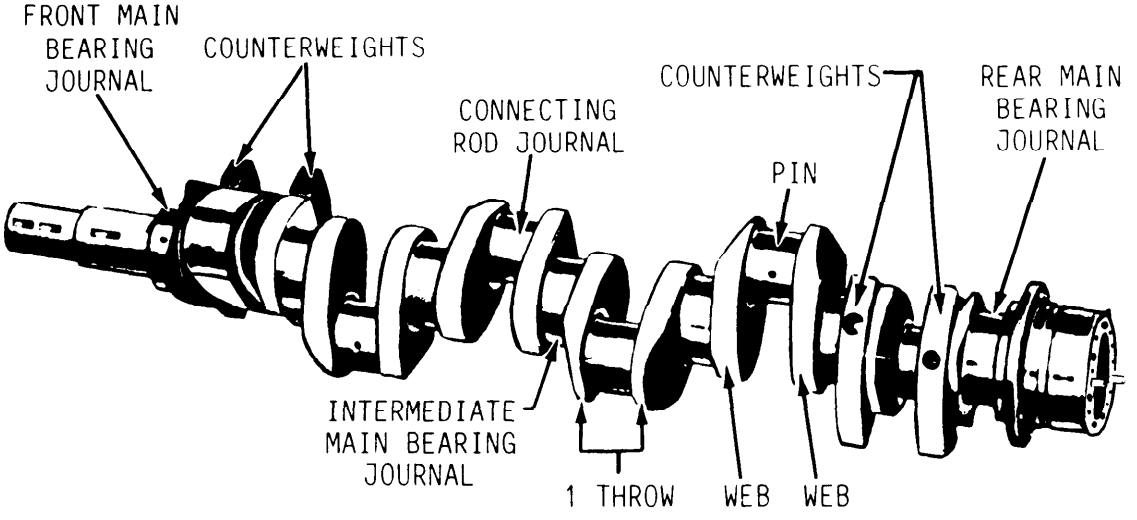
The MAIN JOURNALS serve as the points of support and as the center of rotation for the shaft. As bearing surfaces, the main journals and the connecting rod journals of crankshafts are surface-hardened so that a longer wearing, more durable bearing metal can be used without causing excessive wear of the shaft.

As illustrated in figure 4-19, crankshafts have a main journal at each end of the shaft with an intermediate main journal between the cranks. Each CRANK (throw) of a shaft consists of three parts, two webs and a pin, as shown in figure 4-19. Crank webs are sometimes called cheeks or arms. The cranks, or throws, provide points of attachment for the connecting rods, which are offset from the main journals.

In many crankshafts, especially in large engines, the connecting rod journals and main journals are of hollow construction. Hollow construction not only reduces weight considerably but also increases torque capability of the crankshaft and provides a passage for the flow of lubricating oil (fig. 4-20).

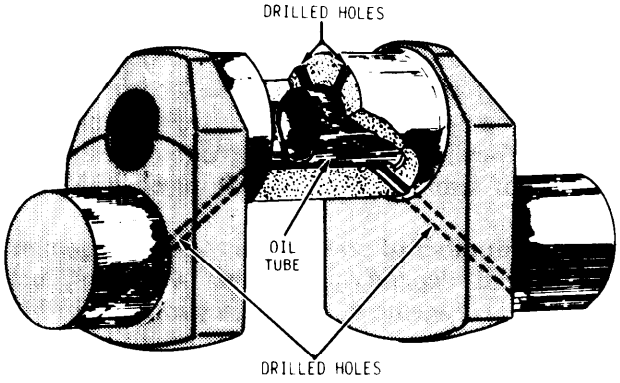
The forces that turn the crankshaft of a diesel engine are produced and transmitted to the crankshaft in a pulsating manner. These pulsations create torsional vibrations, which are capable of severly damaging an engine if they are not reduced, or dampened, by opposing forces. Many engines require an extra dampening effect to ensure satisfactory operation. It is provided by a torsional vibration damper mounted on the free end of the crankshaft. Several types of torsional dampers are currently in use.

On some crankshafts, part of the web of the crankshaft extends beyond the main journal to



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Figure 4-19.—One-piece, 6-throw crankshaft.



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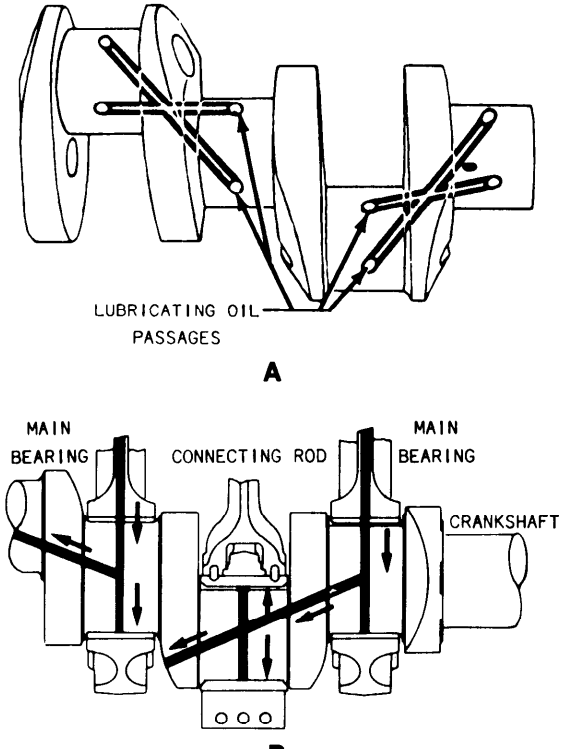
Figure 4-20.—An example of hollow connecting rod journal construction.

form or support counterweights. These counterweights may be integral parts of the web (fig. 4-19) or may be separate units attached to the web by studs and nuts, or setscrews (fig. 4-21).

Counterweights balance the offcenter weight of the individual crank throws and thereby compensate for centrifugal force generated by each rotating crank throw. Without such balance, the crank action will create severe vibrations, particularly at the higher speeds. If such vibrations are not controlled, the shaft would become damaged. Excessive vibration may lead to complete failure of the engine. Counterweights use inertia to reduce the pulsating effect of power impulses in the same manner as the flywheel. Flywheels are described later in this chapter.

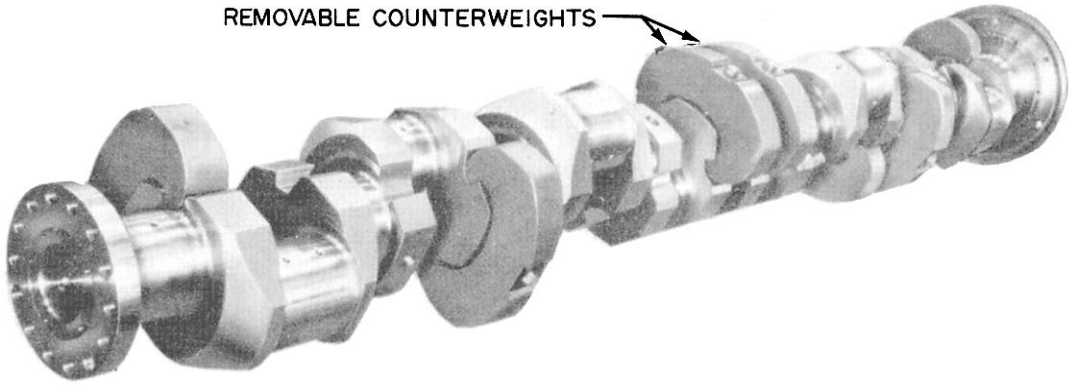
CRANKSHAFTS AND LUBRICATION

Whether a crankshaft is of solid construction (fig. 4-19) or of hollow construction (fig. 4-20), the main journals, the connecting rod journals, and the webs of most shafts have drilled passages for lubricating oil. Two other variations in the interior arrangement of oil passages in crankshafts are shown in figure 4-22. A study of these two



75.83

Figure 4-22.—Examples of crankshaft oil passage arrangement.



75.360

Figure 4-21.—Crankshaft with removable counterweights.

oil passage arrangements will give you an idea of the part the crankshaft plays in engine lubrication.

In the system illustrated in view A of figure 4-22, each oil passage is drilled through from a main bearing journal to a connecting rod journal. The oil passages are in pairs that crisscross each other in such a way that the two oil holes for each journal are on opposite sides of the journal. These holes are in axial alignment with the oil grooves of the bearing shells when the shells are in place. Since the oil groove in a bearing goes at least halfway around the bearing, a part of the groove will always be aligned with at least one of the holes.

In the oil passage arrangement shown in view B of figure 4-22 (the shaft is shown in fig. 4-19), the passage is drilled straight through the diameter of each main and connecting rod journal. A single diagonal passage is drilled from the outside of a crankshaft web to the center of the next main journal. The diagonal passage connects the oil passages in the two adjoining connecting rod journals and main journals. The outer end of the diagonal passage is plugged.

Lubricating oil under pressure enters the main bearing and is forced through the diagonal passage to lubricate the connecting rod bearing. From there it flows through the drilled connecting rod to lubricate the piston pin and cool the piston.

In engines that use crankshaft oil passage arrangements such as those just discussed, the connecting rods are drilled to carry the lubricating oil to the piston pins and piston. (Refer to fig. 4-17.) Not all engines have drilled connecting rods. In some V-type engines, drilled passages supply oil to the main and connecting rod bearings, but oil for the lubrication and cooling of the piston assembly may be supplied by centrifugal force or by separate supply lines. Variations in engine lubricating systems are discussed later in chapter 8.

CRANKSHAFT THROW ARRANGEMENTS

The smooth operation of an engine and its steady production of power depends, to a great extent, on the arrangement of the cranks on the shaft and on the firing order of the cylinders. For uniform rotation of the crankshaft in most multicylinder engines, the power impulses must be equally spaced with respect to the angle of crankshaft rotation. Whenever possible, they must also be placed so that successive explosions do not occur in adjacent cylinders. (This arrangement is not always possible, especially in 2-, 3-, and 4-cylinder engines.)

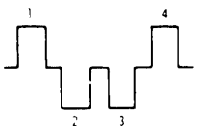
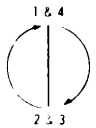
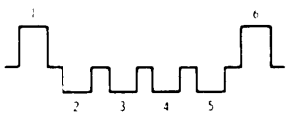
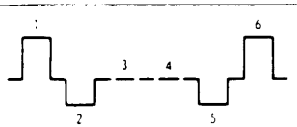
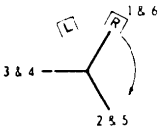
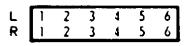
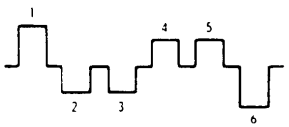
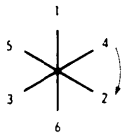
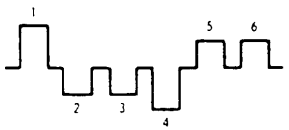
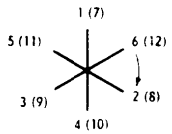
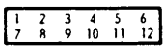
Crankshafts may be classified according to the number of throws—l throw, 2 throws, and so forth. The 6-throw shaft illustrated in figure 4-19 is for a 6-cylinder, in-line, 2-stroke cycle engine. Shafts of similar design can be used in V-type engines.

The number of cranks and their arrangement on the shaft depend on a number of factors, such as the arrangement of the cylinders (in-line or V-type), the number of cylinders, and the operating cycle of the engine. How these factors influence throw arrangement and firing order can be seen in a comparison of examples a through e of figure 4-23. The arrangement of throws with respect to one another and with respect to the circumference of the main journals is generally expressed in degrees. In an in-line engine, the number of degrees between throws indicates the number of degrees the crankshaft must rotate to bring the pistons to TDC in firing order. This is not true in engines where each throw serves more than one cylinder. Figure 4-23 lists the examples of throws with respect to cylinder arrangement, the number of cylinders served by each throw, and the firing order of the cylinders. (The sketches are not drawn to scale and do not indicate relative size, but are for illustrative purposes only.)

In studying the examples in figure 4-23, remember that the crankshaft must make only one revolution (360°) in a 2-stroke cycle; whereas two revolutions are required in a 4-stroke cycle. Note the throw arrangement in example a of a 4-stroke cycle engine. Since the 4-cylinder engine in example a operates on the 4-stroke cycle, throws 1, 3, 4, and 2 (see firing order), must be 180° apart in order for the firing to be spaced evenly in 720° of crankshaft rotation. Note too, that in all the other examples, the throws are equally spaced, regardless of cylinder arrangement, cycle of operation, or number of cylinders.

In examples b and c, the shaft design and the number of degrees between throws are the same. Yet the shaft in example c fires twice as many cylinders. This is possible because one throw, through a fork and blade rod, serves two cylinders which are positioned in 60° banks. Thus, even though both engines operate on the 4-stroke cycle, the 12-cylinder engine requires only 60° shaft rotation between power impulses.

There are six throws shown in examples b and d, yet they are 120° apart in one and 60° apart in the other. Why? The cylinder arrangement, the

EXAMPLE	NUMBER CYLINDERS	CYLINDER ARRANGEMENT	CYCLE	NO. CYL SERVED BY EACH THROW	THROW ARRANGEMENT (SIDE VIEW)	THROW ARRANGMENT (END VIEW)	FIRING ORDER	NO. DEGREES BETWEEN THROWS (SEE SKETCHES)	NO DEGREES SHAFT ROTATION BETWEEN FIRINGS
(a)	4	IN-LINE	4-STROKE	1			1-3-4-2	4 THROWS 180° APART	180
(b)	6	IN-LINE	4-STROKE	1			1-5-3-6-2-4	6 THROWS 120° APART	120
(c)	12	V	4-STROKE	2			 1R, 3L, 4R, 5L, 2R, 1L, 6R, 4L, 3R, 2L, 5R, 6L	6 THROWS 120° APART	60
(d)	6	IN-LINE	2-STROKE	1			1-5-3-6-2-4	6 THROWS 60° APART	60
(e)	12	V	2-STROKE	2			 1-11-5-9-3-10-4-8-2-12-6-7	6 THROWS 60° APART	30

75.328

Figure 4-23.—Examples of crankshaft throw arrangement.

total number of cylinders, and the number of cylinders served by each throw are the same. In examples b and d, the operating cycle is the controlling factor in throw arrangement.

In examples d and e, other variations in shaft throw arrangement and firing order are shown. Note that the differences are governed to a great extent by the cylinder arrangement, the number of cylinders served by the shaft and by each throw, and the operating cycle of the engine.

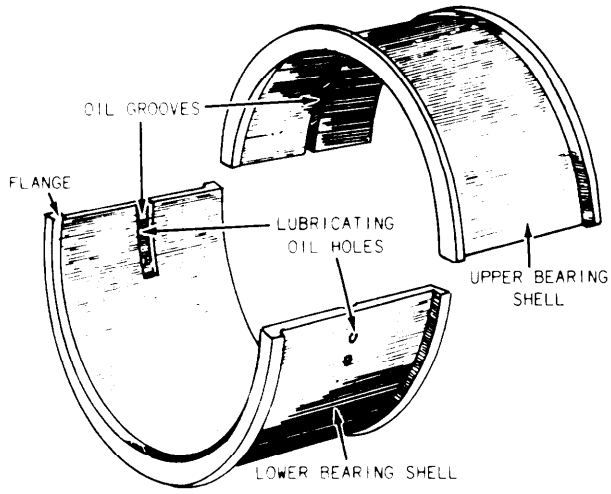
BEARINGS

As mentioned in chapter 3, the bearings of an engine make up an important group of parts. Bearings serve to support rotating shafts and other moving parts and to transmit loads from one part of the engine to another. Engine bearings consist of two basic types: antifriction bearings and friction bearings. Both types are used in Navy diesel engines.

ANTIFRICTION BEARINGS

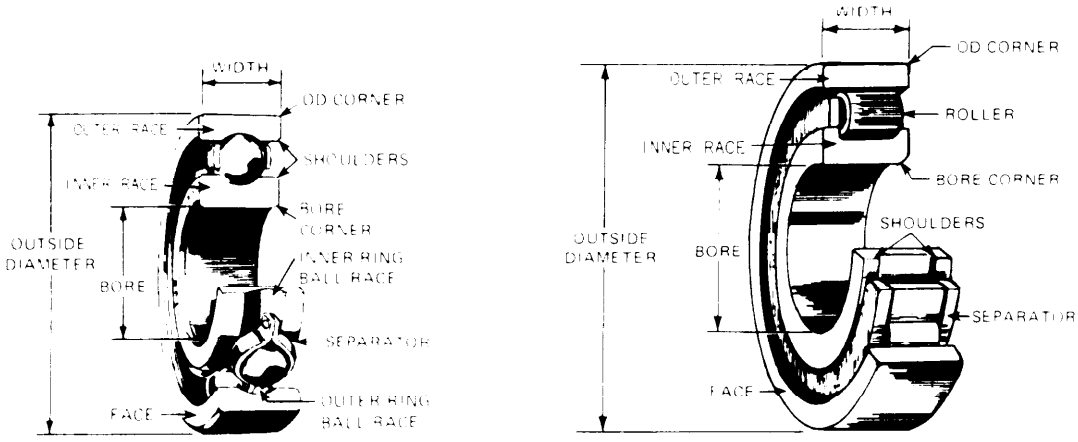
Antifriction bearings can be grouped into six general classifications: ball bearings, cylindrical roller bearings, needle bearings, tapered roller bearings, self-aligning roller bearings, and thrust bearings. The use of antifriction bearings is mostly limited to the exterior areas of an engine. You will find them in use in cooling pumps, fuel-injection pumps, governors, starters, flywheel pilot bearings, turbochargers, and blowers.

All antifriction bearings employ a rolling element (rollers, balls, or needles) between the inner and outer rings (races). Either the inner ring or the outer ring will remain stationary. (Refer to fig. 4-24 for cutaway views of two types of antifriction bearings.) Because of the small contact area between the rolling elements and the inner and outer rings and the necessity for the bearing to withstand the high compression stress, the material used for the construction of roller bearings is usually carbonized steel alloy and that used for ball bearings is usually heat-treated chromium-alloy steel.



75.85

Figure 4-25.—Main journal bearing shells.



A. SINGLE-ROW DEEP GROVE BALL BEARING.

B. CYLINDRICAL (STRAIGHT) ROLLER BEARING.

75.361

Figure 4-24.—Cutaway view of a ball bearing and roller bearing.

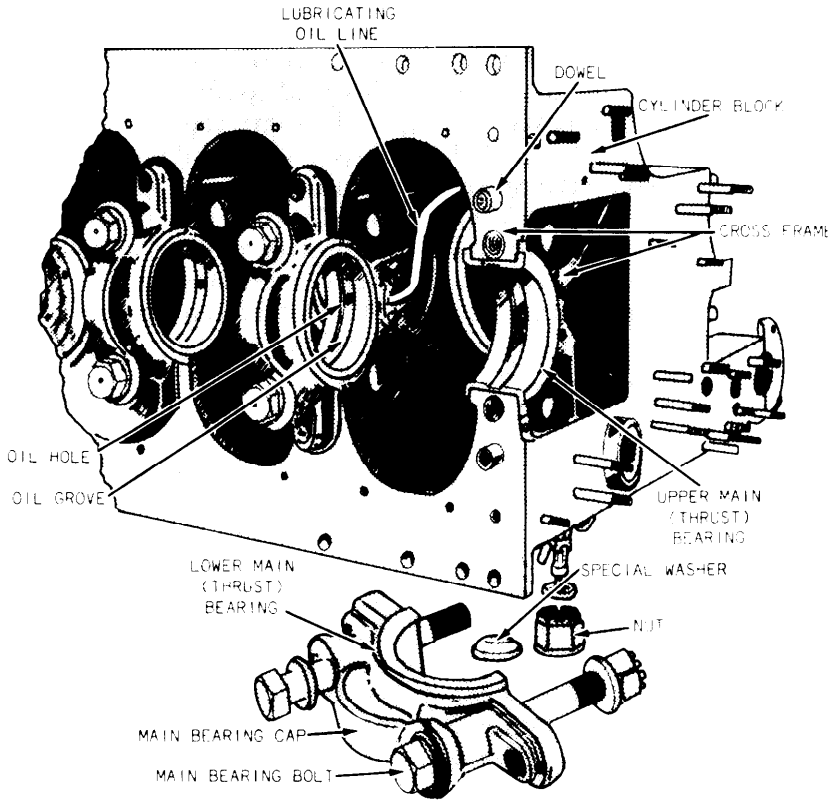
As an Engineman, you will come into contact with various items of equipment that may require bearing replacement. Bearings that are similar in appearance may not be suitable as replacement bearings. Ball and roller bearings are identified by a numerical code which indicates the bore in millimeters or sixteenths of an inch. The internal fit, or tolerance, and any special characteristics are also coded by number. Letter codes indicate the type of bearing, the outside diameter (OD), the width of the cage, the seal or shield, the modification, and the required lubricant.

FRICTION BEARINGS

In diesel engines, friction bearings serve to support the crankshaft, connecting rod, camshaft, and gear train. In some engine applications, friction bearings also support the rocker arm shaft as well as various pumps.

A type of friction bearing that is representative of most of the bearings used in Navy diesel engines is the PRECISION BEARING. Precision-type bearings that act as supports for the crankshaft are referred to as MAIN JOURNAL BEARINGS. In our discussion of friction bearings, we will use the main journal bearing as a representative sample.

Main journal bearings are of the sliding contact, or plain, type consisting of two half shells. (See fig. 4-25.) The location of main engine bearings in one type of block is shown in figure 4-26. The main journal bearings of most marine engines used by the Navy are of aluminum, aluminum alloy, or trimetal construction. In the trimetal type of construction, the bearing has a steel back bonded with an intermediate layer of bronze to which is bonded a layer of bearing material. The bearing material is either lead-based babbitt or tin-based babbitt. Regardless of the construction materials, the function and performance of main journal bearings are basically the same, with the exception of bearings, which are constructed not only to support the crankshaft but also to hold the crankshaft in position axially. This is done by flanges, which are part of the bearings, as shown in figure 4-26. Such flanges are on both halves of the bearing.



75.86

Figure 4-26.—Main bearings in a cylinder block.

These types of bearings are called THRUST bearings. Some engines use separate flat thrust washers, as shown in figure 3-8 of chapter 3, on each side of one main bearing to control the crankshaft thrust (back and forth movement).

Main bearings and their housing and caps are precision machined with a tolerance sufficiently close that, when properly installed, the bearings are in alignment with the journals and fit with a predetermined clearance. The clearance provides space for the thin film of lubricating oil which is forced, under pressure, between the journals and the bearing surfaces. Under normal operating conditions, the film of oil surrounds the journals at all engine load pressures. Lubricating oil enters the bearing shells from the engine lubricating system, through oil grooves in the bearing shells. (See figs. 4-25 and 4-26.) These inlets and grooves are located in the low-pressure area of the bearing.

Main bearings are subjected to a fluctuating load, as are the connecting rod bearings and the piston pin bearings. However, the manner in which main journal bearings are loaded depends on the type of engine in which they are used.

In a 2-stroke cycle engine, a load is always placed on the lower half of the main bearings and the upper half of the piston pin bearings. In the connecting rod, the load is placed upon the upper half of the connecting rod bearings at the crankshaft end of the rod. This is true because the forces of combustion are greater than the inertial forces created by the moving parts.

In a 4-stroke cycle engine, the load is applied first on one bearing shell and then on the other. The reversal of pressure is the result of the large forces of inertia imposed during the intake and exhaust strokes. In other words, inertia tends to lift the crankshaft in its bearings during the intake stroke and exhaust stroke. Additional information on bearings can be found in *Naval Ships' Technical Manual*, chapter 244.

FLYWHEELS

The speed of rotation of the crankshaft increases each time the shaft receives a power impulse from one of the pistons. The speed then gradually decreases until another power impulse is received. If permitted to continue unchecked, these fluctuations in speed (their number depending upon the number of cylinders firing on one crankshaft revolution) would result in an undesirable situation with respect to the driven mechanism as well as to the engine. Therefore, some means must be provided so that shaft rotation can be stabilized. In most engines, this is accomplished by installation of a flywheel on the crankshaft. In other engines, the motion of such engine parts as the connecting rod journals, webs and lower ends of the connecting rods, and such driven units as the clutch and generator serves the purpose. The need for a flywheel decreases as the number of cylinders firing in one revolution of the crankshaft and the mass of moving parts attached to the crankshaft increase.

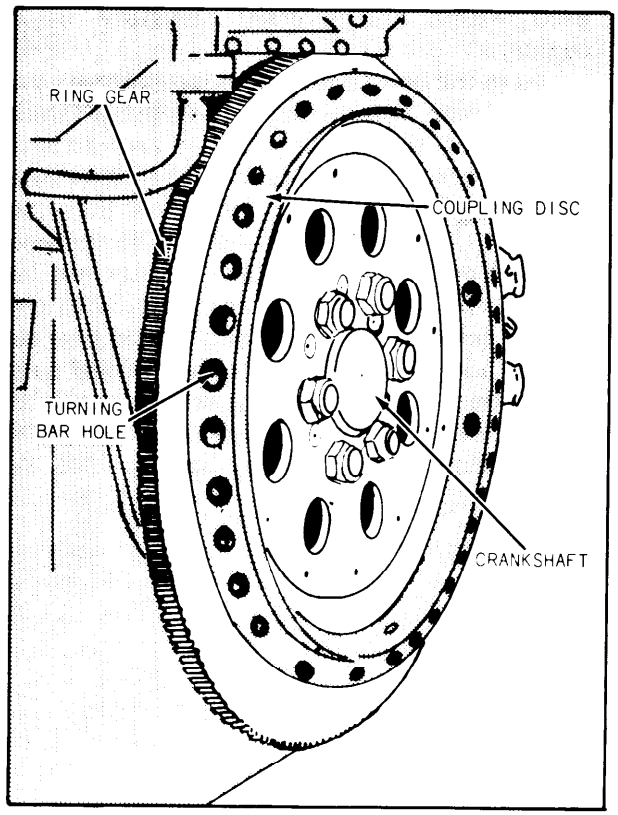
A flywheel stores up energy during the power event and releases it during the remaining events of the operating cycle. In other words, when the speed of the shaft tends to increase, the flywheel absorbs energy. When the speed tends to decrease, the flywheel gives up energy to the shaft in an effort to keep shaft rotation uniform. In doing this, a flywheel (1) keeps variations in speed within desired limits at all loads; (2) limits the increase or decrease in speed during sudden changes of load; (3) aids in forcing the piston through the compression event when an engine is running at low or idling speed; and (4) provides leverage or mechanical advantage for a starting motor.

Flywheels are generally made of cast iron, cast steel, or rolled steel. Strength of the material from which the flywheel is made is of prime importance because of the stresses created in the metal of the flywheel when the engine is operating at maximum designed speed.

In some engines, a flywheel is the point of attachment for items such as a starting ring gear or a turning ring gear. (See fig. 4-27.) The rim of a flywheel may be marked in degrees. With a stationary pointer attached to the engine, the degree markings can be used for a determination of the position of the crankshaft when the engine is being timed.

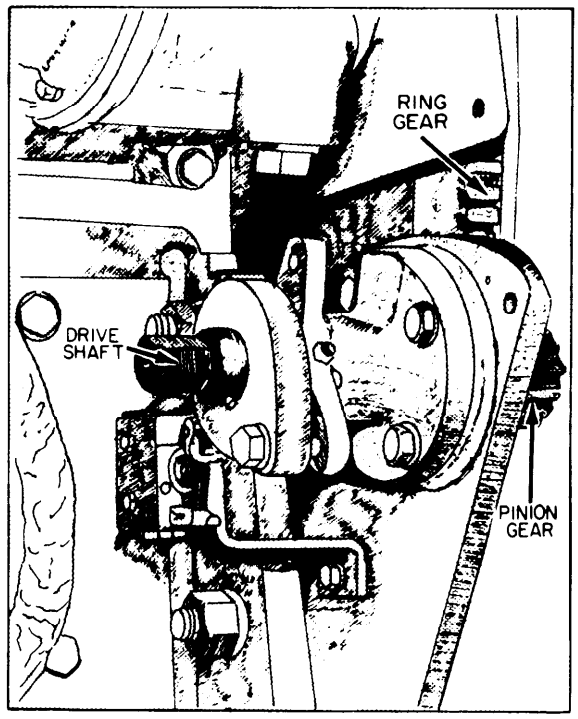
JACKING GEARS

Diesel drive installations are equipped with a means of jacking, or barring, over. A great majority of diesel engines are jacked over by hand. One method of rotating the engine is with the use of a turning bar. In this installation, holes are provided around the circumference of the rim for insertion of the turning bar so that the crankshaft can be manually rotated. (See fig. 4-27.) This is a very simple but effective means that allows for the precise positioning of the crankshaft when required for timing.



75.362

Figure 4-27.—Ring gear and coupling (flywheel).



75.363

Figure 4-28.—Engine barring device.

Still another method of rotating the crankshaft is illustrated in figure 4-28. This engine barring device consists of a pinion and a hex head drive shaft. The drive shaft is mounted in a housing containing an eccentric sleeve arrangement for engaging the pinion with the ring gear on the flywheel.

The barring device shown in figure 4-28 can also be operated by an air (motor) wrench placed over the hex head of the drive shaft. Main drive engines, as well as some auxiliaries, are usually equipped with safety devices that prevent the engine from starting while the jacking gear is engaged. The type of safety devices will depend on the type of starting system used.

SUMMARY

The valve-actuating mechanisms are those parts that transform the rotary motion of a drive mechanism into reciprocating motion. Reciprocating motion is used for the operation of engine cylinder valves. The camshaft is the principal part of a valve-actuating mechanism. Rotary motion of the cams on the camshaft is changed to reciprocating motion, and power is transmitted to the various cylinder valves (intake, exhaust, fuel injection, and air start) by means of rocker arm or tapped assemblies. These assemblies make contact with the cams by the use of cam followers.

The process of transmitting the power developed in an engine to useful energy involves the motion of many parts. The major parts are the piston, connecting rods, and crankshaft; however, many related parts must be considered in the process of changing reciprocating motion to rotary motion. For example, a piston, which may be of the trunk type or the crosshead type, receives the force of combustion and transmits it to the crankshaft through a connecting rod.

To accomplish their functions, pistons are fitted with piston rings, such as compression and oil control rings. Piston rings function to maintain a gastight seal between the piston and cylinder wall, to assist in cooling the piston, and to control cylinder wall lubrication.

Trunk-type pistons are fastened to the connecting rods by pins which may be stationary, semifloating, or full-floating. Side thrust created

by combustion and the motion of the moving parts is received by the cylinder wall through a trunk-type piston. The crosshead assembly absorbs the side thrust in engines fitted with the crosshead type of piston.

The crankshaft, the largest of the moving parts of an engine, receives the power impulses from all cylinders of the engine, transforms the motion of the pistons and connecting rods into rotary motion, and transmits the resulting torque to the flywheel or driven unit.

Other important parts which must be considered in connection with moving parts of an engine are bearings. Bearings may be of the antifriction type or friction type. Both types can be found on diesel installations. Antifriction bearings are commonly used in the engine accessories while friction bearings are commonly used within the internal structure of the engine.

As in the case of the principal stationary parts of the engine, you should be thoroughly familiar with all of the major moving and actuating components of an engine. You should know the functions and operating principles of these parts and how these parts are related to the stationary parts. You should be able to associate each component, as discussed separately, with other related components of the engine and how each part or assembly is related to the cycle of engine operation. If you are uncertain concerning any of these areas, go back and review this information before proceeding to the next chapter.

CHAPTER 5

ENGINE DRIVE MECHANISMS

Frequently, the source of power that operates one engine part is also the source of power for other parts and accessories of the engine. For example, the source of power that operates engine valves may also be the source of power that operates such items as the governor; fuel, lubricating, and water pumps; and overspeed trips. Since mechanisms that transmit power to operate specific parts and accessories may be related to more than one engine system, we will discuss drive mechanisms before getting into the engine systems.

After reading the information in this chapter, you should be able to recognize the basic design, function, and arrangement of various parts associated with drive mechanisms of 2-stroke and 4-stroke cycle diesel engines.

As used in this chapter, DRIVE MECHANISM identifies the group of parts that takes power from the crankshaft and transmits that power to various engine components and accessories. In engines, the drive mechanism does not change the type of motion, but it may change the direction of motion. For example, the impellers of a blower are driven or operated by a rotary motion from the crankshaft transmitted to the impellers by the drive mechanism, an arrangement of gears and shafts. While the type of motion (rotary) remains the same, the direction of motion of one impeller is opposite that of the other impeller as a result of the gear arrangement within the drive mechanism.

A drive mechanism may be a gear, chain, or belt type. The gear type is the most common. Some engines use chain assemblies or a combination of gears and chains as the driving mechanism. Belts are not common on marine engines, but are used as drive mechanisms on gasoline engines.

Some engines have a single-drive mechanism that transmits power to operate engine parts and accessories. In some engines, there may be two or more separate mechanisms. When separate assemblies are used, the one that transmits power to operate the accessories is called the ACCESSORY DRIVE. Some engines have more than one accessory drive. A separate drive mechanism that serves to transmit power to operate engine valves is generally called the CAMSHAFT DRIVE or TIMING MECHANISM.

The camshaft drive, as the name implies, transmits power to the camshaft of the engine. The shaft, in turn, transmits the power through a combination of parts which causes the engine valves to operate. Since the valves of an engine must open and close at the proper moment (with respect to the position of the piston) and remain in the open and closed positions for definite periods of time, a fixed relationship must be maintained between the rotational speeds of the crankshaft and the camshaft. Camshaft drives are designed to maintain the proper relationship between the speeds of the two shafts. In maintaining this relationship, the drive causes the camshaft to rotate at crankshaft speed in a 2-stroke cycle engine and at one-half crankshaft speed in a 4-stroke cycle engine.

There is considerable variation in the design and arrangement of the parts of drive mechanisms found in different engines. The size of an engine, the cycle of operation, the cylinder arrangement, and other factors govern the design and arrangement of the components as well as the design and arrangement of the mechanisms. Some of the variations in drive mechanisms are considered in the descriptions and illustrations that follow. The arrangements of the drive mechanisms described in this chapter are representive of those commonly found in marine engines used by the Navy.

DRIVE MECHANISMS FOR A 2-STROKE CYCLE, IN-LINE DIESEL ENGINE

In some engines, the operating mechanisms consist of a single-drive mechanism. The 6-cylinder, General Motors (GM) 71 engine is an

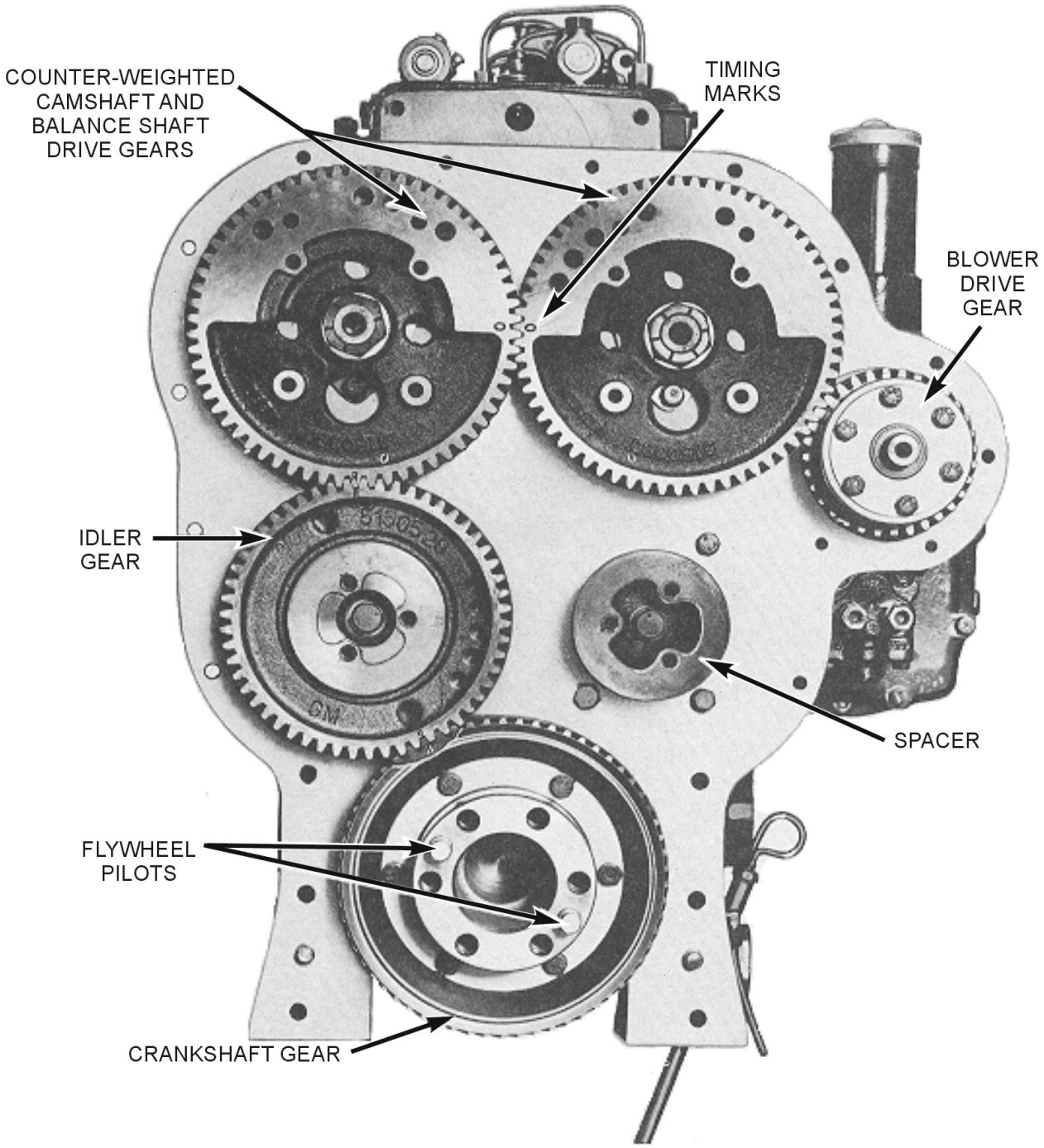


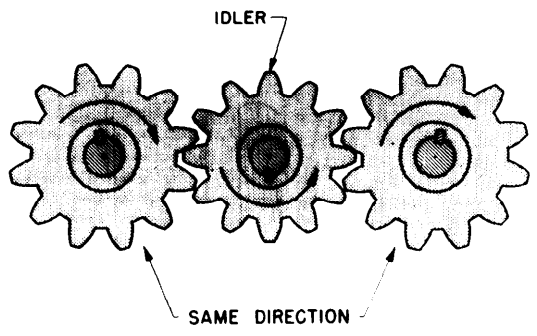
Figure 5-1.—Camshaft and accessory drive (General Motors 6-71).

example of such an engine. A complete assembly that transmits power from the driving part to the driven part, the operating mechanism of the GM 71 consists of gears, shafts, and couplings.

GEARS

When the driving mechanism of an engine consists only of gears, the mechanism is commonly called a gear train. In a gear train, the gears must be accurately cut and heat-treated to resist wear. Helical teeth (teeth placed at an angle) are frequently used in place of spur teeth (teeth placed straight) for greater quietness and more uniform transmission of power. Gears and shafts are used in various arrangements to drive the vital components and accessories of the engine.

The gear train for a GM 6-71 engine is shown in figure 5-1. (The arrangement shown is designed for right-hand rotation.) The gear train of a GM 71 functions as both the camshaft drive and the accessory drive. The train consists of five helical gears completely enclosed at the rear end of the engine. Note that all gears are driven by the crankshaft gear through an idler gear. An idler gear is placed between two other gears to transfer motion from one gear to the other without changing their direction. The use of a single idler gear is shown in figure 5-2. In the GM 71 shown in figure 5-1, the idler gear may be located on either the right or left side of the engine, depending upon the direction of the crankshaft rotation. (Locate the spacer, or "dummy hub.")



12.55

Figure 5-2.—Idler gear.

Since the engine operates on a 2-stroke cycle, the camshaft and balancer gears are driven at the same speed as the crankshaft gear. Either the camshaft gear or the balancer gear may be driven by the crankshaft gear through the idler gear; the drive arrangement depends on the model (right- or left-hand rotation). The camshaft and balance shaft gears are counterweighted for balance purposes.

The accessories of the GM 71 receive power from the blower drive gear, which is driven by the camshaft gear (fig. 5-1). Located on the blower side of the engine and supported by the rear end plate, the blower drive gear transmits power to the blower, governor, water pump, and fuel pump, as shown in figure 5-3. Figure 5-3 also shows the location of the various engine accessories and the shafts, gears, and couplings that transmit the power from the blower drive gear to each of the accessories.

The blower end of the governor drive shaft is serrated or splined, and it engages with corresponding serrations or splines inside the upper blower shaft. The fuel pump is bolted to the rear cover of the blower and is driven from the lower blower rotor shaft, through a device that acts as a universal joint. The water pump is mounted on the front end of the blower and is driven by the rotor shaft, through a coupling. (See fig. 5-3.)

DRIVE MECHANISMS FOR A 2-STROKE CYCLE, V-TYPE DIESEL ENGINE

The in-line engine discussed in the preceding section requires only one drive mechanism (gear train) to transmit power to the valve actuating gear and engine accessories. Our discussion will now cover an engine that uses two separate gear drives (gear trains), one at each end of the engine. The front gear train, as shown in figure 5-4, consists of a crankshaft gear and two idler gears. The idler gears serve to drive the water pump (not shown) and balance the engines. (See balance weights.) The rear gear train (fig. 5-5) consists of a crankshaft gear, three idler gears, and two camshaft gears. The rear idler gears, like the front, also serve to balance the engine. (See balance weights.) The two other gears that are mounted on the rear of the engine as shown in figure 5-5

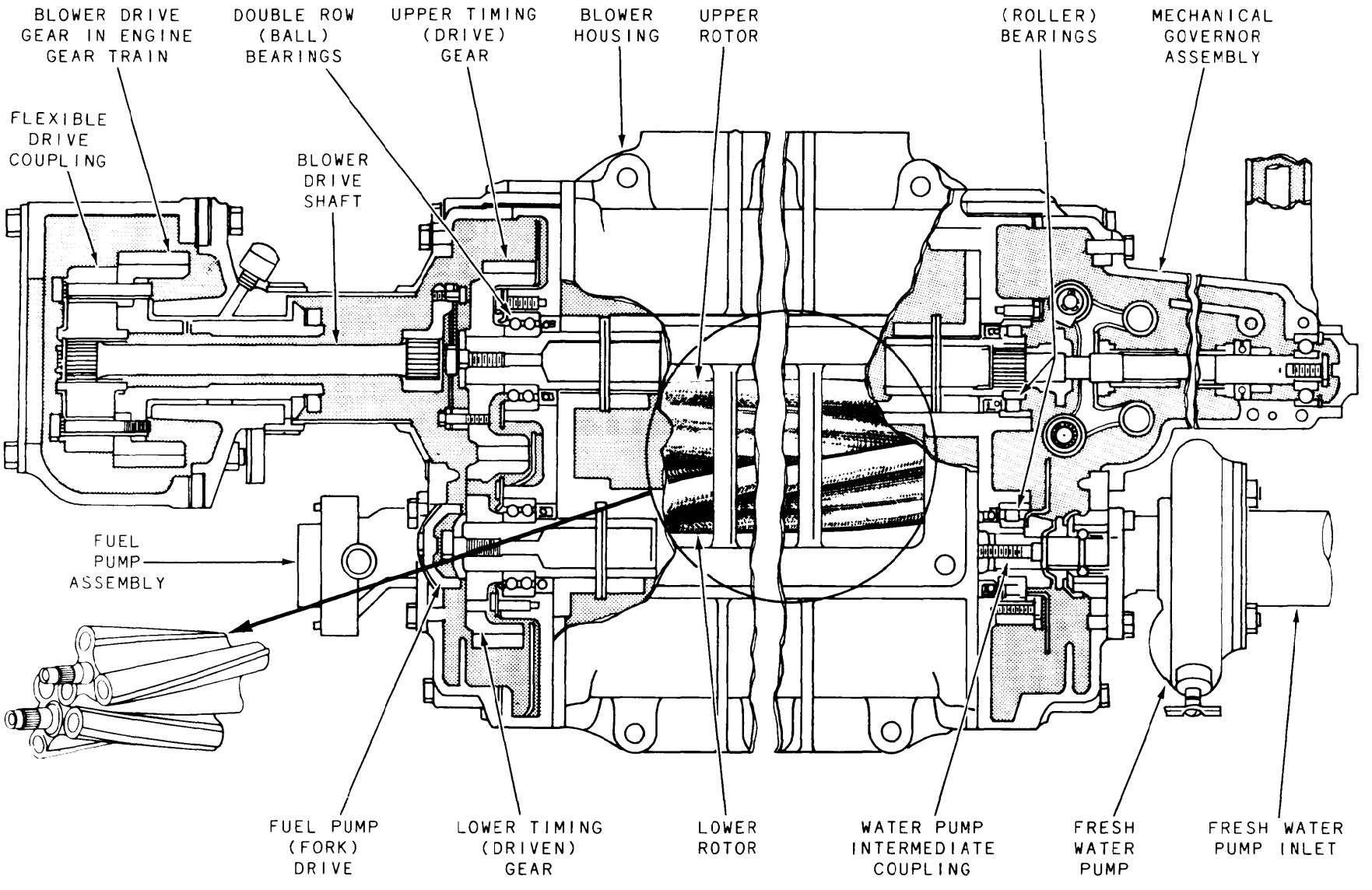
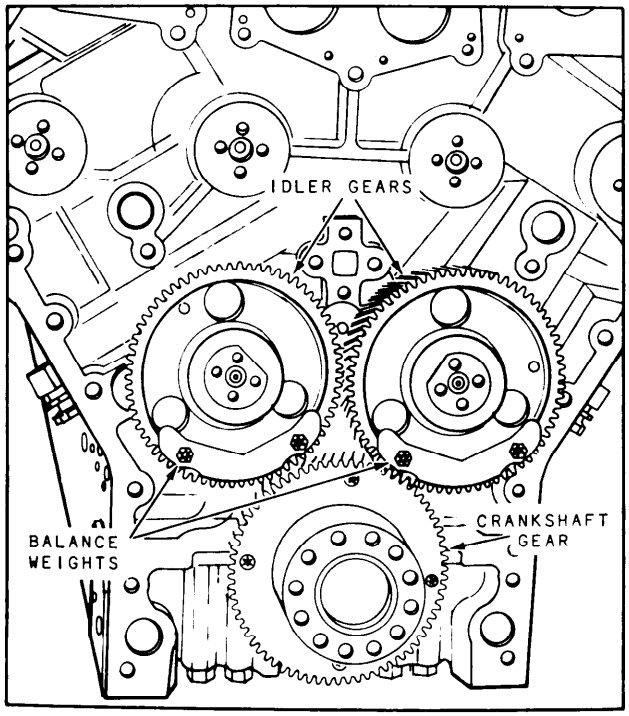


Figure 5-3.—Blower and drive assembly and accessories, including mechanical governor attached to blower (General Motors Series 71).



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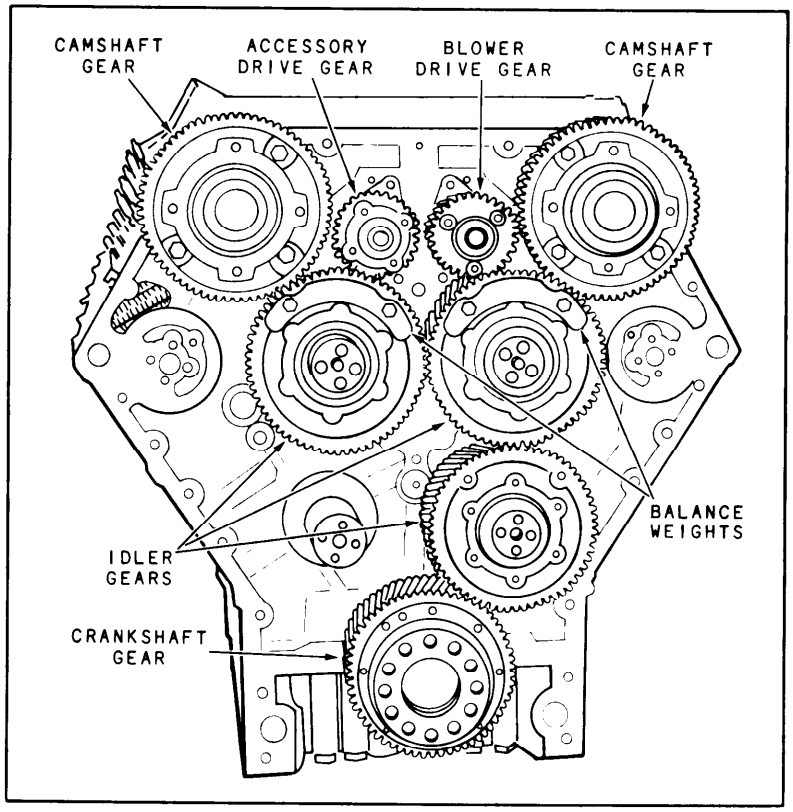
Figure 5-4.—Front gear train of a 16-V 149 series Detroit diesel engine.

are the accessory drive gear and the blower drive gear. The blower drive gear supplies the power that operates many of the same accessories as those on the GM 71 in figure 5-3.

The correct relationship between the crankshaft and the two camshafts must be maintained so that the fuel injection, the opening and closing of exhaust valves, and the engine balance can be properly controlled. Since the camshaft must be in time with the crankshaft, timing marks are stamped on the face of the gears to facilitate correct gear train timing. The timing marks stamped on various gears are shown in figures 5-1 and 5-6. When an engine is assembled, whether it is a 2-stroke or 4-stroke cycle engine, it is important that the appropriate timing marks be lined up on the gears as each gear is installed.

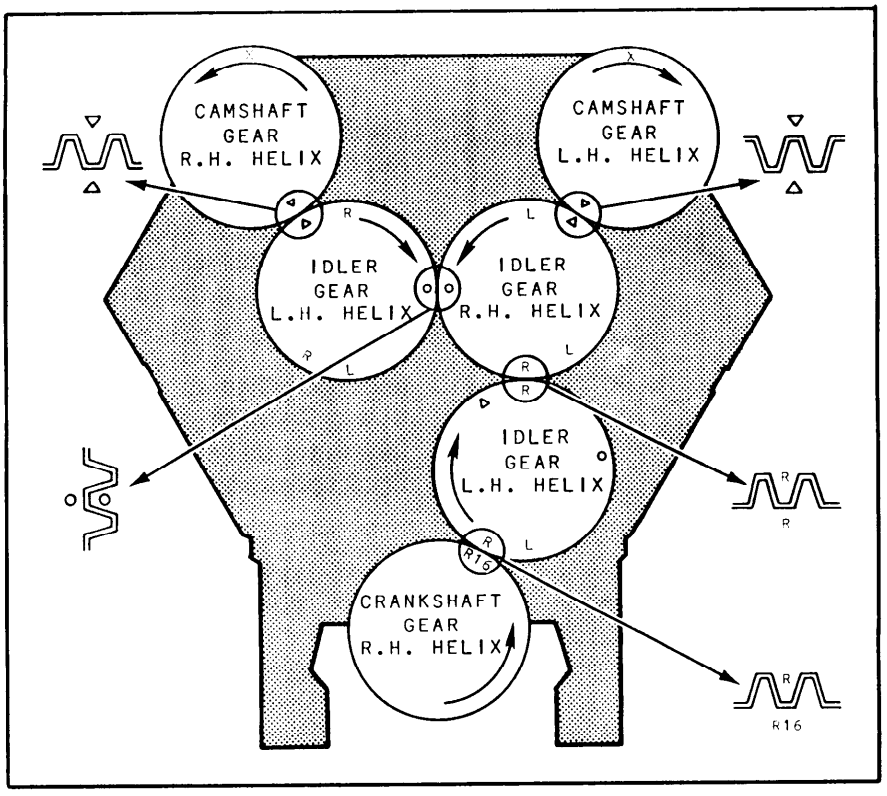
DRIVE MECHANISMS IN AN OPPOSED-PISTON ENGINE

The drive mechanisms of an opposed-piston engine will obviously differ, to a degree, from those of single-acting engines because of design differences. Some of the differences are



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Figure 5-5.—Rear gear train of a 16-V 149 series Detroit diesel 2-stroke cycle engine.



75.345

Figure 5-6.—Rear gear train timing marks on a 16-V 149 series Detroit diesel engine.

because (1) power is supplied by two crankshafts in an opposed-piston engine, instead of one, and (2) the camshaft drives of the engines we have discussed thus far supply power to one or more accessories as well as to the valve-actuating gear. This is not true of the camshaft in an opposed-piston engine since ports are used instead of valves for both intake and exhaust.

Regardless of differences in mechanisms, the basic types of drives—gear and chain—are found in both single-acting and opposed-piston engines. While the two engines described in preceding sections had only gear-type drive mechanisms, the opposed-piston engine used as an example in this section has chain assemblies as well as gear trains incorporated in the mechanisms that supply power to engine parts and accessories.

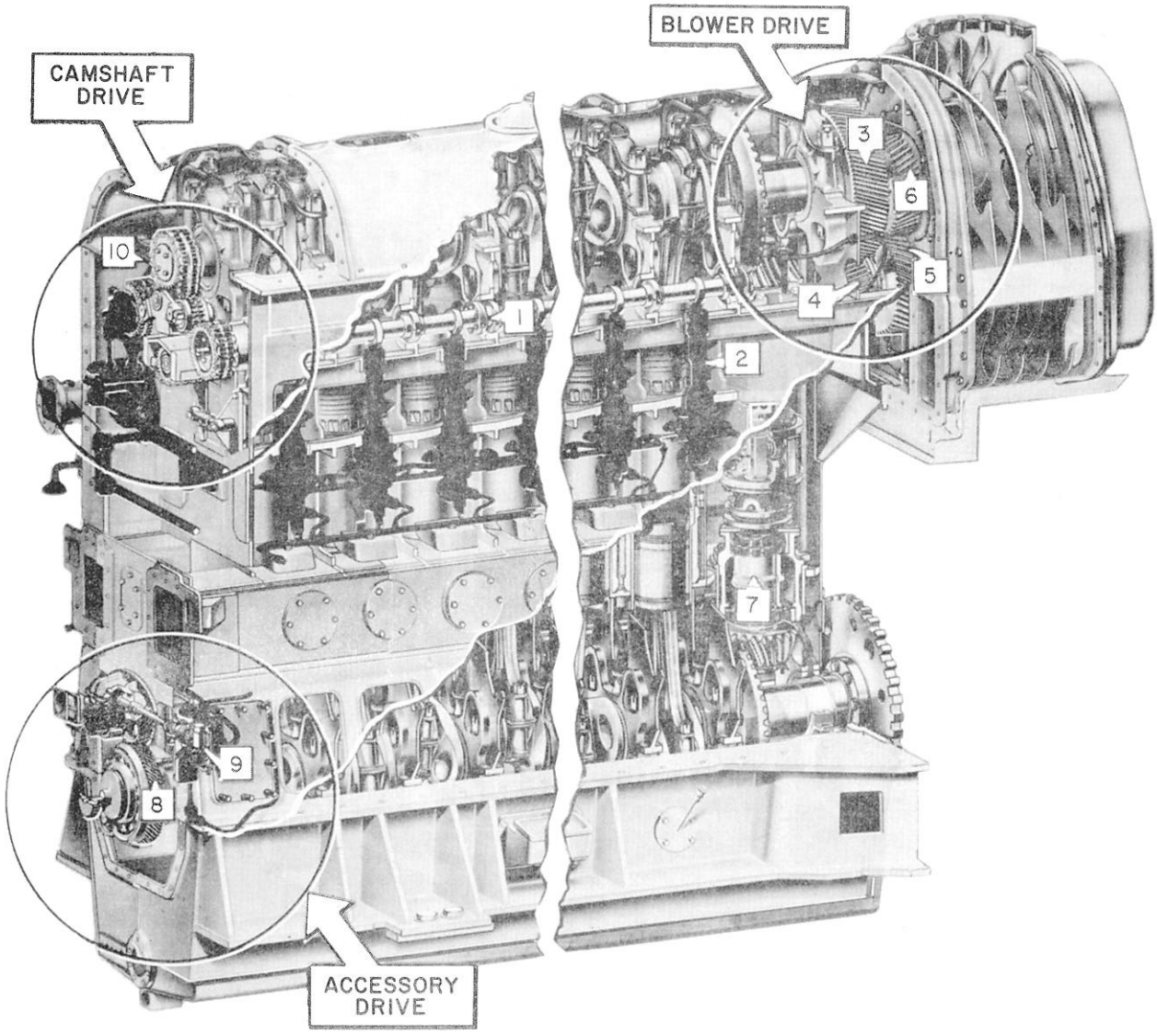
The Fairbanks-Morse (FM) opposed-piston engine has three separate drive mechanisms. The drive that furnishes power to the camshaft and fuel-injection equipment is the chain type. The blower and the accessories are operated by gear-type drives. The location of each drive is shown in figure 5-7.

CAMSHAFT DRIVE-ACTUATING GEAR

The opposed-piston engine does not have cylinder valves; and since two other drives are provided to operate the accessories, the primary purpose of the camshaft drive is to transmit power for, and to time the operation of, the fuel-injection pumps. The camshafts are located in the upper crankshaft compartment (fig. 5-7). The shafts turn at the same rate of speed as the crankshaft.

CHAIN ASSEMBLY

The power required to operate the fuel-injection pumps at the proper instant during the cycle of operation is transmitted through the camshafts from the crankshaft by a chain drive



1 CAMSHAFT	6. UPPER TIMING GEAR
2. FUEL PUMP TAPPET ASSEMBLY	7 VERTICAL DRIVE
3. FLEXIBLE DRIVE GEAR (BLOWER)	8. FLEXIBLE DRIVE GEAR (ACCESSORIES)
4. DRIVE PINION	9. GOVERNOR DRIVE ASSEMBLY
5. LOWER TIMING GEAR	10. CHAIN

75.105

Figure 5-7.—Location of drive mechanisms in an opposed-piston engine (Fairbanks-Morse 38D8 1/8).

(frequently called the timing mechanism). The names and arrangement of the components of the drive are shown in figure 5-8. The drive sprocket is attached to the upper crankshaft at the control end of the engine. A sprocket is attached to the end of each camshaft, and there are three other sprockets for timing and adjustment purposes.

The chain conveys the rotation of the upper crankshaft to the camshaft sprockets by passing over the crankshaft sprocket, under the two timing sprockets, over the two camshaft drive sprockets, and under the tightener sprockets. The timing sprockets are mounted on an adjustable bracket or lever. By moving the lever, the timing of the two camshafts can be adjusted. The adjustable tightener sprocket is used to obtain and maintain the proper slack in the chain.

BLOWER DRIVE MECHANISM

The power to drive the blower is transmitted from the upper crankshaft, through a gear train (fig. 5-7). The train consists of a drive gear, a pinion gear, and the two timing (impeller) gears of the blower.

The drive gear is the flexible type (fig. 5-7). The principal parts of the FLEXIBLE DRIVE GEAR are a spider drive hub (which is keyed to the crankshaft), a gear (within which spring spacers are bolted), and springs (which absorb torsional oscillations transmitted by the crankshaft). A view of the flexible drive gear with end plate removed and the spider drive hub is shown in figure 5-9.

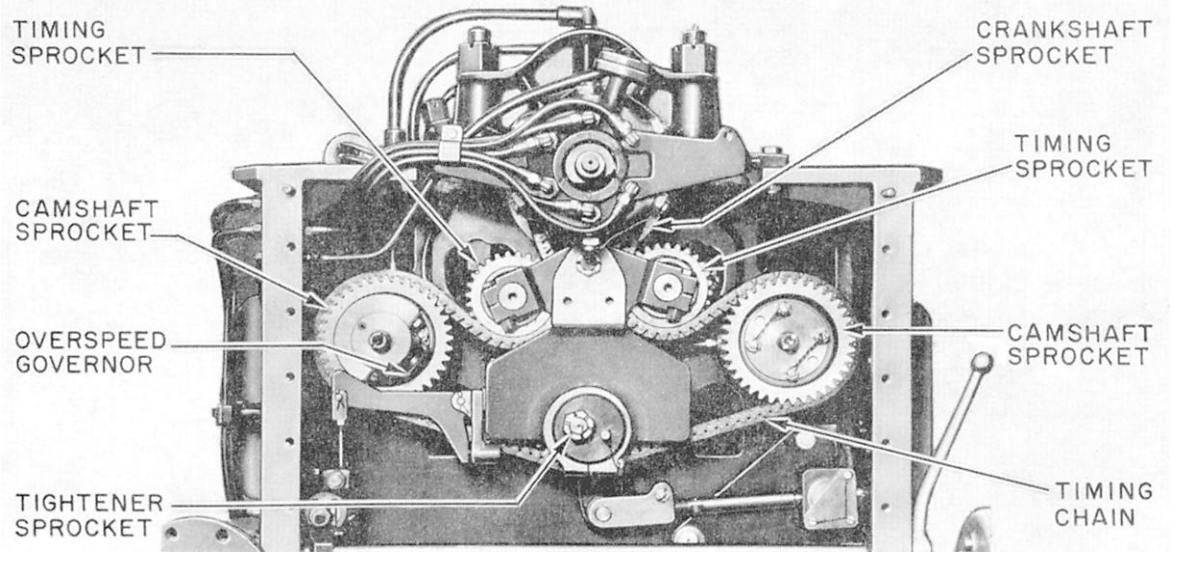
The flexible drive gear meshes with the drive pinion (fig. 5-7). The pinion is keyed to the lower impeller shaft and held in place by a locknut. The lower impeller driving (timing) gear meshes with the upper impeller driven gear (fig. 5-7).

ACCESSORY DRIVE MECHANISM

The majority of the accessories for the FM 38D are driven by a gear mechanism that receives power from the lower crankshaft at the control end of the engine (fig. 5-7). A more detailed view of the accessory drive is shown in figure 5-10. Referring to both these figures as you read the following description will help you become familiar with the components of the drive and with the way that power is transmitted to the driven units.

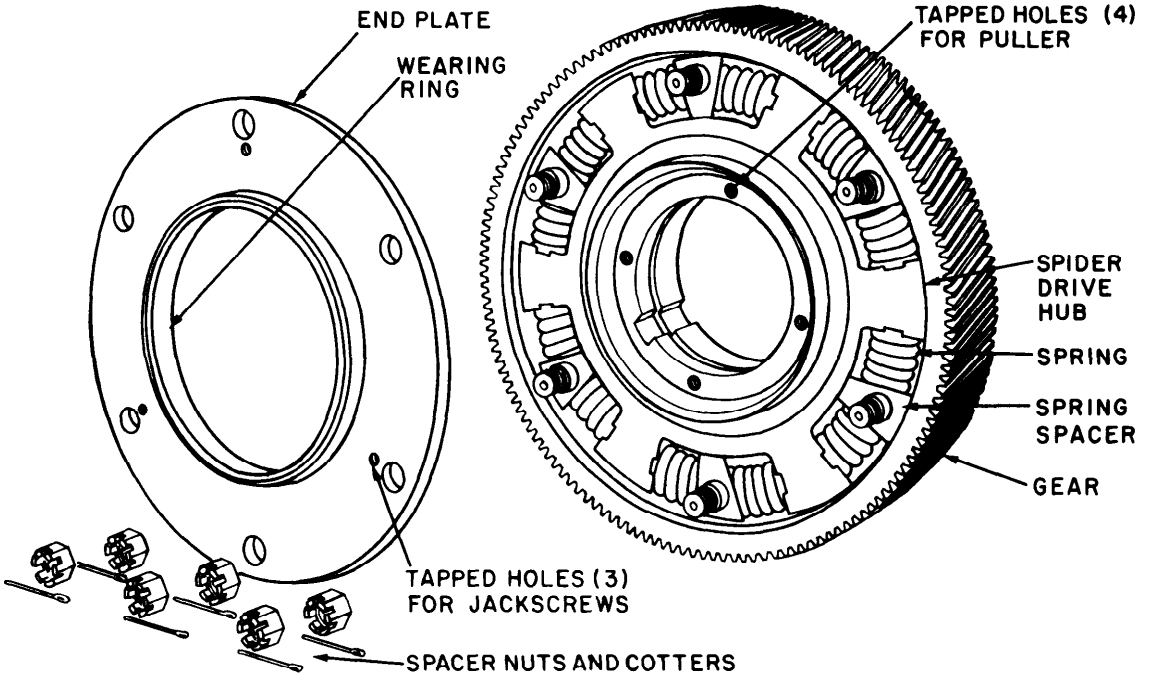
The accessory drive transmits power to the water pumps, the fuel oil pump, the lubricating oil pump, and the governor. The drive gear (fig. 5-7) of the mechanism is bolted to a flange on the crankshaft. The drive gear is the flexible type; therefore, engine shocks transmitted by the crankshaft are absorbed by the drive springs of the gear.

The water pump drive gears mesh directly with the flexible drive gear. The fuel pump drive gear



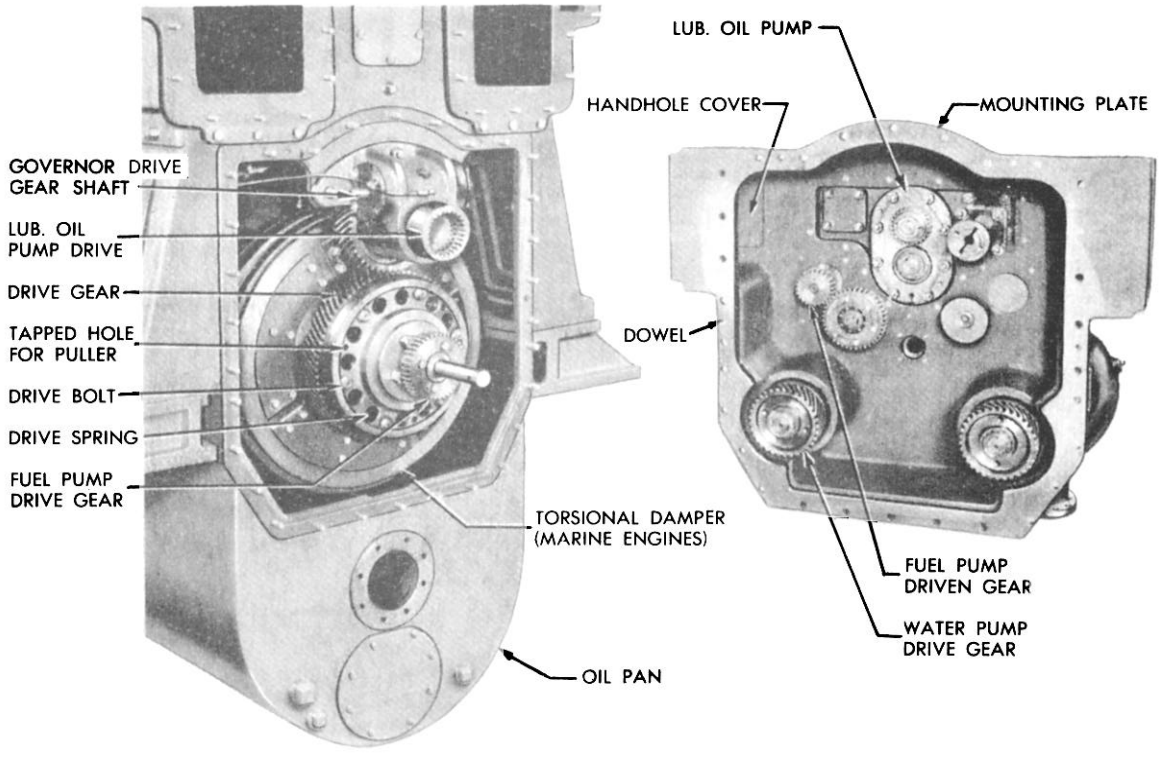
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Figure 5-8.—Camshaft drive and timing mechanism (Fairbanks-Morse 38D8 1/8).



75.108

Figure 5-9.—Blower flexible drive gear (Fairbanks-Morse 38D8 1/8).



75.109

Figure 5-10.—Accessory drive (Fairbanks-Morse 38D8 1/8).

(attached to the flexible drive gear) transmits power to the fuel pump driven gear through an idler. (See the fuel pump driven gear on the mounting plate in fig. 5-10.) The lubricating oil pump drive gear meshes directly with the flexible drive gear. Power is transmitted to the pump through a shaft and an internal gear coupling—the lubricating oil pump drive. The shaft of the lubricating oil pump drive also transmits power to the governor. A gear on the shaft meshes with a mating gear on the governor drive gear shaft. This shaft drives the governor coupling shaft which, in turn, drives the governor, through a beveled gear drive (fig. 5-7).

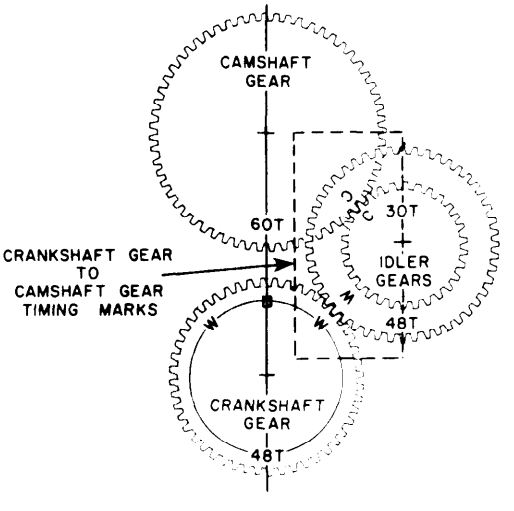
DRIVE MECHANISMS IN A 4-STROKE CYCLE DIESEL ENGINE

The drive mechanisms we have discussed so far have applied to 2-stroke cycle engines. We will now take a look at a gear train of a 4-stroke cycle engine (fig. 5-11). The gear train for the 4-stroke cycle engine is different from that of the 2-stroke cycle engine for two reasons. The first reason is that there is no provision for the driving of a blower since 4-stroke cycle diesel engines are either naturally aspirated or are turbocharged. Turbocharging units are exhaust-driven and require no mechanical drive. Another difference is the need for gear reduction in a 4-stroke cycle engine between the crankshaft and the camshaft. In a 4-stroke cycle engine, the camshaft speed must be exactly one-half the crankshaft speed. Remember, in a 4-stroke cycle engine, the crankshaft must rotate 720° for each power event per cylinder. The method by which the required 2:1 gear reduction is accomplished is by the use of one or more idler gears between the crankshaft gear and the camshaft gear. Refer to figure 5-11 as we explain how the 2:1 gear ratio is obtained in one type of engine. If the crankshaft were to revolve 360 degrees, it would move a total of 48 teeth. This movement is transmitted to the large idler gear, which will also revolve 360 degrees, or 48 teeth. As you can see in figure 5-11, a smaller idler gear with 30 teeth is mounted to the larger idler gear. This smaller gear is where the gear ratio starts to change. As the small idler gear revolves 360 degrees, or 30 teeth, it drives the camshaft gear 180 degrees, or 30 teeth. (The gear with the greater number of teeth will always revolve more slowly than the gear with the smaller number of teeth.) Thus, we now have the 2:1 ratio between the crankshaft and camshaft that is required for a 4-stroke cycle engine to operate. Now compare the gear train of the 4-stroke cycle engine in figure 5-11 to that of the 2-stroke cycle gear train in figures 5-1 and 5-5. You should be able to recognize the difference in these drive mechanisms.

SUMMARY

The drive mechanisms of an engine are those assemblies that transmit power for the operation of engine accessories and certain engine parts. The drive mechanisms may be a chain assembly, gear train, belts, or a combination of any of these parts. Some engines have only one drive mechanism, which is generally called the camshaft drive. Other engines may have a second major drive mechanism called the accessory drive. In most engines, each drive is generally identified by the name of the principal part or the accessory drive, such as blower drive, camshaft drive, and governor drive.

The importance of these drive-transmitting devices is evident if you consider the function of the components to which power is transmitted. The VALVE-ACTUATING MECHANISMS control the fuel, intake air, exhaust gases, and starting air (when applicable) in the cylinders. The engine ACCESSORIES that are driven are those that circulate the cooling water and lubricating oil, supply air for scavenging and supercharging, supply fuel, and control engine speed. If you are unsure as to how these drive mechanisms function, we recommend you review the areas in which you are weak.



75.346

Figure 5-11.—Gear train of a 4-stroke cycle engine showing gear ratio (Waukesha).

CHAPTER 6

INTAKE AND EXHAUST SYSTEMS

Combustion requires air, fuel, and heat; certain ratios of all three are necessary if an engine is to operate. This chapter deals with AIR as it is required to support combustion in the cylinder of an engine. The processes of scavenging and supercharging are considered as well as the group of parts involved in supplying the cylinders of an engine with air and in removing the waste gases after combustion and the power event are finished. The engine parts that accomplish these functions are commonly referred to as the INTAKE and EXHAUST systems.

After reading the information in this chapter, you should be able to describe the purposes, principles of operation, and functions associated with the components of air intake and exhaust systems. You should also be able to trace the path of the intake air and exhaust gases through these systems, and you should understand the significance of scavenging and supercharging and how these processes differ in the operating cycles of 2- and 4-stroke engines.

INTAKE SYSTEMS

This section deals with intake systems of diesel engines only; nevertheless, much of the information dealing with the parts of diesel engine air systems is also applicable to most of the parts in similar systems of gasoline engines.

Although the primary function of a diesel engine intake system is to supply the air required for combustion, the system also cleans the air and reduces the noise created by the air as it enters the engine. An intake system may include an air silencer, an air cleaner and screen, an air box or header, intake valves or ports, a blower, an air heater, and an air cooler. Not all of these parts are common to every intake system. The differences will be explained as these systems are discussed.

SCAVENGING AND SUPERCHARGING

In the intake systems of all 2-stroke cycle diesel engines and some 4-stroke cycle diesel engines, a device, known as a blower, is installed to increase the flow of air into the cylinders. The blower compresses the air and forces it into an air box or manifold, which surrounds or is attached to the cylinders of an engine. Thus, more air under constant pressure is available as required during the cycle of operation.

The increased amount of air, a result of blower action, fills the cylinder with a fresh charge of air. During the process, the increased amount of air helps to clear the cylinder of the gases of combustion. The process is called SCAVENGING. Therefore, the intake system of some engines, especially those operating on the 2-stroke cycle, is sometimes called the scavenging system. The air forced into the cylinder is called scavenge air, and the ports through which it enters are called scavenge ports.

Scavenging must take place in a relatively short portion of the operating cycle; the duration of the process differs in 2- and 4-stroke cycle engines. In a 2-stroke cycle engine, the process takes place during the latter part of the downstroke (expansion) and the early part of the upstroke (compression). In a 4-stroke cycle engine, scavenging takes place when the piston is nearing and passing TDC during the latter part of an upstroke (exhaust) and the early part of a downstroke (intake). The intake and exhaust openings are both open during this interval of time. The overlap of intake and exhaust permits the air from the blower to pass through the cylinder into the exhaust manifold, cleaning out the exhaust gases from the cylinder and, at the same time, cooling the hot engine parts.

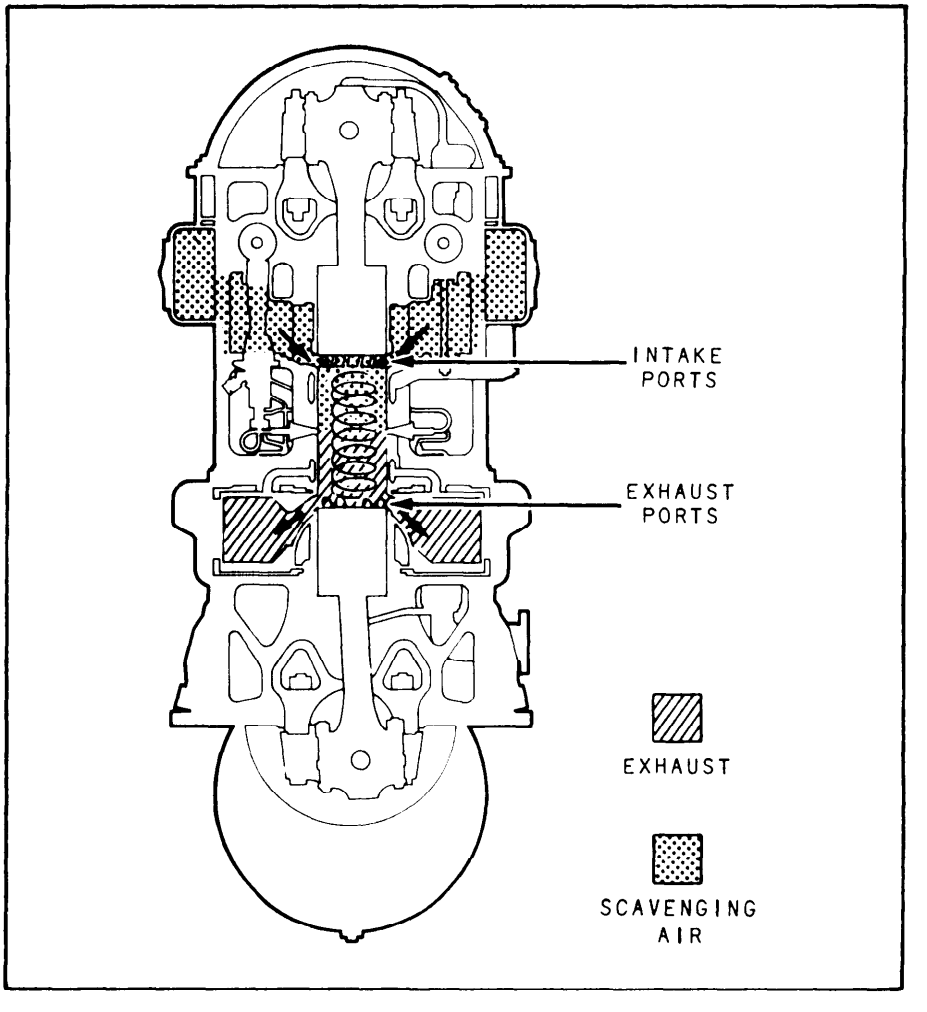
When scavenging air enters the cylinder of an engine, it must be so directed that the waste gases are removed from the remote parts of the cylinder. The two principal methods by which this is accomplished are referred to as PORT

UNIFLOW SCAVENGING and VALVE UNIFLOW SCAVENGING. In the uniflow method of scavenging, both the air and the burned gases flow in the same direction. This action causes a minimum of turbulence and improves the effectiveness of the scavenging action. An example of a port uniflow system is shown in figure 6-1. An example of a valve uniflow system is shown in figure 6-2.

Scavenging and supercharging are not common to all diesel engines. For instance, in some 4-stroke cycle engines, the air enters the cylinder as a result of a pressure difference created by the piston as it moves away from the combustion space during the intake event. This type of intake is sometimes referred to as the suction-type, or naturally aspirated, intake; however, the air is actually forced into the cylinder because of the greater pressure outside the cylinder.

An increase in airflow into the cylinders of an engine can serve to increase power output, in addition to being used for scavenging. Since the power of an engine comes from the burning of fuel, an increase in power requires more fuel; the increased fuel, in turn, requires more air since each pound of fuel requires a certain amount of air for combustion. The supplying of more air to the combustion spaces than can be supplied through the action of atmospheric pressure and piston action (in 4-stroke cycle engines) or scavenging air (in 2-stroke cycle engines) is called SUPERCHARGING.

In some 2-stroke cycle diesel engines, the cylinders are supercharged during the air intake simply by an increase in the pressure of scavenging air. The same blower is used for supercharging and scavenging. Scavenging is done when air is admitted under low pressure into the cylinder while the exhaust valves or ports are open. Supercharging is done with the exhaust ports or valves closed, a condition that enables the blower to force air under pressure into the cylinder and



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Figure 6-1.—Port uniflow system in a Fairbanks-Morse engine.

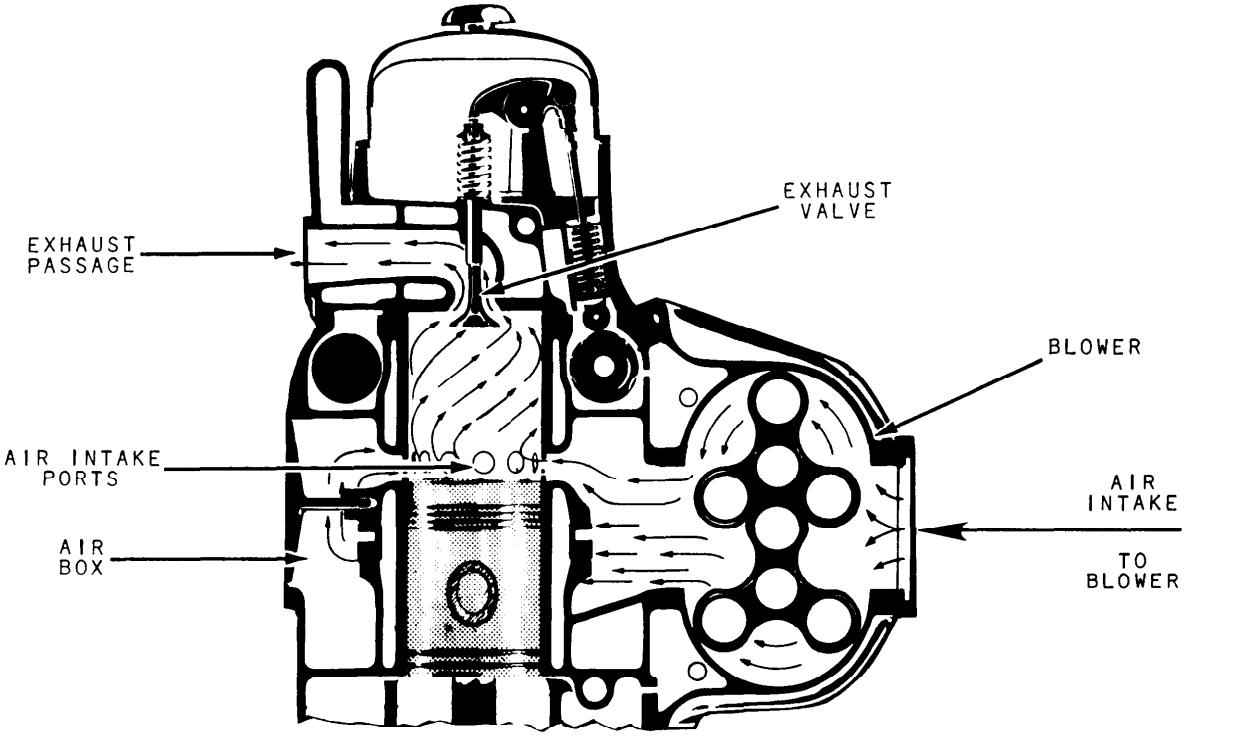


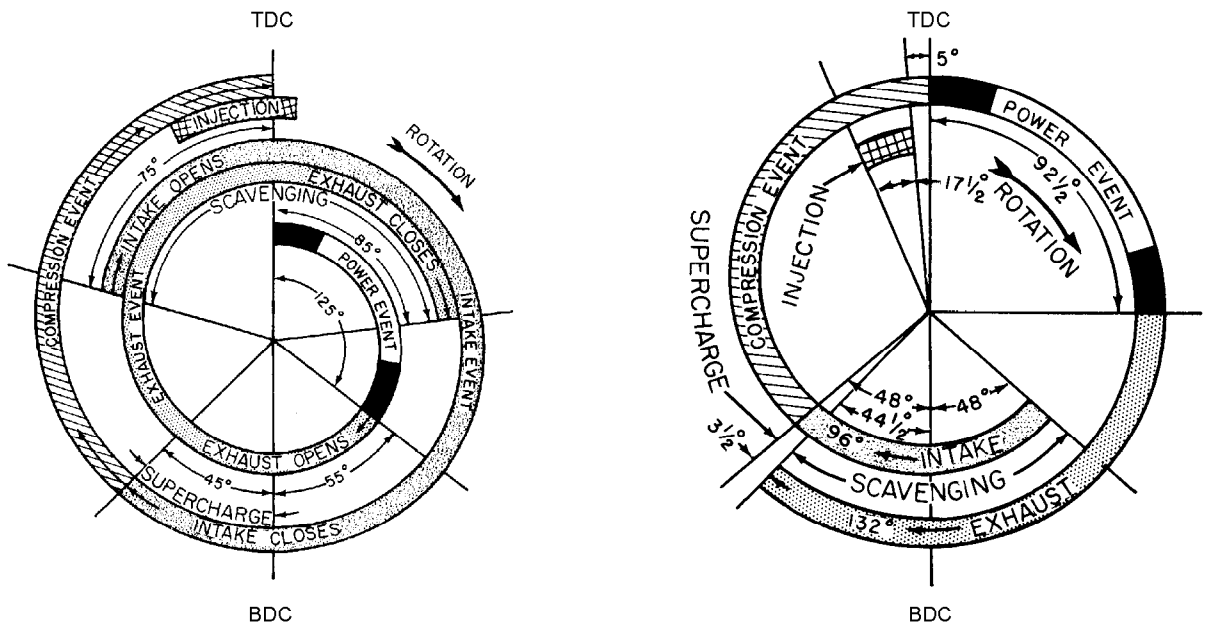
Figure 6-2.—Valve uniflow system in a General Motors 2-stroke cycle diesel engine.

thereby increase the amount of air available for combustion. An engine is referred to as supercharged when the manifold pressure exceeds the atmospheric pressure. The increase in pressure, resulting from the compression action of the blower, will depend on the type of installation. With the increase in pressure and amount of air available for combustion, there is a corresponding increase in combustion efficiency within the cylinder. In other words, an engine of a given size that is supercharged can develop more power than an engine of the same size that is not supercharged.

For a 4-stroke diesel engine to be supercharged, a blower must be added to the intake system since exhaust and intake in an unsupercharged engine are performed by the action of the piston. The timing of the valves in a supercharged 4-stroke cycle engine is also different from that in a similar engine that is not supercharged. In the supercharged engine, the closing of the intake valve is slowed down so that the intake valves or ports are open for a longer time after the exhaust valves close. The increased time that the intake valves are open (after the exhaust valves close) allows more air to be forced into the cylinder before the start of the compression event. The amount of additional air that is forced into the cylinder and the resulting increase in horsepower depends on the pressure in the air box or intake manifold. The increased overlap of the valve openings also permits the air pressure created by the blower to remove gases from the cylinder during the exhaust event. Study figure 6-3 so that you will understand how the opening and closing of the intake and exhaust valves, or ports, affect both scavenging and supercharging. Also, note the differences in these processes as they occur in supercharged 2- and 4-stroke cycle engines.

In figure 6-3, the circular pattern represents crankshaft rotation. Some of the events occurring in the cycles are shown in degrees of shaft rotation for purposes of illustration and easier comparison only. (When dealing with the timing of a specific engine, check the appropriate instructions.)

In studying figure 6-3, keep in mind that the crankshaft of a 4-stroke cycle engine makes two complete revolutions in one cycle of operation, while the shaft in a 2-stroke cycle engine makes



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Figure 6-3.—Scavenging and supercharging in diesel engines. **2.24**

only one revolution per cycle. Also, keep in mind that the exhaust and intake events in a 2-stroke engine do not involve complete piston strokes as they do in a 4-stroke engine.

Four-Stroke Cycle
Scavenging and Supercharging

View A of figure 6-3 is based on the operation of a 4-stroke cycle engine that uses a centrifugal-type blower (turbocharger) to supply the cylinders with air under pressure.

In a supercharged 4-stroke cycle engine, the duration of each event differs somewhat from the length of the same events in a nonsupercharged 4-stroke engine. The intake and exhaust valves are open much longer in a supercharged engine, and the compression and power events are shorter, permitting a longer period for scavenging. When the exhaust event is complete, the turbocharger fills the cylinder with fresh air under pressure before the compression event begins. In other words, the turbocharger supercharges the cylinders.

To understand the relationship of scavenging and supercharging to the events of the cycle, look again at view A in figure 6-3 and follow through the complete cycle. Start your study of the cycle at TDC, the beginning of the power event. At this point, peak compression has been reached, fuel injection is nearly completed, and combustion is in progress. Power is delivered during the downstroke of the piston for 125° of crankshaft rotation. At this point in the downstroke (55° before BDC), the power event ends and the exhaust valves open.

The exhaust valves remain open throughout the rest of the downstroke (55°), throughout all of the next upstroke (180°), and throughout 85° of the next downstroke; a total of 320° of shaft rotation. At a point 75° before the piston reaches TDC, the intake valves open and the turbocharger begins forcing fresh air into the cylinder. For 160° of shaft rotation, the air passes through the cylinder and out of the exhaust valves, clearing the waste gases from the cylinder. The rapid flow of gases escaping through the exhaust manifold drives the turbocharger. The process of scavenging continues until the exhaust valves close at 85° past TDC.

The intake valves remain open, after the exhaust valves close, for an additional 140° of shaft rotation (45° past BDC). From the time the exhaust valves close until the piston reaches approximately BDC, the cylinder is being filled with air from the turbocharger. During this interval, the increase in pressure is too small to be considered because of the increasing volume of the cylinder space. (The piston is in the downstroke.) However, when the piston reaches BDC and starts the upstroke, the volume of the space begins to decrease as the turbocharger continues to force air into the cylinder. The result is a supercharging effect.

During the remainder of the upstroke (after the intake valves close), the supercharged air is compressed. Fuel injection begins several degrees before TDC and ends shortly after TDC. The actual length of the injection period in a specific engine depends on the speed and load of the engine. When the piston reaches TDC, a cycle (two complete crankshaft revolutions and four strokes of the piston) has taken place, and the engine is ready to repeat the cycle.

Two-Stroke Cycle
Scavenging and Supercharging

In comparing views A and B of figure 6-3, note that the length of the supercharging and scavenging periods in a 2-stroke cycle engine is not the same as those in a 4-stroke cycle engine. Also, there is considerable difference in piston location between the times when these processes take place in the two types of engines. In a 4-stroke cycle, scavenging takes place while the piston is traveling through the latter part of the upstroke and the early part of the downstroke, and supercharging takes place when the piston is in the vicinity of BDC. In a 2-stroke cycle, the processes of scavenging and supercharging both take place while the piston is in the lower part of the cylinder. In a 4-stroke cycle engine, a piston does much of the work of intake and exhaust. In a 2-stroke cycle engine, however, the piston does very little work in these two processes. Because of this, many 2-stroke cycle engines use a blower to force air into the cylinder and to clear out the exhaust gases.

View B of figure 6-3 is based on the 2-stroke cycle of operation. If you compare view B with view A (fig. 6-3), the differences in the scavenging and supercharging processes in 2- and 4-stroke cycle engines are more apparent. Start your study of the cycle with the piston at TDC in view B of figure 6-3. Fuel has been injected, ignition has occurred, and combustion is taking place. The power developed forces the piston through the power event until the piston is 92 1/2° (as compared to 125° for the 4-stroke cycle

in view A) past TDC, just a little more than halfway through the downstroke. At this point, the exhaust valves open, gases escape through the manifold, and cylinder pressure drops rapidly.

When the piston reaches a point 48° before BDC, the intake ports are uncovered as the piston moves downward and scavenging begins. (Compare this with the opening of the intake valves in a 4-stroke cycle in view A.) The scavenging air, under blower pressure, swirls upward through the cylinder and clears the cylinder of exhaust gases. The situation in the cylinder when scavenging starts is approximately the same as that illustrated in figure 6-2. Note the position of the piston, the open scavenging ports, the open exhaust valves, and the flow of air through the cylinder. The flow of scavenge air through the cylinder also helps to cool the parts, which are heated by combustion.

Study again view B of figure 6-3. Scavenging continues until the piston is 44 1/2° past BDC (a total of 92 1/2° as compared with 160° in the 4-stroke cycle in view A), at which point the exhaust valves close. In a 2-stroke cycle engine, the exhaust valves remain open during only 132°, as compared with the 320° in the 4-stroke cycle. The scavenge ports remain open for another 3 1/2° of shaft rotation (45° in the 4-stroke cycle), and the blower continues to force air into the cylinder. Even though the ports are open for only a short interval after the exhaust valves close, enough time is available for the blower to create a supercharging effect before the compression event starts.

The piston closes the intake ports at 48° past BDC. The compression event takes place during the remainder of the upstroke, with injection and ignition occurring at TDC. At this point one cycle is ended and another is ready to start.

INTAKE SYSTEM COMPONENTS

There are many variations in the design of the engine parts, which function as a group to properly direct clean air to intake valves or ports. Regardless of design differences, the function of each kind of part remains basically the same. We cannot cover every type or model of each part of engine air intake systems in this text. Therefore, we will discuss only a few of the common types of each of the principal parts of these systems.

Silencers, Screens, and Cleaners

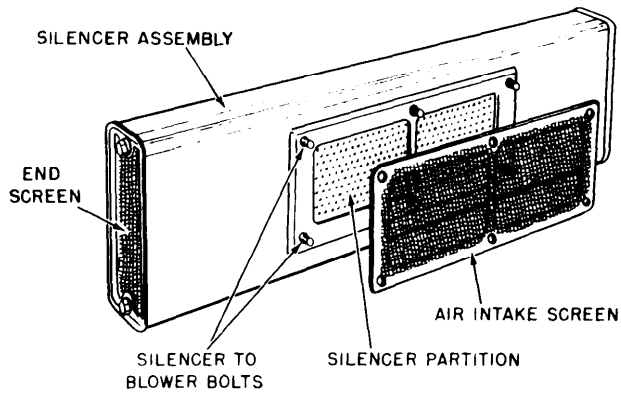
Air must enter the intake system as quietly and as clean as possible. **A** diesel engine uses a great quantity of air. Unless a silencer is installed, the air that rushes through the air-cleaning devices will sound like an extremely high-pitched whistle. Consequently, silencers are generally constructed as part of the air-cleaning components.

One type of air-intake silencer assembly is shown in figure 6-4. This type of silencer is used on some General Motors (GM) series 71 engines.

The silencer assembly is bolted to the intake side of the blower. (See fig. 6-2.) A perforated steel partition divides the silencer lengthwise into two sections. Air enters the end of the silencer and passes through the inner section into the blower. The noise of the air passes through the silencer where it is reduced by a sound-absorbent, flameproof, felted cotton waste, which fills the outer section of the silencer.

Upon leaving the silencer, the air enters the blower through an air-intake screen. (See fig. 6-4.) The air-intake screen prevents particles of foreign material from entering the engine. Unless it is filtered from the intake air, foreign material might seriously damage the blower assembly and internal engine parts, such as pistons, piston rings, and liners.

The silencer-and-screen assembly just described is sometimes referred to as a DRY-type cleaner and silencer. Another type of air cleaner and silencer is the VISCOUS type. In both dry and viscous types, intake air is drawn through a fine mesh or screen which filters the air. The mesh of such cleaners may consist of cotton fabric, wire



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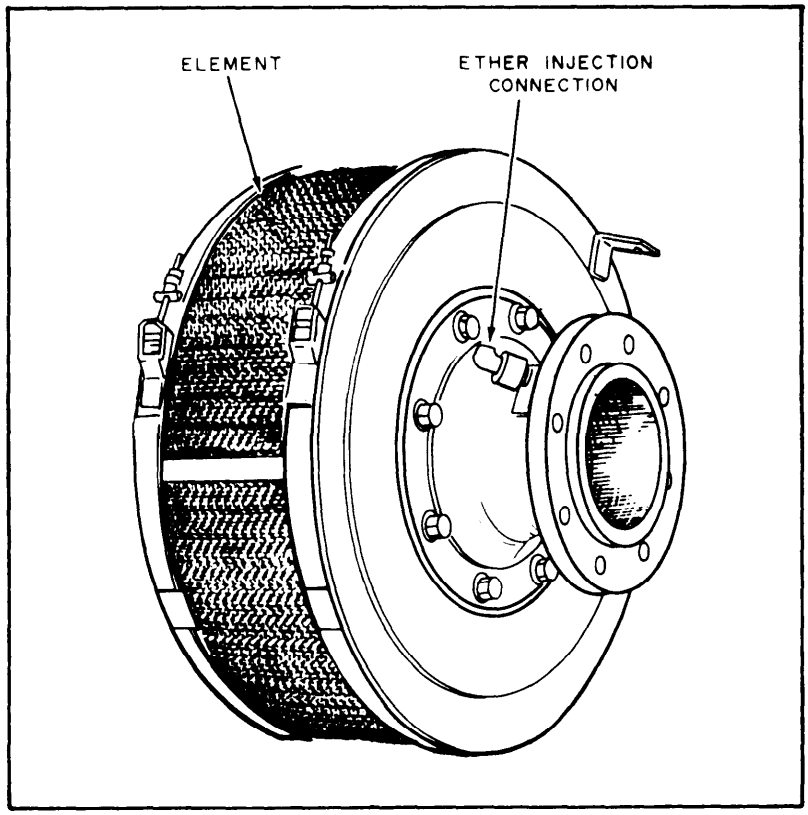
Figure 6-4.—Air-intake silencer assembly (General Motors series 71).

screening, specially wound copper crimp, or metal wool. The principal difference between cleaners of the dry and viscous types is that the mesh of a viscous-type cleaner is wet, usually, with a medium-weight oil. An air cleaner and silencer assembly of the viscous type is shown in figure 6-5. The filter and silencer of this unit form a cylinder silencing chamber, the ends of which are packed with sound-deadening material. Air enters the silencer through the circumferential surface of the silencing chamber. The filter element fits over the air inlet. The element of the filter consists of a series of oil-wetted wire baffles, which collect any airborne dirt entering the chamber.

Another type of intake-air cleaner and silencer includes an oil bath as part of the assembly. A cross section of an oil bath air cleaner is shown in figure 6-6. This type of air cleaner is referred to as a heavy-duty oil bath air cleaner. In heavy-duty oil bath air cleaners, there are two cleaning elements. One is a removable separator screen; the other is a fixed metal-wool element (metal mesh). Follow along as we explain how the oil bath air cleaner functions.

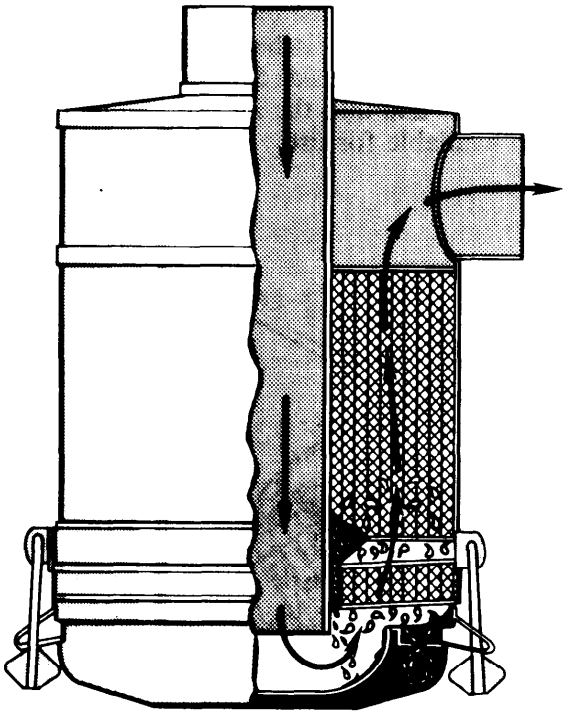
The air is drawn into the cleaner through an opening in the center of the top. As the air reaches the bottom of this passage, it changes direction and flows up around the outside of the center passage through the metal-wool element. The centrifugal force, caused by the sudden change in direction, traps large particles of dirt in the oil in the bottom of the cleaner. Smaller particles of dirt in the oil picked up by the air are trapped in the metal-wool element. It is important not to overfill the oil reservoir during maintenance, as this will cause oil to be drawn into the engine. Light-duty oil bath air cleaners work in the same way, but because of their size, they are not capable of providing the same volume of air to the engine.

The silencer and cleaner assemblies described in the preceding paragraphs are representative of the devices that serve to clean



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Figure 6-5.—Viscous type of air filter and silencer assembly.



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Figure 6-6.—Airflow through a heavy-duty oil bath type of air cleaner.

intake air and to reduce the noise the air makes as it enters the engine. To ensure sufficient cleaning of the intake air, air filters, regardless of type, should be cleaned as specified by the Planned Maintenance System.

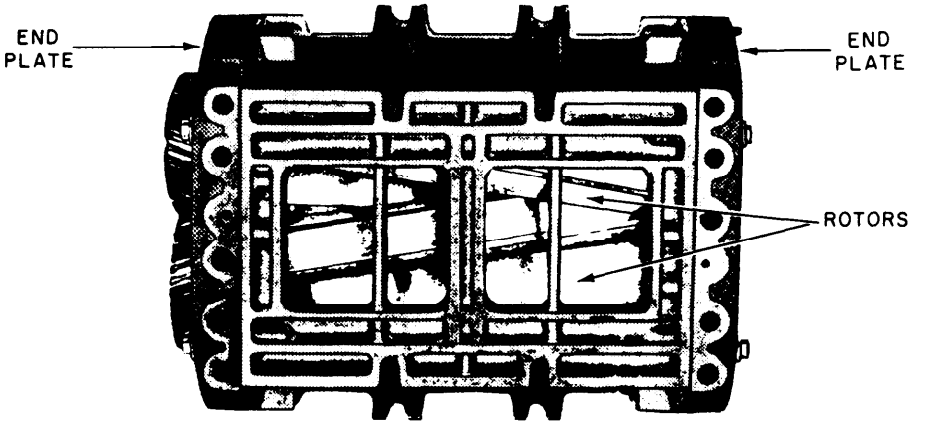
Blowers

Blowers are necessary on most 2-stroke cycle engines to force scavenging air through the cylinders. In addition, a supercharged engine, either 2- or 4-stroke cycle, must have a blower to fill the cylinder with fresh air at a pressure above atmospheric pressure before the compression event starts. Basically, the primary function of an engine blower is to deliver a large volume of air at a low pressure.

There are two principal types of blowers, POSITIVE DISPLACEMENT and CENTRIFUGAL. A positive displacement blower is usually gear-driven directly by the engine, while a centrifugal blower is usually driven by an exhaust-gas turbine. Positive displacement blowers may be divided into two groups; the multiple-lobe type, commonly called the LOBE, or ROOTS, blower; and the AXIAL-FLOW, or Whitefield, blower. Blowers are introduced briefly in *Fireman*, NAVEDTRA 10520-F.

The first example of a blower we will discuss is the roots blower. The roots blower is commonly used on many 2-stroke cycle engines. The other example we will discuss is an exhaust-driven centrifugal type of blower (turbocharger) that is found in many 4-stroke cycle engines and in some 2-stroke cycle engines.

ROOTS BLOWER.—Designed for efficient diesel operation, the roots blower shown in figure 6-7 supplies the fresh air needed for combustion and scavenging. The air volume needed for the engine to perform scavenging is about 40 times

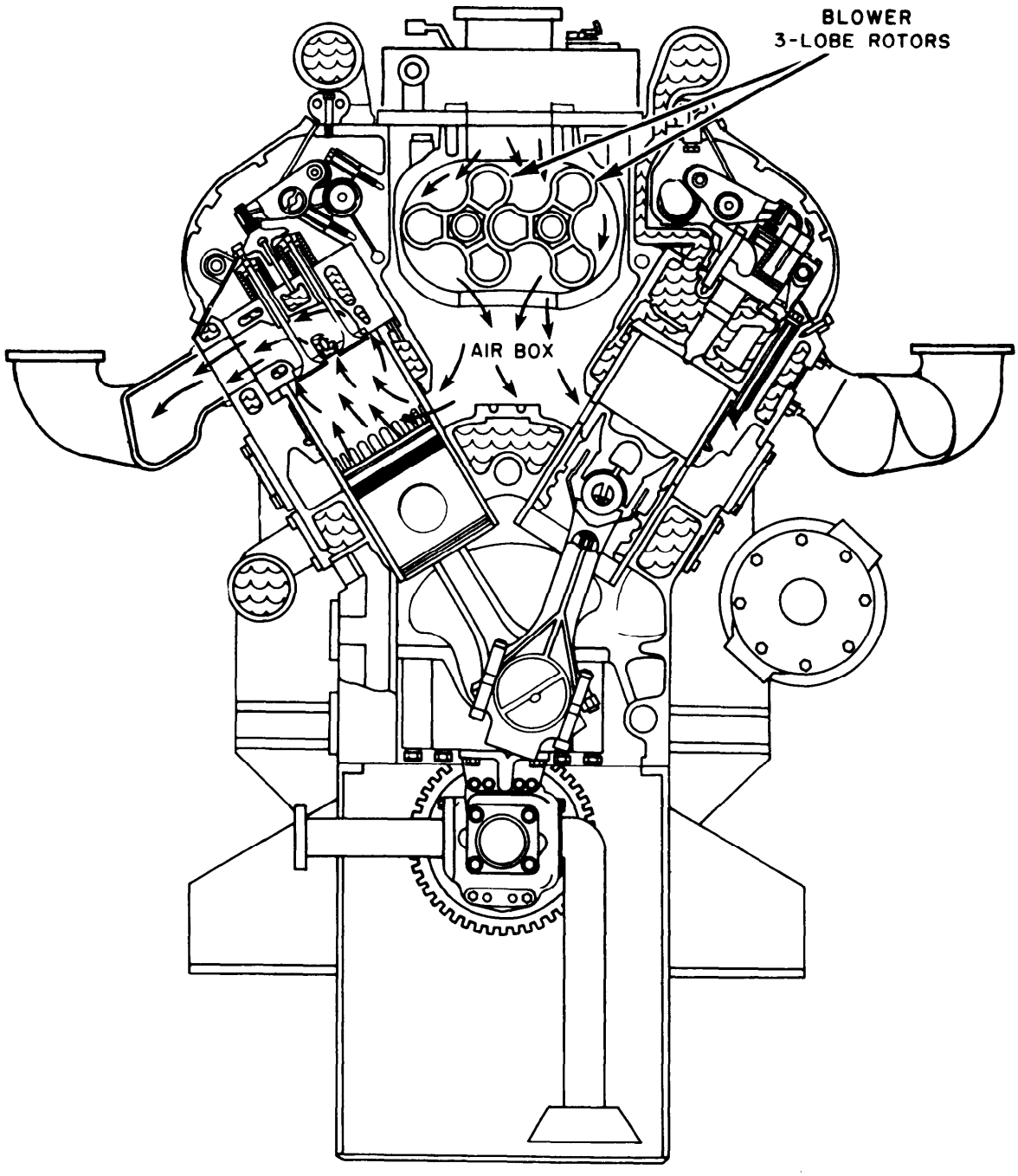


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Figure 6-7.—Roots blower (V-71).

greater than the cylinder volume. The location of the blower on the engine depends on the cylinder arrangement. Figure 6-8 shows the location of the roots blower on a V-type engine. Figure 6-2 shows the blower location on an in-line engine.

The operation of the blower is similar to that of a gear-type pump. Two hollow 3-lobe rotors revolve in opposite directions. (Refer to fig. 6-8.) When the rotors turn, air is drawn in the space between the lobes at the inlet, is trapped, and is carried around to the discharge side. The meshing lobes at the discharge side force the air out of the lobe pockets and into the air box, where the air is then available for use.



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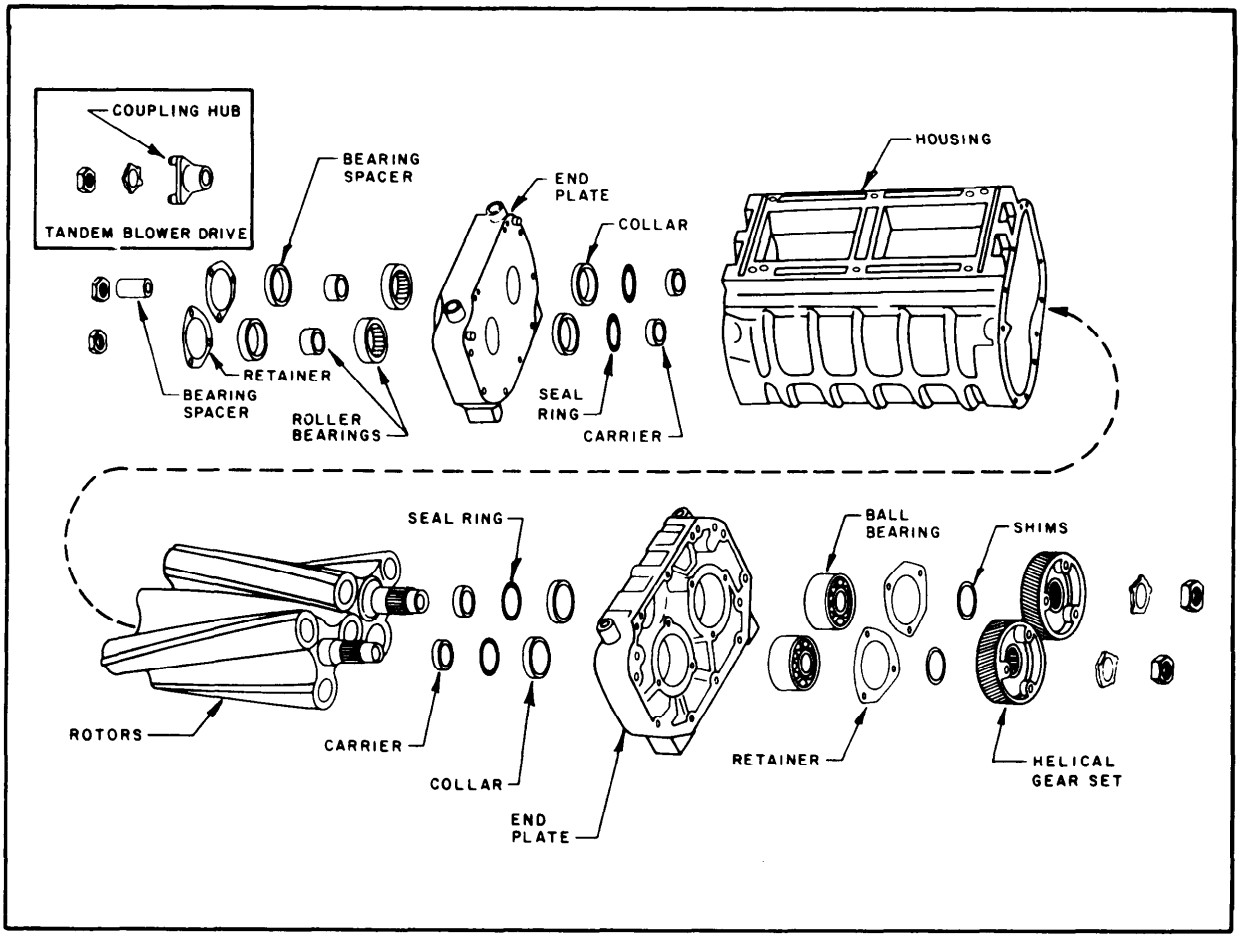
Figure 6-8.—Air intake system through a roots-type blower on a V-type engine (General Motors series 149).

So that a continuously uniform supply of air can be maintained, the rotor lobes are made with a helical (spiral) shape (fig. 6-9). In the helical design, one discharge phase begins before the previous discharge phase is entirely completed, and the lobes are said to overlap. This overlapping tends to produce a smoother discharge of air than could be realized if the rotor lobes were of a straight design. Helical timing gears located on the drive end of the rotor shafts prevent the meshing rotor lobes from touching (refer to fig. 6-9). Each rotor is supported in the doweled end plates of the blower housing by a roller bearing at the front end and by a 2-row radial and thrust ball bearing at the gear end.

Lubrication of the blower bearings, timing gears, and governor drive is provided through oil passages that lead from the main oil galleries of the engine to an oil passage in each end plate of the blower. The rotor lobes require no lubrication since they are prevented from touching by the timing gears.

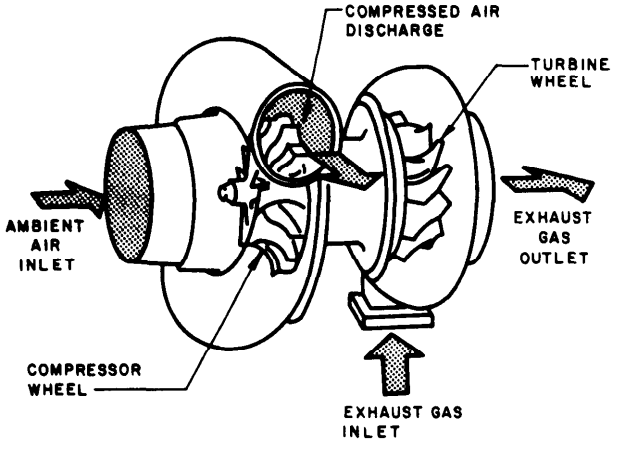
TURBOCHARGER.—Turbochargers are unlike positive displacement blowers, which are driven through a gear train by the engine crankshaft. Positive displacement blowers permit only modest power increases since most of the power developed must be returned to drive the blower. On the other hand, turbochargers produce higher net gains as they use the normally wasted exhaust gas energy for power. Turbocharging can produce power gains of over 50% compared to those of naturally aspirated engines.

In brief, the principles of operation of a turbocharger are as follows: (1) the gases from the exhaust manifold drive a turbine, and (2) the turbine drives an impeller (on the same shaft), which supplies air to the cylinders for scavenging and supercharging. There are several



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Figure 6-9.—Components of a roots type of blower.



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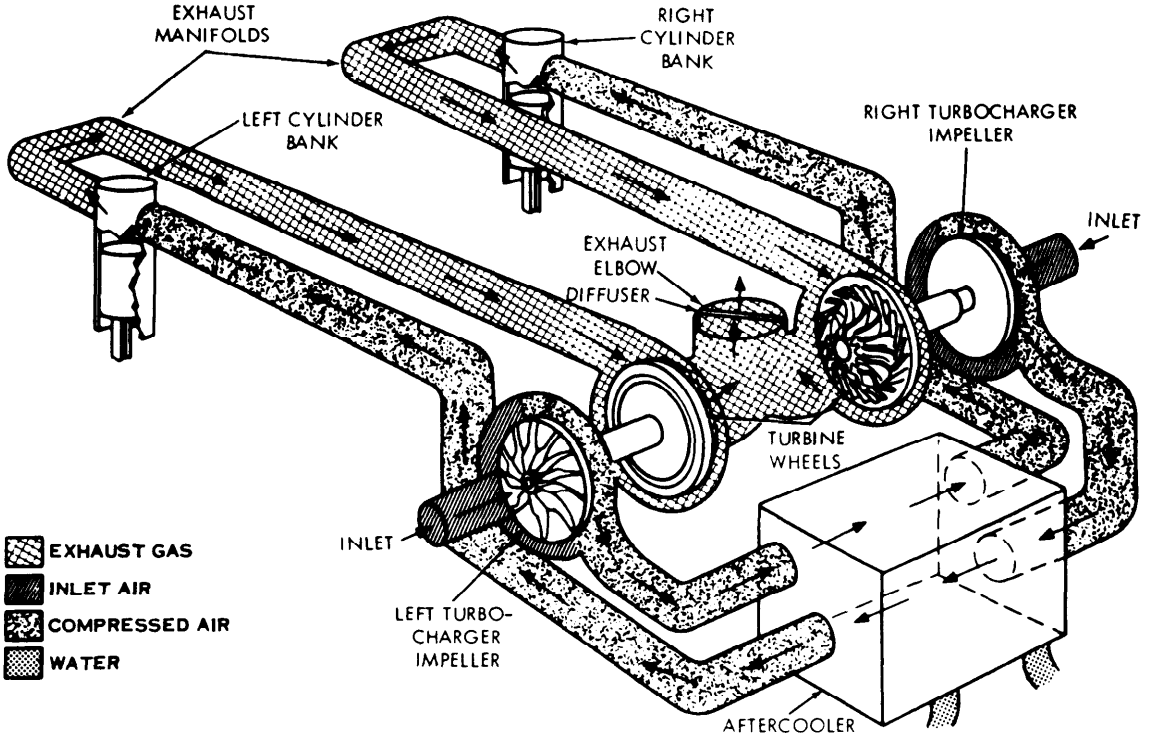
Figure 6-10.—Principles of operation for a turbocharger.

types of centrifugal blowers (turbochargers) in naval service. They all, however, operate on this basic principle.

In our discussion of the turbocharger we will stay with a general description because there are many different types of turbochargers in use within the Navy. Figure 6-10 provides an illustration of a turbocharger. You should refer to figure 6-10 as you read the following information.

The exhaust system of a turbocharger consists of a heat-resistant alloy casting that encloses the turbine wheel and provides an exhaust gas inlet and an exhaust gas outlet. The system furnishes the driving power for the turbocharger by using the high-temperature and high-velocity exhaust gases from the exhaust manifold. The gases enter the turbine casing, striking the turbine wheel and causing it to rotate at a high speed. The speed of the turbine is automatically controlled by the speed and the load of the engine. When the gases have turned the turbine, they are discharged through the exhaust outlet.

The air-intake system of a turbocharger consists of a compression housing and compressor wheel. (Refer to fig. 6-10.) During engine operation, exhaust gases flowing from the engine through the turbine housing cause the turbine wheel to rotate. The compressor wheel, which is mounted on the opposite end of the same shaft, rotates with the turbine. The compressor wheel draws ambient (fresh) air into the compressor housing and compresses the air. The turbocharger responds to engine load change by reacting to the flow of exhaust gases. As the power output of the engine increases, the flow of exhaust gases also increases. This action increases the speed and output of the rotating assembly proportionately,



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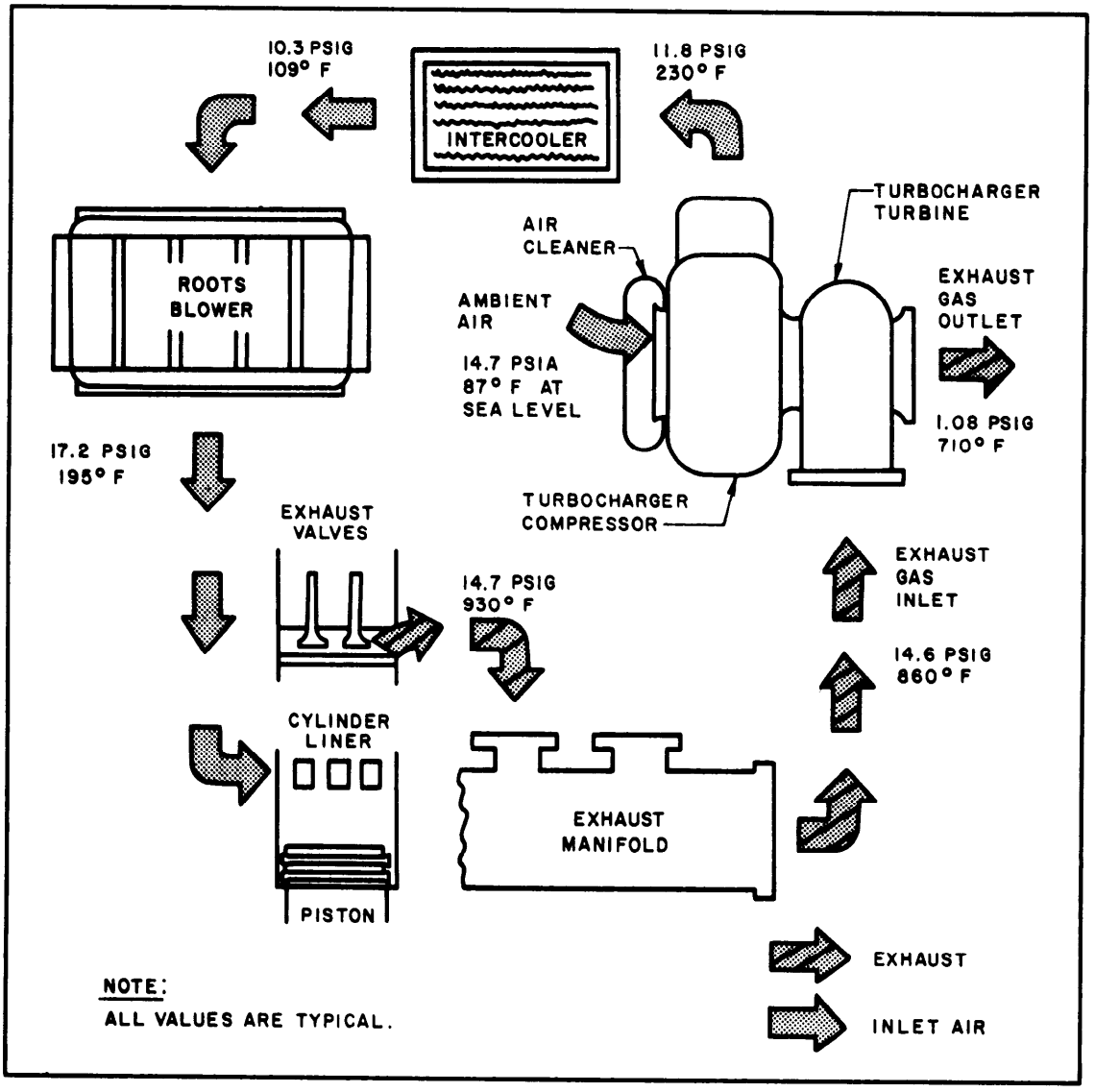
Figure 6-11.—Air induction and exhaust system (Caterpillar D-399 engine).

delivering more air to the intake system of the engine.

Figure 6-11 illustrates the air induction and exhaust system for one type of diesel that uses two turbochargers. Note the arrows that indicate the flow pattern of the exhaust, inlet air, and compressed air systems. As indicated in figure 6-11, the compressed air used for combustion and scavenging is directed through an AFTERCOOLER. Most engines that are turbocharged use aftercoolers to cool the compressed air. Aftercoolers, also referred to as HEAT EXCHANGERS, are small radiators placed between the compressor housing and the intake manifold of the engine. As the compressed hot air passes through the aftercooler, the air is cooled to reduce its volume. Consequently, more air is able to enter the cylinder. The result is lower cylinder pressure, more effective cooling of the cylinder component, and a lower exhaust temperature.

Without the aftercooler, the air temperature entering the intake manifold will increase sharply because of the compression of the air and heat from the turbocharger. This undesirable condition would result in a loss of air density and power, a higher temperature within the cylinder, and a higher exhaust gas temperature.

In some installations, roots blowers and turbochargers are used together within one system. These two components serve to compress the air more efficiently than would be possible if only a blower or a turbocharger were to be used separately. As we discuss this type of system, refer to figure 6-12.



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Figure 6-12.—Engine air system with roots blower and turbocharger assemblies (General Motors 16-V series 149).

In operation, air is drawn into the blower section of the turbocharger through the air cleaner. Air is compressed and the temperature is increased. The high-temperature compressed air is then delivered to the intercooler (heat exchanger), where the temperature is reduced. (Intercoolers are heat exchangers that are usually located between the compressor and the roots blower.) The cooled dense charge of air is then routed to the roots blower inlet. The roots blower further compresses the air and delivers it to the engine. During the intake event, air is forced into the cylinders where it scavenges (cleans) out the combustion gases and fills the cylinder with a clean, dense air charge that is above atmospheric pressure. After the combustion and power event are completed, the exhaust valves open and the hot exhaust gases are discharged to the exhaust manifold. The hot, high-velocity exhaust gases are directed to the turbine section of the turbochargers where they drive the turbine wheel at high speed. During this process, the pressure and the temperature of the exhaust gases are reduced and some of the energy that would otherwise be lost is used to drive the turbocharger. After the exhaust gases leave the turbocharger, they are routed to a muffler.

Even though brief and very general, the preceding account of turbochargers and blowers should sufficiently clarify the principles of operation. The details and specific instructions for a turbocharger, a blower, or any other component in an engine should be obtained from the manufacturer's technical manual.

Intake Air Passages

Air must pass through a number of passages to reach the combustion spaces within an engine. So far, this discussion has considered the passage of air through components that clean, silence, and compress the intake air. From the blower or turbocharger, however, the air is discharged into a unit or passage that conducts it to the intake valves or ports of the cylinders. The design of such a unit as well as the associated terminology will differ depending on the type of engine.

In 2-stroke cycle engines, the passages that conduct intake air to the cylinders are generally referred to as an AIR BOX. The air box surrounds the cylinders (fig. 6-2) and, in many engines, is built into the block. In 2-stroke cycle, V-type diesel engines, the air box consists of the space (within the block) between the two banks of the V-construction and the open space between the upper and lower deckplates of each bank. (Refer to fig. 6-8.) The scavenging air passages in a Fairbanks-Morse, opposed-piston engine are referred to as the AIR RECEIVER. The air receiver is located at the upper part of the block and surrounds the cylinder liners. In some 2-stroke cycle engines, the passage that serves as a reservoir for intake air from the blower is called an AIR HEADER.

Drains are generally provided in air boxes, receivers, and headers to drain off any liquids that may accumulate. A slight amount of vapor from the air charge may condense and settle in the air box, or a small amount of lubricating oil may be blown into the air box as the piston passes the ports on the downstroke following the power event. On some engines, the drains are vented to the atmosphere. In others, a special drain tank collects the drainage from the air box. The purpose of the tank is to prevent drainage of oil into the engine room.

Drains are of primary importance when the air cooler is installed between the blower (or turbocharger) discharge and air intake manifold or receiver. The drains are usually left open during engine operation so that condensation or water from leaky coolers is prevented from being carried into the engine cylinders with the combustion air.

In 4-stroke cycle diesel engines, the intake air passages from the blower to the cylinders differ, in general, from those in 2-stroke cycle engines in that these passages are not an integral part of the block. Instead, a separate unit is attached to the block to conduct intake air to the engine cylinders. The attached unit is generally called an air intake MANIFOLD.

Cylinder Ports and Valves

The amount of air that enters the cylinders from the air box or manifold is controlled by the opening and closing of the cylinder valves or ports. Whether air is admitted to the cylinders of engines through ports or by valves depends upon the type of engine. As we stated earlier, in 4-stroke cycle engines, the amount of air that enters the cylinders is controlled by valves, while ports are used for this purpose in 2-stroke cycle engines. Ports control the discharge of exhaust gases from some 2-stroke cycle engines, and valves perform the same function in all 4-stroke and in many 2-stroke cycle engines.

We have made frequent reference in this chapter to ports and have illustrated their

location in the cylinder liner. (See figs. 6-1, 6-2, and 6-8.) INTAKE PORTS are usually located in such a way that air enters the cylinder in a whirling motion. The turbulence created helps to increase the amount of intake air that is reached by the injected fuel particles. Thus, the power output of the engine is increased. Intake ports as well as EXHAUST PORTS are opened and closed by the piston as it moves back and forth in the cylinder. The valves of an engine are opened and closed at the proper point in the cycle of operation by the valve mechanisms.

Cylinder Test Valves and Safety or Relief Valves

In some large engines, each cylinder is equipped with valves that serve different purposes from those of the intake and exhaust valves. Instead of admitting air to the cylinder or permitting the exhaust gases to escape, these valves may be used for testing or safety purposes. Even though they are not a part of the air system of the engine, these valves are definitely related to the air system since they serve to test or relieve pressure which may develop with the combustion space.

A TEST VALVE is used (1) to vent the cylinder of any accumulated water or oil before an engine is started; (2) to relieve cylinder pressure when the engine is being turned by hand; or (3) to test compression and firing pressures. Test valves are hand operated. (See fig. 6-13.)

Manufacturers use the terms *safety valves* and *relief valves* to identify valves installed in cylinder heads or liners that serve to relieve excessive pressure that may develop when the engine is operating. These valves are of the spring-loaded poppet type. Whether they are called safety valves or relief valves, these valves are designed to open when the cylinder pressure exceeds a safe operating limit.

A sectional view of the safety valve and test valve arrangement is shown in figure 6-13. Note the passage and adapter for a cylinder pressure indicator. Most test and relief valve arrangements have an adapter for the cylinder pressure measuring instrument.

The valves shown in figure 6-13 are fitted in passages within the cylinder head. In some engines, however, the relief valve is attached separately to the exterior of the head or liner. For example, the cylinder relief valve of a Fairbanks-Morse 38D8 1/8 is screwed into an adapter which also has a tapped opening for an indicator valve.

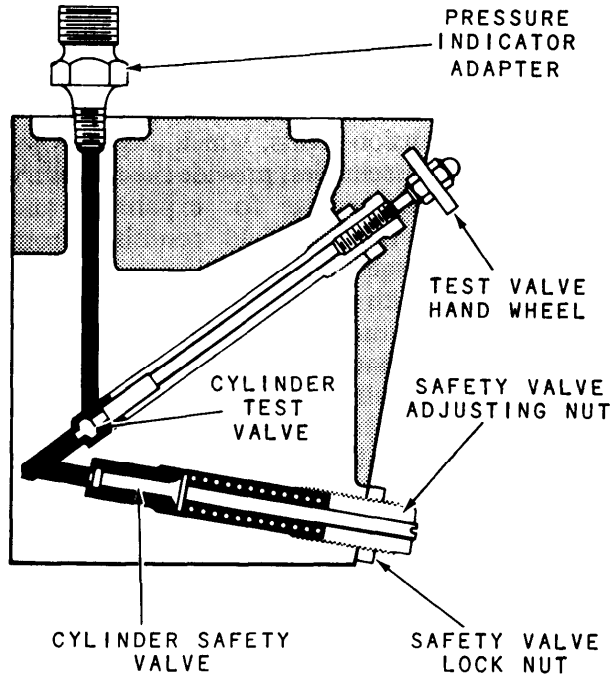


Figure 6-13.—Cylinder test and safety valves.

The adapter is attached to the cylinder liner adapter sleeve.

EXHAUST SYSTEMS

The parts of engine air systems considered so far have provided a passage for air into the cylinders and for the release of gases from the cylinders after combustion. The relationship of blowers, or turbochargers, to both the intake and exhaust systems has also been pointed out.

The system that functions primarily to carry gases away from the cylinders of an engine is called the EXHAUST SYSTEM. In addition to this principal function, an exhaust system may be designed to perform one or more of the following functions: muffle exhaust noise, quench sparks, remove solid material from exhaust gases, and furnish energy to a turbine-driven supercharger. In the following sections, we will discuss the principal parts that may be used in combination to accomplish the functions of an engine exhaust system.

EXHAUST MANIFOLDS

When the gases of combustion are forced from the cylinders of an engine, the gases enter a unit

that is generally referred to as the MANIFOLD. The EXHAUST MANIFOLD for a large diesel is shown in figure 6-14. This exhaust manifold is made up of sections called chamber assemblies along with expansion joints and adapter assemblies. The expansion joints, which are used between chamber assemblies, provide the necessary flexibility to compensate for expansion and contraction of the manifold resulting from temperature changes. Some manifolds are made of steel plate with welded joints and branch elbows of steel castings, while others are made of aluminum. The exhaust manifolds of most marine engines are generally cooled by water flowing through a water jacket surrounding the manifold. The exhaust manifold shown in figure 6-14 is for the passage of gases from the combustion spaces to the exhaust inlet of the turbocharger. Thus, the turbine end of the turbocharger is considered to be part of the exhaust system since it forms part of the passageway for the escape of gases to the exhaust outlet.

After passing through the turbine end of a turbocharged engine or the exhaust manifold of a naturally aspirated 4-stroke cycle engine or being discharged from the exhaust manifold of a 2-stroke cycle engine, the gases pass through the exhaust pipe (flexible or rigid) to the silencer, or muffler.

Silencers, or mufflers, are placed on internal combustion engines mainly to reduce the noise created by the exhaust gases as the exhaust valves or ports open. In addition to acting as silencers, most mufflers also act as spark arresters that trap the burning carbon particles and soot from the mufflers as the exhaust gases are directed to and discharged into the atmosphere.

EXHAUST PYROMETERS

As more fuel is burned in an engine, the hotter the exhaust gases will become. The device that measures the temperature of these gases is called a PYROMETER. By comparing the

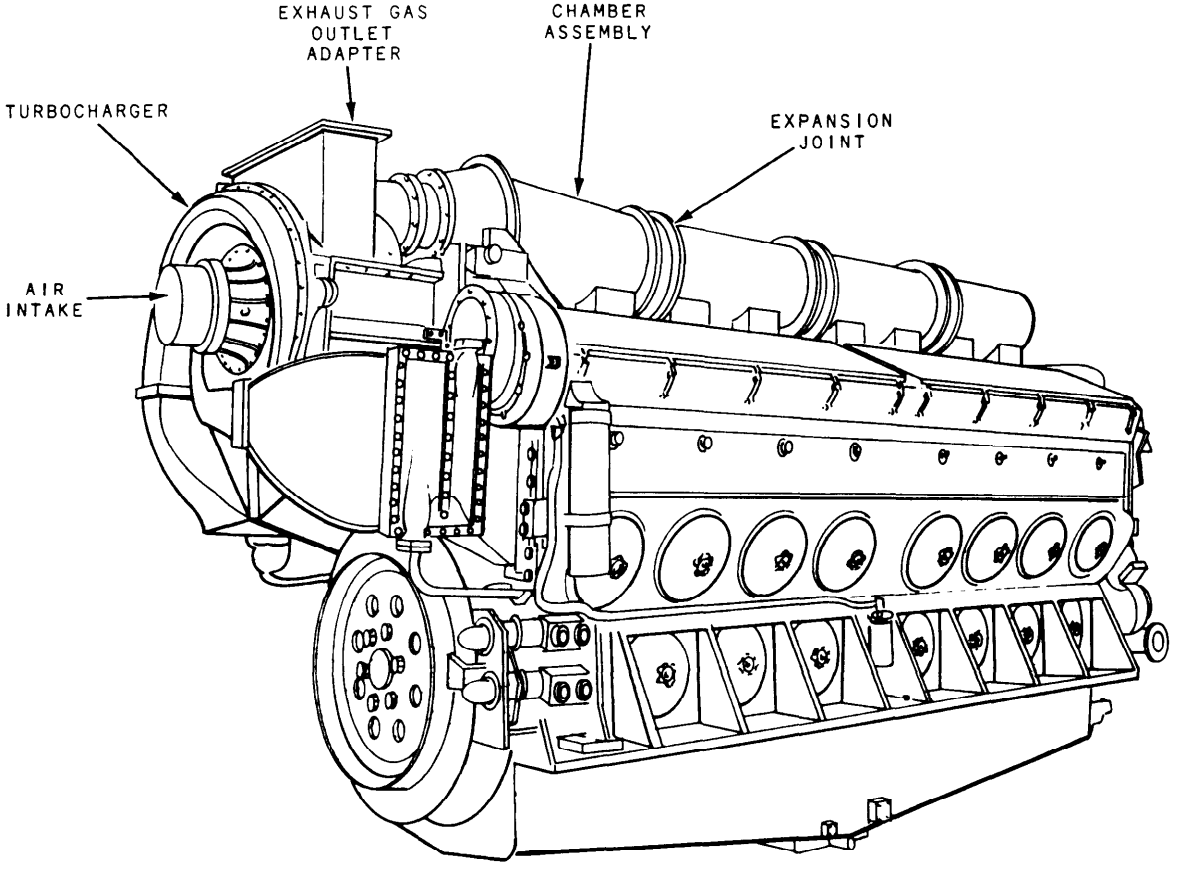
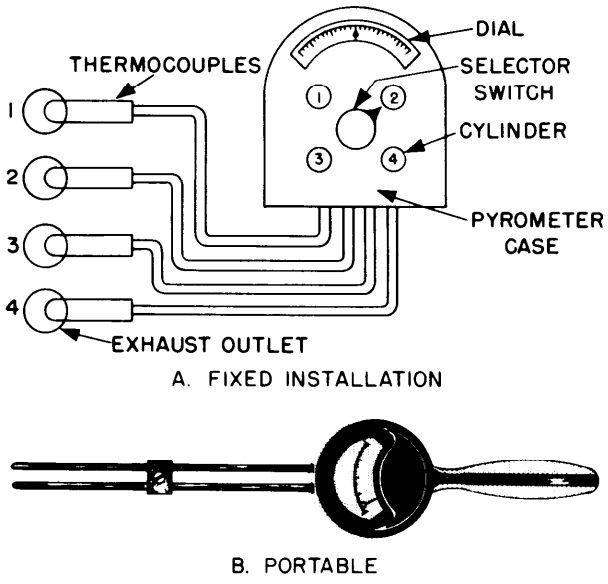


Figure 6-14.—Exhaust manifold of a turbocharged engine.



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Figure 6-15.—Pyrometers used in diesel engine exhaust systems.

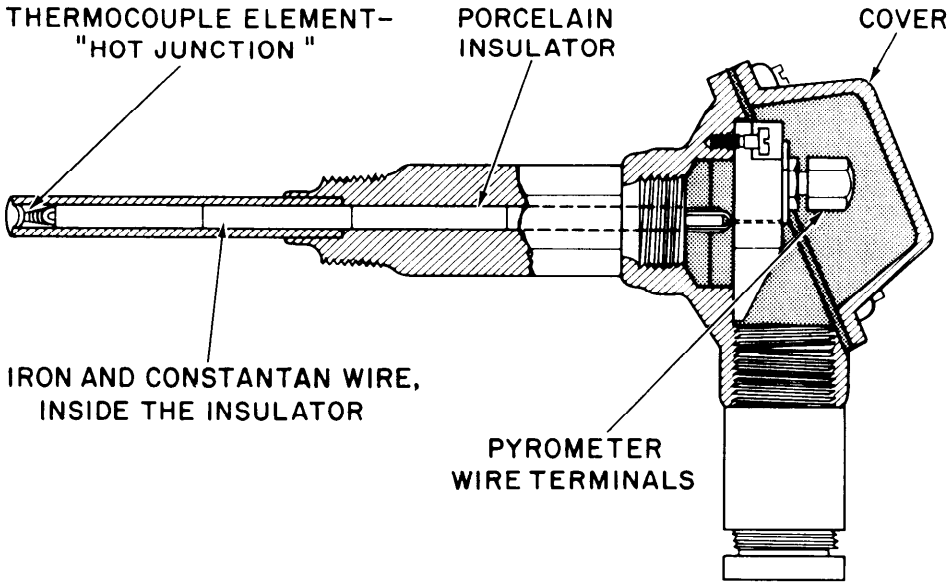
exhaust gas temperature of each cylinder, the operator can determine if the load is balanced throughout the engine.

There are two types of pyrometers that measure exhaust temperature readings-the fixed installation and the portable hand-recording instrument (fig. 6-15). Both types use a thermocouple unit, such as the one shown in figure 6-16, installed in the exhaust manifold.

Pyrometers of the fixed installation type (view A of fig. 6-15) have a thermostatically operated control spring which makes the required temperature corrections automatically. A selector switch is used to show the readings of one cylinder at a time. The portable hand pyrometer (view B of fig. 6-15) has a zero adjuster which must be set by hand and placed in contact temporarily with the terminals of each thermocouple.

The indicating unit of the pyrometer is calibrated to give a direct reading of temperature. However, the pyrometer actually measures the difference between the electric current produced by heat acting on dissimilar metals in the thermocouple hot junction and cold junction. The metals most commonly used in the thermocouple are iron and constantin, which are covered by an insulator. The thermocouple is placed so that the hot junction is in contact with the exhaust gases.

When the hot junction is heated by the exhaust gases, a small voltage develops in proportion to the temperature. This voltage is transferred by the wires to the pyrometer indicator. The pyrometer indicator is actually a sensitive voltmeter that has a scale that is graduated to show temperatures between the hot junction and the cold junction.



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Figure 6-16.—Sectional view of a thermocouple.

Some variations in exhaust temperatures are normal and are to be expected when engines are operating at other than full power. The amount that exhaust temperatures may differ from cylinder to cylinder will depend on the type of engine. Refer to the appropriate manufacturer's technical manual for the allowable limits for your diesel.

PARTS OF OTHER SYSTEMS RELATED TO ENGINE INTAKE AND EXHAUST SYSTEMS

The parts discussed in this chapter are those generally associated with the air systems of most engines. Some engines are equipped with parts that perform special functions. These parts, even though related to the engine air systems, are more frequently considered as parts of other engine systems.

For example, some engines are equipped with intake air heaters or use other methods to overcome the influence of low temperatures in cold weather starting. Devices and methods used for this purpose are discussed in chapter 10. Many engines are equipped with devices or systems which provide crankcase ventilation. Blower action is necessary in many ventilation systems. The systems operate to prevent contamination of engine-room spaces by heated or fume-laden air to reduce the formation of sludge in lubricating oil and to prevent the accumulation of combustible gases in the crankcase and in the oil pan or sump. Devices that serve to ventilate engine crankcases are discussed with the lubricating systems.

SUMMARY

In diesel engines, the passageway for air into the combustion spaces and burnt gases from the combustion spaces is formed by the parts of two systems-the intake and exhaust systems. The combustion spaces serve as the dividing line between these two systems.

The primary purpose of an intake system is to supply to the cylinders a large volume of air for combustion and scavenging. In addition, the system must clean the air and reduce the noise created by the air as it enters the engine. When the air has served its purpose in the cylinder, the waste gases are expelled to the atmosphere by the exhaust system. In the turbocharged engine, the waste gases serve to drive the turbocharger prior to the expulsion of the gases to the atmosphere by way of the exhaust system.

After studying the information in this chapter, you should understand both the purposes and the principles of operation of the components of the air and exhaust systems in an engine and be able to trace the path of the intake air and exhaust gases through the systems.

You should also be able to understand the significance of scavenging and supercharging and how these processes differ in the operating cycles of 2- and 4-stroke cycle engines. If you are uncertain in any of these areas, go back and review those sections of this chapter before preceding to the next chapter.

CHAPTER 7

ENGINE COOLING SYSTEMS

In this chapter, we will primarily discuss closed cooling systems for internal-combustion engines. After reading the information in this chapter, you should recognize the purpose and function of an engine cooling system. You should also recognize the principal components of the basic cooling system design that is used in diesel engines. In the basic maintenance of engine cooling systems, you should understand the need for various chemical inhibitors and how they are used in an engine cooling system for the control of corrosion.

A great amount of heat is generated within an engine during operation. The combustion process produces the greatest portion of this heat; compression of gases within the cylinders and friction between moving parts add to the total amount of heat developed within an engine. Since the temperature of combustion alone is about twice that at which iron melts, it is apparent that, without some means of dissipating heat, an engine could operate for only a very limited time.

When fuel burns in the cylinders of an engine, only about one-third of the heat energy from the fuel changes into mechanical energy and then leaves the engine in the form of brake horsepower (BHP). (Brake horsepower is a measure of the developed power of an engine in actual operation.) The rest of the heat shows up as unwanted heat in the form of (1) hot exhaust gases, (2) frictional heat from the rubbing surfaces, and (3) heating of the metal walls that form the combustion chamber, cylinder head, cylinder, and piston. The job of the cooling system is to remove the unwanted heat from these parts so that the following problems can be prevented:

1. Overheating and the resulting breakdown of the lubricating oil film that separates the rubbing surfaces of the engine
2. Overheating and the resulting loss of strength of the metal itself
3. Excessive stresses in or between the engine parts resulting from unequal temperatures

Unwanted heat is transferred through the mediums of water, lubricating oil, air, and fuel. The water of the closed cooling system removes the greatest portion (approximately one-fourth) of the unwanted heat generated by combustion. The balance of the heat is carried away from the engine by the lubricating oil, the fuel, and the air. If the heat lost through cooling could be turned into work by the engine, the output of the engine would be almost doubled. However, the loss of valuable heat is necessary for an engine to operate.

MAINTAINING ADEQUATE LUBRICATION

The need for the engine to maintain a film of lubricating oil on pistons, cylinder walls, and the load-bearing surfaces of other moving parts is discussed in chapter 8 of this manual. The oil film must be maintained if adequate lubrication is to be provided. The formation of such an oil film depends, to a large degree, on the viscosity of the oil. If the engine cooling system did not keep the engine temperature below a specified level, viscosity would decrease. This condition would result in inadequate lubrication, and metal-to-metal contact would occur with resulting excessive wear of the load-bearing parts. Also, the heat absorbed by the lubricating oil (from the combustion process and from fluid friction in bearings) must be removed so that oxidation of the oil and formation of sludge can be kept to a minimum.

Prevention of overheating is generally thought of as the primary function of an engine cooling system. However, it is possible that a cooling system might remove too much heat. If an engine is operated at lower than normal temperatures, condensation takes place in the crankcase, causing acids and sludge to form in the lubricating oil. Also, cylinder temperatures must be maintained high enough to minimize the condensation of corrosive gases on the cylinder walls.

Excessively low operating temperatures tend to increase ignition lag, a condition that causes detonation. Thus, the cooling system of an engine must maintain the operating temperatures within a specified range. The range of operating temperatures for a given engine can be found in the applicable manufacturer's technical manual.

MAINTAINING CLEARANCES

Each engine is designed by the manufacturer to have specific clearances between the moving parts. If the engine is operated below the temperature range specified by the manufacturer, parts in the engine will fail to expand sufficiently to obtain the desired clearances. Excessive clearances between the reciprocating parts of the engine will cause pounding. Excessive clearances between the bearings and journals will allow the oil to escape before it can reach the areas that are distant from the oil inlet port.

On the other hand, if the engine is operated above the specified temperature range, the parts will expand and insufficient clearances between the moving parts will result. As the clearances are reduced, the required space for the oil film is also reduced. Once the oil film is reduced, inadequate lubrication of the moving parts will occur. As mentioned earlier, inadequate lubrication will cause metal-to-metal contact, accelerated wear, and seizures to occur in the engine.

RETAINING THE STRENGTH OF METALS

High temperatures change the strength and physical properties of the various metals used in an engine. For example, if a cylinder head is subjected to excessively high temperatures, the tensile strength of the metal is reduced. The probability of fracture or cracking is thereby increased. Such high temperatures also cause excessive expansion of the metal, which may result in shearing of the cylinder-head bolts. Overheating can "cook" the seal rings used on the water side of the cylinder liners, causing the sealing surface of the rings to harden. This condition will affect the ability of the material to prevent leakage of the coolant into the oil sump.

Consequently, by removing heat from the engine, the cooling system helps to prevent deterioration of the engine parts. If the parts, such as liners, pistons, valves, and bearings, are allowed to overheat, the tensile strength will be materially reduced, thereby accelerating wear and increasing the probability of failure. If overheating is sufficiently severe, seizure of the engine will result.

TYPES OF COOLING SYSTEMS

The cooling system of a marine diesel engine functions to keep the engine parts and fluids at safe operating temperatures. In the open system, the engine is cooled directly by seawater. In the closed system, fresh water is circulated through the engine. The fresh (jacket) water is then cooled as it passes through a cooling device where heat is carried away by a constant flow of seawater or air. The closed cooling system is the design that is most commonly used on marine internal-combustion engines.

THE OPEN COOLING SYSTEM

An open system means that the liquid that is used to carry heat away from the engine is drawn directly from the water in which the boat or ship operates. This liquid is moved through the system and then discharged overboard. In the open system, there is no freshwater circuit.

The open cooling system is not used on most marine diesel engines for several reasons. The most important reason is that the open cooling system exposes the engine to scale formation, marine growth, and dirt deposits in the piping. You may, however, find the open cooling system in use on some small gasoline engines, such as outboard motors and P-250 fire-fighting pumps. On engines such as these, you must flush the cooling system with fresh water to remove any traces of seawater that might cause corrosion and fouling. For the most part, our discussion of cooling systems throughout this chapter will be limited to closed cooling systems.

THE CLOSED COOLING SYSTEM

A cooling system is classified as closed if it has a freshwater circuit (system) that is self-contained and used continuously for the cooling of the engine. Closed cooling systems are normally operated at pressures greater than atmospheric pressure so that the boiling point of the coolant is raised to a temperature that is higher than 212°F.

Cooling of an internal-combustion engine is accomplished by the use of either a cooler (heat exchanger), keel cooler, or radiator and fan. We will continue our discussion of the closed type of cooling system with a general description of these three types of closed systems. We will then take a more detailed look at the components that make up the closed type of cooling system.

Heat Exchanger Cooling System

The heat exchanger cooling system combines two separate cooling systems—a jacket-water (freshwater) system and the raw-water (seawater) cooling system. The principal components that comprise the freshwater system are an engine coolant pump, one side of the heat exchanger, and the expansion tank and piping.

In the jacket-water (freshwater) cooling circuit, the fresh water is reused continuously for cooling the engine. The order of the parts through which water flows in the freshwater circuit of a cooling system is not always the same. In the majority of installations, however, the coolant is circulated throughout the engine cooling spaces by an attached circulating freshwater pump. The direction of flow of engine coolant must always be such that the temperature of the fresh water will increase gradually as the fresh water passes through the engine. So that thermal shock of the hottest parts of the engine can be prevented, the coolant is directed to flow around the cylinder liners and cylinder head last before it is directed out of the engine. The coolant then flows to a freshwater cooler (heat exchanger) where it is cooled by the seawater cooling circuit. After it leaves the cooler, the fresh water may or may not, depending on the installation, go through the lubricating oil cooler to act as a cooling agent for the lubricating oil. The coolant finally returns to the suction side of the freshwater pump, completing the circuit.

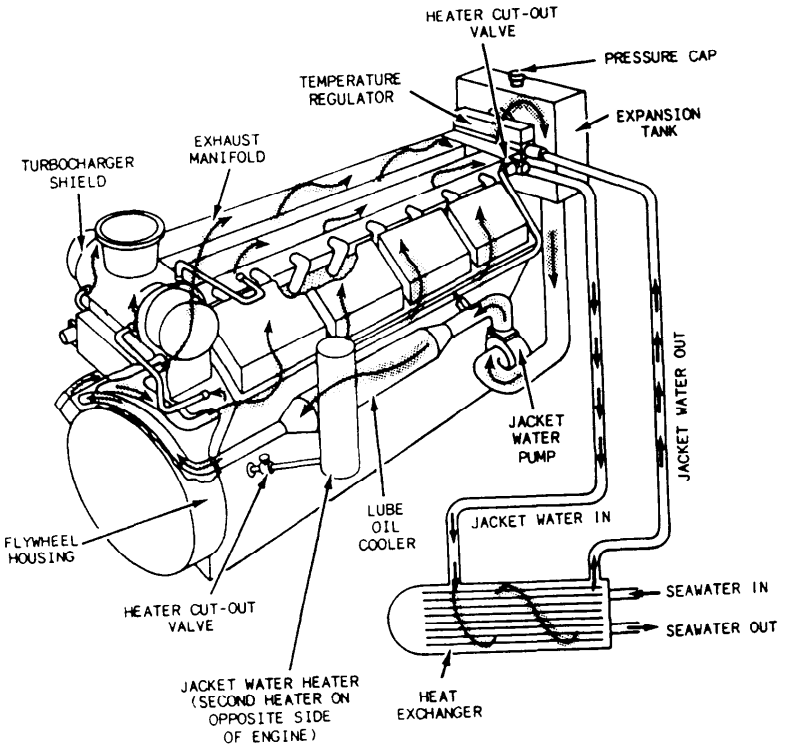
The seawater circuit of the heat exchanger cooling system consists of a centrifugal pump (usually similar to the freshwater pump). On most small engines, the seawater pump is attached. However, on large engines that are used for propulsion or power generation, the seawater pump is a motor-driven pump remote from the engine. The seawater cooling system for a large engine is often equipped with some means for providing emergency cooling water, such as from the firemain system. The centrifugal pump draws seawater through a sea chest, strainer; and sea valves. The pump then discharges the seawater through the freshwater cooler (heat exchanger). (In some installations, an additional strainer is located in the pump discharge.) From the freshwater cooler, the seawater is discharged overboard. The overboard discharge performs varying functions, depending on the individual installation. Normally, it serves to cool the engine exhaust piping and the silencer.

On some engine-generator units, the attached seawater pump furnishes seawater to the generator air coolers as well as to the freshwater coolers and returns the water to the overboard discharge. Throttling valves, or orifice plates, which are frequently placed in lines of the seawater cooling system and the outlet of a generator air cooler, serve to control the flow rate of the water that passes through these heat exchangers. For prevention of scale formations on heat transfer surfaces, the temperature must not exceed 130°F with a minimum flow rate to reduce the effects of erosion.

Figures 7-1 and 7-2 illustrate the freshwater and seawater systems of an engine that employs the heat exchanger type of cooling system. As shown in these illustrations, an aftercooler is part of this system because the engine is a turbocharged unit. In the system in figure 7-1, part of the coolant flows through the cooler and is directed back to the lower passage of the flywheel housing. This coolant is then directed to the cylinder banks on each side of the cylinder block. The coolant (fresh water) circulates around the cylinder block, around the liners, and upward through the cylinder heads to the exhaust manifold. (See directional arrows.) From the exhaust manifold, the coolant flows to the expansion tank where temperature regulators control the flow of coolant to the heat exchangers. When the temperature of the coolant is not high enough to open the regulators, coolant bypasses the heat exchangers to ensure quick warm-ups. A portion of the coolant is bypassed at all times.

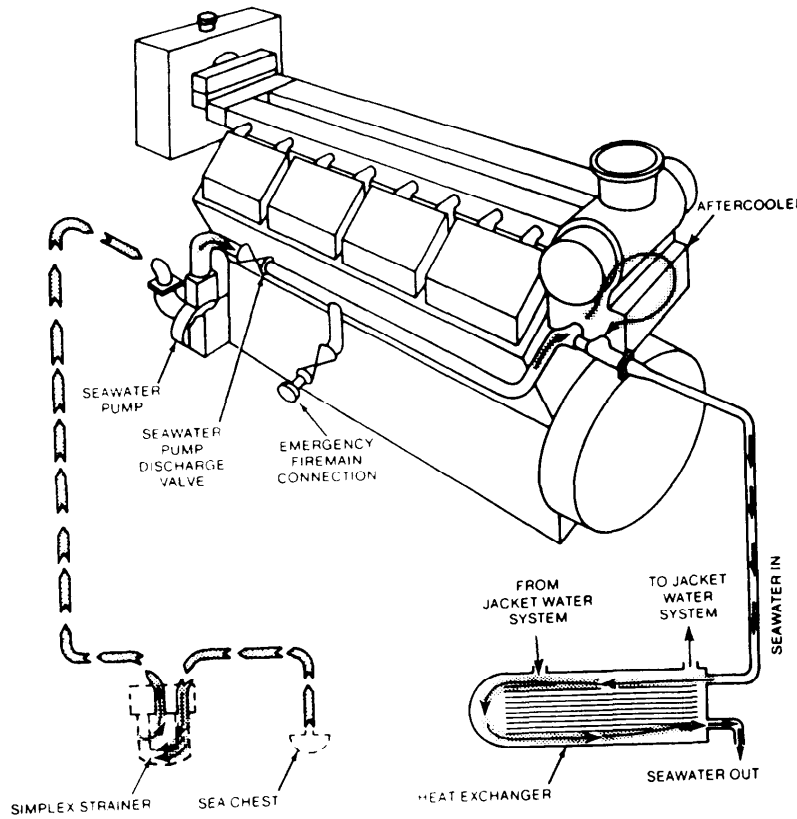
In the jacket-water system we have just described (fig. 7-1), note the heater. (The jacket-water heater is also commonly referred to as the keep-warm heater.) This device is used on some engines prior to starting to preheat the engine by heating the jacket water.

In the seawater circuit shown in figure 7-2, the seawater is drawn through the sea chest to a strainer by the seawater pump. The pump, through piping, directs the flow to the aftercooler for cooling the air and to the heat exchanger for cooling the fresh water. (See directional arrows.)



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Figure 7-1.—Jacket-water (heat exchanger) cooling system.



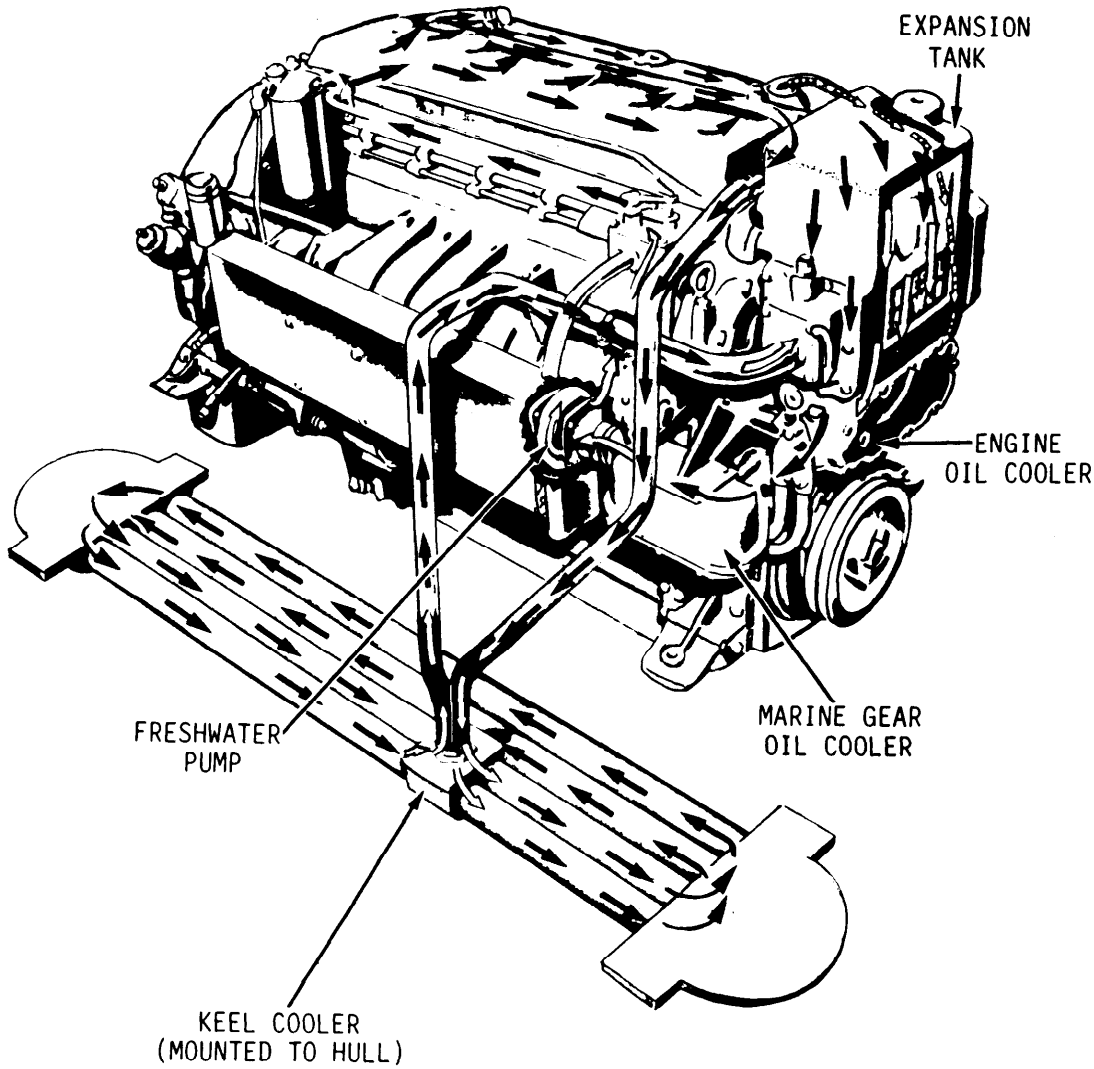
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Figure 7-2.—Seawater cooling system.

Keel Cooling System

In the keel cooling system shown in figure 7-3, heat transfer takes place in the keel cooling coil that is mounted on the hull of the vessel below the waterline. In this system, which is used on small craft, the coolant is moved by a high-capacity freshwater pump from the bottom of the expansion tank through the engine oil cooler and marine gear (transmission) oil cooler to the cylinder block. (See directional arrows.) Openings in the water jacket around the cylinder bores connect with corresponding openings in the cylinder head through which the liquid passes to circulate around the valves and fuel injectors. A portion of the coolant is bypassed from the aft end of the water manifold into the aft end of the jacket surrounding the exhaust manifold and on to the expansion tank.

When the thermostat is open, the major portion of the coolant in the water manifold passes through the thermostat housing and flows directly to and through the keel cooling coils. When the thermostat is closed, that portion of the coolant entering the thermostat housing is bypassed directly to the engine water pump inlet where it remixes with the coolant from the exhaust manifold jacket. The coolant is then circulated through the cylinder block and cylinder head. With the thermostat closed, a quick warm-up is assured since the circulating water does not pass through the keel cooling coils.



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Figure 7-3.—Typical keel cooling system.

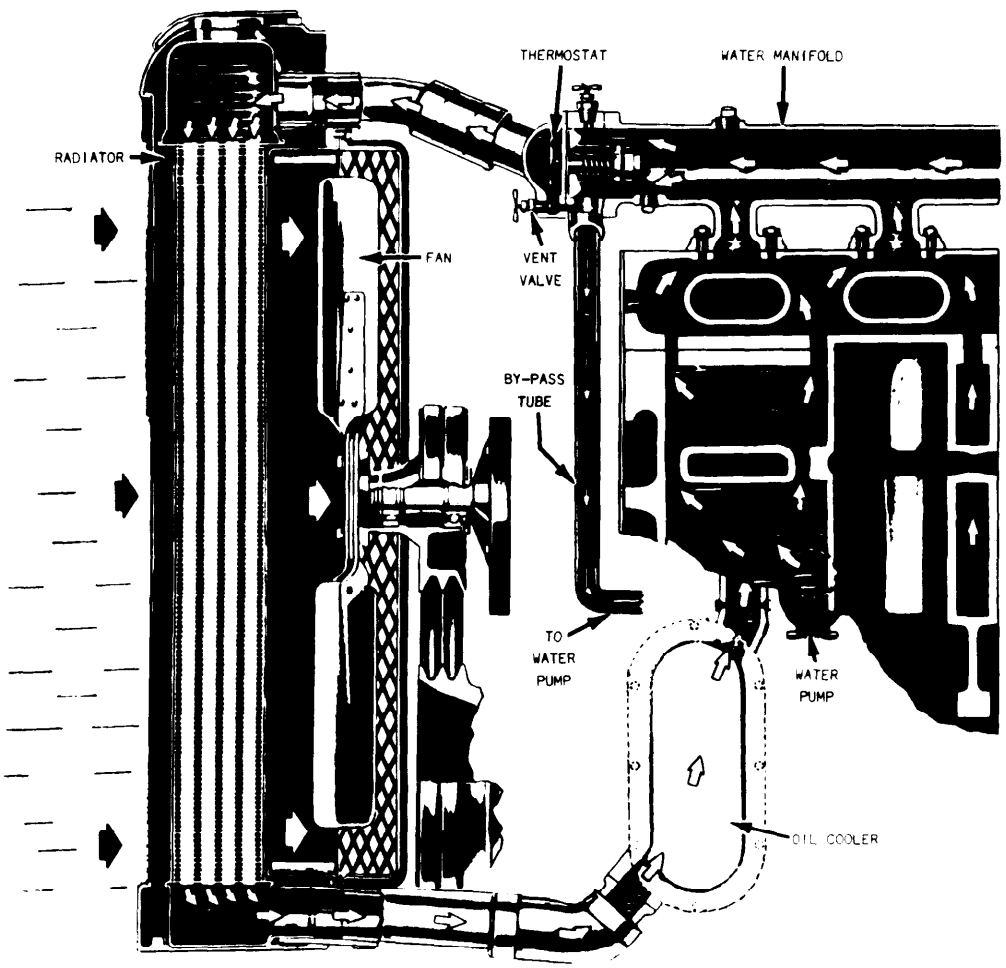
Radiator and Fan Cooling System

The radiator and fan cooling system is shown in figure 7-4. In this system, the engine coolant is circulated through the radiator where it gives up its heat to the stream of air forced through the fins of the radiator by a fan. The fan is belt driven from the crankshaft. The water pump draws the cooling liquid through the oil cooler and discharges it into the lower part of the cylinder block. (See directional arrows.) Openings in the water jacket around the cylinder bores connect with corresponding openings in the cylinder head through which the coolant rises to circulate around the valves and fuel injectors. The coolant then circulates through a water manifold that is bolted to the cylinder head. From the water manifold, the coolant discharges past the thermostat and into the radiator.

With the thermostat open, the coolant circulates through the radiator before returning to the water pump. With the thermostat closed, the coolant is bypassed from the water manifold directly to the pump and recirculated through the engine. In this manner, a quick warm-up of the engine is assured since the circulating water does not pass through the radiator.

PRINCIPAL COMPONENTS OF A CLOSED COOLING SYSTEM

The cooling system of an engine may include such parts as pumps, coolers, radiators, water manifolds, valves, expansion tanks, piping,



75.371

Figure 7-4.—Typical cooling system with radiator and fan.

strainers, and instruments. Even though there are many types and models of engines used by the Navy, the cooling systems we have discussed include many of the same basic parts. The design and location of parts, however, may differ considerably from one engine to another. The following discussion points out some similarities and differences found in various parts of engine cooling systems.

The cooling systems of diesel and gasoline engines are similar in many ways, both mechanically and in the functions they perform. For these reasons, much of the information that follows is applicable to the cooling systems of both types of engines.

PUMPS

All engine cooling systems have an attached freshwater pump. Some installations also have a detached auxiliary pump. The attached pump serves to keep the water circulating through the cooling system. Since attached pumps are engine driven, it is impossible for cooling water to be circulated in the engine after the engine has been stopped or in the event the attached pump fails. For this reason, some engines are equipped with electric-driven (detached) auxiliary pumps, which may be used if either the freshwater pump or the seawater pump fails. An auxiliary pump may also be used as an after-cooling pump, when an engine has been secured.

The pumps used in the freshwater and seawater circuits of an engine cooling system may or may not be of the same type. In some systems, the pumps in both circuits are identical. In other systems, where pumps are of the same type but where variations exist, the principal differences between the pumps of the two circuits are in size and capacity. In the cooling system of some engines, the seawater pump has a capacity almost double that of the freshwater pump.

Centrifugal pumps are the principal types of pumps used in engine cooling systems. On some engines, a rotary type of pump in which the impeller has flexible vanes is used in the seawater circuit. The basic principles of operation of these types of pumps are discussed in *Fireman,* NAVEDTRA 10520 (latest edition).

Centrifugal pumps are more common in engine cooling systems, particularly in large diesel engines, than pumps of other types. In centrifugal pumps, water is drawn into the center of the impeller and thrown at high velocity into the casing surrounding the impeller where the velocity decreases and the pressure increases correspondingly. Sealing devices, usually of the mechanical seal type, are provided to prevent leakage of water, oil, grease, or air around the impeller shaft. Pump location and method of drive will vary according to engine design. Additional information on pumps can be found in chapter 13 of this manual.

COOLERS (HEAT EXCHANGERS)

As a Fireman, you learned that devices that transfer heat from one fluid to another are called HEAT EXCHANGERS. You also learned that these devices are used as either heaters or coolers and that the same device may be used for both purposes. In internal-combustion engines, heat exchangers are used primarily for cooling. For this reason, the devices in engines that remove heat from a hot fluid (liquid or gas) by transferring the heat to a cooler fluid are commonly referred to as COOLERS.

Fluids Cooled

The primary function of heat exchangers that are used in diesel engines is to remove heat from the jacket water and the lubricating oil. On some engines, coolers are used to reduce the temperatures of engine intake air and generator cooling air and to cool engine exhaust gases. In most engine installations, the fresh water in the engine cooling system is cooled by seawater. Lubricating oil and air may be cooled by seawater or by fresh water, depending on the installation. Thus, on the basis of the fluids cooled, you will encounter freshwater coolers, lubricating oil coolers, and air coolers. All coolers operate on the same principle; coolers used in various installations and for the cooling of various fluids may differ, however, in appearance and in details of design.

Classification of Coolers

Coolers may be classified in several ways: by the relative direction of flow of the two fluids (parallel flow, counterflow, and crossflow types); by the number of times either fluid passes the other fluid (single-pass and multipass types); by the path of heat (indirect-contact or surface type and direct-contact type); and by construction features of the unit (shell-and-tube type). The coolers used in cooling systems of engines are

commonly identified on the basis of construction features.

Types of Coolers

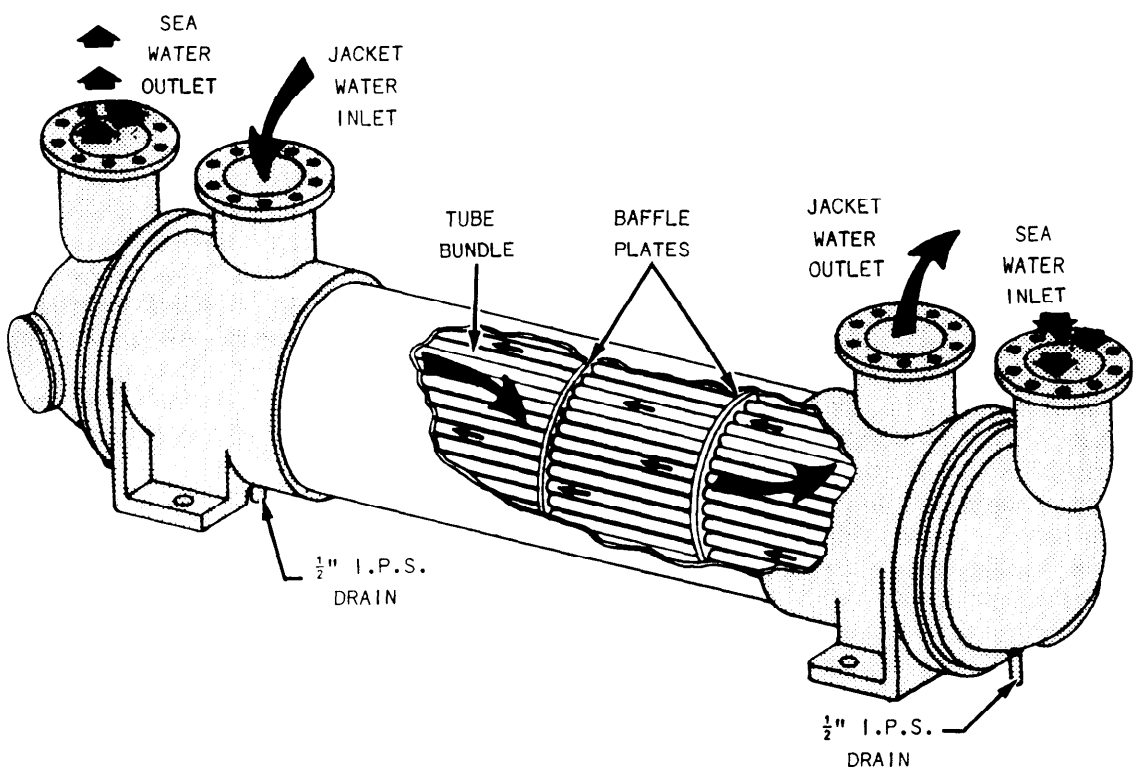
The shell-and-tube type is a general classification that includes all coolers in which the two liquids are prevented from mixing by the thin walls of the tubes of the element. Modifications of the shell-and-tube cooler have resulted in two other types of coolers: the strut-tube cooler and the plate-tube cooler. These coolers are of the shell-and-tube type in that the fluids are prevented from mixing. Because of design features, however, the coolers used in engines are commonly identified as being either strut or plate-tube types.

SHELL-AND-TUBE COOLERS. —The cooling systems of many engines are equipped with coolers of the shell-and-tube type. Shell-and-tube coolers serve to cool lubricating oil and fresh water. Coolers that are used for the cooling of lubricating oil are somewhat smaller than those that are used for the cooling of water. One model of a shell-and-tube cooler is shown in figure 7-5.

The shell-and-tube cooler consists principally of a bundle (also called a bank or nest) of tubes encased in a shell. The cooling liquid generally flows through the tubes. The liquid to be cooled enters the shell at one end, is directed to pass over the tubes by baffles, and is discharged at the opposite end of the shell. In other coolers of this type, the cooling liquid flows through the shell and around the tubes; the liquid to be cooled passes through the tubes.

The tubes of the cooler are attached to the tube sheets at each end of the shell. This arrangement forms a tube bundle that can be removed as a unit from the shell. The ends of the tubes are expanded to fit tightly into the holes in the tube sheets; they are flared at their outer edges to prevent leakage.

One tube sheet and a bonnet are bolted to the flange of the shell. This sheet is referred to as the stationary-end tube sheet. The tube sheet at the opposite end "floats" in the shell, a design that allows for expansion of the tube bundle. Packing rings, which prevent leakage past the floating-end tube sheet, are fitted at the floating end between the shell flange and the bonnet. The packing joint allows for expansion and prevents the mixing of



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Figure 7-5.—Jacket-water shell-and-tube cooler.

the cooling liquid with the liquid to be cooled inside the shell by means of a leak-off, or lantern, gland that is vented to the atmosphere.

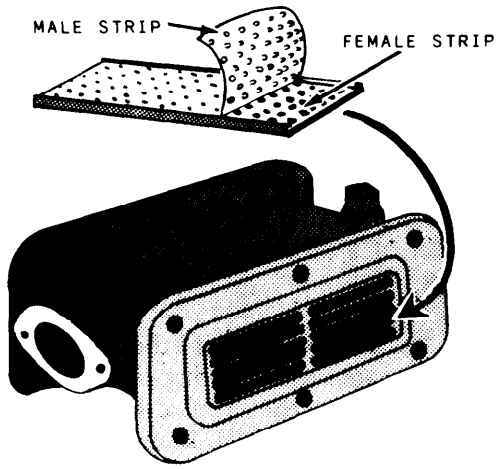
Transverse baffles are arranged around the tube bundle in such a manner that the liquid is directed from side to side as it flows around the tubes and through the shell. The deflection of the liquid ensures the maximum cooling effect. Several of the baffles serve as supports for the bank of tubes. These baffles are of heavier construction than those that only deflect the liquid.

The flow of the liquid in the tubes is opposite the liquid flow in the shell. (See the directional arrows.) On this basis, the cooler could be classified as the counterflow type. Since heat transfer is through the walls of the tubes, the cooling liquid enters one end of the cooler, flows directly through the tubes, and leaves at the opposite end. The cooler, however, could be more precisely classified as a single-pass, indirect-type cooler.

STRUT-TUBE COOLERS.—Another design of cooler used in the cooling systems of marine engines is the strut-tube type. The strut-tube cooler has an advantage over the shell-and-tube cooler in that it provides considerable heat transfer in a smaller and more compact unit. On the other hand, the shell-and-tube cooler, while larger for an equivalent amount of heat transfer, has an advantage over the strut-tube cooler in that it is able to withstand a higher degree of scaling and larger foreign particles before the cooling system becomes clogged. Strut-tube coolers are commonly referred to as Harrison-type coolers; however, manufacturers other than Harrison produce coolers of the strut-tube type. Sometimes, the term *radiator* is used for coolers with strut-tube construction.

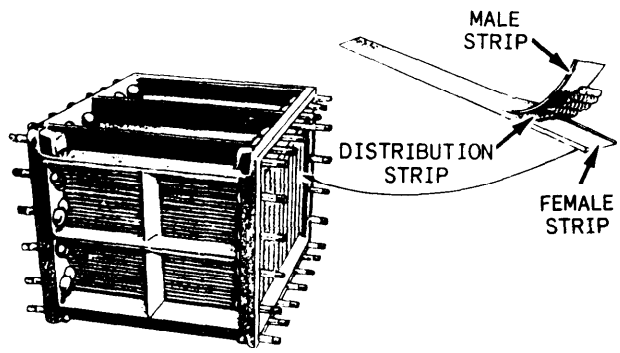
There are many different designs of strut-tube coolers. The tube assemblies of two of these coolers, and the type of tube construction in each, are illustrated in figures 7-6 and 7-7.

Strut-tube coolers are used for the cooling of water and lubricating oil. Water coolers and oil coolers differ principally in design and in the size of the tubes. (See figs. 7-6 and 7-7.) Each of the tubes in both the oil cooler and the water cooler is composed of two sections, or strips. In the strut-tube water cooler, both sections of each tube



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Figure 7-6.—Tube assembly of a strut-type water cooler.



75.213

Figure 7-7.—Tube assembly of a strut-type lubricating oil cooler.

contain either a series of formed dimples or cross tubes brazed into the tubes. These struts (sometimes referred to as baffles) increase the inside and outside contact surfaces of each tube and create turbulence in the liquid flowing through the tube; thus, the heat transfer from the liquid being cooled to the cooling liquid is increased. The struts also increase the structural strength of the tube. In the oil cooler, the tubes are from one-half to one-third as large as the tubes of water coolers, and the sections of the tubes do not contain either dimples or cross tubes. Instead, a distributor strip, which serves the same purpose as the struts in the tubes of the water cooler, is enclosed in each tube.

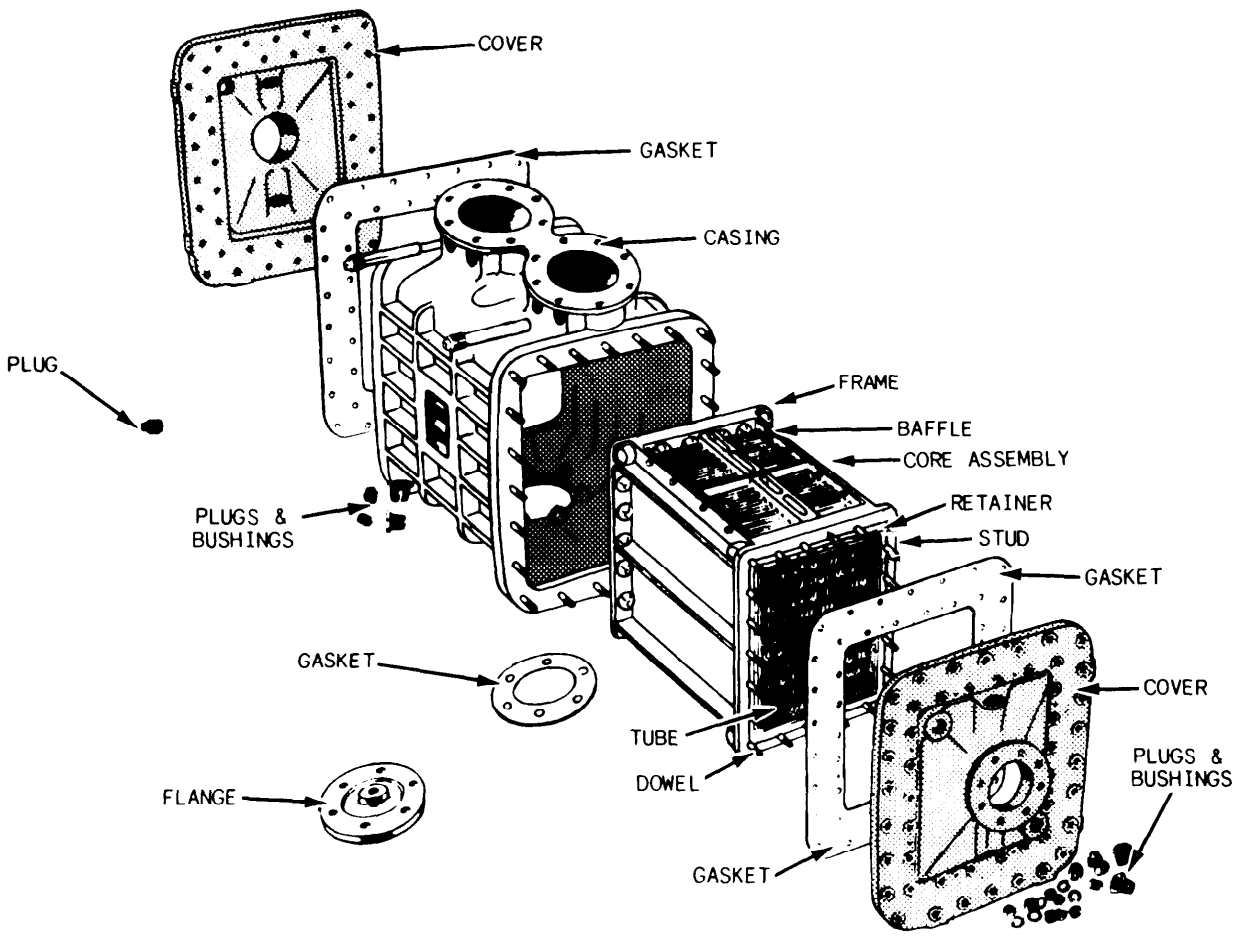
The tubes of a strut-tube cooler are fastened in place with a header plate at each end and are further secured with an intermediate reinforcement

plate. These plates are electroplated with tin to protect the iron parts of the cooler. The tube-and-plate assembly (sometimes called the tube bundle or the core assembly) is mounted in a bronze frame. The frame and the core assembly fit in the cast metal casing, or housing, and are held in place by the two end covers. The casing, core assembly, frame, covers, and other parts of one model of a strut-tube cooler are shown in figure 7-8.

The header plates, at the ends of the tubes, separate the cooling-liquid space in the casing from the cooled-liquid ports in the end covers. The cooled liquid flows through the tubes in a straight path from the cover inlet port to the cover discharge port at the opposite end of the cooler. The intermediate tube plate acts as a baffle to create a U-shaped path for the cooling liquid, which flows around the outside of the tubes from the inlet opening of the casing to the discharge opening.

PLATE-TUBE COOLERS.—Shell-and-tube coolers and strut-tube coolers are used for cooling both oil and water, usually with seawater as a coolant; plate-tube coolers, however, are used only for cooling oil. Seawater or fresh water may be used as the cooling liquid in plate-tube coolers, depending on the installation.

An exploded view of one model of a Harrison plate-tube cooler is shown in figure 7-9. A plate-tube cooler consists of a stack of flat, oblong, plate-type tubes that are connected in parallel with the oil supply and enclosed in a cast metal housing. Each tube of a plate-tube cooler consists



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Figure 7-8.—Components of a strut-tube cooler.

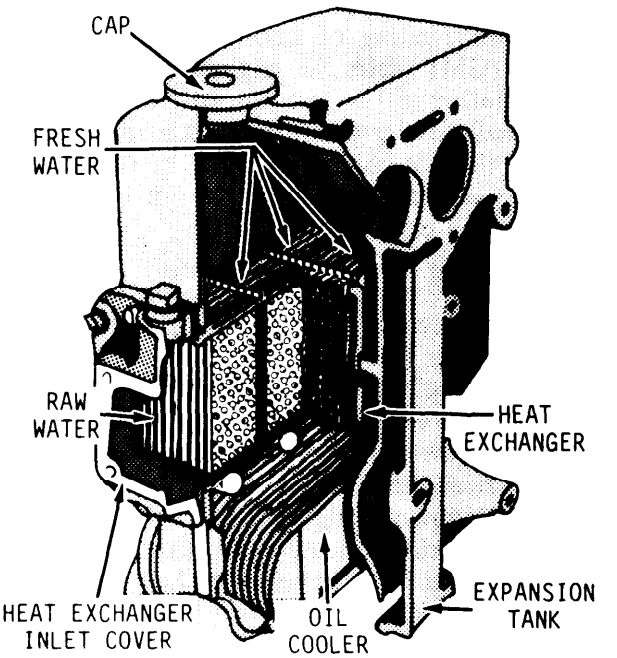
of two sections, or stampings, of copper-nickel. A distributor strip is enclosed in each tube. Several tubes are assembled to form the cooling element, or core, of the cooler.

In a plate-tube cooler, the cooling liquid flows through the casing and over the tubes. The heated oil flows through the tubes. The tubes in the core assembly are spaced so that the cooling water circulates freely over their external surfaces.

Location of Coolers

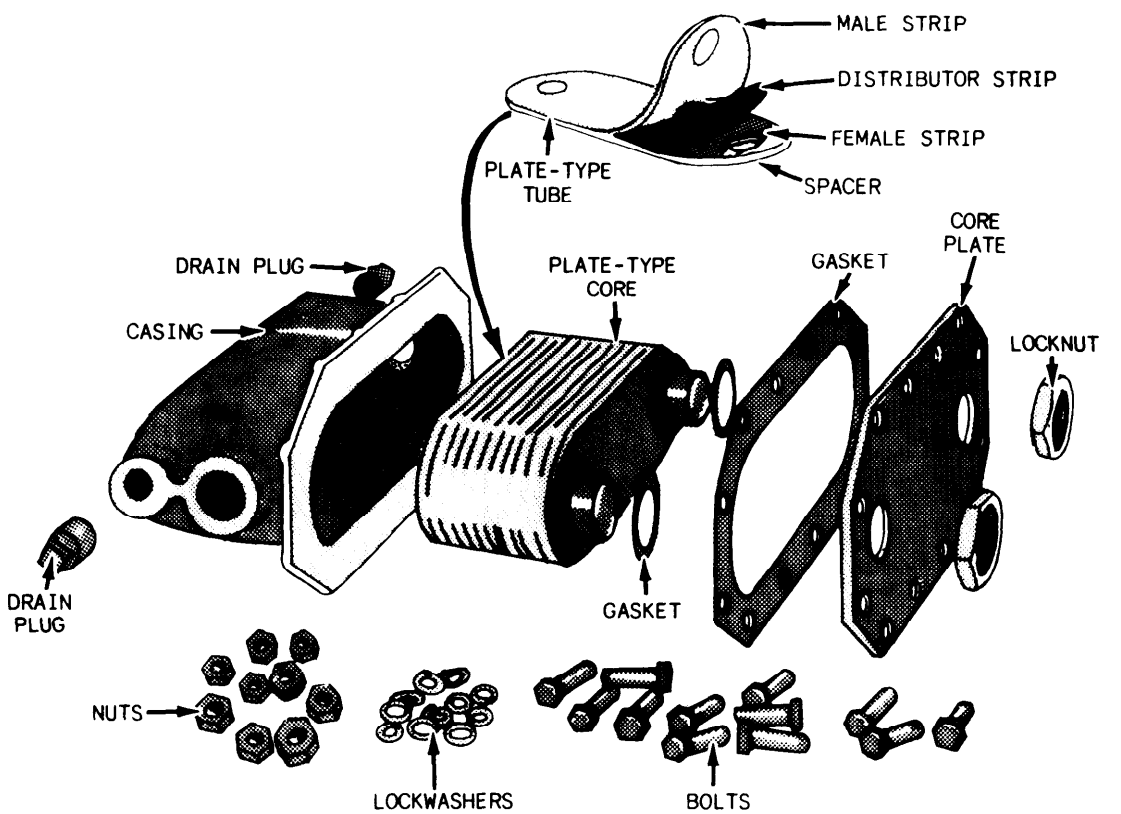
The location of coolers will vary, depending on the engine and the fluid cooled. Some coolers are attached; others are detached. Some freshwater coolers are located on the outside of the hull, well below the waterline. When so located, coolers are frequently referred to as outboard, keel, or hull coolers.

Examples of variations in the locations of freshwater coolers and lubricating oil coolers can be seen in figures 7-1 through 7-4, and 7-10.



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Figure 7-10.—Location of coolers and other cooling system components of General Motors Series 71 engines.



75.373

Figure 7-9.—Plate-tube cooler.

The location of the freshwater coolers and the lubricating oil coolers of the General Motors (GM) series 71 engines (fig. 7-10) is representative of the location of the coolers in many small diesel engines. In this system of engine cooling, the hot coolant leaving the thermostat housing passes through the expansion tank, then through the cells of the cooling core. After leaving the heat exchanger, the engine coolant is picked up by the freshwater pump and circulated through the cylinder block and cylinder heads. The raw water (seawater) is forced horizontally between the cells of the core and serves to lower the temperature of the coolant as it passes through the cells. The location of the coolers in a medium-sized diesel differs from that in smaller engines.

The coolers discussed up to this point have been those that function to lower the temperature of fresh water and lubricating oil. In some engines, the temperature of the supercharged intake air is also reduced. If the temperature of this air, which is heated by compression within the supercharger, is reduced, then the amount of air charge entering the cylinder during each intake event will increase and the power output of the engine will be increased. Coolers that function to lower the temperature of the intake air are primarily of the radiator type and operate on the same principle as coolers that function to cool fresh water and lubricating oil. Air coolers that serve to cool intake air are referred to as intercoolers or after-coolers. The heated air from the supercharger passes around the tubes, where the heat is transferred to the cooling water that is flowing through the tubes. The cooling water is generally from the seawater circuit, but it may be from the freshwater circuit.

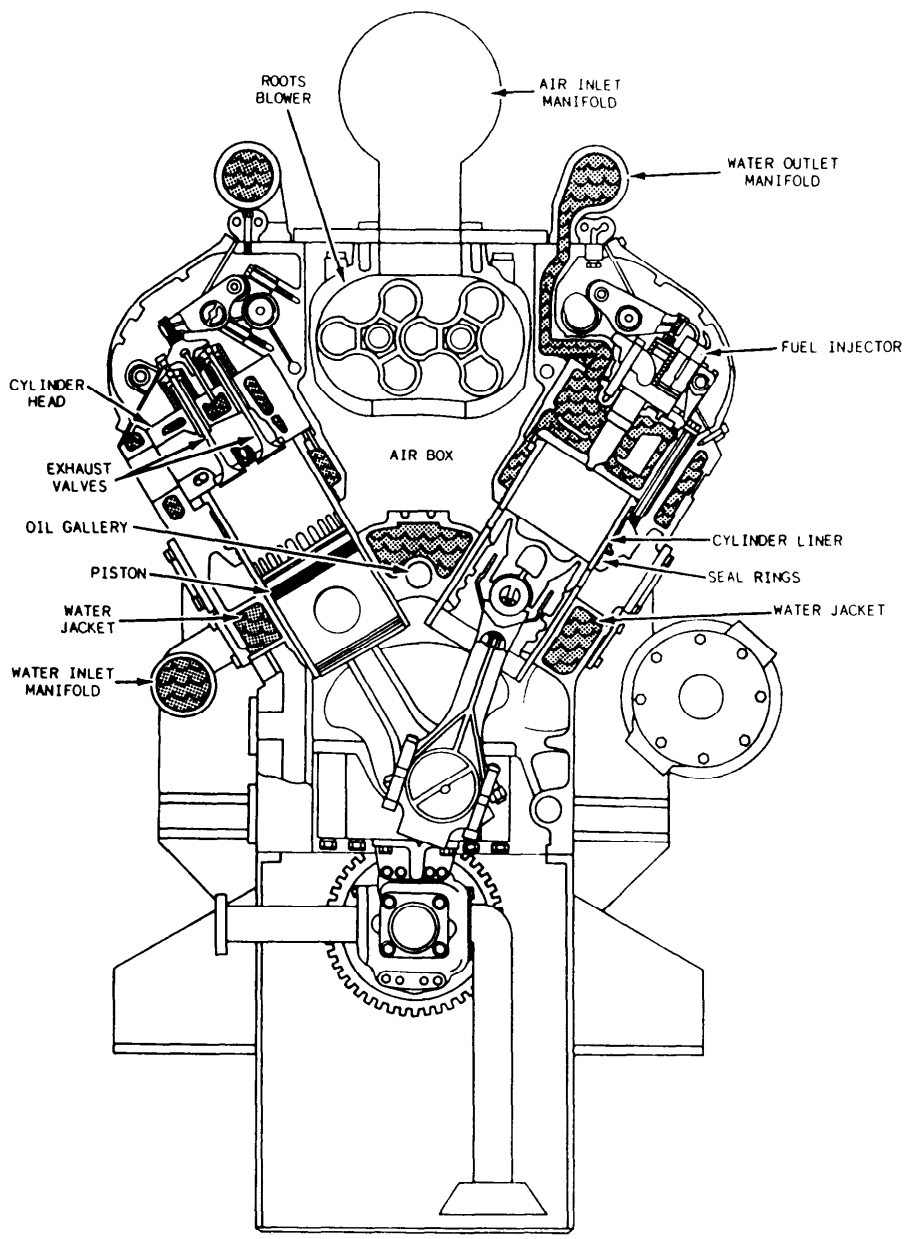
The engine cooling system also functions to cool the air around some engine-generator sets. Generators, unlike internal-combustion engines, cannot be directly cooled by liquids. If a generator develops more heat than can be removed by the surrounding air, a supply of cool air must be provided in a closed air circuit. The heated air from the generator is forced through the cooler, where the temperature is reduced. The air is then recirculated to the generator. Depending on the installation, either fresh water from the engine cooling system or seawater may serve as the cooling medium.

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ENGINE WATER PASSAGES

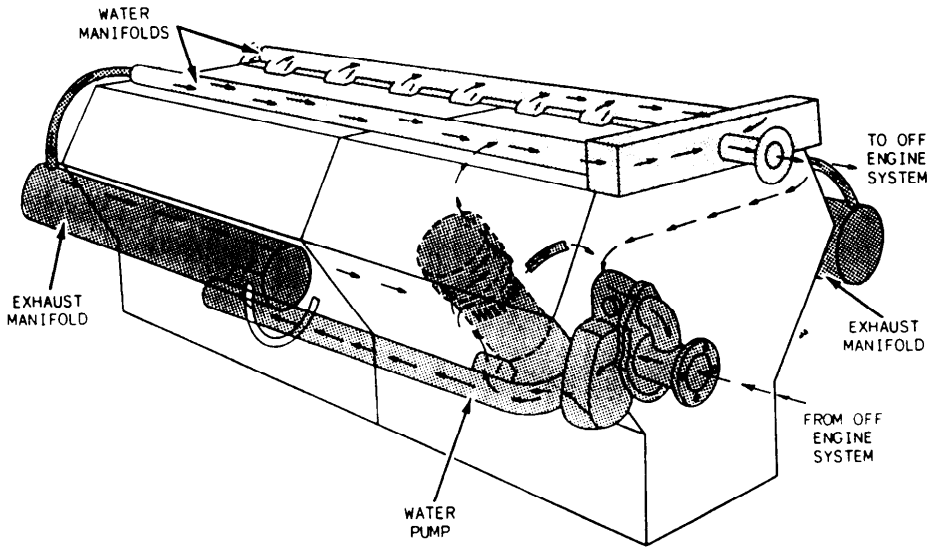
The form, location, and number of cooling passages within an engine vary considerably in different engines. The form of a cooling water passage and its location are controlled by many factors, such as the size of the engine, the cycle of operation, and the cylinder arrangement. Many of the water passages found in various engines have been illustrated and mentioned earlier in this manual in connection with engine parts and systems. Additional information on engine cooling passages is given in the following paragraphs. The examples we will use are for illustrative purposes and are not all-inclusive; however, the examples described are representative of the passages that are found in in-line, V-type, and opposed-piston engines.

The location and form of the water passages in a V-type engine are basically the same as those found in an in-line engine. Differences that exist are generally due to the cylinder arrangement. The location and form of these passages at one point in a V-type engine are shown in the cross-sectional view of the 16 V 149 series engine in figure 7-12.



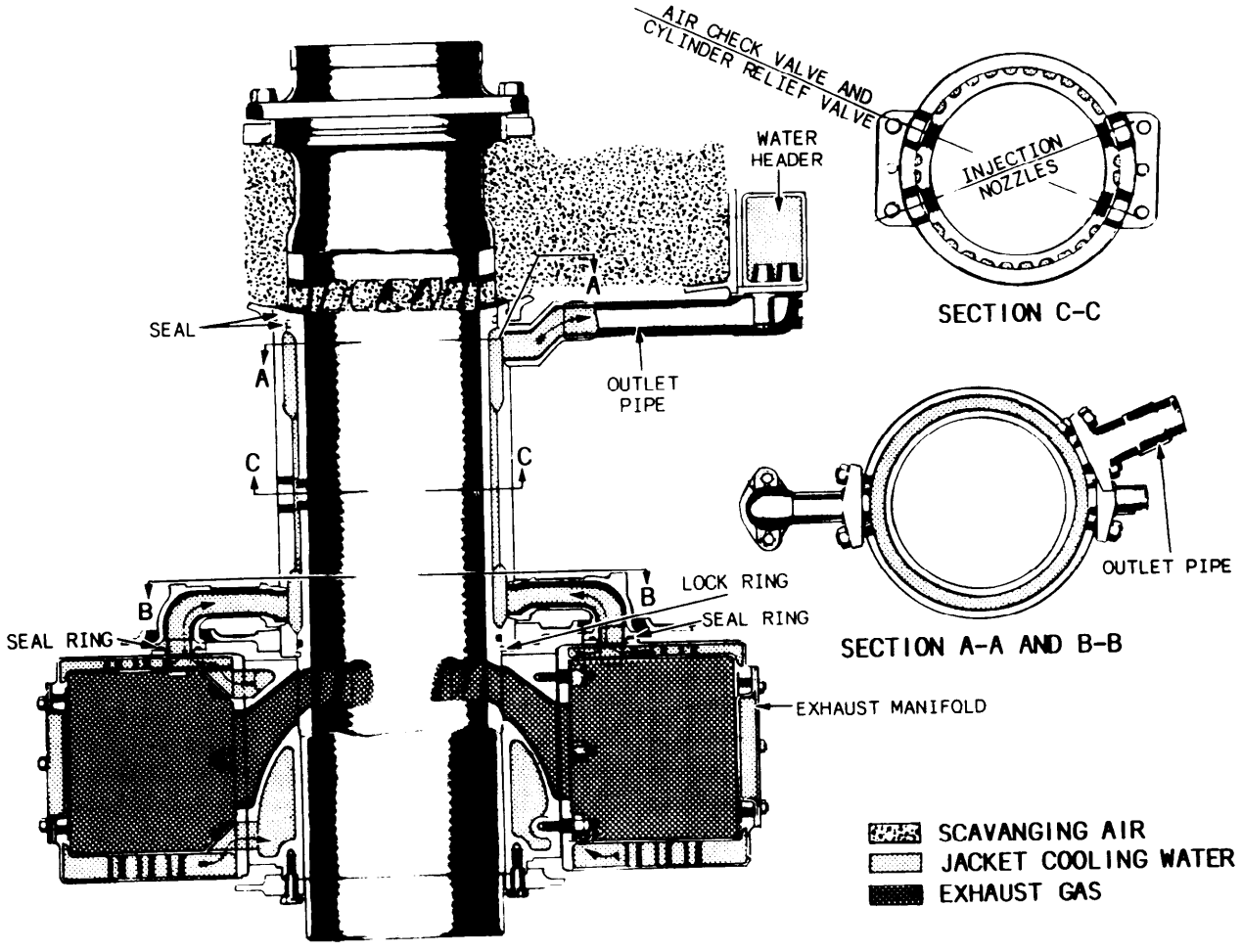
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Figure 7-12.—Location of water passages in a 16 V 149 series engine.



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Figure 7-13.—Engine coolant flow in a 16 V 149 series engine.



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Figure 7-14.—Cooling-water passages in a Fairbanks-Morse 38D8 1/8 opposed-piston engine.

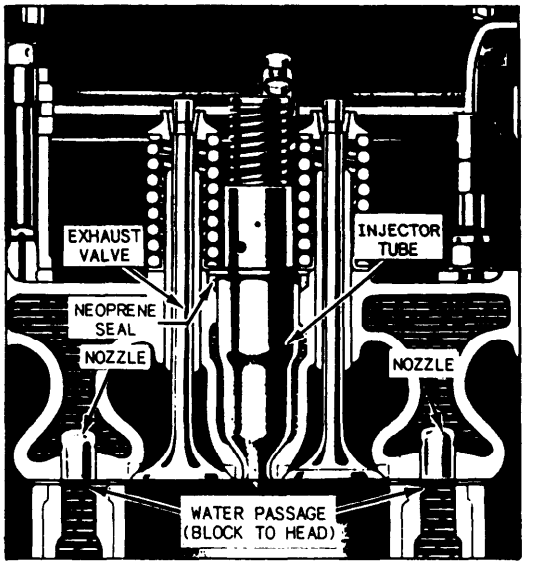
In operation, the water pump draws water from the off engine system and pumps it into the cylinder block through the water jacket, around the cylinder liners, and through the cylinder heads to the water outlet manifolds. (See directional arrows in fig. 7-13.) The flow of water divides in the water outlet manifolds, goes to the exhaust manifolds, and through the jacket-water outlet. The majority of the water is discharged to the jacket-water outlet. From the jacket-water outlet, the water returns to the off engine system for reuse after cooling. Water from the exhaust manifolds enters cored passages in the engine front cover and returns to the pump.

Because of differences in engine design, the location and form of the cooling passages in an opposed-piston engine will differ, to a degree, from those in other types of engines. The lack of cylinder heads eliminates some of the passages common to in-line and V-type engines. While differences of a minor nature exist in the passages of different types of engines, the cooling passages of all engines are similar in many respects. Some ways in which the passages of an opposed-piston engine are similar to those of other types of engines are shown in figure 7-14.

The liner passages of the Fairbanks Morse (FM) 38D8 1/8 shown in figure 7-14 are similar to those found in other types of engines. The location of the water header (manifold) differs in various engines. In the FM 38D8 1/8, the water from the pump usually enters the engine through the water jackets of the exhaust elbows and the exhaust manifolds. In some engines, water enters the cylinder liner through a nozzle-adapter. In the usual arrangement, the water header or manifold in the FM 38D8 1/8 receives water from the cylinder-liner water passages. In other words, the water header of an FM 38D8 1/8 is the last passage in the engine through which water flows before it goes through the cooler and back to the pump.

CYLINDER HEADS

Most engines have cooling-water passages within the cylinder head. In the cylinder head, these passages generally surround the valves. In diesels, the water passages also surround the injectors. Usually, the passages are cast or drilled as an integral part of the head. In some cylinder heads, such as those of various General Motors engines (fig. 7-15), each injector is inserted into a thin-walled copper tube that passes through the water space in the cylinder head. This design



75.377

Figure 7-15.—Liquid cooling around valves and injector in the cylinder head of a General Motors engine.

serves to ensure sufficient cooling. The lower end of the copper tube is pressed into the cylinder head and is flared over; the upper end is flanged and sealed with a neoprene seal. The flared lower end and sealed upper end prevent any leaks around the copper tube. The exhaust passages, exhaust valve inserts, and injector tubes are completely surrounded by cooling water. Cooling of these areas of the cylinder head is further assured by the use of nozzles installed in the water inlet ports of the head. (Refer to fig. 7-15.) Nozzle holes are so positioned in the cylinder head that the comparatively cool water that enters the head is directed at high velocity against the sections of the head that are subjected to the greatest heat.

The passages in the cylinder head receive water from a jacket or from passages, either of which may be an integral part of the cylinder liners or the cylinder block. Water flow to the cylinder head is almost always upward from the liner or block.

FRESHWATER (EXPANSION) TANKS

The freshwater circuit of an engine cooling system includes a tank that is commonly referred to as the expansion tank. Some expansion tanks are identified as the surge tank or supply tank.

The freshwater tank provides a place where water may be added to the system when necessary and provides a space to accommodate changes in water volume that result from expansion and contraction when the water is heated and cooled. The piping arrangement to and from the expansion tank provides for three basic functions: (1) permits excess water in the system to pass back to the tank as the water becomes warm and expands, (2) permits water from the tank to flow into the system when the water becomes cool and contracts, and (3) allows for the resupply of water from the expansion tank in the event of leaks in the system.

Even though the exact locations of expansion tanks vary in different engines, the tank is always located at or near the highest point in the circuit. Examples of tank location are shown in figures 7-1 and 7-3.

The manner in which venting is accomplished in the freshwater circuit of a cooling system will vary, depending on the engine. However, venting generally involves the expansion tank. In some expansion tanks, particularly in the systems of larger engines, a vent pipe from the high point of the circuit carries to the tank any steam or air bubbles that may form in the system. When steam comes in contact with the cooler water in the tank, the steam condenses back into water. The condensation keeps the system free from steam or air pockets. The expansion tank is vented to the atmosphere. A gauge glass, located on the side of the tank, reveals the water level.

In many small engines, the freshwater circuit has no vent and operates under a slight pressure; this arrangement confines the water vapor, thus preventing the loss of water. The only escape for water vapor from a circuit that operates under pressure is through a small overflow pipe.

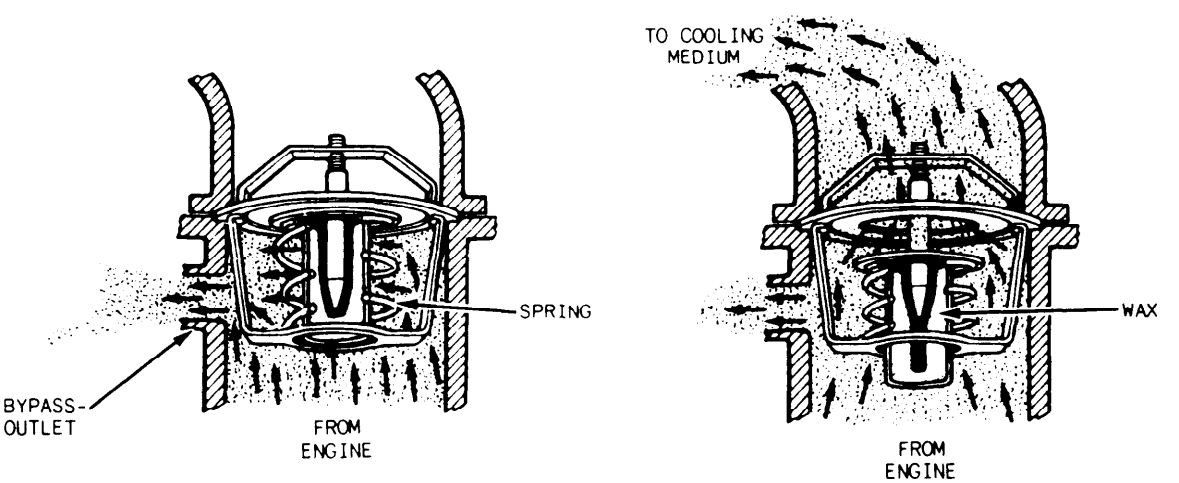
TEMPERATURE REGULATION

The temperature of a liquid in the cooling system of an engine must be regulated to maintain normal operating conditions. One of the principal factors affecting the cooling of an engine is the rate of flow of water through the cooling system. The high flow rate of the water causes the heat to be carried away more quickly. As the velocity of the circulating water is reduced, the discharge temperature of the cooling water becomes higher and more heat is carried away by each gallon of cooling water circulated. As the rate of circulation is increased, each gallon of cooling water carries away less heat and the discharge temperature of the cooling water drops.

Our discussion will now cover the devices that control the engine coolant direction of flow and, therefore, the temperature. These devices can be manually operated or thermostatically operated.

MANUALLY OPERATED THROTTLING VALVES

Throttling valves used in the seawater circuit will regulate the amount of water passing through the seawater side of the freshwater cooler. The throttling valve in the seawater circuit should be adjusted so that it regulates the minimum flow



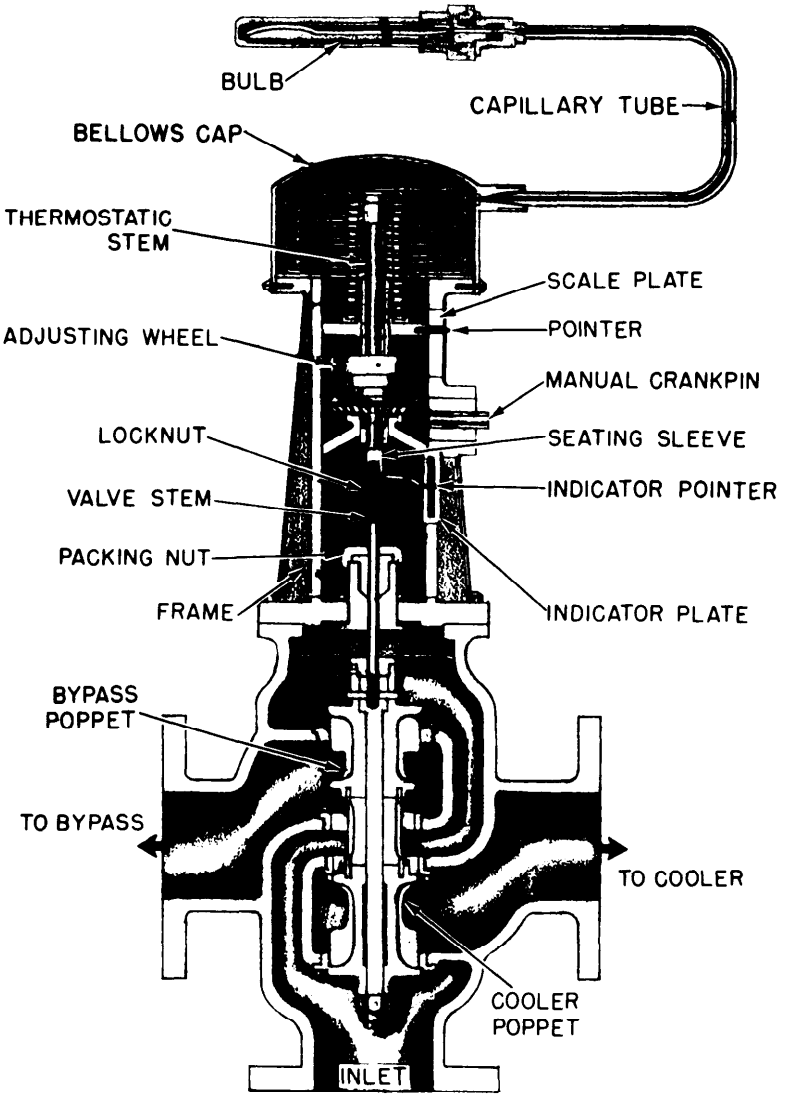
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Figure 7-16.—Conventional type of thermostatic valve operation.

of seawater through the cooler while not exceeding a discharge temperature of 130°F to reduce the effects of errosion and to prevent scale formation on heat transfer surfaces. Where throttling valves are incorporated in the seawater circuit and a thermostatically operated valve is included in the freshwater circuit, the throttling valves serve only to provide a constant flow of seawater or to close the circuit completely. Temperature is then controlled by direction of flow by the action of the thermostatically operated valve in the freshwater circuit.

THERMOSTATICALLY OPERATED BYPASS VALVES

In marine diesel engine installations, automatic temperature control by means of thermostatically operated bypass valves is more common than control by means of throttling valves in the seawater circuit. When used in the jacket-water system, these valves are located between the point where the jacket water leaves the engine block and the component that cools the water. The thermostatic valves used in the cooling systems of engines are of two types: the conventional type, which is also used in automotive engines (an example of this type is shown in fig. 7-16); and the three-way proportioning type (figs. 7-17 and 7-19). Valves of the latter type are commonly called automatic temperature regulators. Conventional thermostatic valves are generally used in small engines; the automatic temperature regulators are commonly used in medium and large engines.



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Figure 7-17.—Automatic temperature regulator.

Conventional Thermostatic Valves

A typical thermostatically controlled system is shown in figure 7-4. This illustration shows the cooling system that is installed on General Motors series 71 diesel engines. These thermostats are designed to open at a specified temperature. This temperature is known as the RATING OF THE THERMOSTAT and is usually stamped on the thermostat. Most thermostats begin to open at their rated temperatures and are fully open at about 20°F above their rated temperatures. For example, a thermostat with a rated temperature of 165°F will start to open at that temperature. At 185°F, the thermostat will be fully open.

The conventional type of thermostatic valve is not adjustable. If a higher or lower operating temperature is desired, the valve must be replaced with a valve of a different rating.

Figure 7-16 illustrates the operation of a thermostatic valve. A spring holds the valve shut when the coolant is cold (view A). Thus, the coolant is stopped from circulating through the cooling medium and is directed to the bypass line where it is forced back to the water pump to be recirculated. As the coolant starts to heat up, a special plastic wax-like substance within the temperature-sensing bulb of the thermostat starts to liquefy and expand (view B). This expansion process begins to force the valve open. As the valve starts to open, some of the coolant will begin to enter the cooling medium. When the temperature of the coolant reaches the operating temperature of the engine, the wax-like substance within the bulb becomes totally liquefied and fully expanded. At this point, the valve is completely open and directs most of the coolant through the cooling medium.

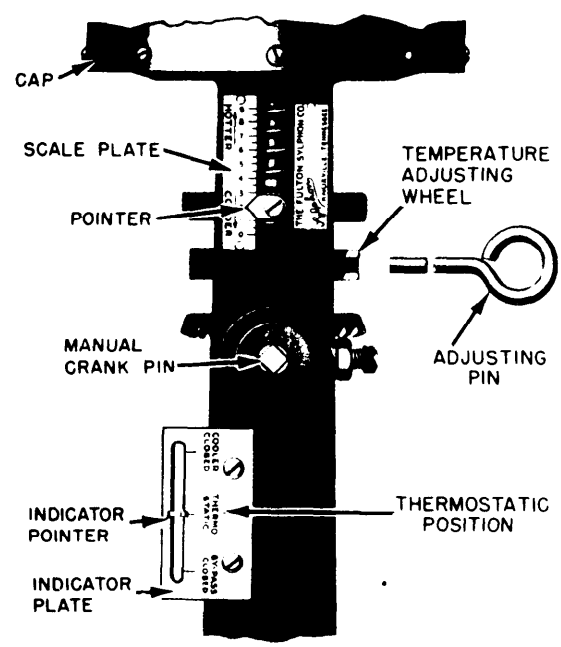
Automatic Regulating Valves

In many engines, the temperature of the fresh water is regulated automatically by a three-way control valve that maintains the temperature of the fresh water at any desired value by bypassing a portion of the water around the freshwater cooler. Even though these regulators are automatic or self-operated, provisions are included for manual operation in the event that the automatic feature fails.

One type of three-way, temperature-sensitive valve for changing the path of water flow is shown in figure 7-17. This valve has a temperature-sensitive element that is placed in the engine jacket-water discharge line. The element contains a liquid (a mixture of ether and alcohol) that gives off a vapor when heated by the jacket water, that produces a pressure that is proportional to the temperature to which the bulb is exposed. The pressure is transmitted through liquid-filled flexible tubing (capillary tube) to a bellows in the head of the valve. The movable end of the bellows is connected to the valve stem. When the bellows expands or contracts, the valve will open or close accordingly. The action of the bellows is opposed by a spring. The compression of the spring can be adjusted so that the specified operating temperature can be readily set.

The regulator operates only within the temperature range marked on the nameplate; it may be adjusted for any temperature within this range. (See fig. 7-18.) The setting is controlled by the range-adjusting wheel, located under the spring seat. A pointer attached to the spring seat indicates the temperature setting on a scale that is attached to the regulator frame. The scale is graduated from 0 to 9, representing the total operating range of the regulator.

In contrast to the valve illustrated in figure 7-17, the three-way automatic regulating valve shown in figure 7-19 does not use a gas or liquid as a sensing or activating element. The



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Figure 7-18.—Scale and indicator plates of an automatic temperature regulator.

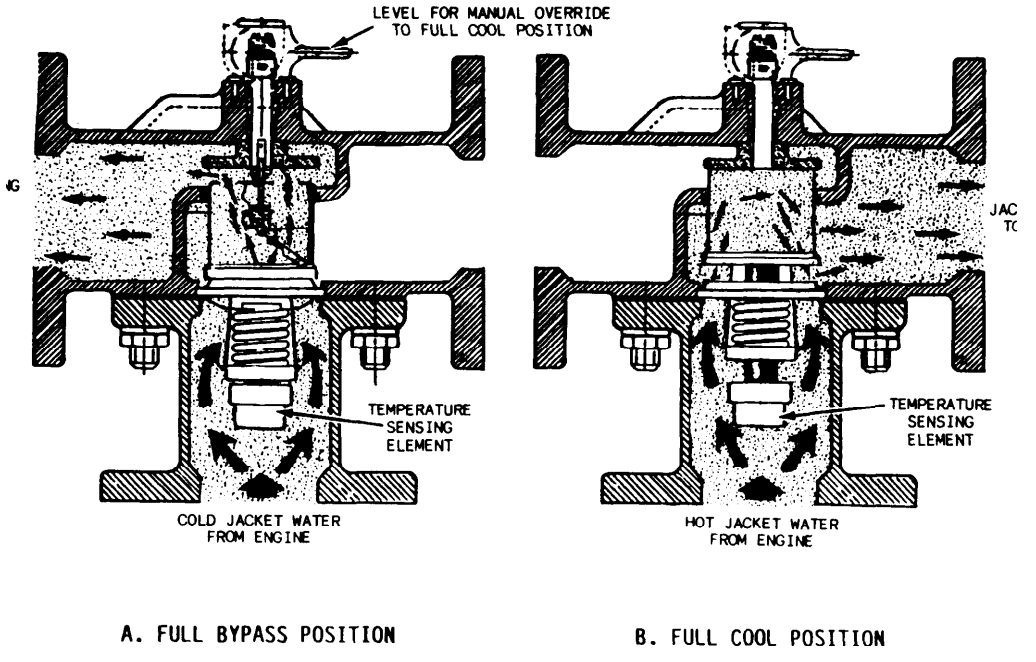


Figure 7-19.—Three-way temperature regulating valve operation.

sensing or activating element in this valve is a "power pellet." The power pellet contains a special wax material (similar to that in the conventional thermostatic valve) that expands with tremendous force as it changes from a solid to a liquid when heat is applied. In this valve (as in the conventional thermostatic valve), the important characteristic of the sensing element is that when the wax material is fully liquefied, expansion stops. The manufacturer uses a different formulation to establish a suitable operating range and limiting action for each three-way automatic regulating valve. The sensing element for each of these valves is set at the normal temperature rating by the manufacturer and cannot be altered once the rating has been set. If a different rating is required, a new valve must be used.

The three-way temperature regulating (control) valve that is located in the freshwater circuit automatically regulates jacket-water flow to the jacket-water cooler to maintain optimum water temperature. These valves are arranged so that flow is normally through the recirculating line which bypasses the cooler and permits the jacket water to be recirculated through the engine. (See fig. 7-19, view A.) In this way, the temperature of the jacket water rises and the valve starts to open. When the jacket water in contact with the valve element starts to exceed normal operating temperature, the valve fully opens to permit full flow to the jacket-water cooler where the excessive heat is given up. (See fig. 7-19, view B.)

It should be noted that the applications of conventional thermostatic valves or automatic regulating valves we have discussed do not control the rate of water flow through the cylinder jackets but vary the flow through whatever cooling medium is used. This design provides for the control of the temperature of the jacket water without a reduction in the rate of flow in the engine that might cause localized hot spots.

When located in the seawater circuit, the regulator controls the amount of seawater flowing through the coolers. When the temperature of the fresh water becomes greater than the temperature for which the regulator is set, the regulator actuates a valve to increase the flow of seawater through the coolers. When the temperature of the fresh water is below the temperature for which the regulator is set, the regulator actuates a valve to decrease the flow of seawater through the coolers.

Temperature regulators are used not only to control the temperature of the fresh water but also to control indirectly the temperature of the oil discharge from the lubricating oil cooler. Control of lubricating oil temperature is possible because

the water that is passed through the regulator and the freshwater cooler is the cooling agent in the lubricating oil cooler.

WATER AND CHEMICAL REQUIREMENTS OF A COOLING SYSTEM

Since the purpose of an engine cooling system is to keep engine parts and working fluids at safe operating temperatures, you must take preventive actions to keep corrosion and scale formation to a minimum. To help prevent undesirable operating conditions in an engine, you must meet two basic requirements. First, you must use an acceptable type of water for the cooling system. Second, you must chemically treat the water with the proper corrosion inhibitor.

WATER

When you fill the freshwater cooling system of an engine, you must use an acceptable type of water. An important part of a coolant treatment program for any engine is the use of water that contains minimum amounts of hardness, chloride, and sulfate. The water you must use for filling or topping off cooling systems or for mixing treatment chemicals is indicated by the following categories:

1. Shore source water that meets the requirements of *Naval Ships' Technical Manual,* chapter 220, volume 2, for shore-source feedwater.
2. Shipboard boiler feedwater or condensate that meets the requirements of *Naval Ships' Technical Manual,* chapter 220, volume 2.
3. Water produced by shipboard distilling plants, demineralizers, or reverse osmosis units.
4. Water produced by shore-based distilling plants, demineralizers, or reverse osmosis units.

If water indicated by these categories is not available, use clean, fresh water. Clean, fresh water includes shipboard potable water or city water.

CHEMICALS

The chemicals you will use for treating fresh water in engine cooling systems will vary according to the composition of the metal you are trying to protect, the application of the engine, and the climate to which the engine is subjected. Because of these variations, our discussion of engine cooling system treatments will be general. Complete information on this subject can be obtained in the *Naval Ships' Technical Manual,* chapter 233.

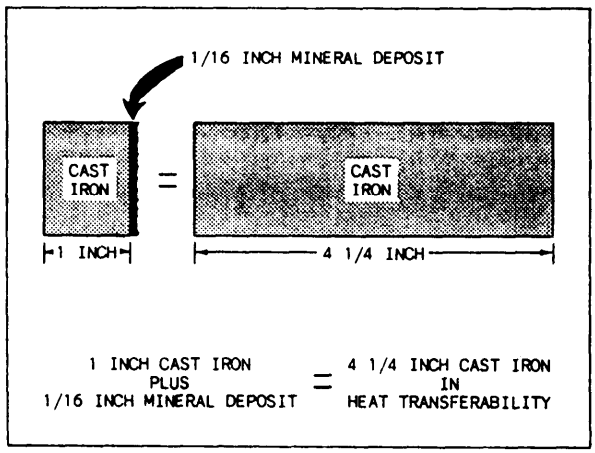
Our discussion will cover some of the chemicals that are authorized for the treatment of freshwater systems in engines. Remember, however, that the water treatment methods that will be discussed in this chapter are preventive treatments only. These treatments will not remove scale that has already formed in the cooling system.

A CORROSION INHIBITOR is a water-soluble chemical compound that protects the metallic surfaces of the cooling system against corrosive attack. Depletion of all types of inhibitors occurs through normal operation, Therefore, strength levels must be maintained by addition of inhibitors as required after the coolant is tested.

The importance of a properly inhibited coolant cannot be overstressed. A coolant that has insufficient inhibitors, the wrong inhibitors, or worse, no inhibitors at all invites the formation of rust and scale deposits within the cooling system. Rust, scale, and mineral deposits can wear out water pump seals and coat the walls of the cylinder block water passages and the outside walls of the cylinder liners. As these deposits build up, they insulate the metal and reduce the rate of heat transfer. For example, a 1/16-inch deposit of rust or scale on 1 inch of cast iron is equivalent to 4 1/4 inches of cast iron in heat transferability. (See fig. 7-20.)

An engine affected in this manner overheats gradually—over a period of weeks or months. Liner scuffing, scoring, piston seizure, and cylinder head cracking are the inevitable results. An improperly inhibited coolant may also become corrosive enough to "eat away" coolant passages, erode seal ring grooves, and cause leaks to develop. If sufficient coolant accumulates on top of a piston, a hydrostatic lock can occur while the engine is being started. This, in turn, can result in a bent connecting rod. As a precaution against these possibilities, an engine should be barred over by hand before being started.

An improperly inhibited coolant can also contribute to cavitation erosion. Cavitation erosion is caused by the collapse of bubbles (vapor pockets) that form on the coolant side of an engine component. The collapse results from a pressure differential in the liquid caused by the vibration of the engine part. As bubbles collapse,



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Figure 7-20.—Reduction of heat transfer capacity from rust or scale deposits.

they form pinpoints of very high pressure. Over a period of time, the rapid succession of millions of tiny bursting bubbles can wear away (erode) internal engine surfaces.

Components such as freshwater pump impellers and the water sides of wetted cylinder liners are especially susceptible to cavitation erosion. In extreme cases their surfaces can become so deeply pitted that they appear to be spongy, and holes can develop completely through them.

When this training manual was written, there were five types of corrosion-inhibitor treatments authorized for use in naval engine cooling systems. These treatments include:

1. Sodium chromate-disodium phosphate
2. Soluble oil
3. NALCOOL 2000
4. Inhibited antifreeze (MIL-A-46153)
5. MIL-A-53009

We will briefly discuss each of these treatments.

Sodium Chromate-Disodium Phosphate (Chromate)

Sodium chromate provides a source of alkaline chromate. The alkaline chromate leads to the formation of a protective layer on metal surfaces that helps to minimize corrosion action. Disodium phosphate aids in maintaining the alkalinity of the coolant. The term used to identify the alkalinity of the treated cooling water is pH. The pH unit does not measure alkalinity directly; however, it is related to alkalinity in such a way that a pH number gives an indication of the alkalinity or acidity of the cooling water. The alkalinity of the coolant allows the chromate to retain its effectiveness as a corrosion inhibitor. Chromate will not protect aluminum or prevent scale deposits.

Soluble Oil

Soluble oil is a corrosion inhibitor which when properly added to the water in an engine cooling system provides a protective film on metal surfaces. The protective film helps minimize the effects of corrosion. When an insufficient amount of soluble oil is present in the engine cooling system, adequate corrosion protection will not be provided.

The normal concentration of soluble oil is between 1 and 2 percent. For each 100 gallons of coolant capacity for an engine, you would use only 1 gallon of soluble oil. (You should mix the oil with distilled water before adding it to the engine.) When used in amounts in excess of 2 percent, soluble oil can cause an insulating film to form on heat transfer surfaces. This oil film will restrict heat transfer and cause an otherwise normal running engine to overheat. A high level of soluble oil may also result in separation of the oil from the water. This condition will reduce the effectiveness of the oil to prevent corrosion in the cooling system of the engine. It should be noted that although soluble oil is used for the prevention of corrosion, it will not prevent or eliminate scale deposits.

NALCOOL 2000

NALCOOL 2000 chemically protects all metals in the cooling system from corrosion and cavitation-erosion while simultaneously preventing harmful mineral scale deposits. It is buffered so that it neutralizes the acids that are formed in the cooling system. NALCOOL 2000 stops cavitation in three ways: (1) by forming a physical barrier (a chemical film); (2) by preventing corrosion of the metal surface, thus strengthening its resistance to cavitation; and (3) by reducing foaming, which means less air entrapment, a major cause of cavitation.

Ships that are authorized to use NALCOOL 2000 must use inhibited antifreeze (MIL-A-46153) when freezing protection is required. Although inhibited antifreeze contains some corrosion inhibitors, your ship must use NALCOOL 2000

with inhibited antifreeze to ensure adequate corrosion protection. Diesel engines that require the NALCOOL 2000 treatment are particularly susceptible to cavitation corrosion of the cylinder liners if this treatment is not used.

NOTE: When you are making the conversion from NALCOOL 2000 to the required inhibited antifreeze/NALCOOL 2000 combination, you must first dump the cooling system. You must dilute the antifreeze with water in the cooling system before adding the NALCOOL 2000. Do not combine concentrated antifreeze and NALCOOL 2000, as the inhibitor chemicals will become insoluble and separate from the solution.

Inhibited Antifreeze (MIL-A-46153)

Inhibited ethylene glycol antifreeze (MIL-A-46153) must be added to the freshwater cooling systems of engines that are subjected to freezing temperatures.

Inhibited antifreeze consists of ethylene glycol and corrosion-inhibiting chemicals. A mixture (solution) of ethylene glycol and water has a lower freezing point than either water or ethylene alone. Thus, treating a cooling system with a mixture of 50 percent antifreeze and 50 percent water provides freeze protection against temperatures down to –30°F. If conditions are such that additional freezing protection is needed, up to 67 percent antifreeze can be used. This mixture provides freeze protection down to –77°F.

The corrosion inhibitors in the antifreeze will protect the metals from corrosion. They also provide an alkaline buffer which neutralizes acidic by-products that result from combustion blow-by gases that leak into the coolant system. Do not use antifreeze concentrations that are less than 33 percent, because this concentration will not contain a high enough percentage of corrosion inhibitors to provide adequate corrosion protection.

NOTE: Use only MIL-A-46153 inhibited antifreeze. This antifreeze is labeled U.S. GOVERNMENT PROPERTY, ETHYLENE GLYCOL, ANTIFREEZE. The label also contains the stock number. Verify that the stock number matches the appropriate number (depending on container size) given in *Naval Ships' Technical Manual,* chapter 233. Remember, different brands of commercial antifreezes are formulated with different corrosion-inhibiting chemicals which may or may not be effective for your ship. The different inhibitors may be incompatible with each other and with the inhibitors in MIL-A-46153 antifreeze. In addition, the required antifreeze test procedures will produce accurate results only for coolant treated with MIL-A-46153 inhibited antifreeze.

CAUTION

NEVER use antifreeze concentrations greater than 67 percent; otherwise, the following situations will occur:

1. Less freezing protection will be provided. Pure antifreeze freezes at 9°F.
2. The engine may overheat, because ethylene glycol has a lower heat capacity than water.

Antifreeze is not compatible with either soluble oil or sodium chromate. For conversion from chromate or soluble oil to antifreeze or vice versa, it is essential that the cooling system be thoroughly flushed for complete removal of all treatment chemicals.

MIL-A-53009

The chemical additive MIL-A-53009 consists of a blend of inhibitor chemicals in a liquid solution. The inhibitors neutralize the acidic by-products that result from the combustion blow-by gases that leak into the coolant. To prevent corrosion, the inhibitors form protective layers on the metal surfaces of the cooling system.

Do not use MIL-A-53009 and inhibited antifreeze together in the same engine cooling system. Overtreatment with MIL-A-53009 and inhibited antifreeze can result in the formation of deposits in heat exchangers. This condition can cause overheating. Refer to *Naval Ships' Technical Manual,* chapter 233, for information concerning the required conversion procedures.

At the time of the writing of this manual, the five types of corrosion inhibitor treatments we have just discussed were those authorized for use in naval engine cooling systems. As an Engineman, you must stay informed as to the current requirements for your ship. For detailed guidance on the type of corrosion inhibitor that you must use as well as the required testing and treatment procedures, refer to the *Naval Ships' Technical Manual,* chapter 233.

SAFETY PRECAUTIONS

Sodium chromate, NALCOOL 2000, inhibited antifreeze, and MIL-A-53009 are hazardous chemicals. You must avoid any contact with the skin or eyes. If your eyes have been in contact with these chemicals, you must flush your eyes with potable water for at least 15 minutes immediately after exposure. Seek medical attention. If areas of your skin have been affected, flush your skin with cold water immediately after exposure. Then wash the areas thoroughly with soap and water. Avoid breathing the solution spray or the sodium chromate powder. These chemicals are poisonous when taken internally.

When you are handling these chemicals, you should wear protective clothing, such as a face shield, rubber gloves, and apron. When handling sodium chromate powder, you should also wear a dust respirator.

Soluble oil is less hazardous than the other inhibitors; however, it can be irritating to your skin and eyes. While handling soluble oil, use the same protective equipment as you would when you are handling the other corrosion inhibitors. If your skin or eyes should come into contact with soluble oil, you should also use the same removal procedures you would use for the other chemicals.

You must always take suitable precautions to prevent contamination of the ship's potable freshwater system. You must especially prevent backflow of the engine cooling water through the filling connection. Remember, specifications require that an air gap remain between the freshwater supply and the fill connection. This design must not be altered.

Corrosion-inhibitor-treated coolants must be disposed of according to the procedures in the *Environmental and Natural Resources Protection Manual*, OPNAVINST 5090.1 (latest edition) and the *Naval Ships' Technical Manual*, chapter 593.

SUMMARY

In this chapter, we have covered three types of closed cooling systems: (1) heat exchanger, (2) keel cooler, and (3) radiator and fan. The heat exchanger and keel cooling systems use fresh water to cool the engine and seawater to cool the fresh water. In the heat exchanger system, seawater is pumped from the sea, through a sea chest and strainer, to the heat exchanger, and overboard. In the keel cooling system, fresh water is circulated to the keel cooler, which is in direct contact with the seawater. The radiator and fan cooling system uses a stream of air that passes through the radiator to cool the fresh water.

In our discussion of engine cooling systems, we identified the need for freshwater treatment and use of the five corrosion-inhibitor treatments approved for naval service: (1) sodium chromate-disodium phosphate, (2) soluble oil, (3) NALCOOL 2000, (4) inhibited antifreeze, and (5) MIL-A-53009. These chemicals present health hazards when they come in contact with the skin or eyes or are taken internally.

If you are uncertain as to the design of the closed cooling systems we have discussed or the various required freshwater treatments, you should reread this chapter before continuing to chapter 8.

CHAPTER 8

ENGINE LUBRICATING OIL SYSTEMS

Lubrication is as important for reliable engine operation as air, fuel, and heat are to combustion. Lubrication is considered to be one of the most important factors in the operating life of an internal-combustion engine. The lubrication requirements of shipboard machinery are met in various ways, depending on the design of the machinery. It is important not only that the proper type of lubricant be used, but also that the lubricant be supplied to the engine parts at the specified flow rate and temperature and that provisions be made for removal of any impurities that enter the system.

After studying the information in this chapter, you should be able to understand the basic theories of lubrication, the factors affecting lubrication, the functions and characteristics of greases and lubricating oils used aboard ship, and the design and function of components in various lubricating oil systems, including tanks, pumps, coolers, and filtering devices that you, as an Engineman, may be required to operate or maintain. You should also be able to understand the importance of standards and procedures and how they are established and enforced through the Lube Oil Quality Management Program.

For proper operation of an engine, the contacting surfaces of all moving parts of the engine must be prevented from touching each other so that friction and wear can be reduced to a minimum. Sliding contact between two dry metal surfaces under load will cause excessive friction, heat, and wear. Friction, heat, and wear can greatly be reduced, of course, if metal-to-metal contact is prevented. When a clean film of lubricant is used between the metal surfaces, metal-to-metal contact is automatically reduced. The lubricating film used between load bearing surfaces in machinery is provided by a specified oil or grease.

THEORY OF LUBRICATION

Friction is the natural resistance to motion caused by surfaces that are in contact with each other. The purpose of lubrication is to reduce the harmful effects of friction by changing *sliding* friction to *fluid* friction. Before discussing the characteristics of sliding and fluid friction, we must first define the two main categories of friction: static and kinetic. The friction that exists between a body at rest and the surface upon which it is resting is called STATIC friction. The friction that exists between the surfaces of moving bodies (or between one moving body and a fixed body) is called KINETIC friction. Static friction is greater than kinetic friction. To *put* a body in motion, you must overcome static friction and inertia. To *keep* a body in motion, you must overcome kinetic friction.

There are three types of kinetic friction: sliding, rolling, and fluid. Sliding friction occurs when the surface of one solid body slides across the surface of another solid body. Rolling friction occurs when the surface of a curved body, such as a cylinder or a sphere, rolls across another surface. Fluid friction is the internal resistance to motion exhibited by a fluid.

Fluid friction occurs because of two properties of a lubricant: cohesion and adhesion. COHESION is the attraction between the molecules of a substance that tends to hold the substance together. ADHESION is the attraction between molecules that tends to cause unlike surfaces to stick together. Consider a paddle, for example, that is being used to stir a liquid. Cohesion between the molecules of the liquid tends to hold the liquid together. This tendency retards the motion of the liquid. However, adhesion between the molecules of the liquid and those of the paddle cause the liquid to stick to the paddle. This tendency further causes friction between the paddle and the liquid. In the theory of lubrication, cohesion and adhesion are important properties of a liquid. Adhesion is the

property of a lubricant which, in liquid form, causes the lubricant to stick (adhere) to the parts being lubricated. Cohesion is the property which holds the lubricant together and enables it to resist breakdown under extreme pressure. Later in this chapter, we will discuss other important properties of a lubricant.

Different materials have varying degrees of cohesion and adhesion. In general, solid bodies are highly cohesive but only slightly adhesive. Most liquids are highly adhesive but only slightly cohesive.

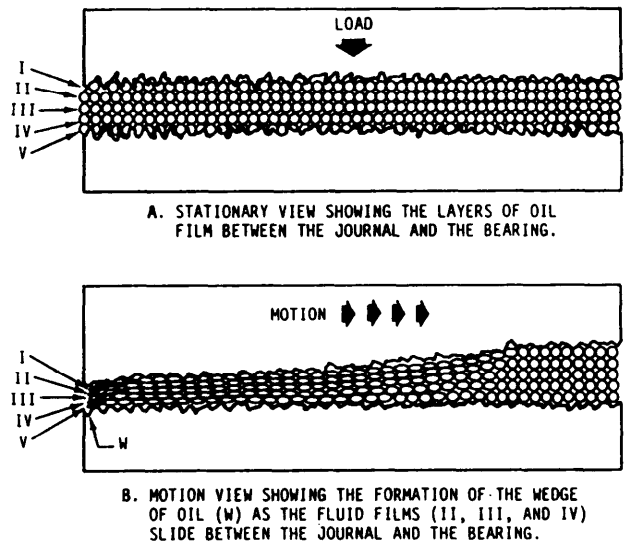
FLUID LUBRICATION

One of the properties of a liquid is that it cannot be forced into a smaller space than it already occupies. A liquid is, for all practical purposes, incompressible. It is this incompressible property of a liquid that allows for moving metal surfaces to be kept separated from each other by fluid lubrication. Because of the importance of incompressibility, most materials that are used for lubrication purposes are in liquid form. As long as the lubricant film remains unbroken, fluid friction is able to replace sliding friction and rolling friction.

In any process involving friction, some power is always consumed and some heat is always produced. Overcoming sliding friction consumes the greatest amount of power and produces the greatest amount of heat. Overcoming fluid friction consumes the least amount of power and produces the least amount of heat.

LANGMUIR THEORY

A presently accepted theory of lubrication is based on the Langmuir theory regarding the action of the fluid films or layers of oil between two surfaces, one or both of which are in motion. According to this theory, at least three layers of oil exist between two lubricated bearing surfaces. These layers of oil are shown in figure 8-1. Two of the oil films shown are boundary films and are indicated by roman numerals I and V. A BOUNDARY film is a condition in which the oil film is neither so thin as to cause seizure nor so thick as to create a full film of oil between the shaft and the bearing. As shown in view A, one of the boundary films (I) clings to the surface of the rotating journal. The other boundary film (V) clings to the stationary lining of the bearing. However, boundary film lubrication alone is not sufficient to protect metal surfaces from friction

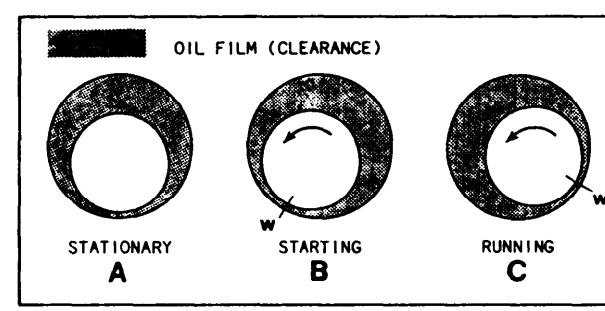


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Figure 8-1.—Theory of oil film lubrication showing boundary and fluid oil films.

and wear. Between the two boundary films are one or more FLUID films that slide layer upon layer. These fluid films are indicated in views A and B by roman numerals II, III, and IV. Refer to view B of figure 8-1. When the rotating journal is set in motion, a wedge of oil (W) is formed. Contact between the two metal surfaces is prevented when oil films II, III, and IV slide between boundary films I and V.

This theory is again illustrated in figure 8-2. Views A, B, and C of figure 8-2 represent a journal or shaft rotating in a solid bearing. The clearances are enlarged in each view to show the formation of the oil film. The shaded portion in



47.78

Figure 8-2.—Journal rotation in a solid bearing showing the distribution of the oil film.

each view represents the clearance filled with oil. The position of the oil wedge (W) is shown with respect to the position of the journal as the journal starts and continues in motion.

In view A, the oil film is in the process of being squeezed out while the journal is at rest (stationary). As the journal begins to turn (view B), the oil adhering to the surface of the journal is carried into a space between the journal and the bearing. As shown in view B (starting), the oil film increases in thickness and tends to lift the journal away from the bearing. (Remember, a liquid is incompressible.) As the shaft speed increases, the journal takes a position similar to that in view C (running). It is estimated that in a diesel engine the pressure in the oil wedge can build up to several hundred psi. This pressure, along with the correct viscosity of the oil, is necessary so that the fluid films can slide into place and prevent metal-to-metal contact. Without this protection, boundary line lubrication alone cannot prevent the damage to metal surfaces that would result from sliding and rolling friction.

FACTORS AFFECTING LUBRICATION

A number of factors determine the effectiveness of oil film lubrication. They include load, temperature, viscosity, flow rate, speed, alignment, condition of the bearing surfaces, running clearances, and purity of the lubricant. Many of these factors, of course, are interrelated and interdependent.

A lubricant must stick to the bearing surfaces and support the load at operating speeds. More adhesiveness is required to make a lubricant stick to bearing surfaces at high speeds than at low speeds. At low speeds, greater cohesiveness is required to keep the lubricant from being squeezed out from between the bearing surfaces.

Large clearances between bearing surfaces require the use of a lubricant with a high viscosity and cohesiveness that will provide an adequate lubricating oil film. The larger the clearances, the greater resistance the lubricant must have so it will not be pounded out. (If the lubricant is pounded out, the lubricating oil film will be destroyed.) High unit loading of a bearing will also require the use of a lubricant with a high viscosity. A lubricant that is subjected to high loading must be sufficiently cohesive to hold together and maintain the oil film.

GREASES

Operating temperatures, the rate at which lubrication must be supplied, and the design of the equipment may make the use of oil impractical. Greases are used at points where oil will not provide proper lubrication. Machinery manufacturers provide either pressure or cup fittings for the application of the grease. The maintenance requirement card (MRC) and the equipment guide list (EGL) will provide all the necessary information for the proper lubrication of a component: the type of grease required, the type of grease fitting on the component, the specific location of the fitting, and any additional information you may need to perform the lubrication procedures in a safe, efficient manner. You MUST follow specific lubrication instructions, since some greases are for general use and others are for special purposes. You will better understand maintenance problems involving lubrication if you are familiar with the principal factors of the composition and classification of greases.

Some lubricating greases are simple mixtures of soaps and lubricating oils. Others are more unusual, such as silicones and dibasic acids, which are exotic liquids. These may be thickened with metals or inert materials so that enough lubrication is provided. Requirements for oxidation inhibition, corrosion prevention, and extreme pressure performance are met by the addition of special substances (additives).

Lubricating greases are supplied in three grades: soft, medium, and hard. The soft greases are used for high speeds and low pressures (light loads); the medium greases are used for medium speeds and medium pressures (medium loads); the hard greases are used for slow speeds and high pressures (heavy loads).

CLASSIFICATION OF LUBRICATING GREASES

Navy specifications have been drawn to cover the several grades of lubricating greases. The grades most common in use in engine rooms are ball and roller bearing grease and extreme pressure grease.

Ball and Roller Bearing Grease (MIL-G-24508)

Ball and roller bearing grease is for general use in equipment designated to operate at temperatures up to 300°F. For temperature

applications above 300°F, high-temperature, electric-motor, ball and roller bearing grease (MIL-L-15719) must be used.

Extreme Pressure Grease (MIL-G-17740)

Extreme pressure grease has antirust properties and is suitable for lubrication of semienclosed gears, or any sliding or rolling metal surfaces where the load may be high and where the equipment may be exposed to salt spray or moisture. It is intended for use in temperature ranges within 0° to 140°F.

Graphite Grease (VV-G-671)

Graphite grease may be applied with compression grease cups to bearings operating at temperatures that do not exceed 150°F. The three grades of graphite grease are as follows:

Grade 1 Soft	For light pressures and high speeds
Grade 2 Medium	For medium pressures and medium speeds
Grade 3 Medium Hard	For high pressures and slow speeds

GREASE LUBRICATION SYSTEMS

Grease lubrication is used in many locations where it is difficult to keep lube oil at the bearing surface. The grease is applied either through grease cups or grease fittings.

Grease Cup Lubrication

Dirt in lube oil will generally settle out, but dirt in grease will remain mixed within the grease and will become abrasive. For this reason, you must be particularly careful to prevent contamination, especially where grease cups are used. Before you open the container, carefully remove all dirt from the exterior. Do NOT allow any dirt to enter either the opening or the grease cups. You should frequently empty, clean, and refill the cups with fresh grease.

Pressure Greasing

Pressure fittings provide an easy means for lubricating numerous low-speed, lightly loaded, or widely separated bearings. They are not, however, good for use on electric generators and motors, as pressure fittings used on these units may force grease out of the bearing and onto the windings. Pressure fittings are similar to those on an automobile where grease guns are used for lubrication. You must use only one type of grease to fill a grease gun. You should mark the grease gun to identify the type of grease it contains so that you will not use the wrong lubricant. Before using the grease gun, you should clean the pressure fittings and gun tip. Apply pressure to the fitting until grease comes out around the edges of the bearing. In bearings fitted with felt or other seals, you must be careful to avoid breaking the seals by over-pressure. If you use excessive pressure while you are lubricating the needle type of roller bearings, you may unseat the needles.

BALL AND ROLLER BEARING LUBRICATION

The oil or grease used to lubricate ball and roller bearings (roller contact bearings) serves many important functions. It provides a lubricating film among the balls, rollers, and retainers and between the surfaces of the ends of the rollers and the races. The oil or grease disperses heat caused by rolling friction and prevents corrosion of highly polished parts. It also helps keep dirt, water, and other foreign matter out of the parts. You must use the lubricant recommended for each machine, and you should avoid too much lubrication. Information about greases is given in the *Naval Ships' Technical Manual*, chapter 262.

LUBRICATING OILS

Lubricating oils approved for shipboard use are limited to those grades and types necessary to provide proper lubrication under all anticipated operating conditions.

For general lubrication and in hydraulic systems that use petroleum-based lubricants, the Navy must use certain oils. These special viscosity series of oils are strengthened with oxidation and corrosion inhibitors and antifoam additives. Deck machinery uses compounded oils, which are mineral oils with additives.

Special lubricating oils are available for a wide variety of services. The *Federal Supply Catalog* has a list of these oils. Among the most important specialty oils are those used for lubricating refrigerant compressors. These oils

must have a very low pour point and must be maintained with a high degree of freedom from moisture.

Lubricants for reciprocating internal-combustion engines are commonly known as detergent or dispersive oils. These lubricants contain additives that keep combustion products such as fuel, soot (unburned carbon), and oxidation (acid-forming) products in suspension, thereby reducing the amount of contaminants deposited on engine parts. These engine oils also contain additives that reduce wear and inhibit rusting, foaming, and oxidation. These advantages are particularly important in modern, high-speed, turbocharged marine diesel engines.

Shipboard diesels operate satisfactorily on a single viscosity grade, MIL-L-9000 (military symbol 9250). However, for engines that may be operated in an environment of 0°C (32°F) or below, MIL-L-2104 (military symbol OEHDO 10) oil is recommended. For standardization, engine oil is generally used in reduction gears associated with shipboard diesels. Although 9250 oil is not formulated as a gear oil, it performs well in such applications. For additional information on lubricating oils, refer to the *Naval Ships' Technical Manual,* chapter 262.

CLASSIFICATION OF LUBRICATING OILS

The Navy identifies lubricating oils by number symbols. Each identifying symbol consists of four digits and, in some cases, appended letters. The first digit shows the series of oil according to type and use; the last three digits show the viscosity of the oil. The viscosity digits indicate the number of seconds required for a 60-milliliter (ml) sample of oil to flow through a standard orifice at a certain temperature. Symbol 9250, for example, shows that the oil is a series 9 oil which is specified for use in diesel engines. It also shows that a 60-milliliter sample should flow through a standard orifice in 250 seconds when the temperature of the oil is 210°F. Another example is symbol 2135 TH. This symbol shows that the oil is a series 2 oil, which is suitable for use as a force-feed lubricant or as a hydraulic fluid. It also shows that a 60-milliliter sample should flow through a standard orifice in 135 seconds when the oil is at a certain temperature (130°F, in this case). The letters H, T, TH, or TEP added to a basic number indicate a primary specific usage within the general category.

PROPERTIES OF LUBRICATING OILS

Lubricating oils used by the Navy are tested for a number of properties. These include (1) viscosity, (2) pour point, (3) flash point, (4) fire point, (5) auto-ignition point, (6) demulsibility, (7) neutralization number, and (8) precipitation number. Standard test methods are used for each test.

The properties of lube oil are briefly explained in the following paragraphs.

1. VISCOSITY—The viscosity of an oil is its tendency to resist flow. A liquid of high viscosity flows very slowly. In variable climates, for example, automobile owners change oil according to prevailing seasons. Oil changes are necessary because heavy oil becomes too thick or sluggish in cold weather, and light oil becomes too thin in hot weather. The higher the temperature of an oil, the lower its viscosity becomes; lowering the temperature increases the viscosity. On a cold morning, it is the high viscosity or stiffness of the lube oil that makes an automobile engine difficult to start. The viscosity must always be high enough to keep a good oil film between the moving parts. Otherwise, friction will increase, resulting in power loss and rapid wear on the parts.

Oils are graded by their viscosities at a certain temperature. Grading is set up by noting the number of seconds required for a given quantity (60 ml) of the oil at the given temperature to flow through a standard orifice. The right grade of oil, therefore, means oil of the proper viscosity.

Every oil has a viscosity index based on the slope of the temperature-viscosity curve. The viscosity index depends on the rate of change in viscosity of a given oil with a change in temperature. A low index figure means a steep slope of the curve, or a great variation of viscosity with a change in temperature; a high index figure means a flatter slope, or lesser variation of viscosity with the same changes in temperatures. If you are using an oil with a high viscosity index, its viscosity or body will change less when the temperature of the engine increases.

2. POUR POINT—The pour point of an oil is the lowest temperature at which the oil will barely flow from a container. At a temperature below the pour point, oil congeals or solidifies. Lube oils used in cold weather operations must have a low pour point. (NOTE: The pour point is closely related to the viscosity of the oil. In

general, an oil of high viscosity will have a higher pour point than an oil of low viscosity.)

3. FLASH POINT—The flash point of an oil is the temperature at which enough vapor is given off to flash when a flame or spark is present. The minimum flash points allowed for Navy lube oils are all above 300°F. However, the temperatures of the oils are always far below 300°F under normal operating conditions.

4. FIRE POINT—The fire point of an oil is the temperature at which the oil will continue to burn when it is ignited.

5. AUTOIGNITION POINT—The auto-ignition point of an oil is the temperature at which the flammable vapors given off from the oil will burn. This kind of burning will occur without the application of a spark or flame. For most lubricating oils, this temperature is in the range of 465° to 815°F.

6. DEMULSIBILITY—The demulsibility, or emulsion characteristic, of an oil is its ability to separate cleanly from any water present—an important factor in forced-feed systems. You should keep water (fresh or salt) out of oils.

7. NEUTRALIZATION NUMBER—The neutralization number of an oil indicates its acid content and is defined as the number of milligrams of potassium hydroxide (KOH) required to neutralize 1 gram of the oil. All petroleum products deteriorate (oxidize) in air and heat. Oxidation produces organic acids which, if present in sufficient concentrations, will cause deterioration of (1) alloy bearings at elevated temperatures, (2) galvanized surfaces, and (3) demulsibility of the oil with respect to fresh water and salt water. The increase in acidity with use is an index of deterioration and is measured as a part of the work factor test. This test is not applicable to 9250 oil.

8. PRECIPITATION NUMBER—The precipitation number of an oil is a measure of the amount of solids classified as asphalts or carbon residue contained in the oil. The number is reached when a known amount of oil is diluted with naphtha and the precipitate is separated by centrifuging—the volume of separated solids equals the precipitation number. This test detects the presence of foreign materials in used oils. An oil with a high precipitation number may cause trouble in an engine. It could leave deposits or plug up valves and pumps.

FUNCTIONS OF LUBRICATING OIL IN AN ENGINE

A lubricating oil with the necessary properties and characteristics will (1) provide a film of proper thickness between the bearing surfaces under all conditions of operation, (2) remain stable under changing temperature conditions, and (3) not corrode the metal surfaces. If the lubricating oil is to meet these requirements, the engine operating temperature must NOT exceed a specified limit.

In internal-combustion engines, lubricating oil serves six functions:

1. Controls friction between load-bearing surfaces
2. Reduces wear by preventing metal-to-metal contact between moving parts
3. Limits the temperature by carrying away heat from fluid friction and combustion of fuel
4. Reduces corrosion by coating metal parts and by flushing debris from between moving parts
5. Dampers mechanical shock in gears
6. Forms a seal on the walls of the cylinders

Some of these functions and characteristics are discussed in the sections that follow.

Protective Film

Direct metal-to-metal contact of load-bearing surfaces is similar to the action of a file as it wears away metal. The filing action is a result of very small irregularities in the metal surfaces. The severity of the filing action depends on the finish of the surfaces, the force with which the surfaces are brought into contact, and the relative hardness of the materials. Lubricating oil fills the tiny cavities in bearing surfaces and forms a film between the sliding surfaces to prevent high friction losses and rapid wear of engine parts. The lack of a proper oil film will result in a seized (frozen) piston, wiped bearings, and stuck piston rings.

Cooling

Lubricating oil assists in cooling the engine because the constant flow of oil carries heat away from localized “hot spots.” The principal parts from which oil absorbs heat are the bearings, the journal surfaces, and the pistons. In some engines,

the oil carries the heat to the sump where the heat dissipates in the mass of oil. However, most modern internal-combustion engines use a centralized pressure-feed lubrication system. This type of system has an oil cooler (heat exchanger) where the heat in the oil is transferred to the water circulating in the jacket-water cooling system.

Sludge Control

Gummy or carbonaceous material that accumulates in lubricating oil is called SLUDGE. Most engine lubricating oils have some natural ability for preventing conditions that may cause sludge to form and for carrying sludge that does form in a finely suspended state until it is removed by filtering equipment. Chemicals are added to some oils to improve the ability of the oils to prevent the formation of sludge.

The formation of sludge is greatly reduced when the lubricating oil has the proper stability. STABILITY is defined as the ability of the oil to resist oxidation and deterioration for long periods. Proper stability is essential for a strong oil film to be maintained throughout the normal temperature ranges of an operating engine. A strong oil film provides the required oiliness, or film strength, to form a seal between the piston and the cylinder wall. With the oil seal in place, burned fuel and exhaust gases cannot get by the piston rings to form sludge.

Various factors tend to cause sludge to form in an engine. Carbon from the combustion chambers or from the evaporation of oil on a hot surface, such as the underside of a piston, will cause sludge to form. Gummy, partially burned fuel, which gets past the piston rings, or an emulsion of lubricating oil and water, which may enter the lubricating oil system, will also tend to form sludge.

Sludge in the lubricating oil system of an engine is harmful for several reasons. In addition to carbon and gummy material, sludge may contain abrasive ingredients, such as dust from the atmosphere; rust as a result of water condensation in the engine; and metallic particles resulting from wear of engine parts. Sludge in engine lubricating oil causes premature wear of parts and eventual breakdown of the engine. Sludge may clog the oil pump screen or collect at the end of the oil passage leading to a bearing, thereby preventing sufficient oil from reaching the parts to be lubricated. Sludge may coat the inside of the crankcase, act as an insulator, and blanket the heat inside the engine. This condition will cause the oil temperature to increase and induce oxidation. Sludge may accumulate on the underside of the pistons and prevent proper heat transfer, thereby raising piston temperatures. Sludge in lubricating oil also contributes to sticking piston rings, a condition that will affect the ability of the rings to seal the cylinder.

LUBRICATING OIL SYSTEMS

The reliability and performance of modern diesel engines are directly dependent on the effectiveness of their lubricating systems. To be effective, an engine lubricating system must successfully perform the functions of minimizing friction between the bearing surfaces of moving parts, dissipating heat, and keeping the engine parts clean by removing carbon and other foreign matter. In almost all modern internal-combustion engines, the system that provides the oil for these functions is the forced-lubrication type of design.

Although there are many variations in lubricating systems for internal-combustion engines, the components and method of operation are basically the same for all designs. The following discussion of the basic components can be applied to almost any variation or design of lubricating system.

COMPONENTS OF A LUBRICATING OIL SYSTEM

The lubricating system of an internal-combustion engine consists of two main divisions: (1) one that is inside the engine, and (2) one that is outside the engine. The internal system consists mainly of passages and piping. The external system includes several components which aid in supplying the oil in the proper quantity, at the proper temperature, and free of impurities. In the majority of lubricating oil systems for internal-combustion engines, the external system includes such parts as tanks and sumps, pumps, coolers, strainers, and filters.

TANKS AND SUMPS

The lubricating systems of propulsion installations use tanks to collect, store, and recirculate oil after it has been used for lubrication and cooling. Some installations have a sump or drain tank under the engine to collect the oil as it drains from the engine crankcase. Separate storage and sump

tanks are not common in auxiliary engines; these engines generally contain the oil supply directly within the engine oil pan.

PUMPS

Positive-displacement, rotary-gear pumps deliver oil under pressure to the various parts of the engine. Since the pumps are gear driven by the engine camshaft or, in some engines, directly by the crankshaft, the oil is supplied at flow rates adjusted to the needs of the engine. Changes in engine speed will cause corresponding changes in pump output.

The operating pressure is normally controlled by one or more pressure-regulating valves, which open or close as necessary to maintain the specified flow rate to various load-bearing parts of the engine. These spring-actuated devices divert excess oil directly to the engine sump or back to the inlet of the lubricating oil pump.

Detached lubricating pumps on large diesel engines fill the sump tanks from the storage tanks and flush and prime the lubricating oil system. You should be thoroughly familiar with these components before attempting to transfer oil or to flush and prime the engine. When priming or flushing the engine, you should know that prolonged flushing or priming of the lubricating oil system on any engine may cause oil to accumulate in the air intake passages and cause overspeeding upon starting. To prevent this, you must observe the following precautions:

1. Prime the engine lubricating oil system before the engine is turned over by hand or by motor-driven jacking gear. This ensures that a film of oil is deposited to prevent friction when parts start to move.
2. Continue to prime the engine ONLY until the engine lubricating oil pressure gauge registers a slight pressure or until you see oil at each main bearing.
3. Before starting the engine after a prolonged shutdown, inspect the air receiver and blower discharge passages and remove any accumulation of lubricating oil.

COOLERS

The lubricating oil systems of most engines use coolers (heat exchangers) to maintain the oil temperature within the most efficient operating range. Oil, passing through the operating engine, absorbs heat from the metal parts. Since engine oil is recirculated and used over and over, it is continually absorbing additional heat. Unless the heat is removed, the oil temperature will rise to excessive values. At extremely high temperatures, oil tends to oxidize rapidly and form carbon deposits. Excessive engine operating temperatures also cause an increase in the rate of oil consumption. Consequently, oil coolers are required to remove excess heat from the oil so that the oil will retain its lubricating qualities.

The coolers used to remove heat from lubricating oil are of the same type as those used to remove heat from other fluids common to internal-combustion engines. These coolers are referred to as shell and tube, strut tube, or plate tube coolers. (These coolers were discussed in detail in chapter 7 of this manual.)

FILTERING DEVICES

Oil must be clean before it goes into the lubricating system of an engine. Oil must also be cleaned regularly while it is being recirculated through the engine. Dust and dirt particles from the intake air get into the oil system. Flakes of metal from the engine parts are also picked up and carried in the oil. Carbon particles from incomplete combustion in the cylinders work into the oil. Heat causes the oil itself to deteriorate and form sludge and gummy material which may coat load-bearing or heat-transfer surfaces, or circulate through the oil system. Some water will get into the oil, even when precautions are taken.

The lubricating oil system of an engine uses strainers and filters to remove abrasives and foreign materials which tend to increase wear of engine parts and cause the lubricating oil to deteriorate. A variety of strainers and filters are used in Navy installations. According to Navy terminology, all metal-edge and wire-mesh devices are classed as STRAINERS. Devices that have replaceable, absorbent cartridges are called FILTERS. Filters remove smaller particles than strainers. The location and number of strainers and filters will vary, depending on the type of installation.

Strainers

Lubricating oil strainers may be either simplex or duplex. A duplex strainer is two strainer elements in one assembly. A manual valve directs

the flow of oil through either of the elements. When duplex strainers are used, one element can be bypassed, and the element can be removed and cleaned without disturbing the flow of oil through the other element to the engine.

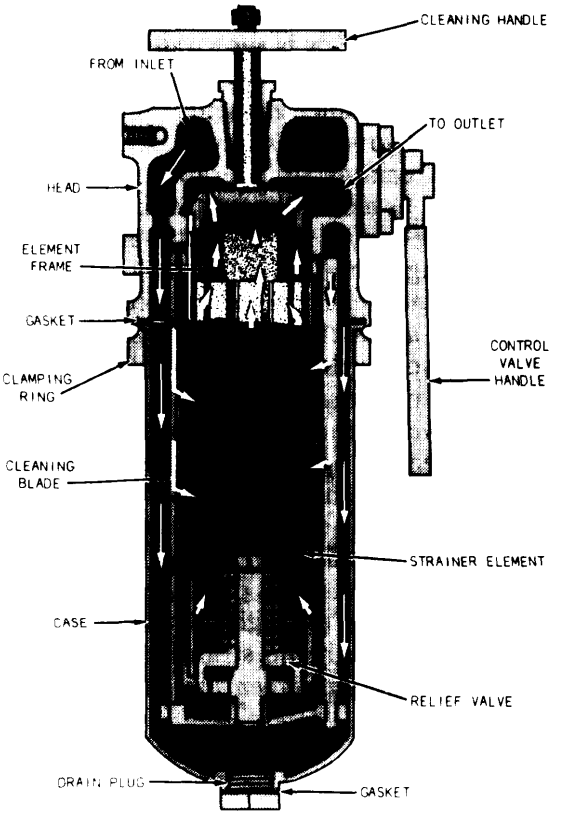
Every approved lubricating oil strainer has a built-in, spring-loaded or differential area, pressure-relief valve. The valve must be sufficiently large to bypass all of the oil around a clogged strainer to maintain an uninterrupted flow of oil to the engine.

Metal-edge strainers consist of a strainer element surrounded by a case that serves as a sump to collect foreign material and water. The element has an edge-wound metal ribbon or a series (stack) of edge-type disks. Most strainers have devices for manually rotating the strainer element against metallic scrapers, which remove the material caught by the element. Strainers usually have vents for releasing air from the system.

EDGE-WOUND METAL RIBBON STRAINER.—An edge-wound metal ribbon strainer is shown in figure 8-3. This strainer cleans the oil required by the engine except when the element is removed for cleaning or servicing. Under normal operating conditions, the oil comes into the strainer at the top and descends to surround the ribbon element. The oil then passes through the element, into the center, and then upward to the outlet passage.

To remove the element, turn the control valve handle to the BYPASS position. This position will divert the oil flow through the strainer head and will allow you to remove the element without interrupting the oil flow to the engine.

Another type of element consists of a closely compressed coil of stainless steel wire. The wire has been passed between rollers so that it is a wedge-shaped wire or ribbon with one edge thicker than the other. On one side of the wire, projections are spaced at definite intervals. The other side of the wire is smooth. The projections on one side of the wire touch the smooth side of the wire on the adjacent coil to provide appropriate spacing between adjacent coils. The thick edge of the wire is on the outside of the coil. A tapered slot is therefore formed from the outside to the inside of the coil, with the narrowest part of the slot on the outside. With this arrangement, dirt particles small enough to pass through the outside, or narrowest, portion of the slot will not become stuck halfway through the slot and clog the oil flow. The dirt removed from the oil remains on the outside of the element and can be readily removed when the element is rotated with the cleaning handle. As the element rotates, the cleaning blade scrapes foreign material from the element.



75-191

Figure 8-3.—Edge-wound metal ribbon lubrication oil strainer.

The control-valve handle on the strainer operates the bypass valve. When the handle is in the ON position, the lubricating oil is flowing through the strainer. When the handle is in the BYPASS position, the oil is flowing directly through the head of the unit, and the strainer case and element can be removed and cleaned. The ON and BYPASS positions are indicated on the strainer head.

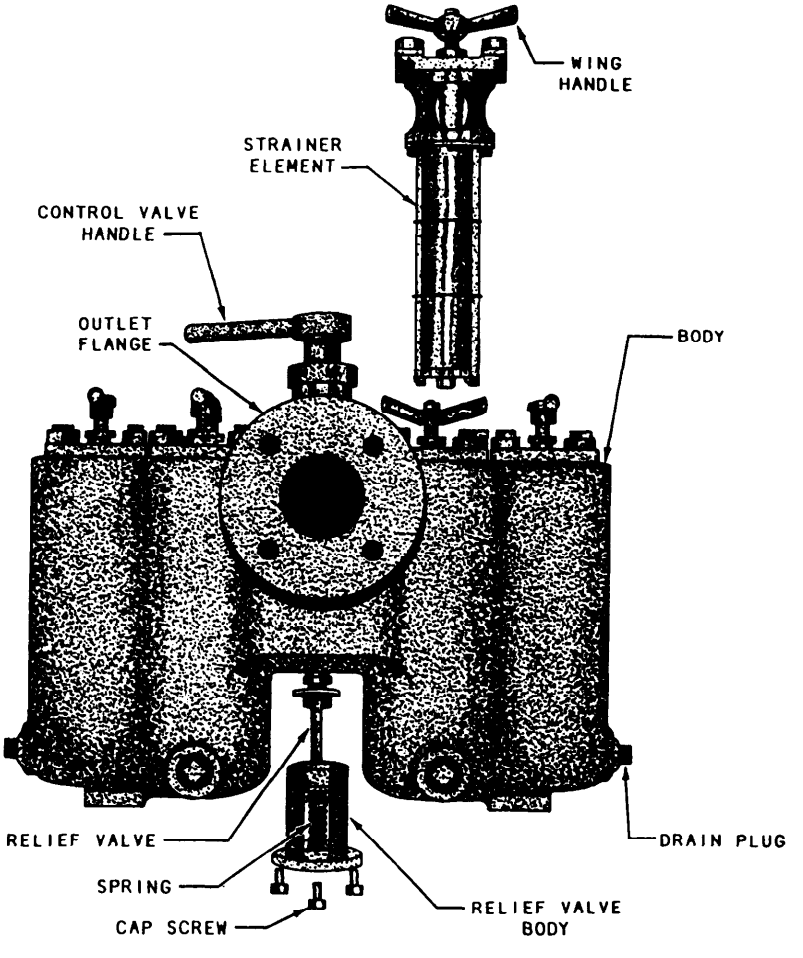
EDGE-DISK STRAINER.—A duplex strainer of the edge-disk type is shown in figure 8-4. The strainer consists of two sections, each of which contains two strainer elements. A control valve between the two sections secures one section while the other remains in operation. The secured section acts as a standby unit; it may be opened for cleaning and inspection without interrupting the straining operation.

A strainer element of the edge-disk type consists of an assembly of thin disks separated slightly by spacer disks. The assembly of an edge-disk strainer element is illustrated in figure 8-5.

The lower end of the disk assembly is closed; the upper end is open to the strainer discharge. Oil enters the strainer assembly and is forced down between the casing and disk assembly and then through the disks into the center of the disk assembly. The oil then passes up through the assembly and out through the discharge outlet. In passing through the strainer, the oil passes through the slots between the strainer disks. A relief valve at the bottom of the strainer element relieves pressure which builds up if the slots become filled with foreign matter. The relief valve bypasses the oil up through the center of the strainer element and out through the strainer discharge when a predetermined pressure is reached.

When the assembly is turned by the external handle, the solids which have lodged against or between the disks are carried around until they meet the stationary cleaner blades. The stationary cleaner blades clean the solids from the strainer surface. The solids are compacted by the cleaner blades and fall into the sump of the strainer.

To keep the strainer in a clean, free-filtering condition, give the wing handle on the element that is not in use one or more complete turns in a clockwise direction, then shift the flow to the element you have cleaned. If the handle turns hard, then the strainer surfaces have heavy deposits of solids on them. You must



75.192

Figure 8-4.—Edge-disk oil strainer.

then remove the head and disk assembly and soak it in a solvent until the solids are removed.

WIRE-MESH (SCREEN) STRAINER.—Strainers installed on the suction or intake side of the pressure pumps are generally of the wire-mesh (screen) type and are referred to as coarse strainers. Some screen-type strainers are located in the oil pan or sump.

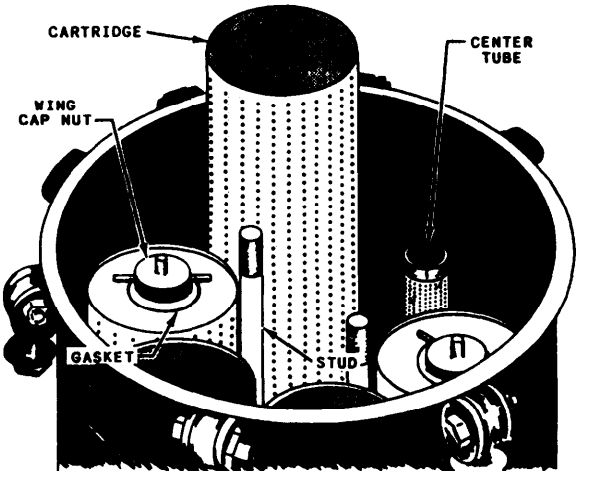
Filters

In filters approved by the Navy, the absorbent material is composed of such substances as cellulose, cotton yarn, and paper disks. Filters may be located directly in the pressure-lubricating oil system, or they may be installed as bypass filters. When installed in the pressure system, a filter must contain a built-in, spring-loaded, pressure-relief valve. The valve must be large enough to bypass all oil to the engine in case the filter element becomes restricted.

A bypass filter has an orifice plate in the line to the filter. This component controls the amount of oil removed from the lubricating oil pressure system. (The amount of oil that flows through a bypass filter is only a small percentage of the oil that flows through the pressure system.) The oil from a bypass filter is returned to the sump tank.

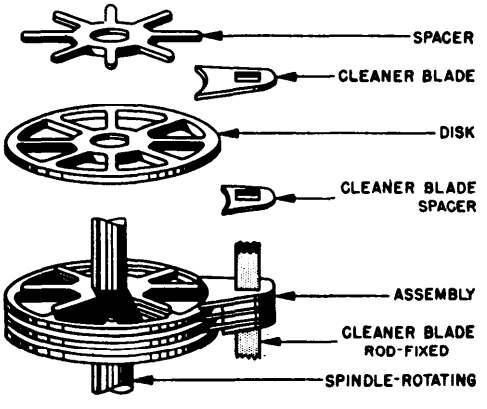
Filters vary as much in design and construction as do strainers. Examples of some of the filters with which you will come into contact are shown in figure 8-6.

TANK-TYPE FILTER.—Figure 8-6 illustrates the basic design of a tank-type filter. A tank-type filter consists of a single tank that holds several filter elements. In some tank-type filters, each filter element holder has a relief valve to protect the element against excessive pressure. Other tank-type filters are constructed to withstand pressure greater than that of the relief valve setting on any of the pumps in the lubricating oil filtering system.



75-196

Figure 8-6.—Tank-type lubricating oil filter.



75.193

Figure 8-5.—Edge-disk strainer element assembly.

Figure 8-7 has been deleted.

SPIN-ON FILTER. —The spin-on filter is not unlike the filter you would find on an automobile engine. The spin-on filter consists of a shell, an element, and a gasket combined into a unitized assembly. An oil filter adapter that contains a bypass valve assembly provides the support for each pair of oil filters.

CANISTER-TYPE FILTER.—The canister-type filter assembly consistsof a replaceable element enclosed within a shell which is mounted in an adapter or base. When the filter shell is in place, the element is restrained from movement by a coil spring. The bypass valve assembly contained in the adapters will be explained in the next section of this chapter.

Up to this point in the chapter, we have discussed only the main components of an engine lubricating system. You should also be familiar with the piping and gauges, thermometers, and other instruments essential for safe, reliable operation of the system. In the remainder of this chapter, we will deal with the types of lubricating oil filtering systems, the flow of oil through a lubricating oil filtering system (including the internal or engine part of the system), how and why lubricating oil systems are ventilated, and the requirements for testing.

FULL-FLOW LUBRICATING OIL SYSTEM

The strainers and filters used with Navy diesel engines are a part of what is generally referred to as the LUBRICATING OIL FILTERING SYSTEM. Currently, engines use a system known as the FULL-FLOW FILTERING SYSTEM. You should refer to figures 8-9 and 8-10 as you read the descriptions of this system.

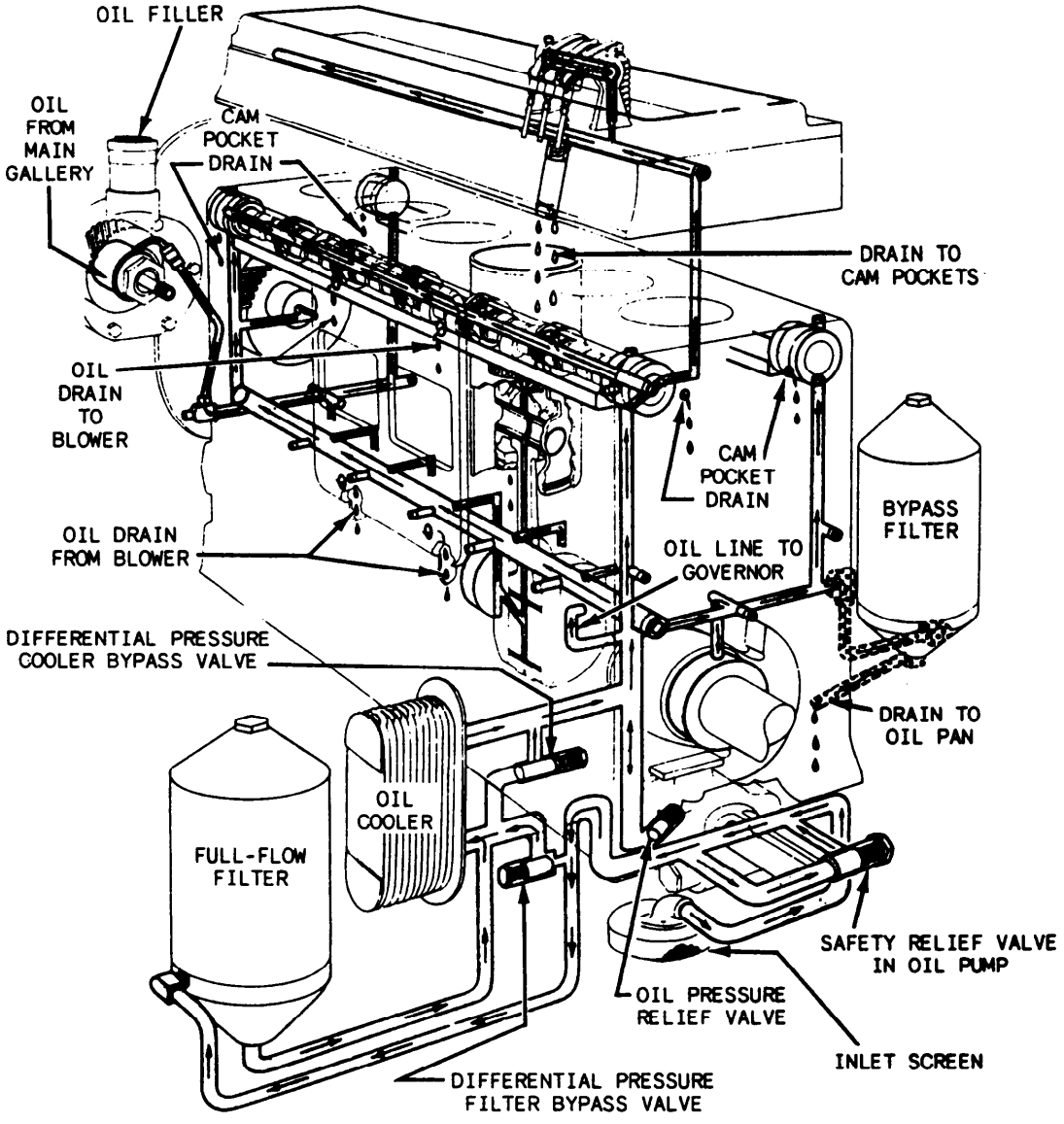
In the full-flow filtering system, all the oil supplied to the engine by the oil pump normally passes through the filter elements, which remove impurities of 25 microns and larger.

Figure 8-8 has been deleted.

NOTE: One micron is one millionth of a meter, or thirty-nine millionths of an inch. An ordinary grain of table salt is about 100 microns, and 25 microns is approximately one-thousandth of an inch.

There are only two conditions where unfiltered lubricating oil is supplied to the engine: (1) when the lubricating oil is cold (high viscosity), and (2) when the filter element is clogged. When one of these conditions exists, a bypass valve opens and a portion of the oil is bypassed around the filter element. The action of the bypass valve results from the resistance of the filter element to allow the oil to pass through it. The resistance creates enough back pressure for the spring-loaded bypass valve to open.

A secondary filtering system, which operates independently of the primary system, is currently being installed on various marine diesel engines.



75.384

Figure 8-9.—Schematic diagram of a typical lubricating oil system in a General Motors series 71 in-line diesel engine.

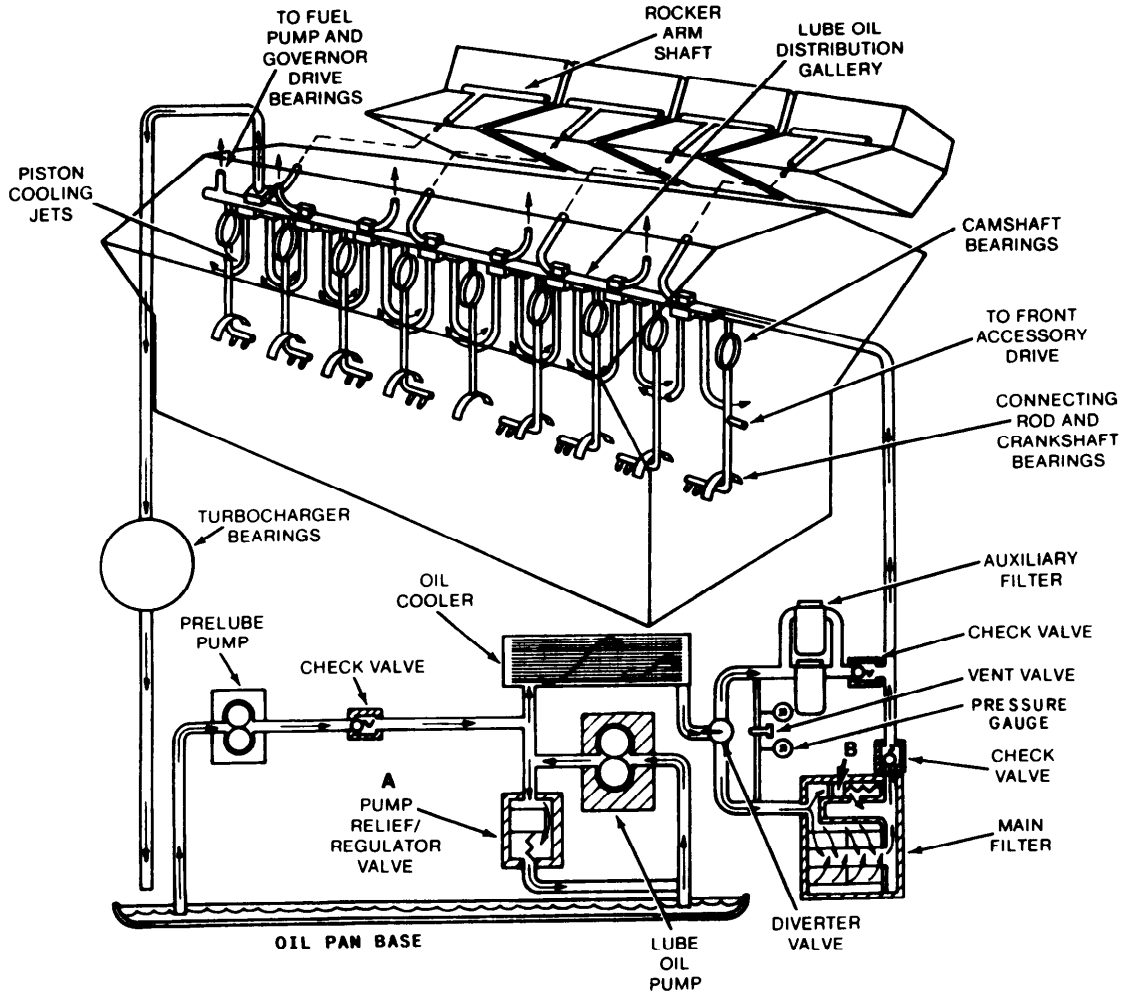


Figure 8-10.—Lubricating oil system in a Caterpillar diesel engine.

The secondary system will filter impurities from the lubricating oil through a 5-micron filter, which is a much finer medium than the 25-micron filter used in the primary system.

FLOW OF OIL THROUGH THE DIESEL ENGINE LUBRICATING OIL SYSTEM

Even though the design and arrangement of various diesel engine lubricating oil systems may appear to be different, the systems of most engines are similar in many aspects. So far our discussion has covered the external components of the engine lubricating oil system. Our discussion will now cover the flow of the oil through both the external and internal components of the General Motors series 71 diesel engine and the Caterpillar diesel engine. Learning to trace the flow of oil through the complete lubrication oil system of a diesel engine will be quite helpful to you when you are dealing with lubrication difficulties.

GENERAL MOTORS SERIES 71 DIESEL ENGINE

Figure 8-9 illustrates a typical lubricating oil system in a General Motors series 71 in-line diesel engine. Refer to figure 8-9 as you trace the flow of oil through this type of lubricating oil system. (Note the directional arrows as we continue our discussion.)

Flow of Lubricating Oil

The lubricating oil is circulated by a gear-type pump mounted on the No. 1 and No. 2 main

bearing caps. The pump is gear driven by the crankshaft. All the oil leaving the pump is forced through the full-flow oil filter to the cooler and then into the oil gallery in the cylinder block. From the oil gallery, the oil is distributed to the various engine bearings. Note that the drains from the cylinder head and other engine parts lead back to the oil pan.

When the pressure in the engine oil gallery exceeds approximately 100 psi, a spring-loaded integral plunger relief valve (A), located in the oil pump body, bypasses excess oil from the discharge to the inlet side of the pump. If the oil cooler should become clogged, the oil will flow from the pump through a spring-loaded bypass valve (B) directly into the oil gallery.

Clean engine oil is assured at all times by the use of a replaceable element type of full-flow oil filter that is incorporated in the lubricating oil system. This filter is installed between the pump and the cooler, and it filters all the lubricating oil before it enters the engine. As mentioned before, there are two conditions under which oil will NOT pass directly through the filtering elements to the engine: (1) when the oil is cold (high viscosity), and (2) when the filters are clogged. When one of these conditions exists, a bypass valve (C) opens and the filter elements are bypassed.

A regulator (relief) valve (D) that is located between the pump outlet and the inlet to the cylinder block works to maintain stabilized lubricating oil pressure within the engine when the engine is operating at all speeds. This valve stabilizes the lubricating oil flow rate regardless of the temperature of the oil. When the oil pressure at the regulator valve exceeds 45 psi, the valve opens and remains open until the pressure falls below the operating pressure.

As a optional feature, a bypass type of filter (E) with a replaceable element may also be used. In this design, a portion of the lubricating oil is continually bypassed through the filter. The filtered oil is then returned to the engine oil pan.

Distribution of Lubricating Oil

Oil from the cooler is directed by a vertical passage to the main gallery of the cylinder block. (Refer to fig. 8-9 and the directional arrows.) As shown in figure 8-9, this gallery distributes the oil to the main bearings and to a horizontal passage at each end of the cylinder block. From each of these two horizontal passages, oil flows to the end bearings of the camshaft and balancer shaft. In addition, oil is forced through an oil passage in the camshaft which lubricates the camshaft intermediate bearings. Oil to lubricate the connecting rod bearings and piston pins, and to cool the piston head, is provided through the drilled crankshaft from the adjacent main bearings. The gear train is lubricated by the overflow of oil from the camshaft pocket. The blower drive gear bearing is lubricated through an external pipe from the rear horizontal oil passage of the cylinder block.

Valve and injector operating mechanisms are lubricated from a longitudinal oil passage on the camshaft side of the cylinder block which connects to the main oil gallery. Oil from this passage enters the drilled rocker arm shafts through the lower end of the rocker shaft bolts and rocker shaft brackets. Excess oil from the rocker arms lubricates the exhaust valves and cam followers.

CATERPILLAR DIESEL ENGINE

The main caterpillar lubricating oil system is illustrated in figure 8-10. Under normal operating conditions, lubricant from the oil pan base is pumped through the oil cooler, through the filter housing, and to the lube oil distribution gallery. A pressure-regulating valve (A) mounted on the oil pan base limits the maximum value of oil pressure. Bypass valves (B) in each filter housing divert the oil to the oil distribution gallery whenever the flow is momentarily restricted because of cold oil. When the oil is warm, only filtered oil is furnished to the engine bearings unless the oil filter elements become restricted. If the filter should become restricted, the bypass valves would open and the oil would flow directly to the lube oil distribution gallery. The lube oil distribution gallery would then direct the oil through the connecting passages to the internal and external components of the engine, the timing gear, and the front accessory drive.

External Components

In the lubrication of the external components of the Caterpillar diesel engine, the turbocharger governor, fuel injection pump housing, and fuel pump driveshaft receive lubricant from the fuel pump and governor drive housing oil manifold. (See fig. 8-10.) Any drain-back oil from these components returns to the oil pan base.

Internal Components

In the lubrication of the internal components, the oil distribution manifold directs the filtered lubricant through passages and tubes to the piston oil spray orifices, valve rocker mechanism, camshaft bearings, crankshaft bearings, connecting rod bearings, fuel pump, and governor drive housing oil manifold.

In the lubrication of the timing gear mechanism, the timing gears are lubricated by the drain-back of oil from the turbocharger, camshaft, and crankshaft. Oil, under pressure, also flows to the camshaft bearings.

In the lubrication of the front accessory drive, the oil distribution manifold delivers oil through a drilled passage to the front main bearing and the front accessory drive.

The information provided in this section is intended to show you that a lubrication system for any engine is an intricate system that must not only supply oil to the components but also supply the correct flow rate of oil at the specified temperature and pressure. The information and illustrations in this section have been provided as examples only. Whenever you need information about a specific diesel engine, you should refer to the NAVSEA technical manual for your engine.

VENTILATION OF INTERNAL SPACES

Most engines have some means to ventilate the internal cavities, or spaces, which are related to the lubricating oil system. Systems may be vented directly to the atmosphere or through the engine intake air system. The latter method is preferred in marine installations where the engine is located in an engine room or other compartment. Venting of heated, fume-laden air directly to the atmosphere in a machinery space will seriously contaminate the air in the space and may create a fire hazard. On the other hand, if the lubricating oil system is not vented in some manner, combustible gases may accumulate in the crankcase and oil pan. Under certain conditions, these gases may explode.

During normal operating conditions, the mixture of oil vapor and air within an engine crankcase is not readily explosive. However, if a working part, such as a bearing or a piston, becomes overheated as a result of inadequate lubrication or clearances, additional oil will vaporize and an explosive mixture will be created. If the temperature of the overheated part is high enough to cause ignition or if a damaged part strikes another part and causes a spark, an explosion may occur.

In addition to the vapor created when lubricating oil contacts extremely hot surfaces, vapor may accumulate in the crankcase as a result of blow-by past the pistons. Blow-by occurs when the piston is compressing the air and during the power event.

There is little danger of a crankcase explosion or other troubles caused by vapors within the engine if the engine is kept in condition according to the prescribed maintenance program. The ventilation system of an engine greatly reduces the possibility of troubles that might occur because of an accumulation of vapors in the crankcase. Nevertheless, even when an engine is maintained according to prescribed procedures, casualties may occur, or conditions may be created which will lead to an explosion in the crankcase of the engine. When such casualties or conditions occur, they are generally due to abnormal operating circumstances or to the failure of a part.

You should be familiar with the possible causes of crankcase explosions so that you can learn how to prevent their occurrence. The importance of knowing what may cause a crankcase explosion and knowing the precautionary or preventive steps required are apparent when the aftereffects of an explosion are considered. A crankcase explosion may cause serious injury to personnel and extensive damage to the engine. Engine-room fires of a serious nature may occur after a crankcase explosion. Some of the mechanical defects which may lead to a crankcase explosion are crankshaft-bearing failure, damaged or excessively worn liners or piston rings, and cracked or seized pistons.

You may already be familiar with the preventive measures necessary to avoid some of the troubles which lead to the overheating or dilution of engine lubricating oil. Considerably more study and practical experience may be required on your part, however, before you learn how to prevent the conditions that can lead to the overheating or dilution of lubricating oil.

OVERHEATED LUBRICATING OIL

The formation of explosive vapor from lubricating oil is greatly accelerated by a rise in the temperature of the lubricating oil. A rise in temperature may be due to such factors as

insufficient circulation of the oil, inadequate cooling of the oil, a faulty temperature-regulating valve, overloading of the engine, or damaged or excessively worn parts. In addition to creating explosive vapors, overheated lubricating oil can have other serious effects. The viscosity of the lubricating oil will be greatly reduced, and the tendency to form acids will be increased.

You, as an Engineman, must take immediate steps to correct any problem associated with overheated lubricating oil. You must maintain the temperature of the lubricating oil within the range of values specified in the NAVSEA technical manual for your engine.

DILUTED LUBRICATING OIL

Dilution of engine lubricating oil with diesel fuel or JP-5 increases the tendency toward vapor formation in the crankcase because both of these fuels have lower flash points than lubricating oil. Petroleum products vary greatly in their flash points. (The flash point is the minimum temperature at which a product of petroleum gives off sufficient flammable vapors to ignite or momentarily flash.) In general, gasoline gives off sufficient vapor to ignite at all temperatures well below freezing; diesel fuel gives off vapor in sufficient quantities to ignite when it is heated to approximately 140°F. On the other hand, a lubricating oil must be heated to a much higher temperature (325° to 510°F, depending on the series and symbol of the oil) before it reaches its flash point. You should remember that dilution alone cannot cause a crankcase explosion. It may, however, contribute to making an explosion possible.

Dilution of engine lubricating oil may be caused by a variety of troubles. In general, dilution of the lubricating oil in diesel engines may result from worn or stuck rings, worn liners or pistons, fuel leaks, or leaky nozzles or injectors. You should also remember that, even though an engine is in good condition, dilution will occur during continuous engine operation at low speeds and under idling conditions. Under these conditions of operation, dilution occurs as a result of the blow-by of unburned fuel particles that accumulate in the combustion spaces. As determined by tests, any diesel lubricating oil that is contaminated by more than 5 percent fuel should be discarded.

In the remainder of this chapter, we will touch briefly on the Navy's Lube Oil Quality Management Program, shipboard testing of diesel engine lube oil, and environmental pollution control.

LUBE OIL QUALITY MANAGEMENT PROGRAM

Because of the importance of lubricating oils to the reliability and operating life of machinery, the Lube Oil Quality Management Program was established. The policies of this program have been set forth in the form of an instruction. Although the procedures of the program may vary from place to place, the objectives are the same. Some of the major points are as follows:

1. How often you should take samples
2. What equipment you should use to take samples
3. The types of tests you must perform on the samples
4. The required logs and records you must maintain
5. The actions you should take based on the tests

The Navy Oil Analysis Program (NOAP) provides spectrographic analyses of your ship's lube oil at a designated laboratory. This program serves to detect accelerated wear in machinery. Oil testing is performed without disassembly of the machinery and the results of the tests are available long before any other trouble is indicated. Lube oil samples are submitted to the laboratory for examination on a periodic basis. The testing activity advises the ship of the test results and provides recommendations. The ship is then responsible for maintaining accurate records of operating hours after major overhauls, oil changes, and completed repairs.

For additional information on the required shipboard tests and procedures you must use to maintain the quality of lubricating oils, refer to the *Naval Ships' Technical Manual,* chapter 262.

SHIPBOARD TESTING OF DIESEL ENGINE LUBE OIL

In addition to submitting the required samples to the NOAP laboratories, you can use the shipboard diesel engine lubricating oil test kit to take samples and perform tests on your ship's diesel engine lube oil (9250). The kit provides a quick and accurate means you can use to check used oil

for fuel dilution, viscosity, and acidity to determine if the oil is within the specified limits.

Oil color change is common in diesel engine lube oil after a few hours of use. The change in color is due to the suspension of fine particles of unburned carbon (soot) that accumulate in the oil. Darkening is not a definite indication that the oil has lost its lubricating properties. Diesel engine lube oil should not be drained solely because of color change.

Water in lubricating oil can usually be detected by the cloudy appearance of an oil sample taken from an operating engine or by small droplets of water that may separate in a sample bottle. A small quantity of free water in the lube oil in a diesel engine should cause no difficulty because it will change to steam and pass into the exhaust system as the engine reaches normal operating temperatures. Any salt accumulation in the oil will be monitored through NOAP. However, when serious water contamination exits, such as free-standing water in the bottom of the sample bottle or if the oil has a cloudy appearance, the oil should be drained and replaced with fresh oil after the source of the leak has been repaired.

The effectiveness of any lubricating system depends on the quality of the lubricant and the condition of the principal parts of the engine. The life of a diesel engine is remarkably long provided the engine is adequately lubricated. Effective lubrication in turn depends on timely completion of required checks, inspections, and maintenance procedures. For additional information, refer to the *Naval Ships' Technical Manual,* chapters 233 and 262.

ENVIRONMENTAL POLLUTION CONTROL

Environmental pollution is the condition that results when chemical, physical, or biological agents in the air, water, or soil alter the natural environment in a way that an adverse effect is created on human health or comfort, fish and wildlife, other aquatic resources and plant life, or structures and equipment. The adverse effects of environmental pollution are economic loss, impaired recreational opportunity, and marred natural beauty.

Because oil pollution has a serious effect on our environment, there are strict regulations and water quality standards that apply to the navigable waters. Oil spill cleanup operations are both difficult and costly. Each year thousands of dollars are spent because of oil spills. The costs of oil spillage are not only in money. Each year, oil spillage affects our natural environment, damages the hulls of yachts or boats, pollutes our beaches, and destroys fish and wildlife. Much of this destruction can be avoided and many organizations, including the United States Navy, are doing as much as possible to prevent such pollution. Current oil and water pollution control regulations are defined in the *Environmental and Natural Resources Protection Manual,* OPNAVINST 5090.1 (latest edition).

Navy ships must operate according to existing federal, state, and local regulations governing the oil content of shipboard water discharge overboard (effluent). Specific regulations applicable to Navy ships are as follows:

1. When the ship is operating within waters 50 nautical miles from the U.S. coast line, the discharge of oil is prohibited in such quantities as to cause a film or sheen upon or discoloration of the surface of the water of adjoining shorelines (discharges greater than 15 to 20 parts per million of effluent may create a sheen), or to cause a sludge or emulsion to be deposited beneath the surface of the water or upon the adjoining shorelines.

2. Navy vessels operating in internal waters and territorial seas (up to 12 nautical miles) of foreign countries must abide by oily waste discharge regulations that are specified in the applicable Status of Forces Agreement (SOFA). If no SOFA exists, vessels must operate consistent with the substantive oil waste discharge standards observed by the military forces of the host country. When the discharge standards for a foreign county are undefined, no oily waste shall be discharged within 50 nautical miles from land unless it is processed through an oil-water separator (OWS). Ships not equipped with an OWS shall retain all oily waste for proper disposal to a shore facility.

The discharge of oil or any oil mixture is not deemed unlawful when such action is required for the safety of the ship or its cargo and for the saving of lives at sea. In addition, the escape of oil or any oily mixture is not considered to be unlawful if it results from damage to the ship or from avoidable leakage. All reasonable precautions must be taken, after occurrence of the

damage or discovery of the leakage, to keep the oil leakage to a minimum.

While in port, a U.S. Navy ship may dispose of oily bilge water by using one or more of the following methods:

1. Oil-water separator (OWS) system—Ships equipped with bilge OWS systems should use the OWS unless prohibited by state standards or local port authorities.
2. Oil disposal rafts (donuts) and oil ship waste offload barges (O-SWOBS)—Ships not equipped with bilge OWS systems should use this method to transfer contaminated oils and oily waste.
3. Permanent shore receiving facilities—Where adequate oil waste collection lines are provided, contaminated oil and oily waste can be pumped directly ashore.

In the event of an oil spill, the Naval Sea Systems Command has developed a shipboard oil spill containment and cleanup kit for quick response "first aid" capability. Quick reaction by a trained crew (oil spill party) can result in containment, and often, collection of the entire spill. Additional information can be obtained in the *Environmental and Natural Resources Protection Manual,* OPNAVINST 5090.1, and the *Naval Ships' Technical Manual*, chapter 593.

SUMMARY

Lubricating systems of the pressure type are found in marine diesel engines. Pressure lubricating systems generally include pumps, strainers, pressure-regulating valves, filters, bypass valves, and coolers, in addition to the necessary piping and passages.

Even though the lubricating systems of various engines differ in some aspects of design, all the systems are quite similar with respect to oil flow. In general, the pump draws oil from the source of supply (oil pan, sump, or separate tank) and forces the oil through a strainer, a filter, and a cooler before the oil enters the engine. Upon entering the engine, the oil generally flows into a main oil header, which may be either a passage in the block or a separate line suspended in the block. The main oil gallery supplies oil to the various parts of the engine that require lubrication.

Ventilation of the engine crankcase is essential for efficient and safe engine operation. Unless the crankcase of an engine is properly ventilated, harmful vapors will accumulate in the crankcase. These vapors come primarily from two sources. Some of the vapors are formed when the lubricating oil comes in contact with the hot internal surfaces of the engine. Vapors so formed are explosive. These vapors must be removed from the crankcase; otherwise, a local hot spot within the engine might ignite the charge. Vapors may also accumulate in the crankcase because of the blow-by between the pistons and the cylinder liners. Blow-by occurs when the piston is compressing the air or the fuel-air charge during the power event. In all engines, products of combustion escape past the piston rings and into the crankcase during the power event. Products of combustion contain water vapor which condenses when it comes in contact with a cool surface. Such condensation causes corrosion and contaminates the lubricating oil.

Because of the importance of lubricating oil, the Lube Oil Quality Management Program was established. By following this program, you should be able to identify problems before they create a breakdown. Remember, planned maintenance of your ship's diesel engine is always preferred over breakdown maintenance.

If you are uncertain concerning any of the information in this chapter on engine lubricating systems, we recommend that you reread the sections in which you are having problems before you proceed to the next chapter.

CHAPTER 9

DIESEL FUEL SYSTEMS AND ENGINE CONTROL DEVICES

In the first part of this chapter, we will discuss the common types of fuels and the hardware systems that store, clean, transfer, and finally inject the fuel into the engine for burning. In the second section, we will describe how the injection of fuel is controlled to maintain the engine at a set speed.

After studying the information in this chapter, you should be able to identify the characteristics of engine fuels in terms of properties, combustion, volatility, and turbulence. You should also be able to identify diesel engine fuel systems in terms of external fuel systems and fuel injection systems. You should be able to describe the jerk-type, distributor-type, and unit fuel injector systems in terms of design and function of components and methods of operation. Additionally, you should understand how the operating speed of a diesel engine is controlled. Finally, you should be able to identify methods you can use to purge air from the fuel system of a diesel engine.

DIESEL ENGINE FUEL REQUIREMENTS

The fuels burned in the internal-combustion engines used by the Navy must meet the specifications prescribed by the Naval Sea Systems Command. Thus, the problem of selecting a fuel with the required properties is not your responsibility. Your primary responsibility is to follow the rules and regulations dealing with the proper use of fuels. You must strictly adhere to all prescribed safety precautions. You must also take every possible precaution to keep fuel as free as possible from impurities. Even though proper handling and use are your prime responsibilities with respect to fuel, knowing the characteristics of fuels will help you understand some of the problems in engine operation and maintenance.

At the time of manufacture, fuels are generally clean and free from impurities. However, the processes of transferring, storing, and handling fuel tend to increase the danger of contamination with foreign materials, a condition that can interfere with engine performance. Sediment and water in fuel can cause engine wear, gumming, and corrosion in the fuel system. Foreign materials in fuel can also cause an engine to operate erratically with a loss in power. For these reasons, periodic inspection, cleaning, and maintenance of fuel handling and filtering equipment are necessary.

Because of the differences in the combustion processes and in the fuel systems of diesel and gasoline engines, the fuels for these engines must be refined to meet different requirements. In general, diesel engines require a particularly clean fuel; otherwise, the closely fitted parts of the injection equipment will wear rapidly and the small passages that create the fuel spray within the cylinders will become clogged. The diesel fuel must have a composition that permits it to be injected into the cylinders in a fine mist or fog. Diesel fuel must also have ignition qualities that permit the fuel to ignite properly and burn rapidly when it is injected into the cylinders.

VOLATILITY AND ENGINE OPERATION

The ability of a liquid to change to vapor is known as VOLATILITY. All liquids tend to vaporize at atmospheric temperatures, but their rates of vaporization vary. The rate of vaporization increases as the temperature increases and as the pressure decreases. (Temperature is more important than pressure.) In general, for a given temperature, a highly volatile fuel will vaporize more readily and at a faster rate than a fuel with a lower volatility.

The volatility of fuel affects engine starting, length of warmup period, fuel distribution, and engine performance. (When compared to diesel fuel (F-76), gasoline is much more volatile.) High volatility, however, can also result in fuel dilution of the lube oil in the crankcase. The ways

in which volatility can affect engine operation are discussed in the sections that follow.

INJECTION, IGNITION, AND COMBUSTION

The self-ignition point of a fuel is a function of temperature, pressure, and time. In a properly operating diesel engine, the intake air is compressed to a high pressure (increases the temperature), and the injection of fuel starts a few degrees before the piston reaches TDC. The fuel is ignited by the heat of compression shortly after fuel injection starts and combustion continues throughout the injection period. Combustion in a diesel engine is much slower than it is in a gasoline engine, and the rate of pressure rise is relatively small.

Immediately after injection, the atomized fuel partially evaporates with a resultant chilling of the air in the immediate vicinity of each fuel particle. However, the extreme heat of compression rapidly heats and vaporizes the fuel droplets to the self-ignition point and combustion begins. The fuel particles burn as they mix with the air. The smaller particles burn rapidly, but the larger particles take more time to ignite because heat must be transferred into them to bring them to the self-ignition point.

There is always some delay between the time fuel is injected and the time it reaches the self-ignition point. This delay is commonly referred to as IGNITION DELAY or lag. The duration of the ignition delay is dependent upon the characteristics of the fuel, the temperature and pressure of the compressed air in the combustion space, the average size of the fuel particles, and the amount of turbulence present in the space. As combustion progresses, the temperature and pressure within the space rise rapidly; therefore, the ignition delay of fuel particles injected later in the combustion process is less than in those injected earlier. In a diesel engine, the delay period between the start of injection and the start of self-ignition is sometimes referred to as the first phase of combustion. The second phase of combustion is ignition of the fuel injected during the first phase and the rapid spread of the flame through the combustion space, as injection continues. The resulting increases in temperature and pressure reduce the ignition lag for the fuel particles entering the combustion space during the remainder of the injection period.

Remember, only a portion of the fuel has been injected during the first and second phases. As the remainder of the fuel is injected, the third or final phase of combustion takes place. The increase in temperature and pressure during the second phase is sufficient to cause most of the remaining fuel particles to ignite with practically no delay in the third phase as they come from the injection equipment. The rapid burning during the final phase of combustion causes an additional, rapid increase in pressure.

The knock that occurs during the normal operation of a diesel engine should not be confused with detonation. Generally, DETONATION in a diesel engine is caused by a simultaneous combustion of all particles of the fuel spray in the cylinder. COMBUSTION (DIESEL) KNOCK in a diesel engine is directly related to the amount of ignition delay and will take place at the end of the second phase. Diesel knock occurs from the rapid burning of large amounts of fuel (gathered in the cylinder before combustion begins). Whether combustion is normal or whether detonation occurs is determined by the amount of fuel that is ignited instantaneously. The greater the amount of fuel that ignites at one time, the greater the pressure rise and the more severe the knock.

Detonation in a diesel engine is generally caused by too much delay in ignition. The greater the delay, the greater the amount of fuel that accumulates in the cylinder before ignition. When the ignition point of the excess fuel is reached, all of this fuel ignites simultaneously, causing extremely high pressures in the cylinder and an undesirable knock. Thus, detonation in a diesel generally occurs at what is normally considered to be the start of the second phase of combustion. Detonation in a diesel may occur when the engine is not warmed up sufficiently or when fuel injection equipment is not operating properly. These conditions may allow excessive fuel to accumulate in the cylinder.

Even though diesel fuel must have the ability to resist detonation, it must ignite spontaneously at the proper time under the pressure and temperature conditions existing in the cylinder. The ease with which a diesel fuel ignites and the manner in which it burns determines the ignition quality of the fuel. The ignition quality of a diesel fuel is determined by its CETANE RATING, or CETANE NUMBER. In fact, the cetane rating of a diesel fuel is identified by its cetane number. The higher the cetane number, the less lag there is between the time the fuel enters the cylinder and the time it begins to burn.

The cetane number of a diesel fuel is derived from a comparison test. The cetane number of diesel fuel is the numerical result of an engine test designed to evaluate fuel ignition delay. To establish the cetane number scale, two reference fuels are used, cetane and heptamethylnonane. Cetane has an excellent ignition quality (100), and heptamethylnonane has a very poor ignition quality (15). The cetane rating of a fuel in which the ignition quality is unknown can be determined by a comparison of the performance of the fuel with that of a reference fuel. The cetane number represents the percentage of pure cetane in a reference fuel that will just match the ignition quality of the fuel being tested. A higher cetane number means a quicker burning of the fuel, a condition that tends to result in easier engine starting, particularly in cold weather.

TURBULENCE AND COMBUSTION IN DIESEL ENGINES

In both gasoline and diesel engines, the fuel and air must be properly mixed to obtain efficient combustion. In gasoline engines, mixing of the fuel and air takes place outside the cylinder. Depending upon the design of the system, mixing will occur in one of two places: (1) within the carburetor in the carburator-type system or (2) at the intake ports in the fuel injection-type systems. In both designs the proper mixture is forced into the cylinder to be compressed. In the diesel engine, however, fuel in the form of small particles is sprayed into the cylinder after the air has been compressed, thus mixing takes place within the cylinder. If each particle of fuel is to be surrounded by sufficient air to burn it completely (that is, if proper air-fuel mixture is to be obtained), the air in the combustion space must be in motion. This air motion is called TURBULENCE.

Various means are used to create turbulence. Design of engine equipment and parts and, in some engines, a process called precombustion enter into the creation of proper turbulence within the cylinder of an engine.

METHODS OF CREATING TURBULENCE

Fuel is distributed in the cylinders of a diesel engine by injection nozzles, which atomize the fuel and direct it to the desired portions of the combustion space. FUEL INJECTION creates some turbulence, but not enough for efficient combustion.

In 2-stroke cycle engines, scavenging-air PORTS are designed and located so that the intake air enters the cylinder with a whirling or circular movement. The movement of the air continues through the compression event and aids in mixing the air and fuel when injection occurs.

While fuel injection and the ports in 2-stroke cycle engines aid in creating air movement, additional turbulence is created in most engines by special shapes in the COMBUSTION SPACE. These shapes may include the piston crown and that portion of the cylinder head that forms part of the main combustion space. In some engines, auxiliary combustion chambers are provided as part of the combustion space to aid in mixing the fuel and air.

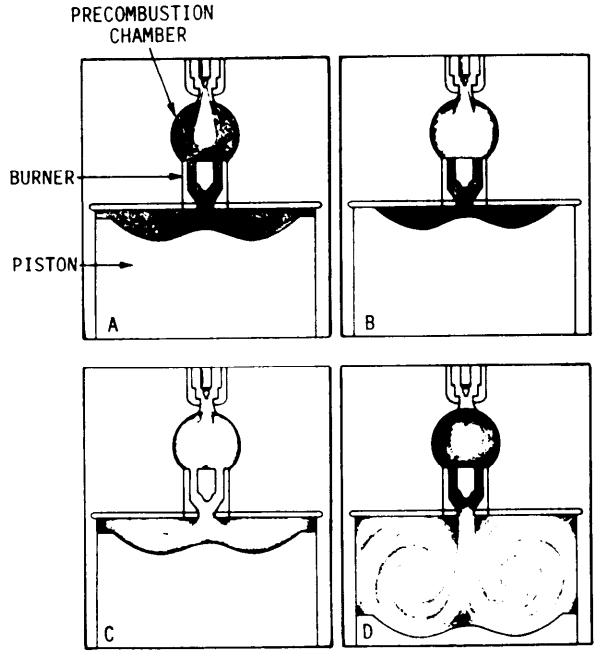
Even though there are many types of combustion chambers, all are designed to produce one effect-to bring sufficient air in contact with the injected fuel particles to provide complete combustion at a constant rate. Combustion chambers may be broadly classified under four types: open, precombustion, turbulence, and divided chamber. The last three terms are more commonly used to identify auxiliary combustion chambers; all are associated with the process called PRECOMBUSTION.

Of the three types of chambers, the open combustion chamber is the simplest in design. The fuel is injected directly into the top of the combustion space. The piston crown and (in some designs) the cylinder head are shaped to cause a swirling motion of the air as the piston moves toward TDC during the compression event. There are no special chambers to aid in creating turbulence. Open combustion chambers require higher injection pressures and a greater degree of atomization than other types to obtain the same degree of turbulence and mixing.

PRECOMBUSTION AND TURBULENCE

Some diesel engines have an auxiliary space or chamber at or near the top of each main combustion space. These chambers receive all or part of the injection fuel and condition it for final combustion in the main combustion chamber of the cylinder. This conditioning, called precombustion, involves a partial burning of the fuel before it enters the main combustion space. Precombustion helps to create the turbulence needed for the fuel and air to be properly mixed. Because of differences in designs, the manner in

which precombustion aids in creating turbulence differs from one type of auxiliary combustion chamber to another. For this reason, we will discuss three types of auxiliary chambers by their common names—PRECOMBUSTION CHAMBERS, TURBULENCE CHAMBERS, and AIR or ENERGY CELLS.



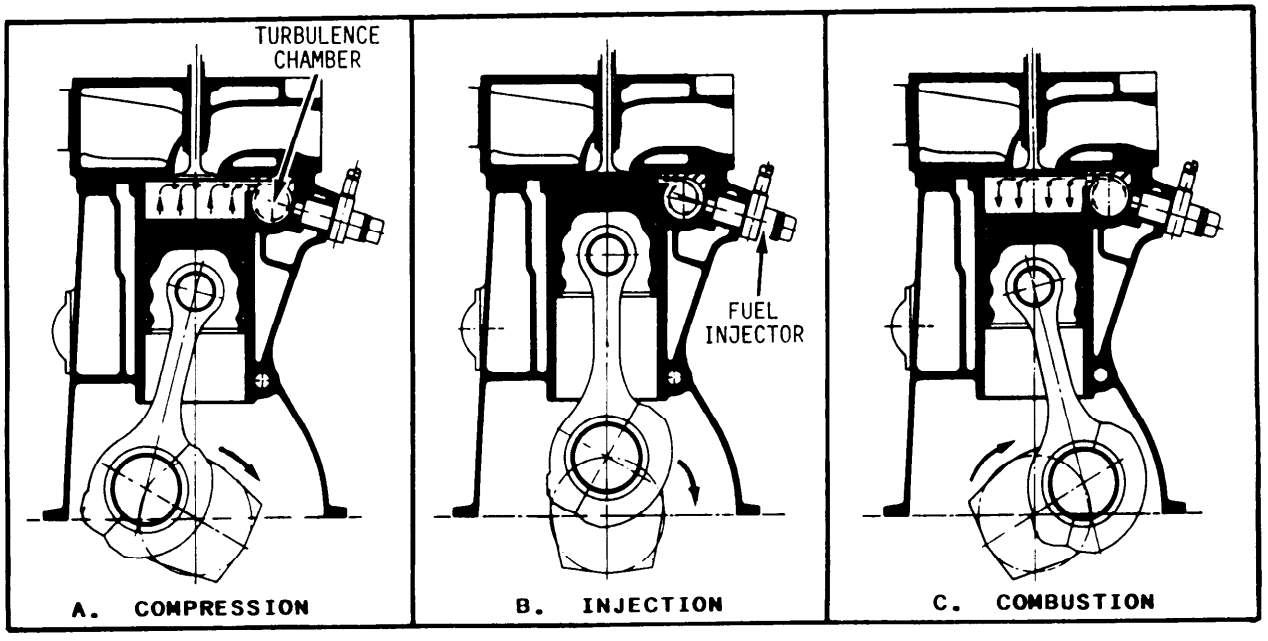
75.226

Figure 9-1.—Precombustion chamber.

Look at figure 9-1 to see how the precombustion chamber creates turbulence. The precombustion chamber, spherical in shape, is located in the cylinder head directly over the center of the piston crown. The precombustion chamber is connected to the main combustion space of the cylinder by a multiple orifice called a burner. During the compression event, a relatively small volume of compression-heated air is forced through the burner into the precombustion chamber. Heat stored by the burner increases the temperature of the compressed air and facilitates initial ignition.

Fuel is atomized and sprayed into the hot air in the precombustion chamber (view A) and combustion begins (view B). Only a small part of the fuel is burned in the precombustion chamber because of the limited amount of oxygen. The fuel that does burn in the chamber creates enough heat and pressure to force the fuel, as injection continues, into the cylinder at great velocity (view C). The velocity of the fuel entering the main combustion space and the shape of the piston crown help to create the necessary turbulence within the cylinder (view D).

Engines that have precombustion chambers do not require fuel injection pressures as great as engines that have open-type chambers. Also, the



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Figure 9-2.—Turbulence chamber.

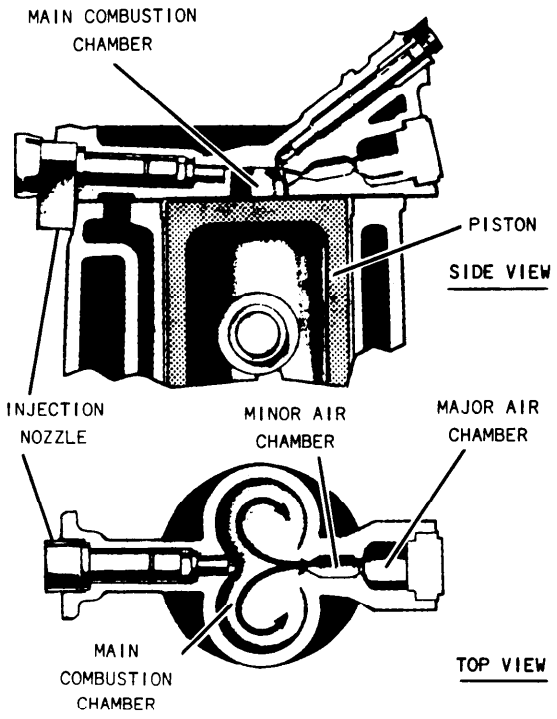
spray of injected fuel can be coarser, since the precombustion chamber functions to atomize the fuel further before the fuel enters the cylinder.

Some engines have auxiliary combustion chambers. They differ from precombustion chambers in that nearly all of the air supplied to the cylinder during the intake event is forced into the auxiliary chamber during the compression event. Auxiliary chambers in which this occurs are sometimes referred to as TURBULENCE CHAMBERS. There are several variations of turbulence chambers, one of which is illustrated in figure 9-2.

Note in figure 9-2 how turbulence, indicated by the arrows, is created in the auxiliary chamber as compression (view A), injection (view B), and combustion (view C) take place. In engines with turbulence chambers, there is very little clearance between the top of the piston and the head when the piston reaches TDC. (See view B of fig. 9-2.) For this reason, a high percentage of the air in the cylinder is forced into the turbulence chamber during the compression event. The shape of the chamber (usually spherical) and the size of the opening through which the air must pass help to create turbulence. The opening to the turbulence chamber becomes smaller as the piston reaches TDC, thereby increasing the velocity of the air. Velocity plus deflection of the air as it enters the auxiliary chamber creates considerable turbulence. Fuel injection (view B of fig. 9-2) is timed to occur when the turbulence in the chamber is the greatest. This ensures a thorough mixing of the air and fuel. The greater part of combustion takes place within the turbulence chamber and is completed as the burning gases expand and force the piston down in the power event.

In some high-speed diesel engines, turbulence is created by an auxiliary chamber referred to as an ENERGY (AIR) CELL. Energy cells differ in design and location. In most engines, the cells are located in the cylinder heads. One type of energy cell that is located in the cylinder head is a divided chamber and turbulence chamber. The Lanova cell is the divided chamber type. Figure 9-3 shows cross-sectional top and side views of a divided auxiliary combustion chamber.

Refer to figure 9-3 as we discuss how the energy cell system works. Study the construction and operation of a typical system, the Lanova design, shown in figure 9-3. This design employs a combustion chamber consisting of two rounded spaces cast in the cylinder head. The inlet and exhaust valves open into the main combustion chamber. The fuel-injection nozzle lies



75.228

Figure 9-3.—Divided combustion chamber.

horizontally, pointing across the narrow section where the lobes join. Opposite the nozzle is the two-part energy cell, which contains less than 20 percent of the main-chamber volume.

The action is as follows: During the compression stroke, the piston forces air into the energy cell. Near the end of the stroke, the nozzle sprays fuel across the main chamber in the direction of the mouth of the energy cell. While the fuel charge is traveling across the center of the main chamber, between a third and a half of the fuel mixes with the hot air and burns at once. The remainder of the fuel enters the energy cell and starts to burn there, being ignited from the fuel already burning in the main chamber.

At this point, the cell pressure rises sharply, causing the products of combustion to flow at high velocity back into the main combustion space. This sets up a rapid swirling movement of fuel and air in each lobe of the main chamber, promoting the final fuel-air mixing and ensuring complete combustion. The two restricted openings of the energy cell control the time and rate of expulsion of the turbulence-creating blast from the energy cell into the main combustion

space. Therefore, the rate of pressure rise on the piston is gradual, resulting in smooth engine operation.

The divided combustion chamber is similar, in some respects, to other types of chambers. It is similar to an open combustion chamber in that the main volume of air remains in the main combustion chamber and principal combustion takes place there. Both the divided chamber and the turbulence chamber depend on a high degree of turbulence to ensure thorough mixing and distribution of the fuel and air. However, turbulence in a divided combustion chamber is dependent on thermal expansion caused by combustion in the energy cell and not on engine speed as in other types of auxiliary combustion chambers.

NAVAL DISTILLATE DIESEL FUEL

The fuel normally used in diesel engines is naval distillate (NATO symbol F-76), but other fuels such as JP-5 (NATO symbol F-44) and naval distillate lower pour point (NATO symbol F-75) are also used. Code F-76 and F-75 fuels are compatible and can be mixed in all proportions. Code F-44 and F-75 fuels are authorized for use in diesel engines where there is a logistic advantage for use. At present, most ships carry naval distillate fuel (F-76) for boilers and for diesel engines.

SHIPBOARD FUEL TESTING

Normally, fuel is procured through the military supply system. It is reasonable to assume that fuel received from the military supply system will meet the requirements of the applicable military fuel specification because of the extensive quality surveillance procedures used by this system. However, when delivered to ships by fleet oilers, fuel can be contaminated by solids and water. Solids and water must be removed by the receiving ship through settling and stripping or by use of purification equipment.

The fuel testing equipment items described in this section will help you identify the solids and water that must be removed by stripping and determine whether the purification equipment is functioning adequately to remove the solids and the water.

Required shipboard fuel testing equipment items for all ships are as follows:

Name of Test	Equipment (methods)
Visual	Glass sample bottle
Bottom sediment and water (BS&W)	Laboratory centrifuge
Flashpoint	Pensky-Martens closed-cup tester
API gravity	Hydrometer range: 29-41 and 39-51

In addition to these four tests, if you are an Engineman assigned to a ship with gas turbine propulsion plants or helicopter in-flight refueling (HIFR) capability, you will be required to have the following additional testing equipment:

1. A.E.L. free water detector Mk II
2. A.E.L. contaminated fuel detector Mk III

For detailed information on shipboard testing, consult the *Naval Ships' Technical Manual,* chapters 541 and 542.

FUEL SYSTEMS

In this section we will deal with diesel engine fuel systems. Fuel systems are divided into two groups: external fuel systems and fuel injection systems.

EXTERNAL FUEL SYSTEMS

The fuel system in a diesel-powered naval vessel must be installed, operated, and maintained with the same care and supervision as the ship's engines. Inspections, maintenance, and operation of fuel tanks and fuel-handling equipment must be carried out according to the Ships' 3-M Systems and the *Naval Ships' Technical Manual,* chapters 541 and 542.

The fuel is pumped from the storage tank to the service or day tank, and from there it is delivered to the fuel injection equipment on the engine. It is good practice to remove sediment and water from the fuel before it enters the service tank. This is usually done with a centrifugal purifier. The fuel is transferred from the service tank by an engine-driven pump (also called a

booster, transfer, or primary pump) through a metal-edge strainer and a cartridge-type replaceable element filter to a header at the inlet of the fuel injection equipment installed on the engine. Excess fuel (that is NOT used for combustion) is returned to the service tank.

The service or day tank is usually vented to the atmosphere and mounted at a high point in the fuel system, which allows the weight of the fuel to pressurize the external system and prevent air from leaking into the system. The presence of air in the fuel will interfere with proper operation of the fuel injection equipment.

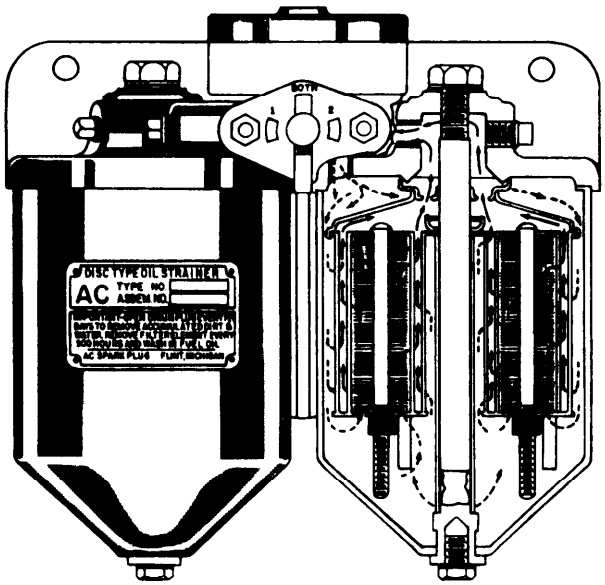
The engine-driven fuel transfer pump is the positive-displacement type. Usually the fuel transfer pump is equipped with a built-in relief valve to ensure constant pressure to the injection equipment. The fuel strainer is located on the suction side of the transfer pump, and the filter is connected into the system on the discharge side of the pump. The pressure drop across these filters and strainers increases with time. For this reason, some systems have a relief valve in the line before the cartridge filter so that the bypassed fuel can be returned directly to the supply tank. The relief valve provides a more constant fuel supply pressure.

The primary metal-edge fuel strainer used in Navy installations is a duplex type, which is actually two complete strainers connected by a suitable header or piping. This arrangement allows either strainer to be completely cut out of the system for cleaning or repair while all of the fuel flows through the other strainer. Figure 9-4 shows a typical metal-edge strainer. A magnified view of a portion of the element is shown in figure 9-5. The fuel flows from the outside to the inside. In Navy-approved strainers, the spaces between the leaves, or ribbons, which act as fuel passages, are between 0.001 and 0.0025 inch. The pressure drop across these strainers must not be allowed to exceed 1.5 psi when a fuel flow is equal to the full capacity of the fuel pump. In some engines, a duplex strainer is placed between the fuel supply tank and the transfer pump and, during operation, may be working under a vacuum.

The secondary, cartridge-type, fuel filter contains elements that must conform to Navy specifications. The pressure drop across clean and new elements should not be allowed to exceed 4.5 psi. The elements should be changed when the pressure drop reaches the value specified in the manufacturer's instruction book. The sump of the filters and strainers should be drained as often as practicable, preferably when the fuel is flowing.

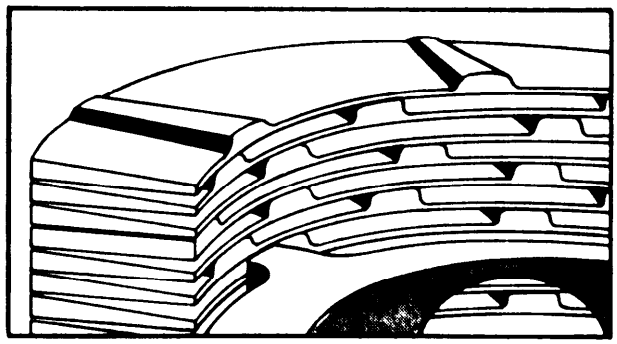
CENTRIFUGAL PURIFIERS

Detailed instructions are furnished with each purifier concerning its construction, operation, and maintenance. When you are responsible for the operation and maintenance of a purifier, study the appropriate NAVSEA technical manual and follow the instructions carefully. The following sections will provide general information on the methods of purification and the principles of operation of centrifugal purifiers.



256.148

Figure 9-4.—Primary fuel metal-edge strainer.



256.149

Figure 9-5.—Enlarged section of ribbon in strainer.

Centrifugal purifiers are used for purification of both fuel and lubricating oil. A purifier may remove both water and sediment, or it may remove sediment only. When water is involved in the purification process, the purifier is usually called a SEPARATOR. When the principal contaminant is dirt or sediment, the purifier is used as a CLARIFIER. Purifiers are generally used as separators for the purification of fuel. When used for purification of a lubricating oil, a purifier may be used as either a separator or a clarifier. Whether a purifier is used as a separator or a clarifier depends on the water content of the oil that is being purified.

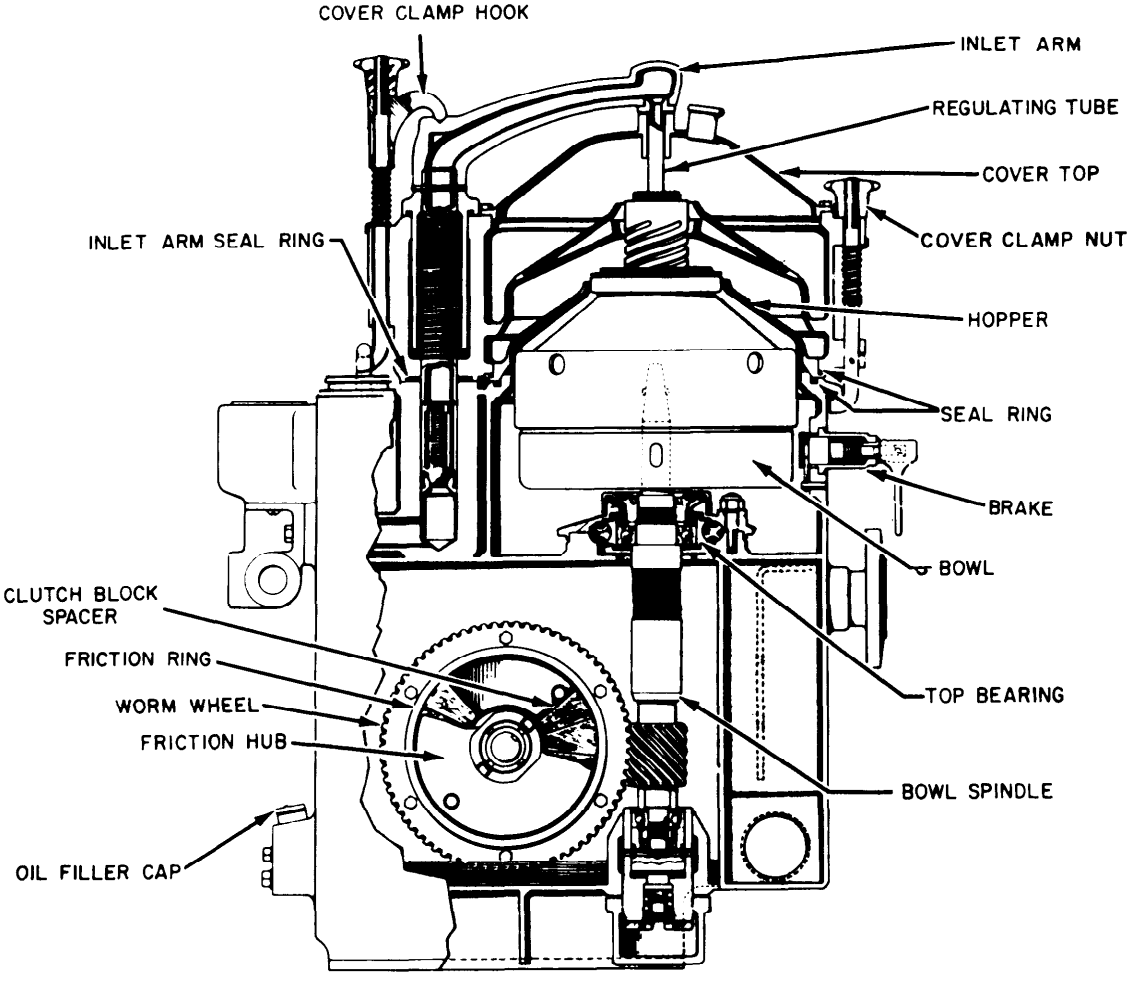
NOTE: According to the Naval Sea Systems Command (NAVSEA) at the time of the writing of this training manual, purifiers are not authorized for use with diesel engine lubricating oil systems.

The following general information will help you understand the purification process, the purposes and principles of purifier operation, and the basic types of centrifugal purifiers in use in naval service.

PRINCIPLES OF OPERATION

In the purification of fuel, centrifugal force is the fundamental principle of operation. Centrifugal force is force that is exerted upon a body or substance by rotation. Centrifugal force impels the body or substance outward from the axis of rotation.

A centrifugal purifier is essentially a container which is rotated at high speed while contaminated fuel is forced through, and rotates with, the container. However, only materials that are insoluble in the fuel can be separated by centrifugal force. For example, JP-5 or naval



47.83

Figure 9-6.—Disc-type centrifugal purifier (DeLaval).

distillate cannot be separated from lubricating oil, nor can salt be removed from seawater by centrifugal force. Water, however, can be separated from fuel because water and fuel do not form a true solution when they are mixed. Furthermore, there must be a difference in the specific gravities of the materials before they can be separated by centrifugal force.

When a mixture of fuel, water, and sediment stands undisturbed, gravity tends to form an upper layer of fuel, an intermediate layer of water, and a lower layer of sediment. The layers form because of the specific gravities of the materials in the mixture. If the fuel, water, and sediment are placed in a container which is revolving rapidly around a vertical axis, the effect of gravity is negligible in comparison with that of the centrifugal force. Since centrifugal force acts at right angles to the axis of rotation of the container, the sediment with its greater specific gravity assumes the outermost position, forming a layer on the inner surface of the container. Water, being heavier than fuel, forms an intermediate layer between the layer of sediment and the fuel, which forms the innermost layer. The separated water is discharged as waste, and the fuel is discharged to the service tank or the day tank. The solids remain in the rotating unit.

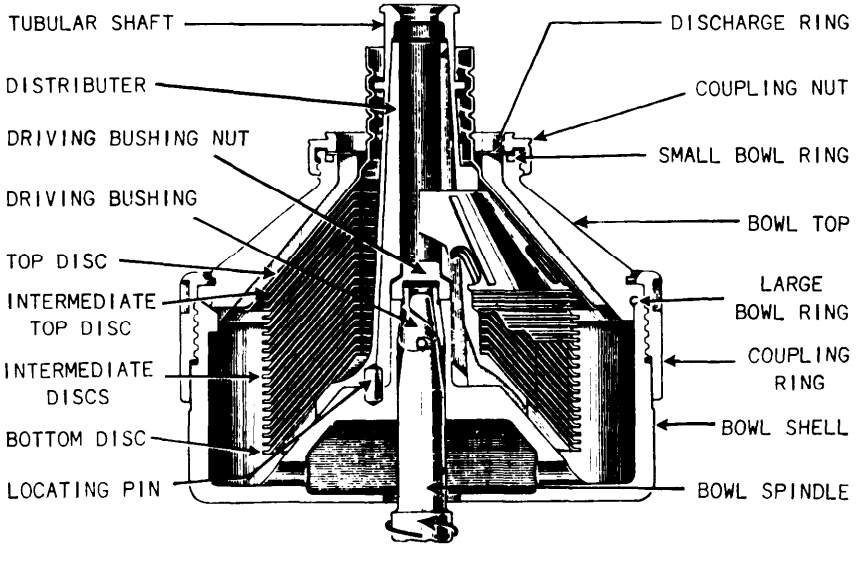
Separation by centrifugal force is further affected by the size of the particles, the viscosity of the fluids, and the time during which the materials are subjected to the centrifugal force. In general, the greater the difference in specific gravity between the substances to be separated and the lower the viscosity of the fuel, the greater will be the rate of separation.

TYPES OF CENTRIFUGAL PURIFIERS

Two basic types of purifiers are used in Navy installations. Both types use centrifugal force. Principal differences in these two machines exist, however, in the design of the equipment and the operating speed of the rotating elements. In one type, the rotating element is a bowl-like container that encases a stack of discs. This is the disc-type DeLaval purifier, which has a bowl operating speed of about 7,200 rpm. In the other type, the rotating element is a hollow cylinder. This machine is the tubular-type Sharples purifier, which has an operating speed of 15,000 rpm.

Disc-Type Purifier

A sectional view of a disc-type centrifugal purifier is shown in figure 9-6. The bowl is mounted on the upper end of the vertical bowl spindle, which is driven by means of a worm wheel and friction clutch assembly. A radial thrust bearing at the lower end of the bowl spindle carries the weight of the bowl spindle and absorbs any thrust created by the driving action. The parts of a disc-type bowl are shown in figure 9-7.



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Figure 9-7.—Components of a disc-type purifier bowl (DeLaval).

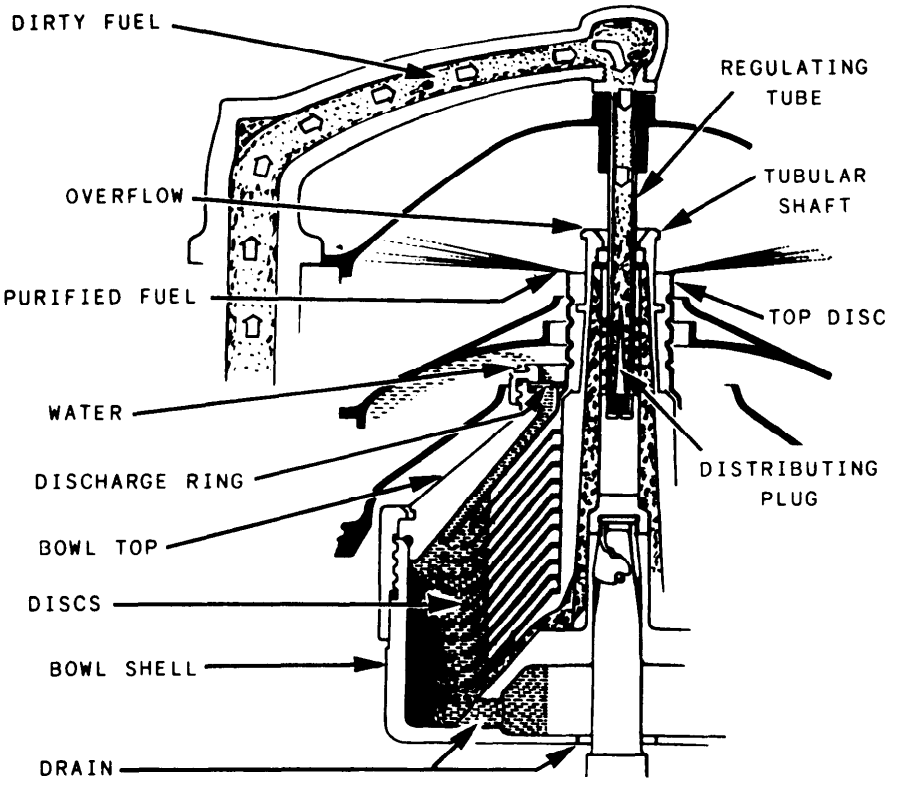
The flow of fuel through the bowl and additional parts is shown in figure 9-8. Contaminated fuel enters the top of the revolving bowl through the regulating tube. The fuel then passes down the inside of the tubular shaft, out the bottom, and up into the stack of discs. As the dirty fuel flows up through the distribution holes in the discs, the high centrifugal force exerted by the revolving bowl causes the dirt, sludge, and water to move outward. The purified fuel is forced inward and upward, discharging from the neck of the top disc. The water forms a seal between the top disc and the bowl top. (The top disc is the dividing line between the water and the fuel.) The discs divide the space within the bowl into many separate narrow passages or spaces. The liquid confined within each passage is restricted so that it can flow only along that passage. This arrangement minimizes agitation of the liquid as it passes through the bowl. It also forms shallow settling distances between the discs.

Any water, along with some dirt and sludge, separated from the fuel, is discharged through the discharge ring at the top of the bowl. However, most of the dirt and sludge remains in the bowl and collects in a more or less uniform layer on the inside vertical surface of the bowl shell.

Tubular-Type Purifier

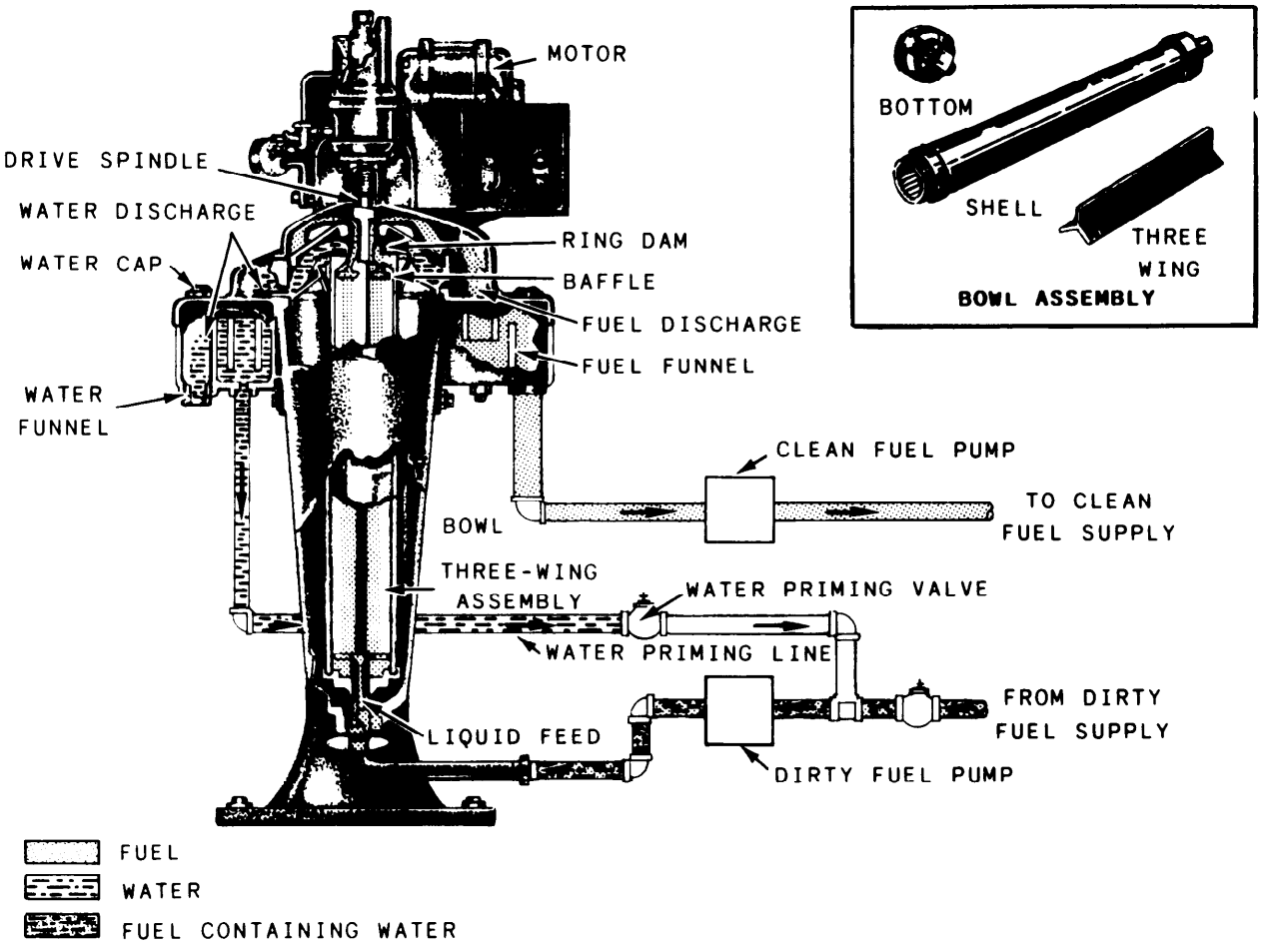
A cross section of a tubular-type centrifugal purifier is shown in figure 9-9. This type of purifier consists essentially of a hollow rotor or bowl which rotates at high speeds. The rotor has an opening in the bottom to allow the dirty fuel to enter. It also has two sets of openings at the top to allow the fuel and water to discharge. The bowl, or hollow rotor, of the purifier is connected by a coupling unit to a spindle. The spindle is suspended from a ball bearing assembly. The bowl is belt-driven by an electric motor mounted on the frame of the purifier.

The lower end of the bowl extends into a flexibly mounted guide bushing. The assembly restrains movement of the bottom of the bowl, but it also allows the bowl enough movement to center itself during operation. Inside the bowl is a device consisting of three flat plates that are equally spaced radially. This device is commonly referred to as the THREE-WING DEVICE, or



47.85

Figure 9-8.—Flow of fuel through a disc-type purifier (DeLaval).



47.88

Figure 9-9.—Flow of fuel through a tubular-type purifier (Sharples).

just the three-wing. The three-wing rotates with the bowl and forces the liquid in the bowl to rotate at the same speed as the bowl. The liquid to be centrifuged is fed, under pressure, into the bottom of the bowl through the feed nozzle.

After the bowl has been primed with water, separation is basically the same as it is in the disc-type purifier. Centrifugal force causes clean fuel to assume the innermost position (lowest specific gravity) and the higher density water and dirt are forced outward towards the sides of the bowl. Fuel and water are discharged from separate openings at the top of the bowl. The location of the fuel-water interface within the bowl is determined by the size of a metal ring called a RING DAM, or by the setting of a discharge screw. The ring dam or discharge screw are also located at the top of the bowl. Any solid contamination separated from the liquid remains inside the bowl all around the inner surface.

Specific instructions for the operation of a purifier should be obtained from the NAVSEA technical manual that is provided with the unit. The following general information applies to the basic operation of purifiers in naval service.

When a purifier is operated as a separator, the bowl must be primed with fresh water before any fuel is admitted to the purifier. The water seals the bowl, and the spinning bowl creates an initial equilibrium of layers of liquid according to specific gravities. If the bowl is not primed, the fuel will be lost through the water discharge ports.

The time required for purification and the output of a purifier depends on many factors. Two important factors are the size of the sediment particles and the temperature of the incoming dirty fuel. In order for any purifier to operate at its rated capacity in gallons per hour, the fuel must be heated to a specified temperature. In this way,

the viscosity of the fuel is reduced. (The fuel becomes thinner.) A lower viscosity does two things: (1) it lowers the specific gravity, and (2) it enables the fuel more easily to give up any water which may be entrained.

The viscosity of the fuel determines to a great extent the length of time required for purification. The more viscous the fuel, the longer the required time is for the fuel to be subjected to centrifugal force. In other words, decreasing the viscosity of the fuel by heating will speed up the purification process and will increase the capacity of the purifier. To reach a higher temperature, the fuel must pass through a heater. In this way, the fuel will reach the proper temperature in the heater before it enters the purifier bowl.

Proper care of any fuel purifier requires that the bowl be cleaned as required and that all sediment be carefully removed. How often you clean a purifier depends on the amount of foreign matter in the fuel to be purified. If the amount of foreign matter in a fuel is not known, you should shut down the machine and check it. The amount of sediment found in the bowl at this time will indicate how often you should clean the purifier.

Detailed procedures for operating and maintaining purifiers are furnished by NAVSEA technical manuals, PMS, and the Engineering Operational Sequencing System (EOSS). Carefully follow these written procedures when you are operating or performing maintenance on purifiers.

It should be obvious from the preceding information that the purpose of the external fuel system is to store and deliver clean fuel to the fuel injection equipment.

FUEL INJECTION SYSTEMS

The fuel injection equipment used on Navy diesel engines is the mechanical type. Some engine manufacturers make and install their own fuel injection equipment. Others rely on manufacturers who specialize in fuel injection equipment and who design and modify their products to meet the requirements of the engine manufacturer. This equipment will vary in construction and method of forcing fuel into the combustion chamber; however, in every case, the fuel injection equipment for any diesel engine must accomplish several basic functions.

FUNCTIONS

The five general functions that fuel injection equipment must accomplish are metering the fuel, injecting the fuel, timing the injection process, atomizing the liquid fuel, and creating pressure for dispersion of the fuel. Each of these functions is defined as follows:

1. METERING—To measure accurately the amount of fuel to be injected, according to engine speed and load
2. INJECTING—To force and distribute the fuel into the combustion chamber
3. TIMING—To allow fuel injection into each cylinder to start and stop at the proper time
4. ATOMIZING—To break liquid fuel up into tiny particles
5. CREATING PRESSURE—To create the high pressure required to force fuel into the pressurized combustion chamber

You can easily recall these functions by remembering the initials MITAC. All five functions are required for effective combustion of fuel in the cylinders of a diesel engine. Now we will discuss the role of each of these factors and how all of the factors work together.

Metering

Accurate metering, or measuring, of fuel means that for a given engine speed, setting, and load, the same quantity of fuel must be delivered to each cylinder just before each power stroke of the engine. If this does not happen, engine speed will be erratic and the horsepower output of the engine will not be uniform. Smooth engine operation and even distribution of the load between cylinders requires that the same amount (volume) of fuel is delivered to a particular cylinder each time it fires, and that equal volumes of fuel are delivered to all cylinders of the engine.

Injecting

The fuel system on the engine must control the rate of injection which, in turn, determines the rate of combustion. The rate of fuel injection at the start must be low enough so that excessive fuel does not accumulate in the cylinder during the first phase (physical) of injection delay (before combustion begins). Injection should then proceed at such a rate that the rise in pressure in the combustion chamber is not too great.

However, the rate of fuel injection must be such that the fuel is introduced as rapidly as possible to obtain complete burning of the fuel-air mixture. An incorrect rate of injection affects engine operation in the same way as improper timing. When the rate of injection is too high, the symptoms are similar to those caused when fuel injection is too early. When the fuel injection rate is too low, the symptoms are similar to those caused when fuel injection is too late.

Timing

In addition to measuring the amount of fuel and rate of fuel injection, the fuel injection equipment must cause these events to occur at the proper time. Correct timing is vital to ensure that complete combustion takes place and that maximum energy is obtained from the fuel. (In other words, the engine develops rated horsepower for each pound of fuel burned.) When fuel is injected too early in the cycle, ignition may be delayed because the temperature of the air charge in the cylinder is not high enough. On the other hand, late injection results in rough, noisy operation of the engine.

Noisy engine operation occurs when the engine cannot convert as much energy from the fuel into the horsepower required to move the load. Late injection permits some fuel to be wasted by wetting of the cylinder walls and piston crown. This condition, of course, results in poor fuel economy, higher than normal exhaust gas temperatures, and smoky exhaust.

Atomizing

Shortly before the top of the compression stroke, at a point controlled by the mechanical injection timing arrangement, one or more jets of fuel are introduced into the combustion chamber. As explained previously, ignition of fuel does NOT occur immediately on injection. The fuel droplets absorb heat from the compressed air swirling around the combustion chamber. This process is necessary because it causes the liquid fuel to VAPORIZE so it can burn! The duration of the second phase (chemical) of ignition delay is controlled by the design (shape) of the combustion chamber, fuel and air inlet temperatures, degree of atomization of the fuel, and the quality of the fuel. When the fuel-air mixture reaches a temperature at which self-ignition occurs, the flame begins to spread. Injection of the remaining volume of fuel for the cylinder continues during this time. The ignition delay period must be short so that diesel knock can be avoided.

Once the flame has been completely initiated, the fuel being delivered to the cylinder is that which is being injected into the burning mixture. This fuel vaporizes and burns almost instantaneously. This process is the third phase of fuel injection. Liquid fuel must be injected into each cylinder in the form of a fine spray. Proper atomization increases the surface area of the fuel, which must be exposed to oxygen molecules in the air so that complete burning of the fuel can take place and the rated horsepower can be developed. To avoid simultaneous combustion of all droplets of the fuel spray (detonation), the injected spray is usually in the form of fine droplets to start ignition (beginning of second phase) and larger droplets later in the phase. The degree of atomization of the fuel is controlled by the diameter and shape of the nozzle orifice(s) or opening(s), injection pressure, and the density of the air charge in the combustion chamber.

Creating Pressure

The quality (volume) of fuel, the rate at which it is injected into the cylinders of an engine, and the timing and duration of the injection event are all controlled by the fuel injection equipment. At the beginning of injection, fuel pressure may be as low as 1800 psi to as high as 30,000 psi, depending upon the design of the equipment. The fuel injection equipment must raise the pressure of the fuel enough to overcome the force of the compressed air charge in the combustion chamber and ensure proper dispersion (distribution) of the fuel being injected into the combustion space. Proper dispersion of the atomized fuel in the air charge is an important factor for complete combustion to take place. Dispersion of the fuel is affected, in part, by the atomization process and the PENETRATION of the fuel, which determines the distance through which the fuel droplets travel after leaving the injector tip or nozzle. If the atomizing process results in fuel droplets that are too small, they will not have sufficient weight to penetrate very far into the air charge. Too little penetration results in the fuel igniting and burning before it is properly dispersed through the air charge in the combustion space. Since penetration and atomization tend to oppose each other, a compromise in the degree of each

is necessary in the design of the fuel injection equipment.

FUEL INJECTION EQUIPMENT

There are three methods commonly used for the mechanical injection of fuel (at the proper amount, time, and duration) into the cylinders of a diesel engine. These methods are as follows:

1. Pump controlled (jerk pump)
2. Distributor
3. Unit injector

NOTE: A fourth method, known as pressure-time (PT) uses unit injectors. This method is unique to Cummins diesel engines and is not considered to be common; therefore, it will not be explained in this rate training manual.

The three methods listed above will be explained in the sections that follow.

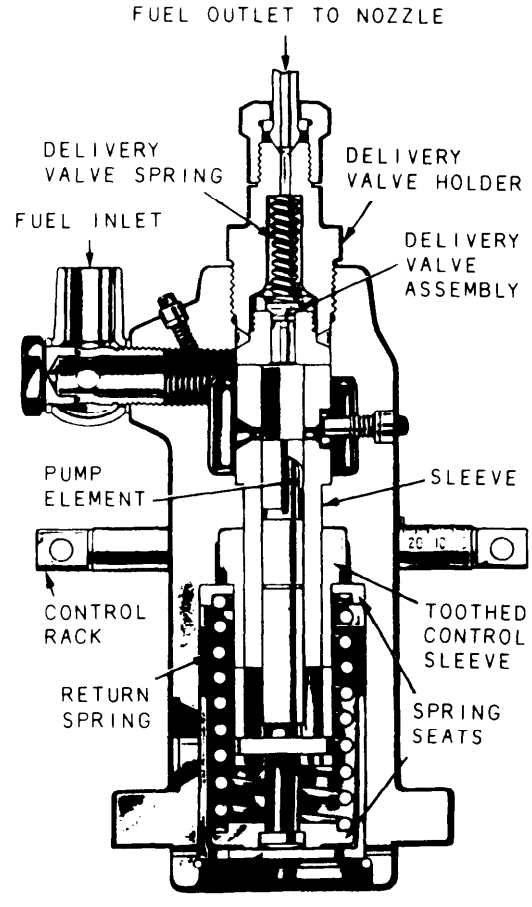
JERK PUMP FUEL INJECTION SYSTEM

Jerk pump fuel injection systems consist of high-pressure pumps and pressure-operated spray valves or nozzles that are separate components. In some engines, such as the Alco, there is only one pump and one nozzle for each cylinder. In other engines, such as the Fairbanks-Morse opposed piston engine, each cylinder has two pumps and two nozzles. Most of the injection event is carried out by the pump itself. The pump raises pressure, meters the fuel, and times the injection. The nozzle is simply a spring-loaded check valve that reacts to the pressure supplied from the high-pressure pump.

NOTE: A major manufacturer of jerk pump fuel injection systems is the American Bosch company. The system may use either of two different types of pumps, designated APF or APE. The letter F in APF identifies a pump that does not have its own drive, and the letter E in APE indicates a pump with a self-contained drive.

Bosch APF Pump

Type APF pumps are of the single-cylinder design with the plunger pump for each cylinder contained in separate housing (fig. 9-10). In a 6-cylinder engine, for example, there are six separate APF pumps. Each pump is cam driven and fuel volume is regulated by the setting of the control rack.



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Figure 9-10.—Type APF single cylinder, fuel injection pump.

Bosch APE Pump

Figure 9-11 illustrates a typical Bosch APE fuel injection pump. Type APE pumps are assembled with all the individual cylinder plungers in a single housing. View A of figure 9-11 shows a typical fuel supply system. View B of figure 9-11 shows the pump assembly for a 6-cylinder engine. The injection pumps are operated from a single camshaft in the bottom part of the housing. The cam lobes are arranged so that the firing order is consistent with the engine firing order. Each revolution of the camshaft provides one fuel charge from each outlet.

Although our discussion will be on the APE pump system, the APF pump operates on the same principles. Therefore, the information on

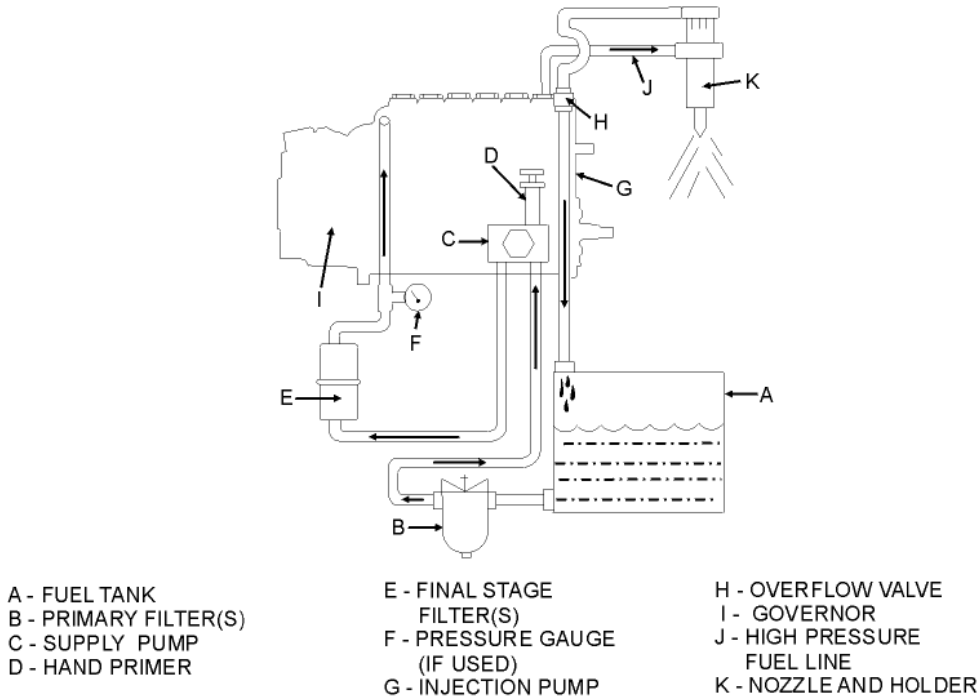
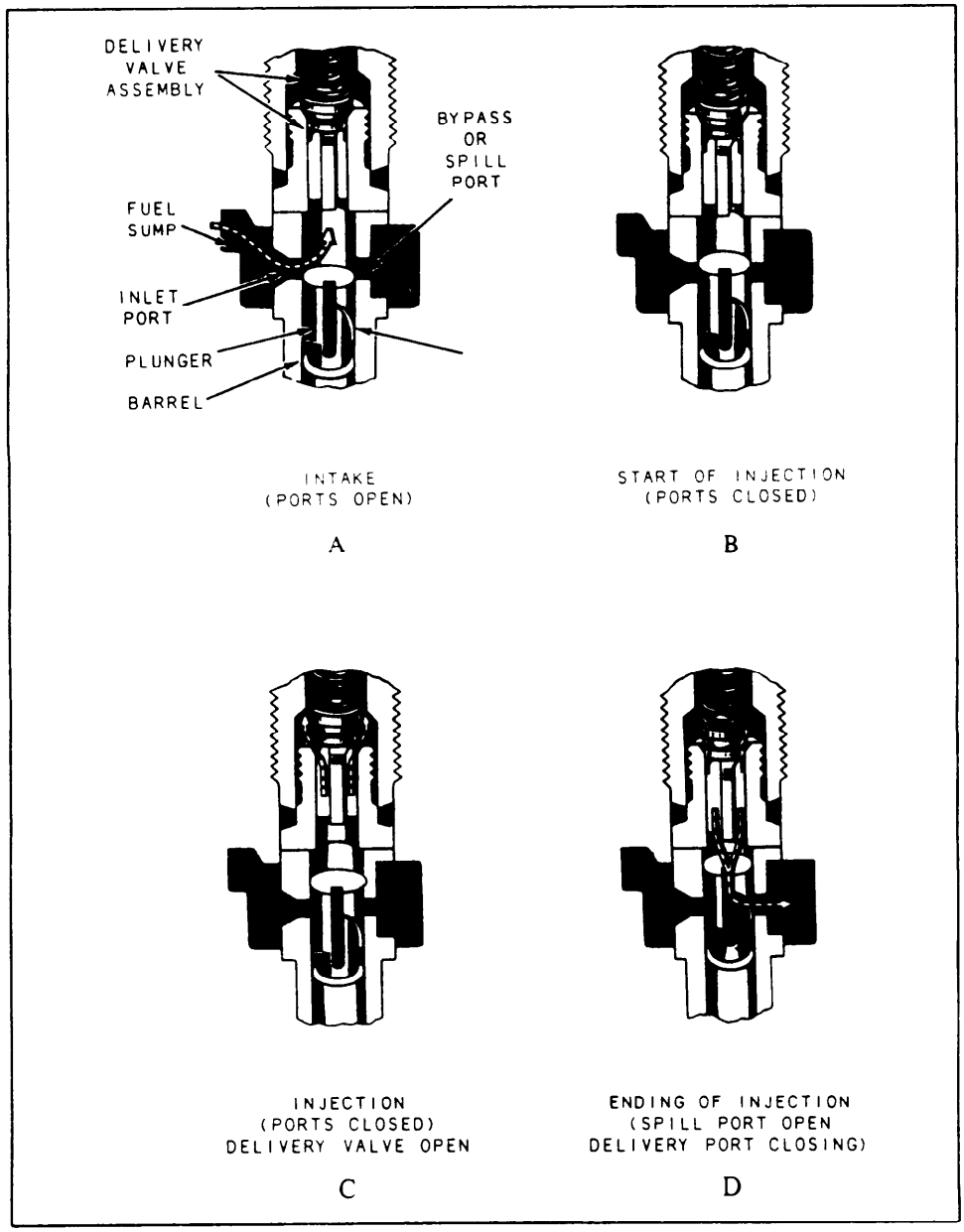


Figure 9-11.—Typical Bosch APE fuel supply system and fuel injection pump.

the pumping principle, metering principle, and delivery valve operation also applies to the APF pump.

GENERAL OPERATING PRINCIPLES.—As we discuss the operating principles of the APE pump system, refer to views A and B of figure 9-11. (Unless otherwise indicated, the letters used in parentheses in our explanation refer to the letters used in view A of fig. 9-11.) Refer to view A as you follow our explanation.

The supply pump (C) is a plunger-type, cam-activated pump that is equipped with inlet and outlet check valves and a hand-priming pump (D). The supply pump draws fuel from the fuel tank (A) through a primary filter (B) and discharges the fuel to a final stage filter (E). An arrow is stamped on the supply pump housing to indicate the direction of fuel flow. From the final stage filter, the fuel then flows into the injection pump sump (fuel gallery) which provides all six plunger and barrel assemblies with fuel. An overflow valve



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Figure 9-12.—Pumping principles of an APE pump.

assembly (H), which regulates and maintains the pump sump (gallery) pressure, is attached to the injection pump housing (G). The overflow valve assembly also permits any air in the system to work its way out and return to the fuel tank.

When the pump plunger is in its lowest position, fuel from the sump (gallery) enters the barrel ports and fills the volume above the plunger. The upward movement of the plunger (through cam action) seals off the barrel ports and forces fuel (now under high pressure) through the delivery valve assembly and high pressure tubing (J) to the holder and nozzle assembly (K).

Fuel entering the nozzle holder inlet flows through passages to the nozzle, which contains a spring-loaded valve. Fuel pressure exerts a force against the lower end of the valve, which is opposed by the spring force. At a preset pressure, the spring force is overcome and the valve rises, thus permitting the fuel to flow through the nozzle spray holes (orifices) and into the combustion chamber.

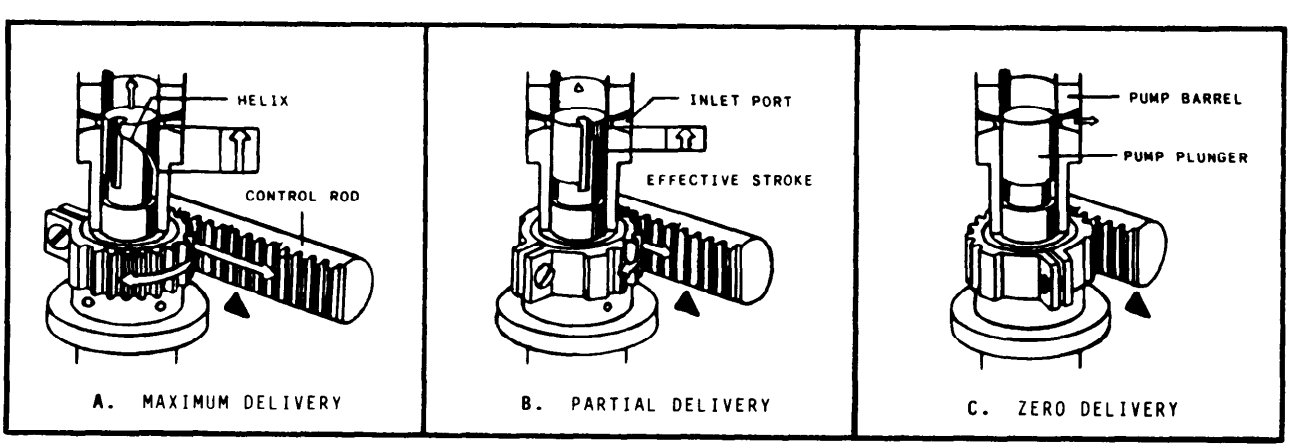
The slight fuel leakage between the nozzle valve and body (required for nozzle lubrication) is returned to the fuel tank through a leak-off line. Normally, the nozzle leak-off line is connected to the pump return line; thus both are returned to the fuel tank in a single line.

So far, our discussion has been general. We will now discuss in more detail the principles by which the fuel is pumped, metered, and delivered to the nozzle.

PUMPING PRINCIPLE.—We will first discuss the pumping principle behind the action of the APE fuel pump as it operates to pump fuel. Refer to view A of figure 9-12. When the plunger is at the bottom of its stroke, fuel from the pump sump flows through the barrel ports and fills the volume above the plunger. The sump fuel initially fills the vertical slots and connecting cutaway areas of the plunger.

Upward movement of the plunger seals off the barrel ports, thus trapping fuel in the barrel (fig. 9-12, view B). Additional upward movement of the plunger (fig. 9-12, view C) forces fuel through the delivery valve, high-pressure tubing, nozzle, and finally to the combustion chamber. Fuel delivery will stop when the plunger helix uncovers the barrel port (fig. 9-12, view D). This action releases the trapped fuel through the slot in the plunger and out through the barrel ports.

METERING PRINCIPLE.—Refer to figure 9-13 as you read how the fuel is metered and controlled. The positioning of the plunger helix is automatically controlled by movement of the speed governor output shaft, which is attached to the rear of the pump housing. The governor, through linkages, positions the control racks that rotate the segment gears and control sleeves which, in turn, radially position the plunger flange and helix. The fuel control rod (rack) teeth engage the plunger gear teeth to control fuel metering. Lateral movement of the fuel rack causes the plungers to rotate. This action, in turn, determines



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Figure 9-13.—Effects of plunger rotation on fuel delivery (metering principle).

the effective stroke of the plunger by plunger helix position in relation to the barrel port.

The amount of fuel delivered is controlled by the position of the plunger helix. When the plunger is rotated to a position as illustrated in view A, the effective part of the stroke (that position of the stroke from the closing of the barrel ports by the top of the plunger to the point where the edge of the helix raises above the barrel ports) is long, and fuel delivery is at a maximum. When the plunger is rotated to a position as shown in view B, the effective part of the stroke is reduced since the helix will uncover the barrel ports sooner (at a lower position). This action reduces the volume of fuel delivered to the cylinder. When the vertical slot on the plunger is in line with one of the barrel ports, as illustrated in view C, there is no effective stroke and therefore no fuel delivery.

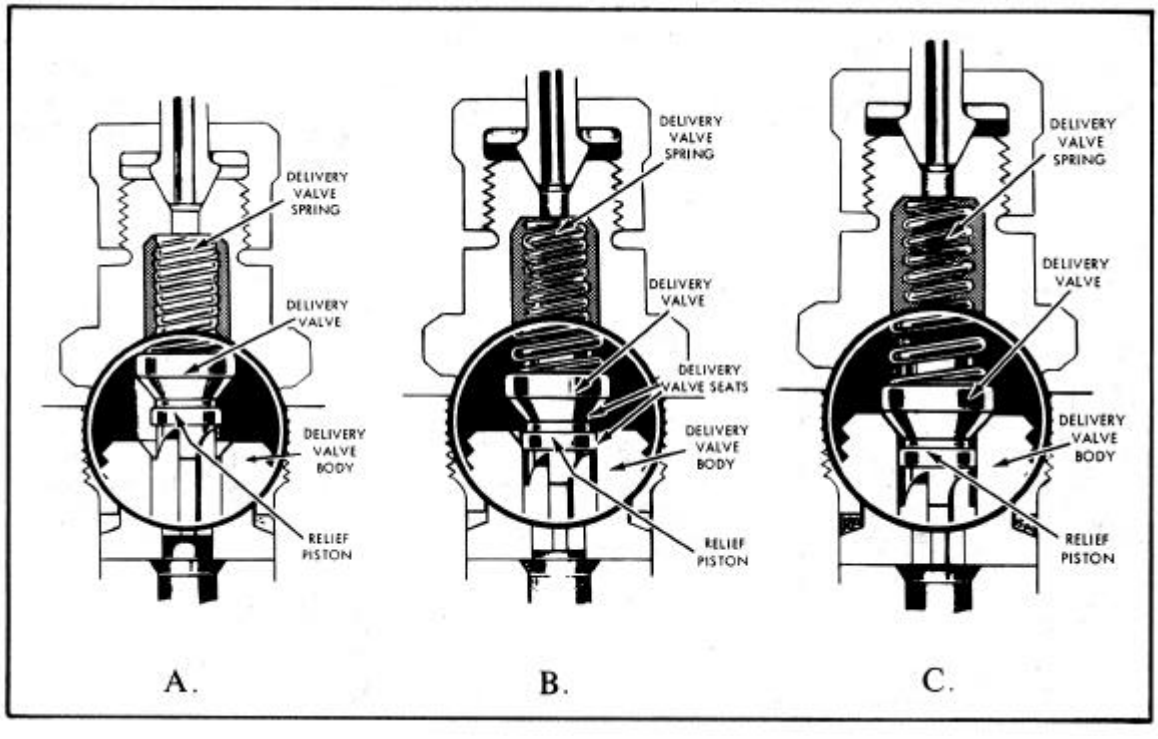
DELIVERY VALVE OPERATION.—As we discuss the delivery valve operation of the APE pump, you should refer to figure 9-14. The delivery valve assembly that was illustrated in figure 9-12 is shown close up in figure 9-14. The delivery valve assembly is located directly above the plunger. The delivery valve assembly assists the injection function by preventing irregular losses of fuel from the delivery to the supply side of the system between pumping strokes.

The delivery valve assembly consists of a valve with a conical seat and a valve body with a corresponding mating seat. Opening pressure is controlled by the force of the delivery valve spring that engages the top of the valve.

Since liquid fuel trapped in the barrel is essentially incompressible, pressure is created after the plunger, on its upward stroke, closes off the barrel ports. When this hydraulic pressure overcomes the force of the delivery valve spring, the valve opens and fuel passes through it into the injection tubing.

When the edge of the plunger helix passes the lower edge of the barrel port, there is a rapid drop in fuel pressure below the delivery valve (view A), and the force of the valve spring, combined with the high differential in pressure, begins to return the valve to its seat.

As the valve starts downward into the valve body (view B), the lower edge of its retraction piston enters the valve bore. At that moment, the flow of fuel by the delivery valve stops. In view C, the continued downward movement of the valve (retraction piston) increases the volume on



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Figure 9-14.—Delivery valve in three positions.

the high-pressure side by the amount of the piston retraction (its displacement volume) and, consequently, reduces the residual pressure in the injection tubing and nozzle holder. This lower pressure promotes rapid closing of the injection nozzle valve and diminishes the effect of hydraulic pressure waves that exist in the tubing between injections, thereby minimizing the possibility of the nozzle reopening (a secondary injection) before the next regular delivery cycle.

PLUNGERS.—Plungers include three different types of helixes-a lower helix, an upper helix, and both an upper and a lower helix. (The shape and the position of the helix governs the fuel delivery curve, the beginning *or* ending of injection, or both the beginning *and* ending of injection.)

For the lower helix plunger (fig. 9-15, view A, and fig. 9-13), the effective stroke (injection) always begins at the same time, regardless of where the plunger is rotated because the top end that closes the ports is flat. The end of injection can be varied because of the sloping design of the helix. Injection has a constant beginning and a variable ending. This type of plunger is used in pumps marked "timed for port closing."

For the upper helix plunger (fig. 9-15, view B), the beginning of the effective stroke varies as the plunger is rotated because the top edge, which closes the ports, is sloping. Thus, the beginning of delivery is variable and the ending is constant. Plungers of this type are used in pumps marked "timed for port opening."

A third type of plunger (fig. 9-15, view C) has a variable beginning (upper helix) and a variable ending (lower helix) design. Rotation of this type of plunger varies both the beginning and the ending of delivery of the fuel.

DISTRIBUTOR FUEL INJECTION SYSTEM

In our discussion of the distributor fuel injection system, we will use the DPA type for our example because of its wide use on Navy small craft. The DPA pump is a compact unit that is lubricated throughout by fuel and requires no separate lubrication system. It contains no ball or roller bearings, gears, or highly stressed springs. Sensitive speed control is maintained by a governor that is either mechanically or hydraulically operated within the pump itself.

Design and Components

In the DPA distributor type of injection pump, the fuel is pumped by a single element. The fuel charges are distributed in the correct firing order by a rotary distributor that is integral with the pump. Therefore, equality of delivery to each nozzle is an inherent feature of the pump. Since the timing interval between injection strokes is determined by the accurate spacing of the distribution ports and the operating cams do not have to be adjusted, accurate timing of delivery is also an inherent feature of the pump.

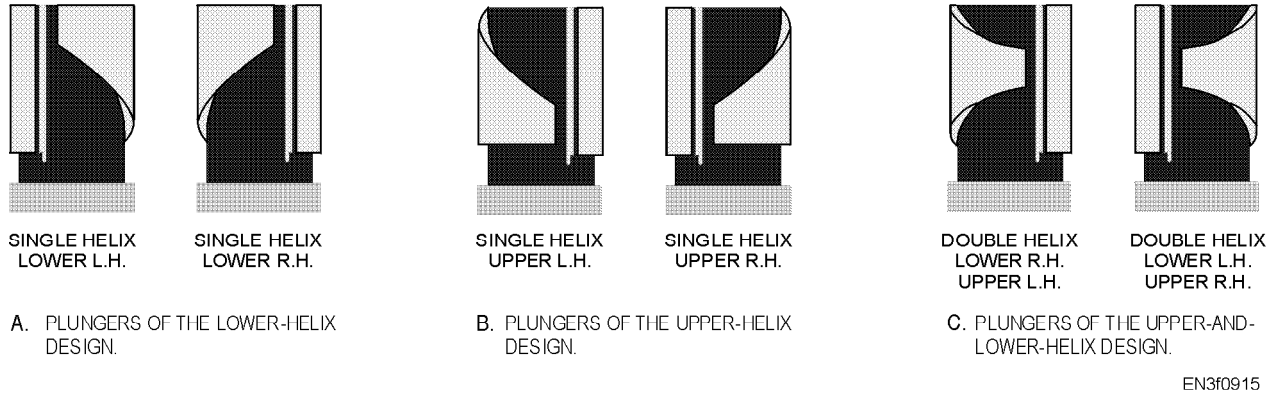


Figure 9-15.—Plunger types.

There is a central rotating steel member known as the pumping and distributing rotor. The rotor is a close fit in a stationary steel cylindrical body, called the hydraulic head. The pumping section of the rotor has a transverse bore containing two opposed pump plungers. These components rotate inside a cam ring in the pump housing, and operate through rollers and shoes sliding in the rotor. The cam ring has as many internal lobes as the engine has cylinders. The opposed plungers have no springs but are moved outward hydraulically by fuel pressure.

The pumping and distributing rotor is driven by splines from a drive shaft. At its outer end, the rotor carries a vane-type fuel transfer pump. With a piston-type regulating valve housed in the end plate, the transfer pump serves to raise the pressure of the fuel to an intermediate level, known as the transfer pressure.

Operation

The DPA pump is driven at half engine speed. As the rotor turns, a charging port in the rotor aligns with the metering port in the hydraulic head. Fuel at metered pressure then flows into the central passage in the rotor and forces the plungers apart. The amount of plunger displacement is determined by the amount of fuel that can flow into the element while the ports are aligned. The fuel inlet port closes as rotation continues. As the rotor turns, the fuel

Figure 9-16 has been deleted.

remains isolated into the rotor. As the single distributor port in the rotor comes into alignment with one of the outlet ports in the hydraulic head, the plungers are forced quickly together by the action of the cam. At this point, high pressure is generated, and the pressurized fuel passes via a high-pressure line to an injector. From the injector, the fuel passes to the engine combustion chamber. This entire cycle of operation is repeated once for each engine cylinder per pump revolution. Typical DPA system for a 4-cylinder engine.

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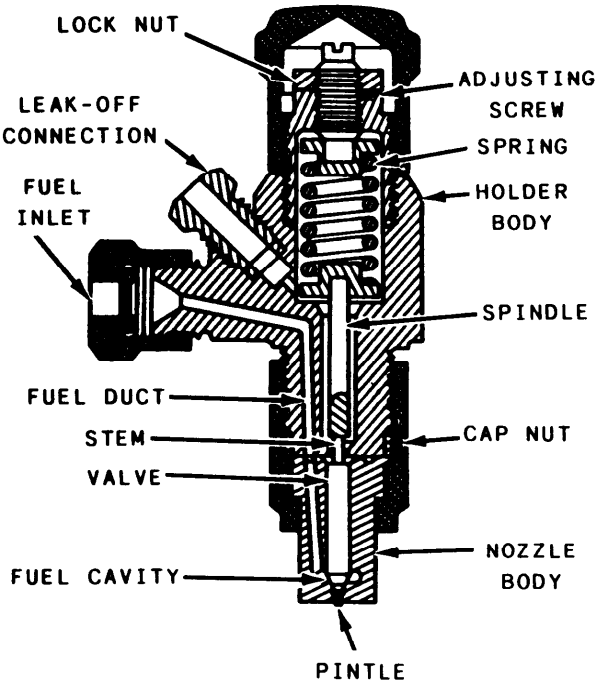
Injection Nozzles

An injection nozzle assembly serves to position the nozzle accurately in the engine cylinder. An injection nozzle assembly will contain the necessary spring and pressure adjustment means to provide for the proper action of the nozzle valve. An injection nozzle assembly will also provide a means by which fuel can be conducted the the nozzle and the combustion chamber of the engine. Although manufacturers produce a wide variety of nozzles to meet the requirements of several different combustion systems and engine sizes, there are essentially two basic groups of injection nozzles: the pintle nozzles and the hole nozzles.

Refer to the cutaway sectional view of a Bosch injection nozzle assembly in figure 9-20. Notice the details of the nozzle holder and the pintle-type nozzle. The high-pressure fuel from the injection pump enters the nozzle holder body through a metal-edge strainer. From the strainer, the fuel goes through a drilled fuel passage that extends to the bottom of the nozzle holder body. The nozzle, with its spray tip, is held against the bottom of the nozzle holder by the cap nut. A groove in the top of the nozzle forms a circular passage for the fuel between the nozzle and the holder. (Refer to fig. 9-21.)

Several vertical ducts (shown in detail in fig. 9-20) carry the fuel from the circular passage to the fuel cavity, near the bottom of the nozzle. The nozzle valve cuts in sharply to a narrower diameter in the fuel cavity, providing a surface against which the high-pressure fuel in the fuel cavity can act to raise the valve from its seat in the spray tip. When the valve is raised from its seat, the fuel sprays out to the combustion chamber through

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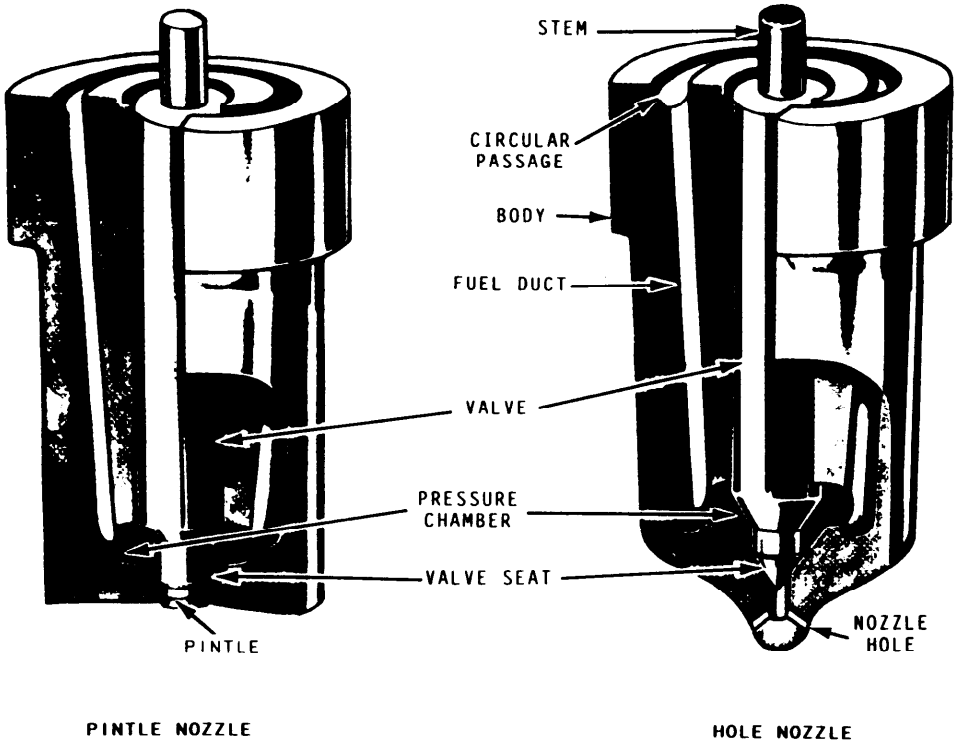
Figure 9-20.—Sectional view of a Bosch injection pintle-type nozzle assembly.

a ring of small holes (hole nozzle), or around the pintle and out through the single hole (pintle nozzle).

The valve has a narrow stem that projects into the central bore of the nozzle holder where it bears against the bottom of the spindle. The spindle is held down by the pressure-adjusting spring. Whenever the upward force of the high-pressure fuel acting on the needle valve exceeds the downward force of the spring, the valve can rise. The moment the spring force is greater, the valve will snap back to its seat. The spring tension is regulated by a pressure-adjusting screw or shims.

Regardless of the close-lapped fit of the valve, some fuel will leak past the valve and rise through the central bore of the nozzle holder. This fuel lubricates the moving parts and carries away heat from the injector. The bypassed fuel then drams off through the fuel dram connection to a drip tank. There is a bleeder screw that can serve to bypass fuel to the nozzle, sending the fuel directly to the fuel drain.

The pintle nozzle and the hole nozzle are compared in views A and B of figure 9-21. Refer to figure 9-21 as you read the following descriptions.



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Figure 9-21.—Pintle Nozzle and hole nozzle.

PINTLE NOZZLE.—The valve of the pintle nozzle (fig. 9-21, view A) has an extension that protrudes through the hole in the bottom of the nozzle body and produces a hollow cone-shaped spray. The included angle of the spray cone may be up to a maximum of 60 degrees, depending on the type of combustion chamber in which it is used. A pintle nozzle generally opens at a lower pressure than the pressure at which the hole nozzle opens because fuel flows more readily from the large hole of the pintle nozzle. Although atomization of the fuel is not so complete in the pintle nozzle as it is in the hole nozzle, penetration into the combustion space is greater. Consequently, pintle-type nozzles are used in engines having pre-combustion, divided, air cell or energy-cell combustion chambers, where mixing of fuel and air is largely dependent on combustion reaction or turbulence. In addition, the motion of the pintle tends to inhibit the formation of carbon crust on the tip of the nozzle.

MULTIPLE-HOLE NOZZLE.—The multiple-hole nozzle (fig. 9-21, view B) provides good atomization but less penetration than the pintle nozzle. The multiple-hole nozzle is used with the open type of combustion chamber in which high atomization is more important than penetration. The spray pattern of the hole nozzle is dependent on the number and placement of the holes or orifices.

Spray openings, or orifices, are from 0.006 inch up to about 0.033 inch in diameter, and their number may vary from 3 to as many as 18 for large bore engines.

Regardless of design, all nozzles and tips function to direct the fuel into the cylinder in a pattern that will bring about the most efficient combustion. Obviously, the slightest defect in nozzles and tips will have an adverse effect on engine operation.

UNIT FUEL INJECTOR SYSTEM

Unlike the design of the other two fuel injection systems, the unit injector provides each

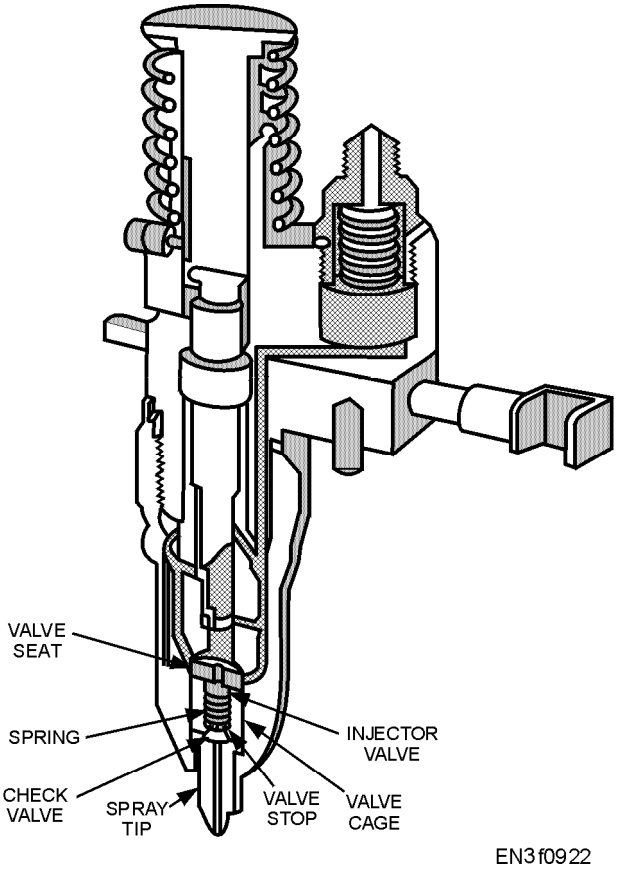


Figure 9-22.—Cutaway view of a crown valve injector.

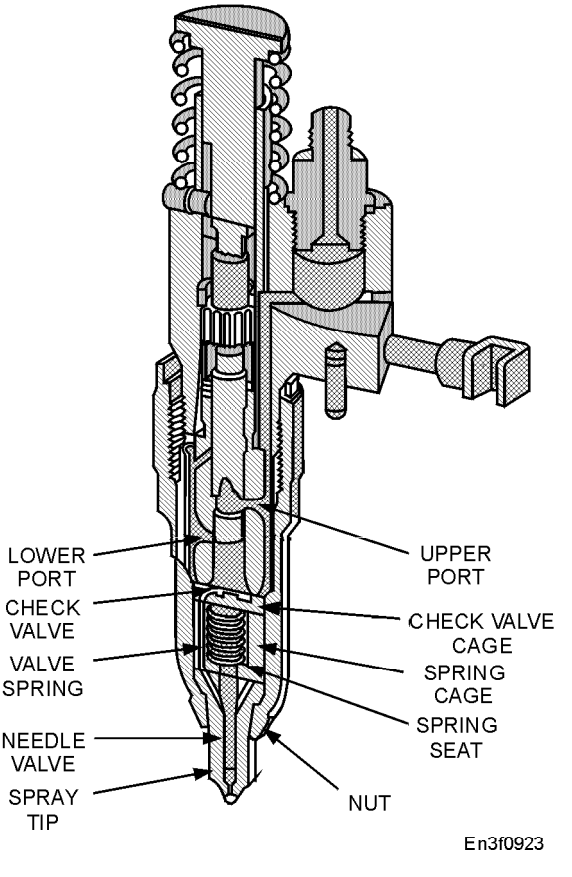


Figure 9-23.—Cutaway view of a needle valve injector.

cylinder with its own high-pressure pump. The unit injector design eliminates the need for a remotely located high-pressure pump and high-pressure external fuel lines, such as those used in the systems we have covered in the preceding sections. The unit fuel injector (UFI) is complete with pumping and timing element, fuel control, and injection valve spray tip assembly to control the quantity, rate, and timing of fuel delivery. The UFI is used on all General Motors engines; therefore, there are various models available to meet the needs of the engines. Our discussion will cover the two most commonly used types: (1) the crown valve and (2) the needle valve injector.

The crown valve injector is shown in figure 9-22. This type of injector was placed in service in 1953 and is still in use within the Navy. In 1962, the needle valve injector incorporating a new tip design was introduced (fig. 9-23). The needle valve injector provides for improved economy and emissions by increased pop pressure (2300 to 3300 psi for the needle valve injector compared with 450 to 850 psi for the crown valve injector) and a more precise method of fuel control than the crown valve type of unit injector. Compare the spray tip assembly in the crown valve unit injector in figure 9-22 with the spray tip assembly of the needle valve unit injector in figure 9-23.

Design and Components

The unit injector is installed in the cylinder head, as shown in figure 9-24. It is held in place by an injector clamp. The cylinder head has a copper tube into which the injector fits snugly with the spray tip projecting slightly into the cylinder clearance space. Water circulates around the copper tube and cools the lower part of the injector. Two fuel lines are connected to each injector; one carries fuel to the injector and the other carries away the fuel that is bypassed. The injector is operated by a rocker arm and push rod assembly, which work off the camshaft. The amount of fuel injected is regulated by the control rack, which is operated by a lever secured to the control tube.

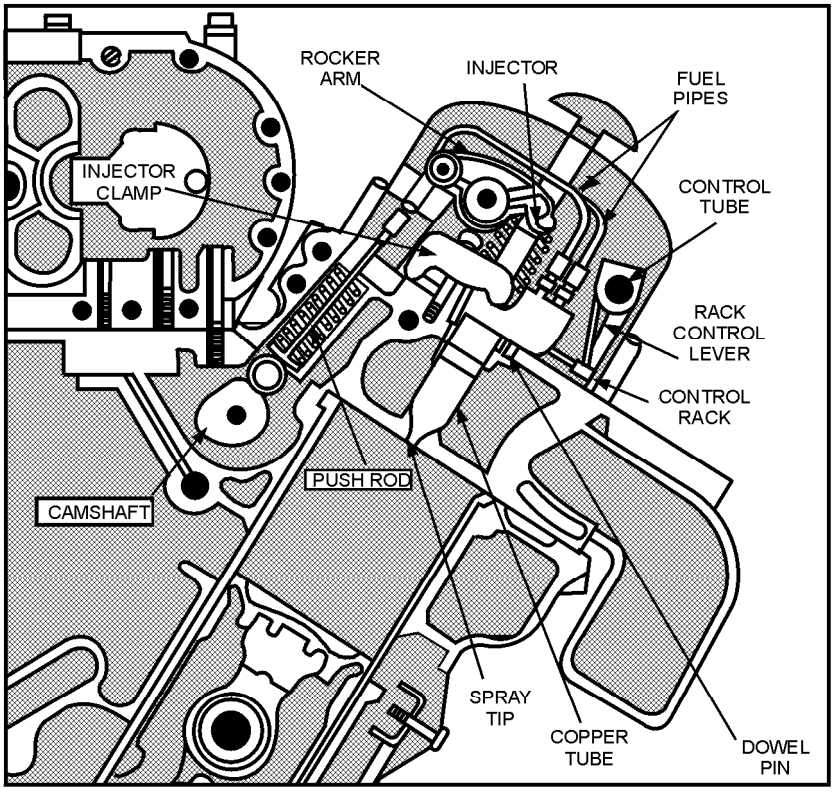


Figure 9-24.—Fuel injector mounting.

Operation

In our discussion of the UFI, we will use the needle valve injector as our main example. Differences between the needle valve and the crown valve are within the tip assembly, and will be pointed out during our discussion. Refer to figures 9-22 through 9-25 as we discuss the operation of the unit injector fuel system.

Fuel, under pressure, enters the injector at the inlet side through a filter cap and filter. (Refer to fig. 9-23.) From the filter, the fuel passes through a drilled passage into the supply chamber, the area between the plunger bushing and the spill deflector, in addition to that area under the injector plunger within the bushing. The plunger operates up and down in the bushing, the bore of which is open to the fuel supply in the annular ring-shaped chamber by two funnel-shaped ports in the plunger bushing.

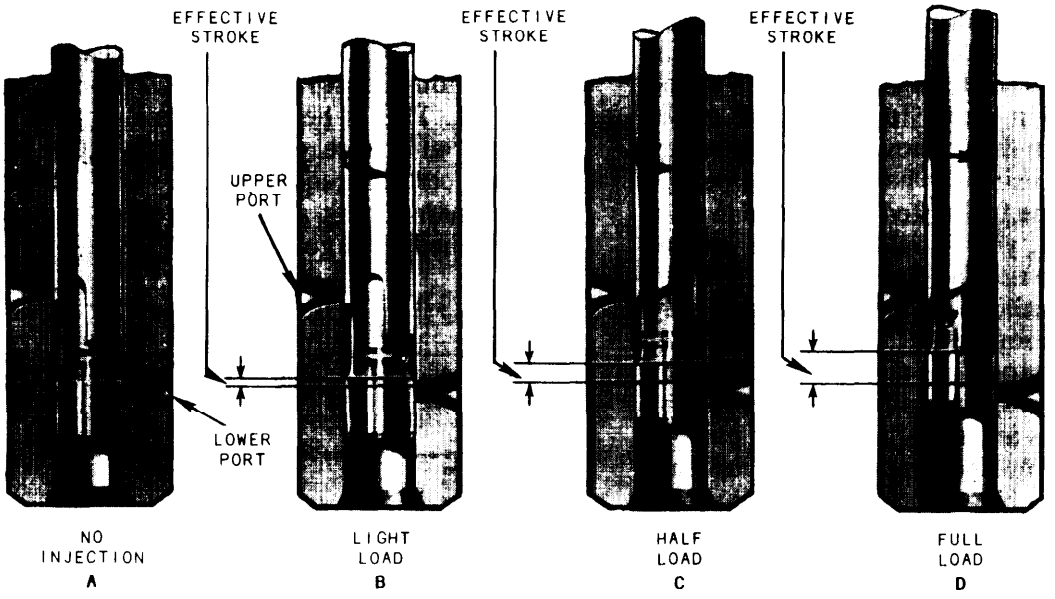
The motion caused by the injector rocker arm is transmitted to the plunger by the follower, which bears against the follower spring. (See fig. 9-23.) In addition to the reciprocating up-and-down motion, the plunger can also rotate around its own axis by the gear, which meshes with the control rack. For the metering of the fuel, an upper helix and a lower helix are machined in the lower part of the plunger. The relation of the helices to the two fuel ports will change as the rotation of the plunger changes.

As the plunger moves downward (due to the force of the injector rocker arm), a portion of the fuel trapped under the plunger is displaced into the supply chamber through the lower port. This action will occur until the port is closed off by the lower end of the plunger. A portion of the fuel trapped below the plunger is then forced up through a central passage in the plunger into the fuel metering recess and into the supply chamber through the upper port until that port is closed off by the upper helix of the plunger. (See fig. 9-23.) With the upper and lower ports both closed off, the remaining fuel under the plunger is subjected to increased pressure by the continuing downward movement of the plunger.

When sufficient pressure builds up, the flat, nonreturn check valve opens. The fuel in the check valve cage, spring cage, tip passages, and tip fuel cavity is compressed until the force of the pressure acting upward on the needle valve is sufficient to open the valve against the downward force of the valve spring. As soon as the needle valve lifts off its seat, as illustrated in figure 9-23 (or as soon as the injector valve is lifted off its seat as illustrated in fig. 9-22), the fuel is forced through the small orifices in the spray tip and atomized into the combustion chamber. When the lower land of the plunger uncovers the lower port in the bushing, the fuel pressure below the plunger is relieved. The valve spring then closes the needle valve (or injector valve), and injection stops. A pressure relief passage is provided in the spring-cage. This passage permits any bleed-off of fuel that may leak past the needle pilot in the tip assembly. The check valve, located directly below the bushing (the needle valve in fig. 9-23) or mounted in the spray tip (the crown valve in fig. 9-22), prevents leakage from the combustion chamber into the fuel injector in case the valve is accidently held open by a small particle of dirt. The injector plunger is then returned to its original position by the injector follower spring.

Figure 9-25 shows the various phases of injector operation indicated by vertical travel of the injector plunger. On the return upward movement of the plunger, the high-pressure cylinder within the bushing is again filled with fuel through the ports. The constant circulation of fresh, cooler fuel through the injector renews the fuel supply in the chamber, helps carry heat from the injector, and also effectively removes all traces of air that might otherwise accumulate in the system and interfere with accurate metering of the fuel. The fuel injector outlet opening, through which the excess fuel returns to the fuel return manifold and then back to the fuel tank, is directly adjacent to the inlet opening.

A change in the position of the helices, by rotation of the plunger, retards or advances the closing of the ports and the beginning and ending of the injection period. At the same time, a change in the position of the helices increases or decreases the amount of fuel injected into the cylinder. Look again at the various plunger positions in figure 9-25. With the control rack pulled out all the way (no injection as shown in view A), the upper port is not closed by the helix until after the lower port is uncovered. Consequently with the rack in this position, all of the fuel is forced back into the supply chamber and no injection of fuel takes place. With the control rack pushed all the way in (full injection), the upper port is closed shortly after the lower port has been covered, thus a maximum effective stroke and maximum injection is produced. From this no injection position in view A to the full injection position (full rack movement) in view D, the contour of the upper helix advances the closing of the ports and the beginning of injection.



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Figure 9-25.—Injection and metering principles of a unit injector.

Purity of the fuel cannot be overstated in any injection system. The unit injectors have spray tip holes as small as 0.005 inch. Pressures of approximately 20,000 psi are developed by a combination of spray hole area restriction and plunger/bushing design. Typically, the plunger and bushing are matched to a diametrical clearance of 60 millionths of an inch to prevent leakage during the injection cycle. As you can see, impurities of any kind can damage the unit.

PURGING THE DIESEL ENGINE FUEL INJECTION SYSTEM

When an engine fails to operate, stalls, misfires, or knocks, there may be air in the high-pressure pumps and in the fuel lines. Unlike liquid fuel, which is incompressible, when air is present in the system, compression and expansion of air will occur and the injector valves will either fail to open or will not open at the proper time.

You can determine the presence of air in a fuel system by bleeding a small amount of fuel from the top of the fuel filter or by slightly loosening an air bleeder screw or plug. If the fuel appears quite cloudy, it is likely that there are small bubbles of air in the fuel.

When working with fuel systems, you should remember that if air is entering a fuel line, the pressure within the fuel line must be lower than atmospheric pressure. The smallest of holes in the transfer pump suction piping will allow enough air to flow into the system to air bind the high-pressure pumps. Carefully inspect all fittings in the suction piping. A loose fitting or a damaged thread condition will allow air to enter the system. On installations where flanged connections are used, be sure to check the condition of the gaskets. Inspect tubing (especially copper) and flexible hose assemblies carefully for cracks that may result from constant vibration or rubbing.

The use of tubing and flexible hose assemblies on diesel engine fuel systems is common. You will find that flexible hose assemblies are used more on the supply or low-pressure side of the injection equipment while tubing is more commonly used on the high-pressure side of the injection equipment. The use of tubing and flexible hose assemblies is also the means by which all pressure gauges of a diesel may be located on a central gauge board away from the system the gauges are monitoring. (Additional information concerning the fabrication and fitting of flexible hose assemblies and tubing can be found in *Tools and Their Uses,* NAVEDTRA 10085-B1 , and in *Fluid Power,* NAVEDTRA 16193-B, chapter 5.)

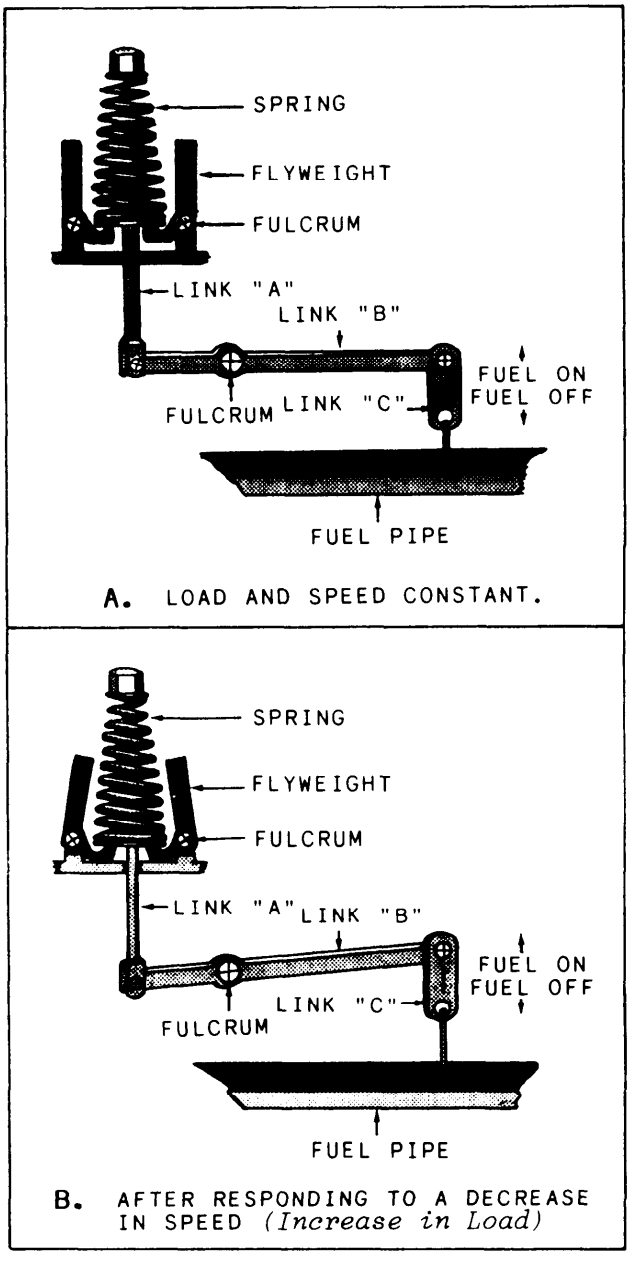
If an engine is allowed to run out of fuel, you can expect trouble from air that enters the fuel system. If there is a considerable amount of air in the filter, a quick method of purging the system of air is to remove the filling plugs on top of the filter and pour in clean fuel until all air is displaced. You can then remove any air remaining in the system by using the hand priming pump. For example, in the fuel system illustrated in view A of figure 9-11, you should open the system between the pump and the filter. Operate the hand priming pump until all air is removed and only clear fuel flows from the line. Then close the line. Repeat the same procedure at other points in the system, such as between strainers and the filters, between the filters and the high-pressure pumps, and at the overflow line connection (excess fuel return line) on the high-pressure pump housing. In small, high-speed diesel engines, you may need to prime only at the overflow connection. Since priming high-pressure lines is time-consuming, attempt to start the engine before purging these lines. However, do not crank the engine for more than the specified interval of time. If the engine still fails to start, you should prime the high-pressure lines. Since the procedure necessary to prime high-pressure lines will vary considerably with different installations, follow the NAVSEA technical manual instructions for the proper procedure.

CONTROL DEVICES IN A DIESEL ENGINE

In this section of the chapter, we will discuss the methods and the devices that serve to control the output of the injection pumps and injectors. By controlling the output of the fuel injector system, these devices ensure control of engine operation.

GOVERNORS

A governor is a speed-sensing device on an engine that serves to maintain a constant speed (in rpm) within the design power rating of a diesel engine. A governor may also serve to limit high- and low-idle revolutions per minute of the engine. All governors used on diesel engines control engine speed by regulating the amount of fuel delivered to the cylinders. An example of engine control without the use of a governor is in the conventional automobile—the engine speed and engine load changes are sensed by the driver. The driver's movement of the throttle is an extension of a conditioned reflex; in other words, the driver acts as the governor. However, the driver will not be capable of reacting to load and speed changes quickly enough insofar as the diesel engine is concerned. This is because diesel engines can run at speeds in excess of 2,000 rpm. The exacting duty of maintaining a constant speed is better accomplished by a governor.



81.156(75)

Figure 9-26.—Simple mechanical governor.

Terminology

Before considering the operating principles of various types of governors, you should become familiar with the following terms:

1. SPEED DROOP is the decrease in speed of the engine from a no-load condition to a full-load condition. Speed droop is expressed in rpm or (more commonly) as a percentage of normal or average speed.

2. ISOCHRONOUS GOVERNING is maintaining the speed of the engine truly constant, regardless of the load. This means governing with perfect speed regulation or zero speed droop.

3. HUNTING is the continuous fluctuation (slowing down and speeding up) of the engine speed from the desired speed. Hunting is caused by overcontrol by the governor.

4. STABILITY is the ability of the governor to maintain the desired engine speed without fluctuations or hunting.

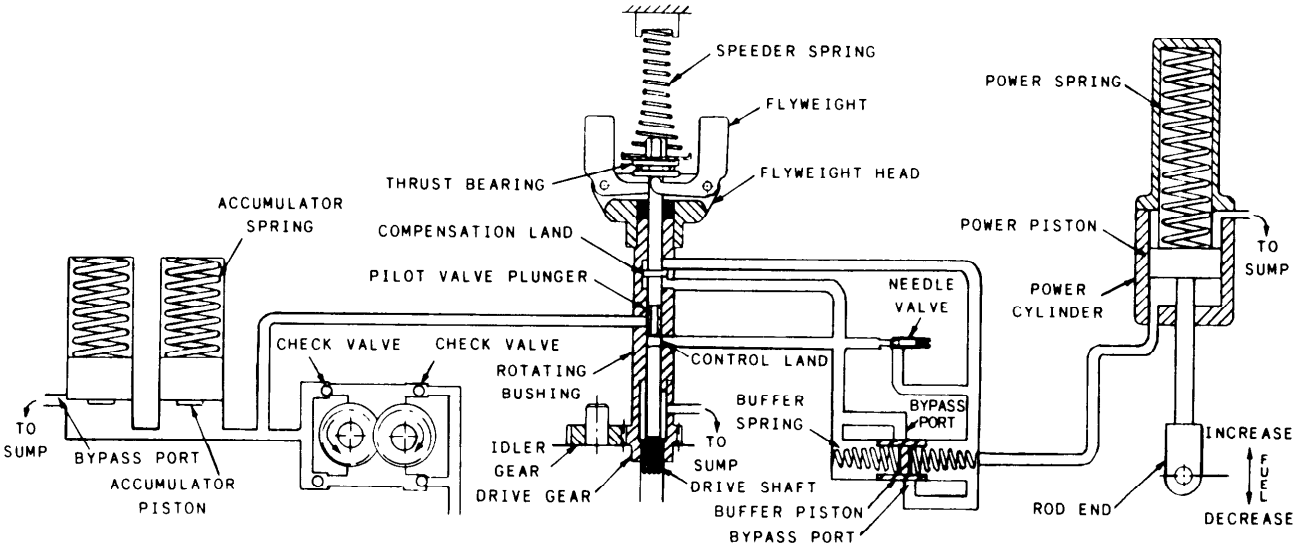
5. SENSITIVITY is the change in speed required before the governor will make a corrective movement of the fuel control mechanism and is generally expressed as a percentage of the normal or average speed.

6. PROMPTNESS is the speed of action of the governor. It identifies the time interval required for the governor to move the fuel control mechanism from a no-load position to a full-load position. Promptness depends on the power of the governor; the greater the power, the shorter the time required to overcome the resistance.

Now that you have read the definitions of some of the terms associated with governors, we will proceed with our comparison between mechanical and hydraulic governors. You should refer to views A and B of figure 9-26 and figure 9-27 as you read this information.

Classification of Governors

Governors for diesel engines used by the Navy can be divided into two general classes—MECHANICAL and HYDRAULIC. Both types of governors serve to regulate engine speed by controlling the fuel injected and are referred to as SPEED-REGULATING GOVERNORS. The mechanical governor is usually simple in design, contains few parts, and is relatively inexpensive. It is frequently used as a speed-limiting device or when extremely sensitive operation is not required. (See fig. 9-26.) The hydraulic governor is more complex in design and contains more parts than the mechanical governor. However, it is more sensitive to speed variations, quicker acting, and more accurate because of the reduction of friction and the small mass of moving parts. Due to the forces exerted by the hydraulic system, it



121.16.1

Figure 9-27.—Hydraulic governor with a compensating device.

is possible to use a smaller, more compact governor to operate the fuel mechanism of large engines than would be possible with a mechanical governor. (See fig. 9-27). Both mechanical and hydraulic governors will be discussed in greater detail later in this chapter.

Governors may also be classified according to the function or functions they perform, the forces they use in operation, and the means by which they operate the fuel control mechanism.

The function of a governor on a given engine is determined by the load on the engine and the degree of control required. Governors are classified according to their function as constant-speed, variable-speed, speed-limiting, and load-limiting.

Some installations require a constant engine speed from a no-load condition to a full-load condition. Governors that maintain one speed, regardless of load, are called CONSTANT-SPEED governors. Governors that maintain any desired engine speed over a wide speed range and that can be set to maintain a desired speed in that range are classified as VARIABLE-SPEED governors. Speed-control devices that serve to keep an engine from exceeding a specified maximum speed and from dropping below a specified minimum speed are classified as SPEED-LIMITING governors. Some speed-limiting governors limit maximum speed only. Some engine installations need a control device to limit the load that the engine will handle at various speeds. Such devices are called LOAD-LIMITING governors. Some governors are designed to perform two or more of these functions.

MECHANICAL GOVERNORS.—A mechanical governor (fig. 9-26, view A) controls the speed of the engine by virtue of the spring-balanced position of the flyweights. When the load is decreased or removed from the engine (such as when a clutch is disengaged) and the speed exceeds its former balanced setting, the increased speed of the flyweights develops a greater centrifugal force that upsets the former flyweight spring balance. A new balance is achieved by the weights as they move outward and further compress the spring. Any movement of the flyweights is reflected in a vertical change in position of link A. When the load is increased on the engine, as in view B of figure 9-26, the fuel that is injected will be inadequate for the increased load and the engine will slow down. The centrifugal force of the flyweights will then decrease and permit the former balanced spring force to move link A down until the new flyweight position again is balanced by the spring. You should note that the linkage movement causes an increase in fuel when the load is increased and a decreased supply of fuel as the load is reduced. From this discussion, it is evident that the mechanical governor controls the fuel supply by virtue of the flyweight position.

HYDRAULIC GOVERNORS.—For its speed-sensitive elements, the hydraulic governor, as shown in figure 9-27, depends on a similar flyweight arrangement to that of the mechanical governor. However, the power supply that moves the fuel mechanism is operated hydraulically rather than through direct mechanical linkage with the flyweights. The flyweights of the hydraulic governor are linked directly to a small pilot valve that opens and closes ported passages, admitting oil under pressure to either side of a power piston that is linked to the fuel control mechanism. Since the flyweights move only a lightweight pilot valve, the inherent design of the hydraulic governor is more sensitive to small speed changes than the design of the mechanical type of governor, which derives all of its working power from the flyweights. The larger and heavier the fuel control mechanism, the more important it is to employ a hydraulic governor.

There is always a lag between a change in fuel setting and the time the engine reaches the new desired speed. Even when the fuel controls are set as required during a speed change, hunting caused by overshooting will occur. As long as engine speed is above or below the desired new speed, the simple hydraulic governor will continuously adjust (overcorrect) the fuel setting to decrease or increase the delivery of fuel. For this reason, a hydraulic governor must have a mechanism that will discontinue changing the fuel control setting slightly before the new setting has actually been reached. This mechanism, used in all modern hydraulic governors, is called a COMPENSATING DEVICE.

One type of compensating device is illustrated in figure 9-27. The buffer piston, buffer springs, and needle valve in the hydraulic circuit between the control land of the pilot valve plunger and the power piston comprise the BUFFER COMPENSATING SYSTEM of the governor. Lowering the pilot valve plunger permits a flow of pressurized oil into the buffer cylinder and power cylinder. This flow of oil moves the power piston up to increase fuel. As the pilot valve plunger moves

up, oil is permitted to flow from the buffer cylinder and power cylinder to the governor sump, and the power piston spring moves the power piston down to decrease fuel. The rate of compensation is adjusted by regulating the oil leakage through the compensating needle valve. If the compensating needle valve is adjusted correctly, only a slight amount of hunting will occur after a load change. This hunting will quickly be dampened out, resulting in stable operation through the operating range of the governor.

OVERSPEED SAFETY DEVICES

Engines that are maintained in proper operating condition seldom reach speeds above those for which they are desired. However, conditions may occur to cause excessively high operating speeds, such as when a ship's propeller comes out of the water in rough seas. Operation of a diesel engine at excessive speeds is extremely dangerous because of the relatively heavy construction of the engine's rotating parts. A high-speeding engine develops inertia1 and centrifugal forces that may seriously damage parts or even cause them to fly apart. Therefore, you must know why an engine may reach a dangerously high speed and how to bring it under control when excessive speed occurs.

In some two-stroke cycle engines, lubricating oil may leak into the cylinders as a result of leaky blower seals or broken piping. Even though the fuel is shut off, the engine may continue to operate, or even "run away," as a result of the combustible material coming from the uncontrolled source. Engines in which lubricating oil may accumulate in the cylinders generally have an automatic mechanism that shuts off the intake air at the inlet passage to the blower. If there is no air shutoff mechanism and if shutting off the fuel will not stop an engine that is overspeeding, a cloth article such as a blanket or a pair of dungarees should be placed over the engine's intake to stop airflow. This action will subsequently stop the engine.

Excessive engine speeds are more commonly found where there is an improperly functioning regulating governor than where lubricating oil accumulates in the cylinders. To stop an engine that is overspeeding because of lubricating oil in the cylinders, stop the flow of intake air. To accomplish an emergency shutdown or reduction of engine speed when the regulating governor fails to function properly, shut off or decrease the fuel supply to the cylinders.

You can shut off the fuel supply to the cylinders of an engine in several ways, either manually or automatically:

1. Force the fuel control mechanism to the NO FUEL position.
2. Block the fuel line by closing a valve.
3. Prevent the mechanical movement of the injection pump.

Overspeed safety devices automatically operate the fuel and air control mechanisms. As emergency controls, these safety devices operate only in case the regular speed governor fails to maintain engine speed within the maximum design limit. Devices that bring an overspeeding engine to a full stop by completely shutting off the fuel or air supply are generally called OVERSPEED TRIPS. Devices that reduce the excessive speed of an engine, but allow the engine to operate at safe speeds, are more commonly called OVERSPEED GOVERNORS.

Overspeed Governors and Trips

All overspeed governors and trips operate on a spring-loaded centrifugal governor element. In overspeed devices, the spring tension is great enough to overbalance the centrifugal force of the weights until the engine speed rises above the desired maximum. When the speed setting of the governor is reached, the centrifugal force overcomes the spring tension and operates the mechanism that stops or limits the fuel or air supply.

When a governor serves as a safety device, the fuel or air control mechanism is operated by the centrifugal force either directly, as in a mechanical governor, or indirectly, as in a hydraulic governor. In an overspeed trip, the shutoff control is operated by a power spring. The spring is placed under tension when the trip is manually set and is held in place by a latch. If the maximum speed limit is exceeded, a spring-loaded centrifugal weight will move out and trip the latch, allowing the power spring to operate the shutoff mechanism. NOTE: If the engine overspeeds and exceeds its rated rpm trip setting, internal inspection of the engine must be accomplished before the engine is restarted.

Overspeed safety devices must always be operative and must never be disconnected for any reason while the engine is operating. All overspeed

safety devices should be tested under the Planned Maintenance System (PMS).

Basic Care of the Governor

Contaminants and foreign matter in the governor oil are the greatest single source of governor troubles. Use only new or filtered oil. Be sure that all containers used for the governor oil are clean. The time interval between governor oil changes depends upon many factors: type of service, operating temperature, quality of oil, and so forth. Anytime the governor oil appears to be dirty or breaking down from contaminants or excessive temperatures, drain the governor while it is hot, flush it with the lightest grade of the same oil, and refill it with fresh oil. In any event, follow the PMS for regular oil drain intervals.

A governor should operate several years before needing replacement if it is kept clean and if the drive from the engine is smooth and free from torsional oscillations. Except for isolated cases, so rare they can be almost disregarded, governors do not suddenly fail or break down. Instead, they wear gradually, and give an external indication of their condition in the form of slight hunting, sluggish operation, and so forth. Further deterioration is at a slow enough rate so that an exchange governor may be ordered for installation and the governor can be changed out at a convenient downtime.

PROPULSION CONTROL SYSTEMS

In modern propulsion systems, an integrated system of pneumatic, hydraulic, and electric circuits provides control of the speed and direction of the propeller shaft. Each control system function may use only one of these three mediums, a combination of two, or a combination of all three. The choice of control medium in each instance is based on the performance of a given control function in the most reliable and efficient manner. In general, the different control mediums are used in the following functions:

1. The basic control medium is pneumatic, and the majority of propulsion control functions are performed by pneumatic circuits.
2. Hydraulic circuits are used whenever a large amount of control element actuating power is required, such as when pitch is applied to controllable pitch propellers.
3. Electric circuits are used extensively for the sensing and indicating of control system conditions and for alarm systems.

The basic requirements for a propulsion control system are threefold. First, it must control the main engines' load, keeping the engines equally loaded. Next, it must maintain propeller shaft speed and direction. Finally, it must maintain the desired pitch since gas turbine ships and most diesel-driven ships have controllable pitch propellers.

The engine speed and load are controlled by the governor of each main engine, through a pneumatic signal sent to the governor, which increases or decreases the tension of the speeder spring.

Control of the propeller shaft speed is done by control of the main engine speed as stated previously. Propeller shaft direction of rotation, ahead or astern, on noncontrollable pitch propeller ships is controlled by clutches and reduction gears. (These mechanisms will be discussed in chapter 12 of this manual.)

In ships with controllable pitch propellers, the pitch is controlled by a signal, either pneumatic or hydraulic, that is sent to an oil distribution (OD) box. There, the signal is converted to a high-pressure hydraulic force which actuates the propeller blades through a piston and cylinder assembly in the propeller hub.

In most ships with propulsion control systems, the machinery can be operated from three different locations. Local control is usually from a panel mounted on or near the machinery to be operated. The local control station is used for the operation of a single unit, such as one main engine, or for setting the pitch on one propeller. The enclosed operating station (EOS) has a console for the operation of one complete propeller shaft, including main engines, propeller pitch control unit, clutches, and all other machinery required for propulsion. On large ships, there may be one EOS for each propeller shaft. On smaller ships, one EOS is used to control and monitor all propulsion machinery for the ship. The third operating station is the pilot-house console, which controls propeller shaft speed and pitch or direction. Generally, this station cannot control the starting or stopping of main engines, operate clutches, or control other individual pieces of propulsion machinery. Both the EOS console and pilot-house console will have instruments that indicate shaft rpm, propeller

pitch, and other indicators required for the monitoring of the propulsion plant.

Generally, propulsion control systems should operate trouble-free for many years with a minimum of care.

Pneumatic systems need a constant source of clean dry air to operate correctly. If the supply of air is dirty or contains oil or water, the various control valves throughout the system will stick and cause malfunctions. All connections should be checked periodically. If leaks should start, a drop in line pressure will create a faulty signal. You can locate any leaks in a pneumatic system by brushing a solution of soapy water on the connectors of the system. An air leak will be indicated by bubbles that will form at the site of the leak.

The worst enemy of any hydraulic system is dirt. Dirt that is allowed to enter the system, either when oil is being added or when other work is being performed, will create problems. Dirt will cause the extremely close clearances of parts in hydraulic components to become damaged. Also, dirt will cause the valves in the system to malfunction.

Electrical systems are all but trouble-free with little routine maintenance required. Occasionally, problems occur because of loose connections or from component failure.

Most propulsion control systems will use a combination of all three mediums: pneumatic, hydraulic, and electric. In troubleshooting a malfunction, you should check only one medium at a time until you can isolate the trouble and make the necessary repairs.

SUMMARY

You should be familiar with factors related to combustion and how these factors affect diesel engines. Know the meaning of turbulence and precombustion and the significance of each to the combustion process of a diesel engine.

In our discussion of fuel systems, we can never overstress the importance of clean fuel. Devices that help maintain the quality of fuel and oil are known as purifiers. Purifiers may be of the disc or tubular type. These purifiers differ in construction and method; however, both operate to remove water and dirt from fuel by centrifugal force. As you can see from the information you have read in this chapter, a great deal of importance is placed on keeping the fuel system in a high state of purity.

From reading our discussion of fuel injection systems, you should be aware of three types of mechanical diesel fuel injection systems: (1) jerk-type, (2) distributor-type, and (3) unit fuel injector type, and how these three systems differ in construction and the methods by which fuel injection is achieved.

Our discussion of fuel injection would not have been complete without an explanation on how the amount of fuel delivered to the cylinders is controlled. The control of the engine speed is dependent on speed-sensitive devices known as governors. There are two basic types of governors, mechanical and hydraulic. The mechanical governor is used when extremely sensitive operation is not required. The hydraulic governors are more sensitive to speed variations. They are quicker acting and more accurate due to the reduction in friction of the mass of moving parts.

A complete understanding of fuel injection and engine control is a must if you are to operate a diesel in a safe and effective manner. If you are uncertain about any of the information in this chapter, we recommend you reread the sections that are giving you trouble before you continue to chapter 10.

CHAPTER 10

ENGINE STARTING SYSTEMS

In this chapter, we will discuss the operating principles of starting systems used with internal-combustion engines. As an Engineman, you will be concerned with four types of starting systems: (1) electric, (2) hydraulic, (3) air motor, and (4) compressed air admission. Electric starting systems are used with gasoline engines and diesel engines used in small craft (boats). The hydraulic starting system is used where nonmagnetic or lightweight characteristics are required. The air motor system is used wherever practicable because it contains sturdier components and requires less maintenance. Air motors are used to start Alco, Detroit Diesel, and Caterpillar engines. The compressed air admission system is used on many larger engines, such as those manufactured by General Motors, Fairbanks-Morse, and Colt-Pielstick.

For a diesel engine to start, it must turn over fast enough to obtain sufficient heat to ignite the fuel-air mixture. If the engine turns over too slowly, the unavoidable small leaks past the piston rings and past the intake and exhaust valves (4-stroke cycle engines) will allow a substantial amount of the air to escape during the compression stroke. In addition to a loss of pressure, the heat loss from the compressed air to the cylinder walls will be greater at low speed because of the longer exposure.

The escape of air and loss of heat result in a lower temperature at the end of the compression stroke. Therefore, there is a minimum speed at which the diesel must turn over before ignition will occur and the diesel will begin firing. The starting speed depends on the size and type of the engine, and the temperature of the air entering the cylinders.

After reading the information in this chapter, you should be able to describe the four types of starting systems and their methods of operation. You should also be aware of the devices that can be used to help a diesel engine start in cold weather. These devices are commonly referred to as starting aids.

ELECTRIC STARTING SYSTEMS

In this section, we will discuss basic electrical systems that apply to small marine craft (boats). You, as an Engineman, may be required to perform basic maintenance on an electrical starting system for a small boat engine when an electrician is not available.

Electric starting systems use direct current because electrical energy in this form can be stored in batteries and can be drawn upon when needed. The battery's electrical energy is restored when the battery is charged with an engine-driven generator or alternator.

The main components of the electric starting system are a storage battery, starting motor, and associated control and protective devices. Figure 10-1 shows a typical cranking system.

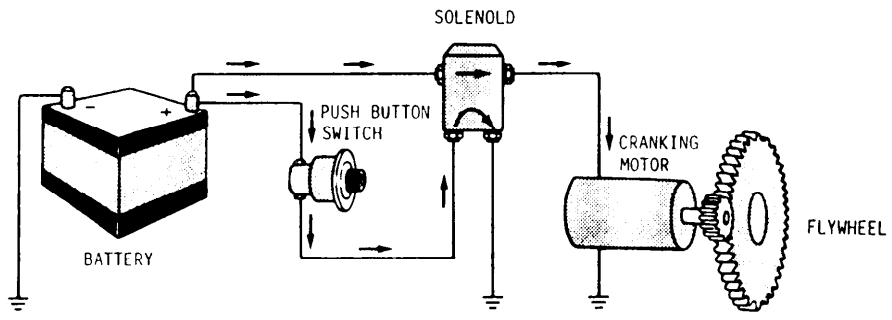


Figure 10-1.—Electrical cranking system and gear reduction.

BATTERIES

The lead acid storage battery provides the power source for starting small boat engines and other types of small and medium size engines. Most starting motors for the engines in small craft are rated for 24 to 28 volts. To supply the required current for starting, four individual 6-volt batteries are connected in series.

For maximum efficiency and long life of the storage battery, periodic inspections are essential. Batteries that serve to start boat engines are subjected to moderately heavy use and may require frequent charging in addition to the charging provided by the engine generator or alternator.

MONITORING THE CHARGING SYSTEM

As an operator, you should be aware of the condition of the charging system of the engine. You can use the ammeter to monitor the charging system. An ammeter is a device that is wired into the electrical circuit to show the current flow to and from the battery and is mounted on the gauge board (panel) along with the other monitoring gauges. After the engine is started, the ammeter should register a high charge rate at the rated engine speed. This is the rate of charge received by the battery to replenish the current the battery has used to start the engine. As the engine continues to operate, the ammeter should show a decline in the charge rate to the battery. The ammeter will not show a zero charge rate since the regulator voltage is set higher than the battery voltage. The small current registered prevents rapid brush wear in the battery-charging generator. If lights or other electrical equipment are connected into the circuit, the ammeter should show discharge when these items are operating and the engine speed is reduced. Information on the electrical devices we have discussed is presented in detail in Navy Electricity and Electronics Training Series (NEETS), modules 1 through 5 (latest editions).

STARTING MOTORS AND DRIVES

The starting motor for a diesel or a gasoline engine operates on the same principle as a direct current electric motor. The motor is designed to turn extremely heavy loads but tends to overheat quickly because it draws a high current (300 to 665 amperes). *To avoid overheating, NEVER allow the motor to run for more than the specified amount of time. Then allow it to cool for 2 or 3 minutes before using it again. Refer to the NA VSEA technical manual for your engine for the recommended cranking and cooling periods.*

The starting motor is located near the flywheel. (See fig. 10-1) The drive gear on the starter is arranged so that it can mesh with the teeth on the flywheel (or the ring gear) when the starting switch is closed. The drive mechanism has two functions: (1) to transmit the turning force to the engine when the starting motor runs and to disconnect the starting motor from the engine immediately after the engine has started and (2) to provide a gear reduction ratio between the starting motor and the engine. (The gear ratio between the driven pinion and the flywheel is usually about 15 to 1. This means that the starting motor rotates 15 times as fast as the engine, or at 1500 rpm to turn the engine at a speed of 100 rpm.)

The drive mechanism must disengage the pinion from the flywheel immediately after the engine starts. After the engine starts, the engine speed may increase rapidly to approximately 1500 rpm. If the drive pinion were to remain meshed with the flywheel and locked with the shaft of the starting motor, at a normal engine speed (1500 rpm), the shaft would spin at a rapid rate of speed (between 22,500 and 30,000 rpm). At such a rate of speed, the starting motor would be badly damaged.

Bendix Drive Mechanisms

Figure 10-2 illustrates a starting motor equipped with a Bendix drive friction-clutch mechanism. The drive mechanism moves the drive pinion so that it meshes with the ring gear on the flywheel.

The pinion of the Bendix drive is mounted on a spiral-threaded sleeve so that when the shaft of the motor turns, the threaded sleeve rotates within the pinion, moving the pinion outward, causing it to mesh with the flywheel ring gear and crank the engine. A friction clutch absorbs the sudden shock when the gear meshes with the flywheel.

As soon as the engine runs under its own power, the flywheel drives the Bendix gear at a higher speed than that at which the shaft of the starting motor is rotating. This action causes the drive pinion to rotate in the opposite direction on the shaft spiral and automatically disengages the

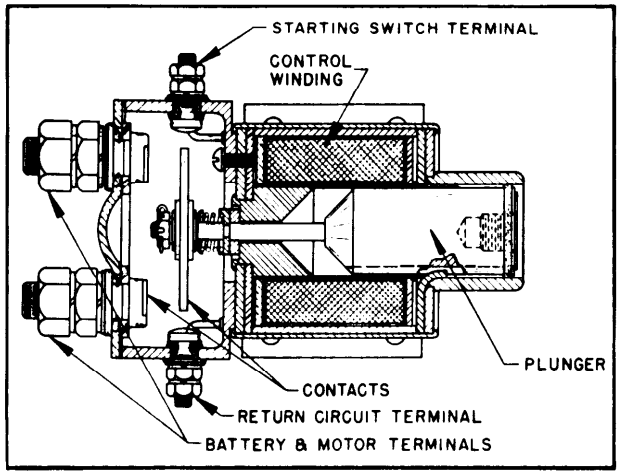
drive pinion from the flywheel as soon as the engine starts.

Special switches are needed to carry the heavy current drawn by starting motors. Starting motors that have a Bendix drive use a heavy-duty solenoid switch (relay switch) to open and close the motor-to-battery circuit and a hand-operated starting switch to operate the solenoid switch. The starting switch is on the instrument panel and may be a push-button or a lever type. The solenoid switch (fig. 10-3) is mounted on and grounded to the starting motor housing so that the wires that must carry the heavy current required by the motor may be as short as possible to prevent voltage loss and overheating resulting from current draw. When the solenoid is energized by the starting switch, the plunger is drawn into the core and completes the circuit between the battery and the starting motor.

Operating precautions on the Bendix drive must be strictly followed. There are times when the engine may start, throw the drive pinion out of mesh, and then stop. When the engine is coming to rest, it may often rock back part of a revolution. If at that moment the pinion is engaged, the drive mechanism may be seriously damaged. Therefore, you must wait several seconds to be sure that the engine is completely stopped before you use the starting switch again.

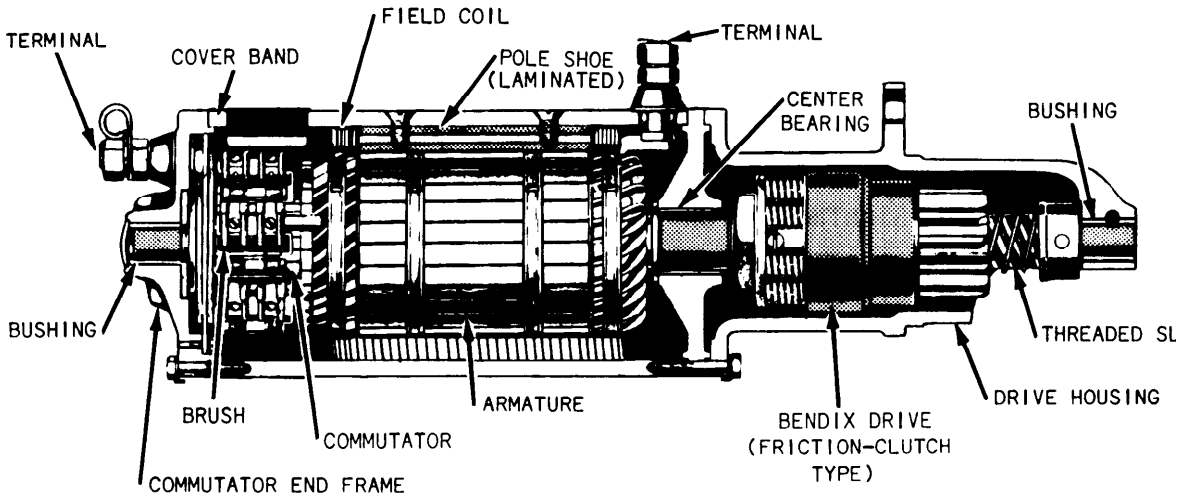
Sometimes the pinion will fail to engage immediately after the starting motor has been energized. When this happens, you will not hear the engine turning over and the starting motor will develop a high-pitched whine. You should immediately de-energize the starting motor to prevent overspeeding. An electric starting motor operating under no-load conditions can quickly overspeed and can be seriously damaged.

If the pinion is to engage and disengage freely, the sleeve and the pinion threads should be free from grease and dirt. The Bendix drive should be lubricated according to instructions in the NAVSEA technical manual.



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Figure 10-3.—A typical solenoid switch assembly.



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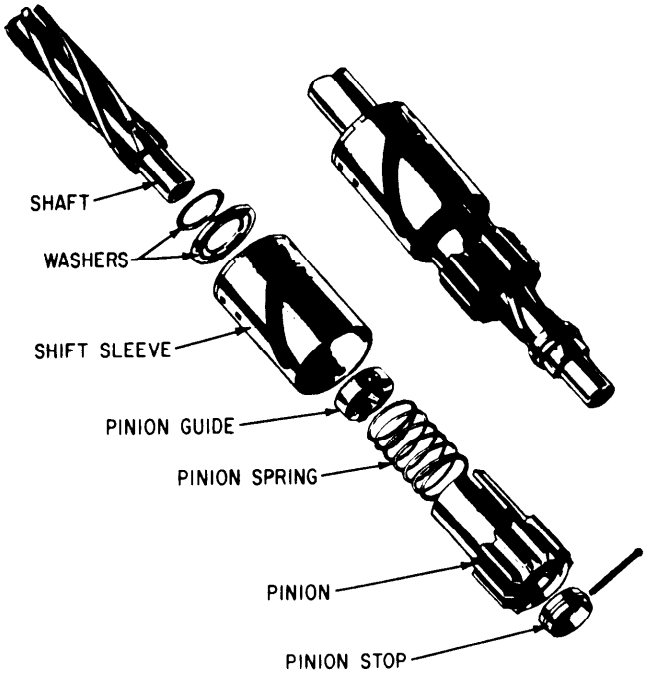
Figure 10-2.—Cross section of a starting motor with a Bendix drive.

Dyer Drive Mechanism

Figure 10-4 shows a starting motor assembly with a Dyer drive mechanism. Figure 10-5 shows an exploded view of the drive assembly. Refer to figures 10-4 and 10-5 as you read the discussion of the Dyer starter mechanism.

The starting motor shown in figure 10-4, equipped with a Dyer shift drive, is operated through a solenoid starting shift and switch. The solenoid assembly is mounted on the starting motor and is connected to the battery and motor. Remote control starting is accomplished by a starter switch on the instrument panel which, upon being closed, energizes the starter solenoid. A heavy-duty plunger inside the solenoid is connected by linkage to the pinion shift lever that operates the Dyer drive. When the starter switch is closed, the battery energizes the coil of the solenoid switch which pulls the pinion gear into mesh with the ring gear on the flywheel. Continuation of the plunger movement closes the solenoid switch contacts, thereby removing the coil from the circuit and permitting the cranking motor to crank the engine.

The Dyer drive consists of a splined section on the armature shaft, a shift sleeve, pinion, gear pinion guide, pinion stop, thrust washers, and springs. (See fig. 10-5.) The thrust washers furnish a thrust bearing for the shift sleeve when it is in the returned position. The springs aid in the lock operation and in the engagement action.

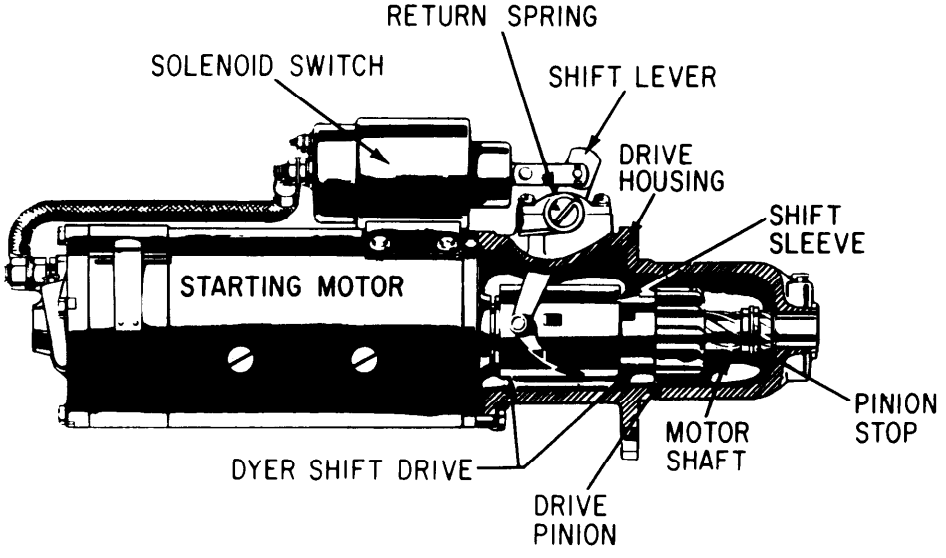


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Figure 10-5.—Dyer shift drive mechanism.

The entire drive is contained in the starting motor drive housing. The movement of the pinion is controlled by a shift lever which is connected directly to the shift sleeve.

The Dyer drive provides a positive engagement of the cranking motor pinion gear with the engine



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Figure 10-4.—A starting motor with a Dyer shift drive.

flywheel before the cranking motor switch contacts are closed or the armature is rotated. This design prevents the pinion gear teeth from clashing with the flywheel ring gear. It also prevents the possibility of broken or burred teeth on either the ring gear or the drive pinion gear. The pinion gear is thrown out of mesh with the flywheel by the reversal of torque as the engine starts.

The operation of the Dyer drive mechanism is similar to that of the Bendix drive. The four stages of operation are shown in figure 10-6. In view A, the mechanism is in the disengaged position. In view B, the starting switch has been energized and the solenoid is pulling its plunger in and is beginning to move the pinion gear toward the ring gear. In view C, the pinion gear has fully meshed with the ring gear, but the motor shaft has not begun to rotate. In view D, the motor shaft is rotating and the shift sleeve has returned to its original position. The drive pinion is moving the flywheel ring gear which cranks the engine.

Sprag Overrunning Clutch Drive

Another type of drive mechanism used by the Navy is the Sprag overrunning clutch. This type

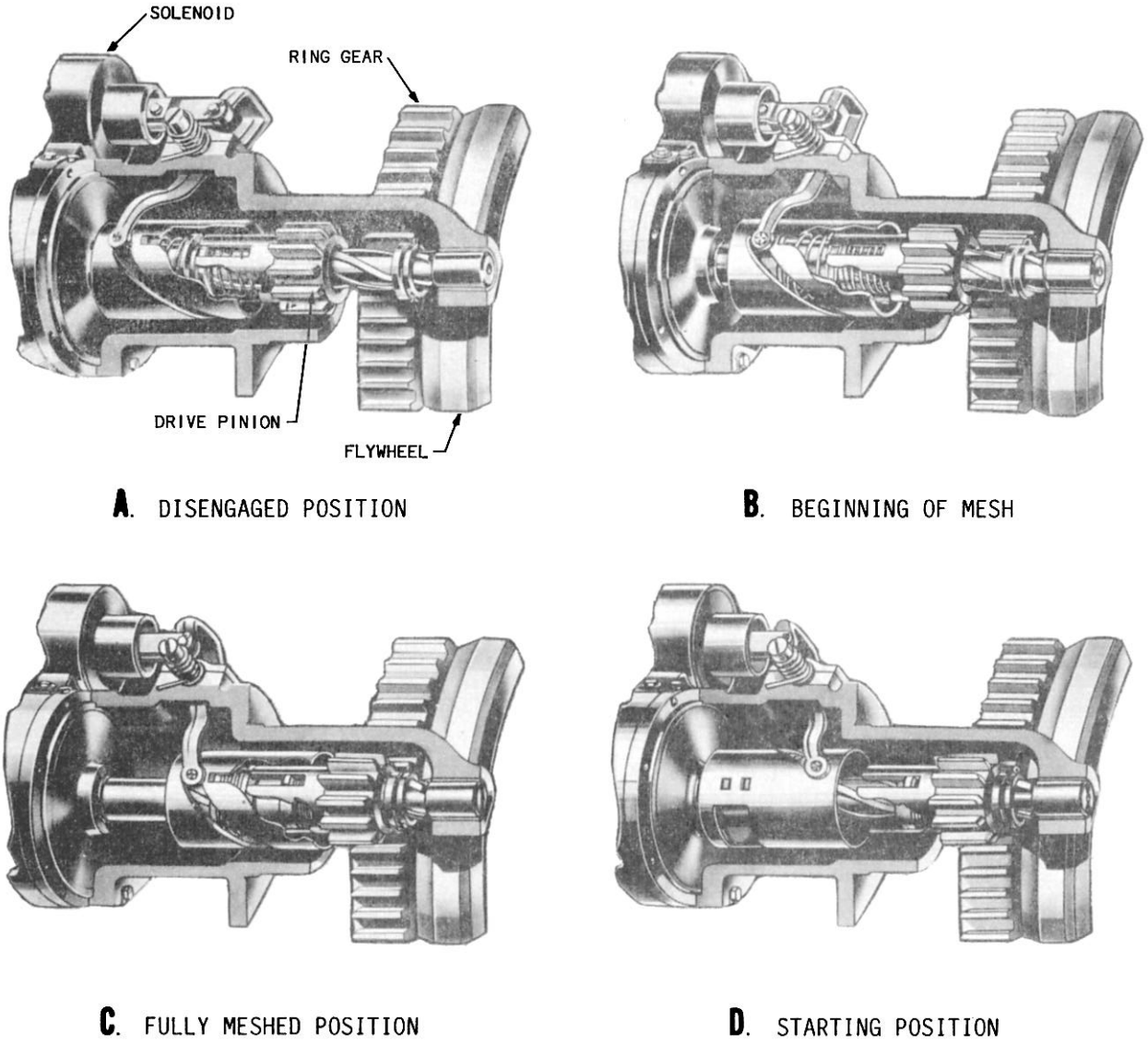


Figure 10-6.—Dyer drive operation.

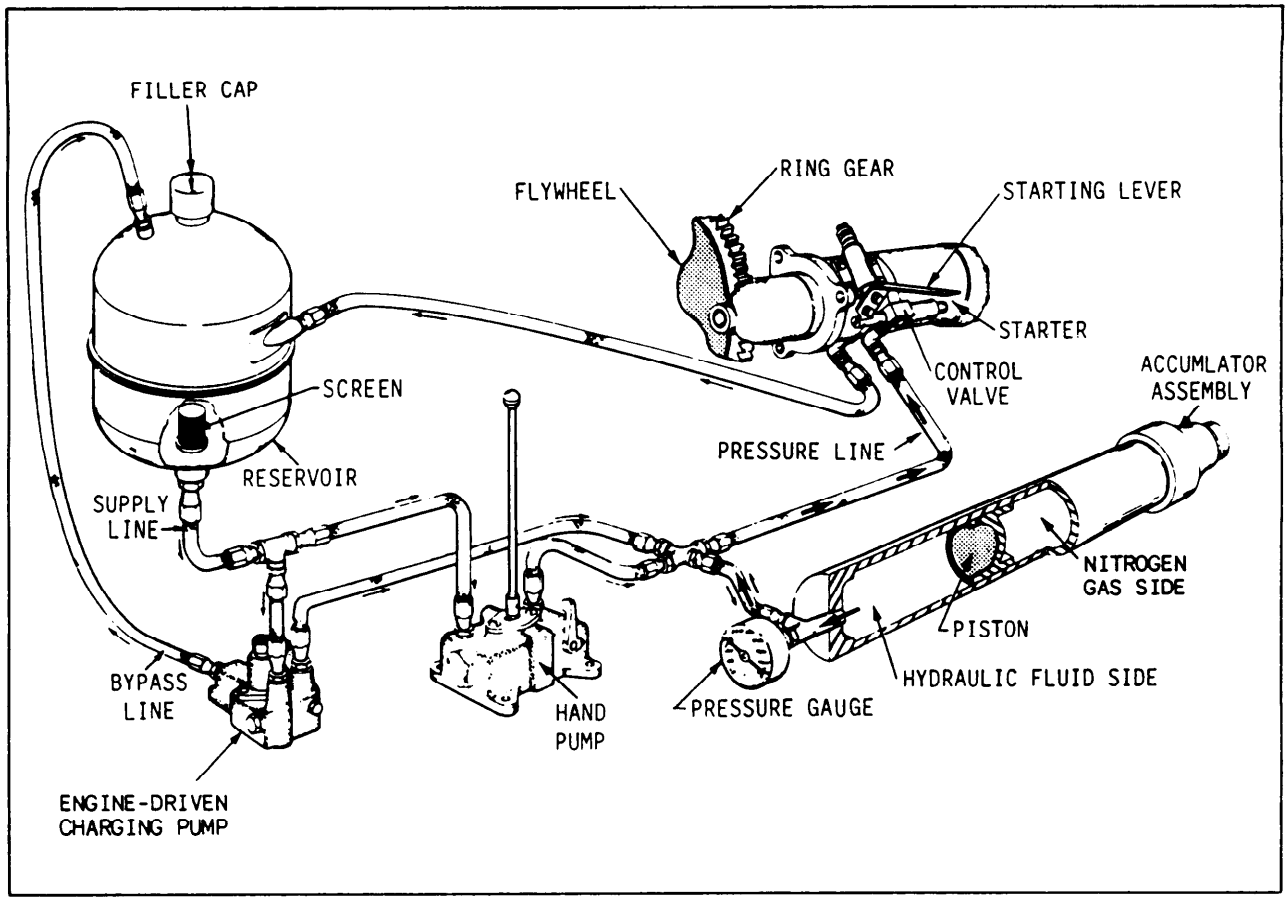
of drive is similar to the Dyer drive in that the pinion is engaged by the action of a lever attached to the solenoid plunger. Once engaged, the pinion will stay in mesh with the ring gear on the flywheel until the engine starts or the solenoid switch disengages. To protect the starter armature from excessive speed when the engine starts, the clutch "overruns" or turns faster than the armature, which permits the starter pinion to disengage itself from the ring gear.

The solenoid plunger and shift lever, unlike the Dyer drive, are completely enclosed in a housing to protect them from water, dirt, and other foreign matter. An oil seal, installed between the shaft and lever housing, and a linkage seal, installed around the solenoid plunger, prevent transmission oil from entering the starter frame or solenoid case. The nose housing of the drive mechanism can be rotated so that a number of solenoid positions can be obtained with respect to the mounting flange.

HYDRAULIC STARTING SYSTEMS

Hydraulic starting systems are used on various small diesel engines. In our discussion, we will use the General Motors hydrostarter system as an example.

The General Motors hydrostarter system, as illustrated in figure 10-7, is a complete hydraulic system used for the cranking of internal-combustion engines. The system is automatically recharged by the engine-driven hydraulic pump after each engine start. The starting potential of this system does not deteriorate during long periods of inactivity. Continuous exposure to hot or cold climates also



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Figure 10-7.—Hydraulic starting system.

has no detrimental effect upon the hydrostarter system. Engine starting torque for a given pressure will remain fairly constant regardless of the ambient temperature.

The hydrostarter system consists of a reservoir, an engine-driven charging pump, a manually operated pump, a piston-type accumulator (with a fluid side and a nitrogen side), a hydraulic, vane-type starting motor, and connecting lines and fittings. Hydraulic fluid oil flows by gravity (or by a slight vacuum) from the reservoir to the inlet of either the engine-driven pump or the hand pump. Fluid discharged by either pump is forced at high pressure into the accumulator and is stored at approximately 3250 psi under the pressure of compressed nitrogen gas. (Nitrogen is used instead of compressed air because nitrogen will not explode if seal leakage permits oil to enter the nitrogen side of the accumulator.) When the starter is engaged with the ring gear on the fly-wheel of the engine, and the control valve is opened, high pressure fluid is forced out of the accumulator by the action of the piston from the expanding nitrogen gas. The fluid flows into the starting motor, which rapidly accelerates the engine to a high cranking speed. When the starting lever is released, the spring action disengages the starting pinion and closes the control valve. This action stops the flow of hydraulic oil from the accumulator. The used fluid returns from the starter directly to the reservoir. (See directional arrows in fig. 10-7.)

During engine operation, the engine-driven charging pump runs continuously and auto-matically recharges the accumulator. When the required pressure is attained in the accumulator, a valve within the pump body opens and the fluid discharged by the pump is bypassed to the reservoir. When the system is shut down, the pressure in the accumulator will be maintained.

The hand pump of the hydrostarter system is a double-action piston pump. It serves to pump fluid into the accumulator for initial cranking when the accumulator has exhausted all the fluid stored in it. The starter is protected from high speeds of the engine by the action of an over-running clutch.

The hydraulic starting system may be used with most small engines now in service without modification other than the clutch and pinion assembly, which must be changed when a conversion from a left-hand to a right-hand rotation is made.

AIR STARTING SYSTEMS

In this section, we will discuss the types of starting systems that derive their power from the pressure of compressed air. The first part of our discussion will cover the ways in which starting air is delivered to the starting system.

SOURCES OF STARTING AIR

Starting air comes directly from the ship's medium-pressure (MP) or high-pressure (HP) air service line or from starting air flasks which are included in some systems for the purpose of storing starting air. From either source, the air, on its way to the starting system, must pass through a pressure-reducing valve, which reduces the higher pressure to the operating pressure required to start a particular engine.

A relief valve is installed in the line between the reducing valve and the starting system. The relief valve is normally set to open at 12 percent above the required starting air pressure. If the air pressure leaving the reducing valve is too high, the relief valve will protect the system by releasing air in excess of a preset value and permit air only at safe pressure to reach the starting system of the engine. Additional information on pressure relief valves and pressure reducing valves will be provided in chapter 13 of this rate training manual.

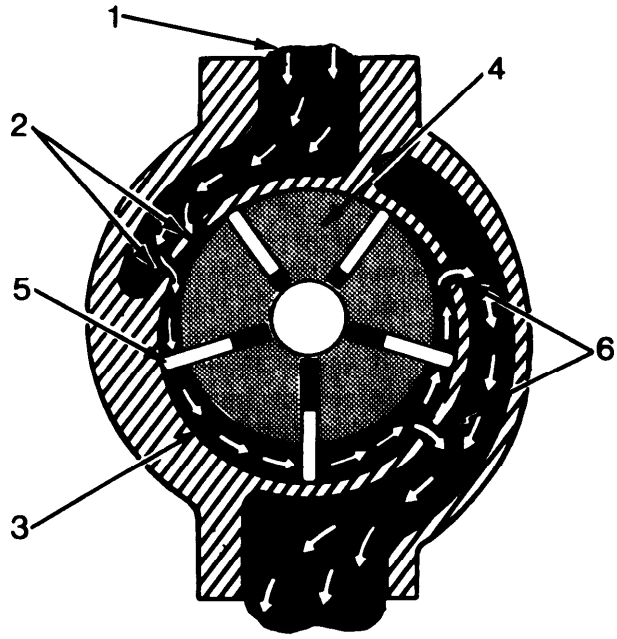
In the following sections, we will discuss two common types of systems that use air as a power source for starting diesel engines—the air starting motor system and the compressed air admission system.

AIR STARTING MOTOR SYSTEM

Some larger engines and several small engines are cranked over by starting motors that use compressed air. Air starting motors are usually driven by air pressures varying from 90 to 200 psi.

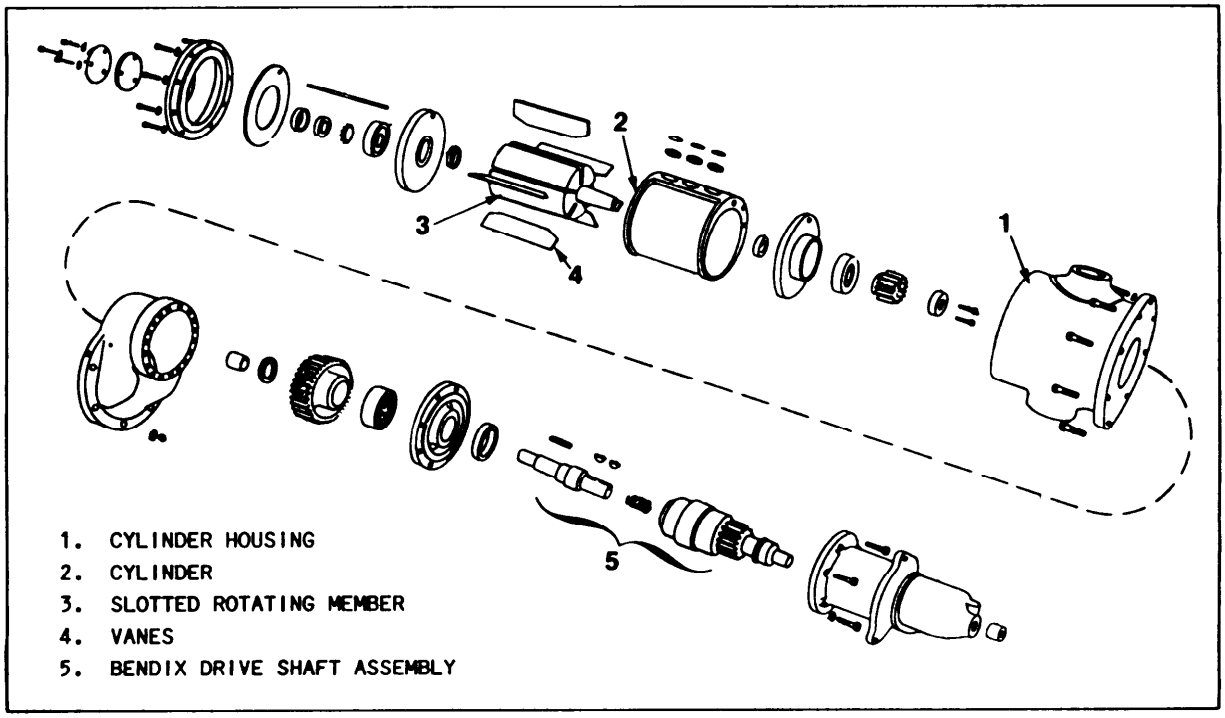
Figure 10-8 shows an exploded view of an air starting motor with the major components identified. Figure 10-9 shows the principles by which the air starting motor functions. As you read the following discussion on the flow of air through the starting motor, refer to figure 10-9. For the relative position of the principal components, refer to figure 10-8.

In figure 10-9, starting air enters through piping into the top of the air starter housing (1) and flows into the top of the cylinder (2). The bore (3) of the cylinder has a larger diameter than the rotor. The rotor (4) inside the cylinder is a slotted rotating member which is offset with the bore of the cylinder. The rotor carries the vanes (5) in slots, allowing the vanes to maintain contact with the bore of the cylinder. The pressure of the starting air against the vanes forces the rotating member to turn approximately halfway around the core of the cylinder, where exhaust ports (6) allow the air to escape to the atmosphere. A shaft and a reduction gear connect the rotating member to a Bendix drive, which engages the ring gear of the flywheel to crank the engine.



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Figure 10-9.—Flow of air through an air starting motor.



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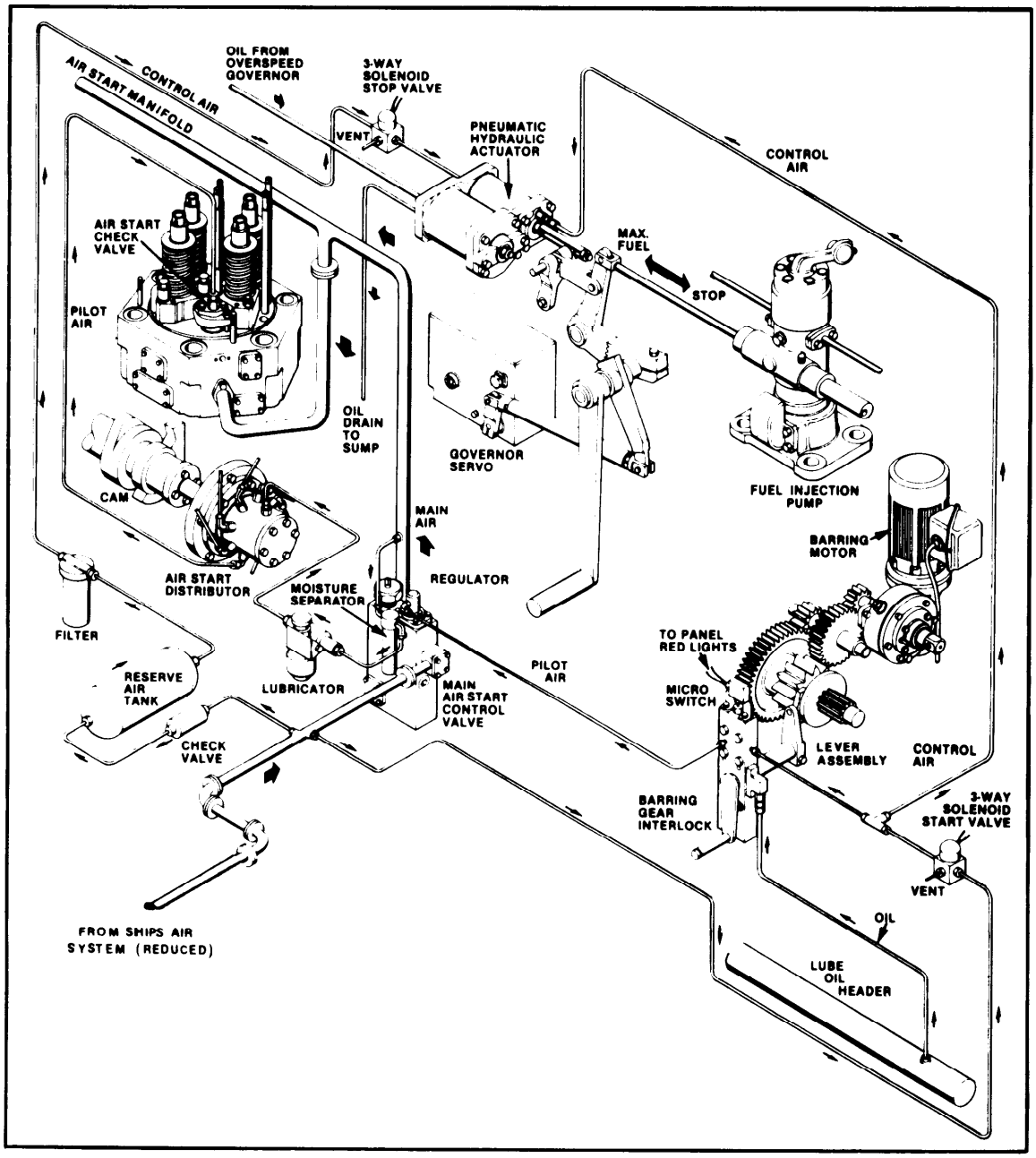
Figure 10-8.—Air starting motor (exploded view).

COMPRESSED AIR ADMISSION SYSTEM

Most large diesel engines are started when compressed air is admitted directly into the engine cylinders. Compressed air at approximately 200 to 300 psi is directed into the cylinders to force the pistons down and thereby turn the crankshaft of the engine. This air admission process continues until the pistons are able to build up sufficient heat from compression to cause combustion to start the engine.

Refer to figure 10-10. The engine is started by the admitting of compressed air into the right-hand bank of cylinders. Control valves and devices that permit compressed air to flow to the cylinders are actuated by control air that is directed through the engine control system.

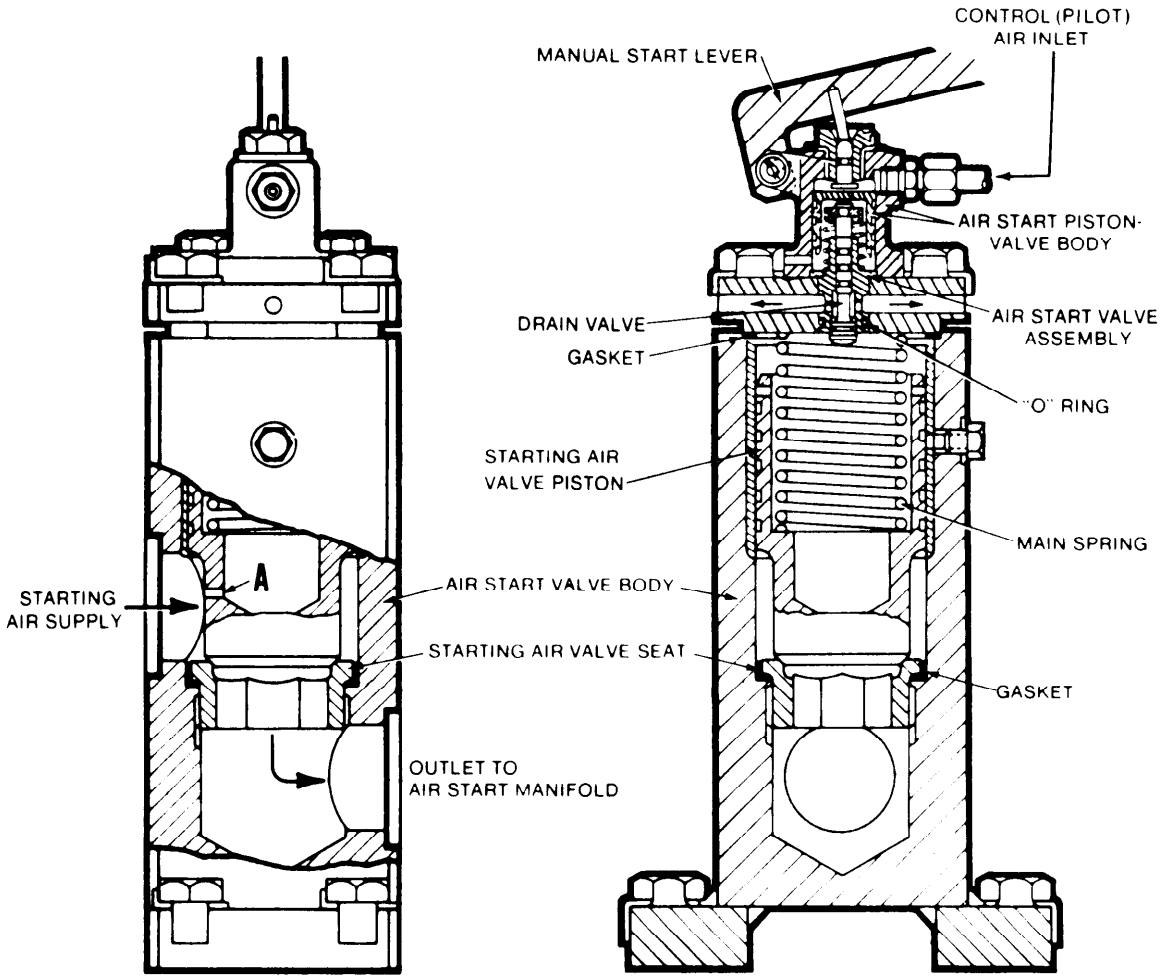
The heart of the engine control system is the main air start control valve. (A cutaway view of



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Figure 10-10.—Compressed air admission starting system (Colt-Pielstick).

this valve is shown in fig. 10-11.) Except when the engine is being cranked, this component acts as a simple stop valve. A small amount of air is routed through the air supply port (A) to the spring side of the starting air valve. This air pressure, along with the force of the main spring, holds the main starting air valve against its seat. (Air pressure is the same on both sides of the piston inside the valve body; however, the surface area inside the piston (at the bottom) is less than the bottom area outside the piston. So the spring is required to hold the piston down against the seat. When air pressure acting on the piston becomes unbalanced, such as when air pressure on the inside of the piston is reduced, air pressure acting on the larger surface area on the outside of the piston will force the piston up off the seat of the starting air valve.) As long as the main starting air valve remains seated, starting air cannot pass through the control valve and enter the air start manifold. However, when compressed air is needed for the engine to start, the drain valve is forced downward, either by air that is brought in through the control air inlet by pilot air or by the pin attached to the manual start lever. When the drain valve is in the proper position, pressurized air above the main spring in the start control valve escapes through the vent ports at the top of the valve body. The resulting release of pressure allows the main starting valve to overcome the spring force and to lift off its seat. In turn, compressed starting air is permitted to pass through the control valve and into the air start manifold. Starting air will continue to pass through the main air start control valve until the drain valve is closed. When the drain valve closes, the area above the piston repressurizes and forces the main starting valve back on its seat. This



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Figure 10-11.—Main air start control valve.

reseating action shuts off starting air through the control valve.

The air start manifold runs parallel to the right bank of cylinders. Jumper lines are connected only to the right bank of cylinders because only one bank of cylinders needs to be attached to the air starting system. The jumper lines connect the air start manifold to the air start check valves in the cylinder head and supply the required air pressure to the cylinders (fig. 10-10).

The entry of starting air into the cylinders is controlled by pilot air. Pilot air leaves the main air start control valve, passes through an air filter and an oiler, and enters the air start distributor. The air distributor is directly driven by the right camshaft. As the camshaft rotates, pilot air is allowed to pass through a line to the appropriate air start check valve in the firing sequence. Pilot air opens each check valve to allow high-pressure starting air to enter the cylinder from the jumper line, force the piston downward, and rotate the crankshaft.

The air start check valve functions as a pilot-actuated air admission valve until the cylinders begin to fire. As the cylinders fire, pressure created by combustion exceeds the pressure of the starting air, this condition forces the air start check valves to close, preventing combustion gases from entering the air start manifold.

At the same time that starting air is delivered to the cylinders, control air at 200 psi is supplied to the forward end of the pneumatic auxiliary start/stop relay and the fuel rack activator piston. The control air causes the piston to pull the fuel racks toward the full-fuel position. Once the engine is started, its speed is controlled by a hydraulic governor with a pneumatic speed mechanism attached for remote engine control. The governor is also equipped with a dial that can be used for local control of engine speed during maintenance, or in an emergency.

The control air that operates the main air start control valve passes through a primary safety device, the barring gear interlock (fig. 10-10). The barring gear interlock prevents the engine from accidentally starting or rotating and also prevents the barring gear from being engaged when the engine is running. The safety feature is provided by the barring lever assembly. When the barring lever assembly is in place, the interlock will not allow control air to reach the main air start control valve, and compressed air will not be admitted to the cylinders.

Basically, all air starting systems operate similarly and contain components that are similar in function to those used in the two types of air starting systems we have discussed.

COLD WEATHER STARTING AIDS

Ignition in a diesel engine is accomplished by a combination of fuel injection and compression of intake air. Diesel engines normally require longer cranking periods than gasoline engines. At low ambient temperatures, a diesel engine is extremely difficult or impossible to start without adequate accessories to assist in the starting process. As the outside temperature drops, battery efficiency is reduced and cranking load becomes high. The increased load results from higher oil viscosity. The cold cylinder walls also chill the incoming air, and the air cannot reach the temperature required for combustion.

The methods used for helping an engine start in cold weather include (1) heating the air in the cylinder (glow plugs); (2) heating the intake air (grid resistor); (3) adding a volatile, easily combustible fluid (ether) to the intake air; or (4) heating the coolant and/or lubricating oil (heaters).

GLOW PLUGS

Deriving its power from the battery, the glow plug is a low-voltage heating element that is inserted in the combustion chamber of each cylinder. The glow plug is used briefly before the cold engine is cranked. In general, the time limit for the use of the glow plug is dependent upon the ambient temperature and the design of the engine. The operating temperature of a glow plug is between 1652° and 1832°F.

GRID RESISTORS

The grid resistor usually consists of an electrical resistance grid mounted on a frame and supported by insulating blocks in the engine air-intake manifold. The grid is preheated by current from the starting battery, before the engine is cranked, and is operated during the cranking period until the engine has reached operating speed.

The basic drawback in the use of glow plugs or the grid resistor as starting aids is that they require battery power that is also needed for cranking. The cranking power of a battery is already reduced at low temperatures. In the following examples, note how the cranking power

of a battery is reduced as the ambient temperature drops:

AMBIENT TEMPERATURE	PERCENTAGE OF CRANKING POWER OF BATTERY
80°F	100 percent
32°F	65 percent
0°F	45 percent

ETHER PRIMERS

A widely used cold weather starting aid for engines of small craft is the ether capsule. The ether capsule serves to inject a highly volatile fluid (ether) into the air intake system to assist ignition of the fuel.

An ether capsule primer (fig. 10-12) consists of a discharge cell, discharge nozzle, and pressure primer capsule, which contains a liquid ether mixture. The discharge cell and the discharge nozzle are connected together by a suitable length of tubing. The discharge cell is a metal enclosure containing a piercing pin and a removable cap for insertion of the pressure primer capsule. When the lever is operated, it forces the capsule against the piercing pin.

The discharge cell is installed at the control station in a vertical position so that the neck of the capsule is always down toward the piercing pin. The discharge nozzle is installed through a pipe connection at the forward end of the intake manifold.

When you are using the ether capsule primer, press the engine starter switch. As soon as the starting motor brings the engine up to cranking speed, operate the discharger lever to discharge the capsule. Continue cranking while the ether mixture is being forced rapidly through the connecting tube to the intake manifold where it is sucked into the cylinders. The capsule requires approximately 15 seconds to discharge, and the diesel engine should start during this interval.

WARNING

Ether must not be used in connection with the grid resistor or glow plug methods. With the high volatility of ether, additional heat could cause ignition in the intake manifold or preignition in the combustion chamber.

HEATERS

Two other types of starting aids are the cylinder-block jacket-water heater and the engine-oil heater. When fuel enters a cold combustion chamber and the intake air is also cold, the fuel fails to evaporate. Instead, it collects in the cylinders, washes the lubrication from the cylinder walls, and dilutes the crankcase oil. These problems are corrected when the coolant or lubricating oil is heated. These heaters function to keep the engine components warm at all times. Moreover, they minimize engine component wear during starting and warmup. The heaters may use steam or electricity as a heat source for the coolant or lubricating oil.

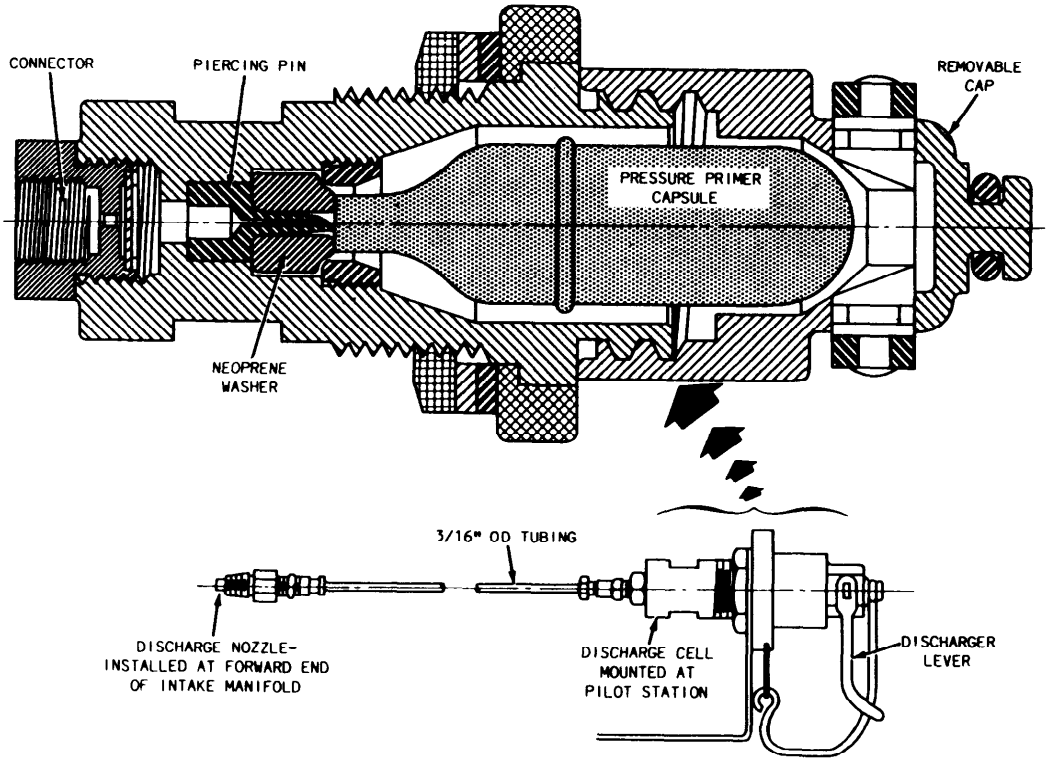
NOTE: Starting aids are not intended to correct deficiencies, such as a weak battery or a poorly tuned engine. They are intended for use when other conditions are normal but the air temperature is too low for the heat of compression to ignite the fuel-air mixture in the cylinders. For additional information on starting aids refer to *Naval Ships' Technical Manual,* chapter 233.

SUMMARY

As an Engineman third class, you must know the purpose and principles of operation of the four types of starting systems used in Navy diesel engines: (1) electric, (2) hydraulic, (3) air motor, and (4) compressed air admission.

You should be aware of the various devices that aid the starting of an engine in cold temperatures. Starting an engine in cold weather may require the use of starting aids that may either (1) heat the air in the cylinder, (2) heat the intake air, (3) inject a highly volatile fluid into the air intake, or (4) heat the lubricating oil and/or the coolant. A commonly used starting aid is the ether capsule. The basic reason for its use is that it will not take away battery power that is needed for cranking.

If you are uncertain about the engine starting systems discussed in this chapter, you should reread the sections that are giving you trouble before continuing to chapter 11.



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Figure 10-12.—Ether capsule primer.

CHAPTER 11

DIESEL ENGINE OPERATING PRACTICES

In this chapter we will apply the material in the preceding chapters to the practical problems of operating diesel engines. Since the diesel engines used by the Navy differ widely in design, size, and application, the procedures we will discuss apply only to general types of installations. Descriptions will apply generally to the various auxiliary and propulsion diesel installations in Navy ships. Detailed and specific information and operating instructions are provided in the manufacturers' manuals for specific installations, in NAVSEA technical manuals, and in ship's doctrine such as the Engineering Operational Sequencing System (EOSS).

After studying the information in this chapter, you should understand the purpose of EOSS and its value in contributing to effective engineering plant operations and casualty control. You should also be able to recognize the fundamental starting, operating, and stopping procedures for a diesel engine under normal operating conditions.

ENGINEERING OPERATIONAL SEQUENCING SYSTEM (EOSS)

Each new class of ship that joins the Navy is more technically advanced and complex than the one before. This means that there is a need for more and better training of personnel who must keep the Navy's ships combat ready. The need for training and the problem of frequent turnover of trained personnel require the type of system that can be used to keep things going smoothly during the confusion of a casualty. The EOSS was developed for that purpose.

The EOSS is a set of procedures and diagrams designed to eliminate problems because of operator error whenever personnel are aligning piping systems or starting and stopping the machinery. The EOSS involves the participation of all personnel from the department head to the fireman on watch. The EOSS consists of detailed written procedures, with charts and diagrams, which were developed for safe operation and casualty control of a specific ship's engineering plant. The EOSS improves the operational readiness of the ship's engineering plant by providing positive control of the plant. This, in turn, reduces operational casualties and extends machinery life.

The EOSS is divided into two subsystems: (1) Engineering Operational Procedures (EOPs) and (2) Engineering Operational Casualty Control (EOCC).

ENGINEERING OPERATIONAL PROCEDURES (EOPs)

The EOPs are prepared specifically for each of the three following levels of operation:

1. Plant supervision (level 1)
2. Space supervision (level 2)
3. Component/system operator (level 3)

The materials for each level or stage of operation contain only the information necessary at that level. All materials are interrelated. Ship's personnel must use these materials together to maintain the proper relationship of each level of operation and to ensure positive control and sequencing of operational events within the plant. Personnel on ships that do not have EOSS should use written operating instructions and a casualty control manual for plant operations.

ENGINEERING OPERATIONAL CASUALTY CONTROL (EOCC)

The EOCC procedures enable plant and space supervisors to RECOGNIZE the symptoms of a possible casualty. They can then ELIMINATE or CONTROL the casualty to prevent possible damage to machinery and to RESTORE plant operation to normal. The EOCC contains procedures and information that describe symptoms, causes, and actions to be taken in the

most common engineering plant casualties. We will discuss casualty control in more detail later in this chapter.

WATCH STANDING

As an Engineman, you will spend much of your time aboard ship as a watch stander. How you stand your watch is very important to the reliability of the engineering plant and the entire ship. You must have the skills to detect unusual noises, vibrations, or odors, which may indicate faulty machinery operation. You must also take appropriate and prompt corrective measures. You must be ready, at all times, to act quickly and independently. You must know the ship's piping systems and HOW, WHERE, and WHY they are controlled. You must know each piece of machinery; how it is constructed, how it operates, how it fits into the engineering plant, and where related equipment is controlled. You must read and interpret measuring instruments. You must understand how and why protective devices function (relief valves, speed-limiting governors, overspeed trips, and alarms). You must recognize and remove fire hazards, stow gear that is adrift, and keep deck plates clean and dry. You must NEVER try to operate a piece of equipment that is defective. You must report all unsafe conditions to the space and/or plant supervisor.

Whatever your watch station, you must know the status of every piece of machinery at your station. You must be sure that the logs are up to date and the status boards are correct, and you must know what machinery is operating before you relieve the watch. Above all, if you don't know—ASK. A noise, odor, or condition may seem abnormal to you, but you may not be certain whether it is a problem. Whenever you suspect any type of abnormal condition, call your immediate watch supervisor.

'You can best gain the respect and confidence of your supervisors and shipmates if you stand an alert watch. Relieve the watch on time or even a little early if possible and be sure you know the condition of the machinery and what you need to do. DON'T TRY TO RELIEVE THE WATCH FIRST AND FIGURE OUT THE DETAILS LATER. The same rules should apply when you are being relieved. Do not be in a big hurry to take off. Make certain your relief understands the situation completely. Before you are relieved, make certain your station is clean and squared away. These little considerations will earn you a good reputation and will improve the overall quality of watch standing within the department.

INSPECTION AND MAINTENANCE

Inspection and maintenance are vital to successful casualty control; they minimize casualties caused by material failures. Through continuous and detailed inspection procedures, you can discover damaged parts, which may fail at a critical time, and eliminate underlying conditions, which will lead to early failure of parts. Underlying conditions will generally include maladjustment, improper lubrication, corrosion, erosion, and other causes of machinery damage. You must pay particular and continuous attention to the following symptoms of malfunctioning equipment:

1. Unusual noises
2. Vibrations
3. Abnormal temperatures
4. Abnormal pressures
5. Abnormal operating speeds

You must thoroughly familiarize yourself with the specific temperatures, pressures, and operating speeds of equipment required for normal operation so that you will detect any departure from normal operation.

If a gauge or other instrument for recording operating conditions of machinery gives an abnormal reading, you must fully investigate the cause. The installation of a spare instrument or a calibration test will quickly indicate whether the abnormal reading is from instrument error. You must trace any other cause to its source.

Because of the safety factor commonly incorporated in pumps and similar equipment, considerable loss of capacity can occur before any external symptoms are apparent. You should be suspicious of any changes in the operating speeds (those normal for the existing load) of pressure-governor-controlled equipment. Variations from normal pressures, lubricating oil temperatures, and system pressures often indicate either improper operation or poor condition of machinery.

When a material failure occurs in any unit, promptly inspect all similar units to determine whether there is any danger that a similar failure might occur. Prompt inspection may eliminate a wave of repeated casualties.

Pay strict attention to the proper lubrication of all equipment, including frequent inspection and sampling to determine that the correct quantity of the proper lubricant is in the unit. It is good practice to make a daily check of samples of lubricating oil in all auxiliaries. Allow samples to stand long enough for any water to settle. When auxiliaries have been idle for several hours (particularly overnight), you should drain a sufficient sample from the lowest part of the oil sump to remove all settled water. Replenish with fresh oil to the normal level.

SYMPTOMS OF ENGINE TROUBLE

When learning to recognize the symptoms that may help you locate the causes of engine trouble, you will find that experience is the best teacher. Even though written instructions are essential for efficient troubleshooting, the information usually given will serve you only as a guide. It is very difficult to describe the sensation you should feel when you are checking the temperature of a bearing by hand; the specific color of exhaust smoke when pistons and rings are worn excessively; and, for some engines, the sound you will hear if the crankshaft counterweights come loose. You must actually work with the equipment before you can associate a particular symptom with a particular problem. Written information, however, can save you a great deal of time and can help you eliminate unnecessary work. Written instructions will make your detection of problems much easier in practical situations.

Symptoms that indicate trouble may be in the form of an unusual noise or instrument indication, smoke, excessive consumption of lube oil, or contamination of the lube oil, fuel, or engine coolant. Figure 11-1 provides a general listing of various trouble symptoms the operator of an engine may encounter. For additional information, you should consult the *Naval Ships' Technical Manual*, chapters 079 and 233.

Noises

Unusual noises that may indicate that a trouble exists (or is impending) are classified as pounding, knocking, clicking, and rattling. You must be able to associate each type of noise with certain engine parts or systems that might be the source of the trouble.

Pounding or hammering is a mechanical knock (and should not be confused with a fuel knock). Pounding or hammering may be caused by a loose, excessively worn, or broken engine part. Generally, troubles of this nature will require major repairs.

Detonation (knocking) is caused by the presence of fuel or lubricating oil in the air charge of the cylinders during the compression stroke. Excessive cylinder pressures accompany detonation. If detonation is occurring in one or more cylinders, you should stop the engine immediately to prevent possible damage.

NOISES	INSTRUMENT INDICATIONS			SMOKE	CONTAMINATION OF LUBE OIL, FUEL, OR WATER
	PRESSURE	TEMPERATURE	SPEED		
POUNDING (MECHANICAL)	LOW LUBE OIL PRESSURE	LOW LUBE OIL TEMPERATURE	IDLING SPEED NOT NORMAL	BLACK EXHAUST SMOKE	FUEL OIL IN THE LUBE OIL
	HIGH LUBE OIL PRESSURE	HIGH LUBE OIL TEMPERATURE	MAXIMUM SPEED NOT NORMAL	BLUISH-WHITE EXHAUST SMOKE	WATER IN THE LUBE OIL
KNOCKING (DETONATION)	LOW FUEL OIL PRESSURE (IN LOW-PRESSURE FUEL SUPPLY SYSTEM)	LOW COOLING WATER TEMPERATURE (FRESH)		SMOKE ARISING FROM CRANKCASE	OIL OR GREASE IN THE WATER
CLICKING (METALLIC)	LOW COOLING WATER PRESSURE (FRESH)	HIGH COOLING WATER TEMPERATURE (FRESH)		SMOKE ARISING FROM CYLINDER HEAD	WATER IN THE FUEL OIL
	LOW COOLING WATER PRESSURE (SALT)	LOW CYLINDER EXHAUST TEMPERATURE		SMOKE FROM ENGINE AUXILIARY EQUIPMENT (BLOWERS, PUMPS, ETC.)	AIR OR GAS IN THE WATER
RATTLING	HIGH COOLING WATER PRESSURE (SALT)	HIGH EXHAUST TEMPERATURE IN ONE CYLINDER			METAL PARTICLES IN LUBE OIL
	LOW COMPRESSION PRESSURE				
	LOW FIRING PRESSURE				
	HIGH FIRING PRESSURE				
	LOW SCAVENGING AIR RECEIVER PRESSURE (SUPERCHARGE ENGINE)				
	HIGH EXHAUST BACK PRESSURE				

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Figure 11-1.—Symptoms of engine trouble.

Clicking noises are generally associated with an improperly functioning valve mechanism or timing gear. If the cylinder or valve mechanism is the source of metallic clicking, the trouble may be due to a loose valve stem and guide, insufficient or excessive valve tappet clearances, a loose cam follower or guide, broken valve springs, or a valve that is stuck open. A clicking in the timing gear usually indicates that there are some damaged or broken gear teeth.

Rattling noises are generally caused by vibration of loose engine parts. However, an improperly functioning vibration damper, a failed antifriction bearing, or a gear-type pump that is operating without prime are also possible sources of trouble when rattling noises occur.

When you hear a noise, first make sure that it is a symptom of trouble. Each diesel engine has a characteristic noise at any specific speed and load. The noise will change with a change in speed or load. As an operator you must become familiar with the normal sounds of an engine. You must investigate all abnormal sounds promptly. You can detect and locate knocks that indicate trouble by using special instruments, such as an engineer's stethoscope, or a "sounding bar," such as a solid metal screwdriver or bar.

Instrument Indicators

An engine operator probably relies more on the instruments to detect impending troubles than on all the other trouble symptoms combined. Regardless of the type of instruments you use, the indications are of no value if inaccuracies exist. Be sure an instrument is accurate and is operating properly. All instruments must be tested at specified intervals or whenever they are suspected of being inaccurate.

Smoke

Smoke is a useful aid for locating some types of trouble, especially if you associate smoke in conjunction with other trouble symptoms. The color of exhaust smoke can also provide you with clues in troubleshooting.

The color of engine exhaust is a good, general indication of engine performance. The exhaust of an engine that is in good condition and operating under normal load has little or no color. A dark, smoky exhaust at normal load indicates incomplete combustion; the darker the color, the greater the amount of unburned fuel in the exhaust. Incomplete combustion may be due to a number of troubles. Some manufacturers associate a particular type of trouble with the color of the exhaust. The more serious troubles are identified below:

1. Bluish-white smoke
   a. Worn or stuck piston rings
   b. Worn cylinder liners
   c. Worn valve guides
   d. Cracked pistons
   e. Leaking injectors
2. Black or gray smoke
   a. Incompletely burned fuel
   b. High exhaust back pressure (clogged exhaust ports, piping, or muffler)
   c. Restricted air inlet (clogged inlet ports, air cleaner, blower inlet screen)
   d. Malfunctioning turbocharger
   e. Improperly timed or faulty injectors
   f. Engine overload (cylinders not balanced)
   g. Low compression (burned valves or stuck piston rings)

Excessive Consumption of Lube Oil, Fuel, or Water

An operator should be aware of engine trouble whenever excessive consumption of any of these vital liquids occurs. The possible troubles indicated by excessive consumption will depend on the system in question. Leakage, however, is one trouble that may be common to all systems. Before starting any disassembly, check for a misaligned system or for leaks in the system in which any excessive consumption is occurring.

ELECTRICAL SYSTEMS

Since most small boat crews do not include an electrician, it will be the responsibility of the boat engineer to troubleshoot and repair any problems in the electrical ignition and lighting systems. The ignition systems have been discussed earlier in this manual, so most of the information here will apply to auxiliary systems.

The electrical system on a typical small boat consists of the following equipment and devices:

1. A battery-charging generator or alternator driven by the propulsion engine
2. An engine starting system
3. A battery used both for starting the engine and for supplying auxiliary loads when the engine is secured

4. A control and distribution panel having switches and fuses for the control and protection of circuits to auxiliary loads
5. Cables for interconnecting the above
6. A voltage regulator

Ungrounded, Two-Wire, 24-Volt System

The electrical system used on Navy small boats is generally a two-wire, ungrounded, 24-volt system. The two-wire system is a necessity on a nonconducting boat hull of wood or plastic. The steel boat hull, like the automobile chassis, makes a good electrical conductor and permits the use of a single-wire electrical system with a grounded or hull return. There are certain reasons, however, for the use of an ungrounded, two-wire system on steel hull boats instead of the single-wire installation.

Because of environmental conditions (such as exposure to saltwater spray), an unwanted ground sometimes occurs on boat electrical systems. Experience has shown that fewer shutdowns occur on ungrounded, two-wire systems than on the single-wire systems. As a result, every effort has been made to provide a two-wire, ungrounded system, and the Electrician's Mate must maintain that system in good condition. An ungrounded system can tolerate the temporary situation of any SINGLE grounded condition, regardless of its location, because no function is affected. A variety of troubles, however, may result when TWO places in the same system become grounded. The more common troubles include blown fuses, failure of the starting system to energize, or faulty operation of any device, such as horns, voltage regulator, lights, and miscellaneous auxiliary loads.

Protection of Circuits

Fuses are normally provided only in the circuits supplying auxiliary loads, such as horns, running lights, cabin lights, spotlights, and communications equipment.

All other circuits, such as the starting motor circuit, solenoid switch control circuit, battery charging circuit, and power supply to the distribution panel, are unfused. This is because the possibility of short circuits or leakage currents is reduced by use of the following equipment, components, and systems:

1. Two-wire, ungrounded electrical system instead of single-wire, grounded
2. Two-wire, ungrounded electrical components of such rugged construction as to make grounding of internal wiring or terminals difficult under normal service conditions
3. Watertight components, such as battery connection boxes, a distribution and control panel, and a starting motor solenoid switch
4. Cables between batteries and starting motor of sufficient size to carry high inrush currents and provided with terminal lugs and end sealing to prevent penetration of moisture
5. Splash guards for attached generators/ alternators
6. Sealed meters or transparent splash shields to protect instruments such as battery charging ammeters
7. Fusing of auxiliary load circuits so that faults in these circuits can be isolated

When you are working around an engine or boat, it will be to your advantage to pay particular attention to how a unit is wired and what type of wiring is used. These observations will make your job of finding and repairing troubles much easier.

When you are on a small boat away from the ship, it will be rather difficult for you to check out a system completely because all the required test equipment will not be available. However, you can check for such things as loose or corroded connections, broken wiring, faulty switches, and burned out lamps or fuses. You can obtain detailed information pertaining to a particular installation from the appropriate NAVSEA technical manual.

OPERATING INSTRUCTIONS FOR DIESEL ENGINES

There may be occasions when a diesel engine must be started, operated, and secured under a variety of demanding conditions, such as emergencies and casualties in engine supporting systems. Operation under such unusual conditions requires that you know and understand the engine installation, the function of supporting systems, and the reasons for the procedures used in normal and emergency operations.

The procedures we will discuss in the following sections are basic steps of engine operation. These procedures do NOT contain every step that must be taken. Remember, circumstances and conditions concerning engine operation will vary. When you are starting or operating an engine or

combating casualties in the engineering plant, use your EOSS.

STARTING PROCEDURES

Diesel engines are started either by hydraulic, electric, compressed air admission, or air-powered starting motors. The general starting procedure for all types of systems consists of (1) making pre-operational checks, (2) aligning supporting systems, and (3) cranking the engine with the starting equipment until ignition occurs and the engine is running.

The steps of the starting procedure will differ depending on whether you are starting the engine after routine securing, after a brief period of idleness, or after a long period of idleness. We will first list the basic steps you should follow for starting an engine that has been routinely secured under normal conditions.

After Routine Securing

To start an engine that has been routinely secured, you should first make ready the supporting systems—cooling, lubrication, and fuel—as follows:

1. Check all valves in the seawater cooling system to ensure that the system is lined up for normal operation.
2. Start the separate motor-driven seawater pump (if it is provided). If an auxiliary engine is cooled from the ship's seawater circulating system, ensure that adequate pressure and flow will be available.
3. Vent seawater coolers, using the vent cocks or vent valves on the heat exchanger shells. (If this is not done, air or gas can accumulate, reducing the effective cooling surface area of a heat exchanger.)
4. Check the level in the freshwater expansion tank. Remember that a cold expansion tank will need a lower fluid level than one that is hot, so leave room for expansion.
5. Check the freshwater cooling system: Set all valves in their operating positions, start the motor-driven circulating pump (if it is provided), vent the system, and check the freshwater level in the expansion tank again. The freshwater level may have dropped if air or gas were vented elsewhere from the system.
6. Check the lubricating system: Check the oil level in the sump; add oil if necessary to bring it to the proper level. Ensure that adequate grease is applied to bearings that require grease lubrication. If oil sump heaters are installed, raise the lubricating oil temperature to 100°F.
7. In idle engines, the lube oil film can be lost from the cylinder walls. It is desirable for you to restore this film before you actually start the engine. (Large diesel engines will restore the film by pressurizing the lube oil system and jacking the engine over without starting it. The pressure in the lube oil system will oil the cylinders, and the pistons will distribute the oil film.) To pressurize the lubricating system, either start the motor-driven lubricating oil pump, or air-driven pre-lube pump (if installed), or operate a hand-operated lubricating oil pump. If the lubricating oil pump is driven by the engine, it will develop pressure when the engine is jacked over. To reduce the load on the jacking gear and prevent an accidental start, open any cylinder test valves or indicator cocks. Then turn the engine over using the jacking gear, which may be motor-driven or hand-operated. As the engine turns over, observe the indicator cocks for excessive moisture. The presence of excessive moisture indicates water or fuel accumulation in the cylinders.
8. When you have performed the preceding operation, disengage the jacking gear and restore the cylinder test valves or indicator cocks to their operating positions.
9. Line up and prime the fuel systems. Check to ensure that there is sufficient clean fuel for the anticipated engine operation.
10. Test the alarm panel for power by manually operating such alarms as the low-pressure lubricating oil alarm and the freshwater high-temperature alarm.
11. Now start the engine with the starting system. Follow the approved written procedures for the type of starting system in use.
12. Once the engine is running, energize the low-pressure lube oil alarm and the water temperature alarm. Pay careful attention to all gauges and other indications of engine condition and performance. Diesel engines tend to be noisy, particularly when they are cold and idling. Familiarity with the normal sounds of the engine will help you avoid unnecessary panic.

If the lube oil pressure does not rise immediately to the operating pressure, STOP the engine and determine the cause of the low pressure.

13. Idle the engine until the lube oil temperature reaches 100°F. Next, apply a light

load of 20 to 30 percent. When the lube oil temperature reaches 120°F, apply the normal load (50 to 80 percent). If possible, avoid placing a load on the engine until the engine has reached operating temperature. Normal or high loading of a cold engine will produce carbon in the cylinder heads, cause excessive engine wear, and dilute the lubricating oil. The procedures for placing the engine "on the line" will depend on the type of installation. In general, it is best to bring the engine up to speed gradually, while being alert for symptoms of trouble when you are initially loading the engine and while the engine is approaching normal range.

After a Brief Period of Idleness

Starting a warm engine, after it was recently secured and if no unusual conditions are suspected, consists of (1) aligning the systems that may have been secured (such as circulating water), (2) disconnecting the engine from the load, and (3) cranking the engine up to starting speed. Carefully observe the lubricating oil pressure. The temperature of coolant may exceed normal operating temperatures for a minute or so until the heat accumulated in the secured engine is removed.

After Overhaul or a Long Period of Idleness

You should make additional checks and inspections when the engine you are starting has been idle for a long period of time or has been recently overhauled. You should perform the following checks:

1. Inspect the parts of the engine system that have been worked on to ensure that the work is complete, that the covers have been replaced, and that it is safe to operate any valves or equipment that have been tagged out of service. (All DANGER tags must be removed.)
2. Check all pipe connections to see whether the connections are tight and whether the systems have been properly connected.
3. Fill the freshwater cooling system with treated water if it has been drained. Be sure coolant is flowing through all parts and components of the system. Vent the system.
4. Make a thorough check of the lubricating system. Check the sump level and fill the sump if necessary. If a separate oil pump is installed, pre-lube the engine. You can consider the system to be pre-lubed when a slight pressure registers on the engine oil pressure gauge. Then make a visual check, with inspection plates removed, to see whether oil is present at all points of the system and in each main bearing. Examine pipes and fittings for leaks. If lubricators are installed, be sure they are filled.
5. Inspect the air receiver, the filter, and the discharge passages of the blower for cleanliness, and remove any oil accumulations.
6. If the engine has a hydraulic governor, inspect the governor oil level. If an overspeed trip is installed, be sure it is in proper operating condition and position.
7. Examine all moving parts of the engine to see that they are clear for running. Check the valve assemblies, including the intake, exhaust, and air-starting valves, and the fuel control linkage for freedom of movement.
8. Inspect the fuel service tank for the presence of water and sediment. Fill the tank with clean fuel if necessary. Start the auxiliary fuel pump (if one is installed) and see whether the fuel pressure gauges are registering properly. Examine the fuel piping and fittings for leaks, especially the fittings and lines inside the engine. Thoroughly vent all air from the fuel system, using the vent cocks. Be sure that the fuel strainers have been cleaned and that new filter elements have been installed.
9. If the engine has an air-starting system, open the lines on the system and blow them out. Reconnect the lines and pressurize the starting-air banks (flasks).
10. Make a final check to ensure that all parts are in place, then open all scavenging-air header and exhaust header manifold drains.
11. Now start the engine, using the procedures for a routinely secured engine.

NORMAL OPERATING PROCEDURES

Operation of a diesel engine cannot be separated from the operation of the equipment the engine is driving. Therefore, for purposes of our discussion, we will assume that you, as the operator, are fully aware of the complete system you are running. Each type of engine and installation has its special operating routine. A systematic procedure has already been established, based on these special requirements and on the experience of the engine operators with the particular installation. You must respect and

follow this procedure. The following information is general and should be considered as incomplete in terms of operation of any specific plant.

While an engine is operating, its performance is monitored and observed for two purposes: (1) to recognize early any unsatisfactory operation or impending malfunctions so that immediate casualty control procedures can be started, and (2) to develop a comparative record over a period of time so that gradually deteriorating conditions can be detected. For the latter purpose, you must keep a complete log of all operating conditions. Observe and record the operating pressures and temperatures in the log at hourly intervals. Compare the entries over a period of time and note any deviations from normal conditions. An example of an engine operating record is provided in figure 11-2.

You must be alert to changing or unusual noises made by the operating machinery. Gradually changing sounds are difficult to detect, especially if you are inexperienced. Often an oncoming watch will detect a new sound that the present watch was not aware of.

When unusual operating conditions occur, load, lubrication, cooling, engine speed, or fuel supply problems are usually responsible, either directly or indirectly. You must be alert to changes in any of these areas. In the next sections, we will provide you with some general guidelines.

Load

The manner of applying a load to an engine and the regulation of the load will depend on the type of load and the design of the system. The procedures for loading an engine, or placing it on the line, are established by the EOSS.

Whenever you are starting a cold engine, allow ample time to build the load up *gradually.* NEVER fully load an engine before it has been warmed up. Gradual application of the load will prevent damage to the engine from such conditions as uneven rates of expansion and inadequate lubrication at low temperatures. (An exception to this rule is the use of emergency generators, set up for automatic mode, in which the engines must take on rated loads as soon as they are started.)

Never operate a diesel engine for prolonged periods with less than one-third of its rated load. Combustion at low load is incomplete, so partially burned fuel and lubricating oil may cause heavy carbon deposits which will foul the valve stems, injector tips, piston rings, and exhaust systems. In addition to these problems, prolonged operation at low-load conditions may cause the exhaust valves to stick and burn, dilute the lubricating oil, scuff the cylinder liners, increase fuel consumption, and cause excessive smoke when the load is increased. If you must operate an engine at less than 30 percent power for more than 30 minutes, you should increase the load to above 50 percent power at the first opportunity.

Diesel engines are designed to operate up to full-load conditions for prolonged periods. However, diesel engines should NEVER be operated at an overload except in an emergency. This includes both excessive torque and engine speed. Overload may be indicated by excessive firing pressures and exhaust temperatures. When conditions indicate an overload, reduce the load immediately.

Lubrication

We discussed the importance of lubrication in chapter 8 of this training manual. The performance of the lubrication system is one of the most important factors of engine operation you can monitor. Indicators continuously show oil temperature and pressure in key parts of the system. While the engine is operating, you should monitor the indicators and sight glasses on a regular basis. An alarm (horn or siren) will usually warn you of low pressure. If an alarm is not installed (as for example on an engine that is used in a small boat), you must continuously monitor the oil pressure and check the oil level. Under typical operating conditions, you should be able to estimate the rate at which the engine burns its lubricating oil and to predict when replenishment will be needed.

The condition and cleanliness of the lubricating oil is critical for long engine life. Therefore, you should clear the metal-edge type of lubricating oil strainers by rotating the cleaning handle. (This procedure should be performed during each watch.) The condition of filters is often indicated by the amount of pressure drop from the inlet to the outlet. Gauges are installed to indicate this differential. You should check these gauges frequently. As mentioned in chapter 8, and as specified by PMS, a test kit is available for you to use to check the condition of the lubricating oil.

DIESEL ENGINE OPERATING RECORD – ALL SHIPS

NAVSEA 9231/2 (8-76) (FORMERLY NAVSEC 9410/2) S/N 0116-LF-082-3110

RETAIN 2 YEARS – THEN DISPOSE ACCORDING TO CURRENT DISPOSAL INSTRUCTIONS

U.S.S.	TIME ZONE DESCRIPTION	CLOCKS SET – BACK OR AHEAD HRS. MINUTES AT	LOCATION ☐ AT SEA ☐ IN PORT	DATE

CHECK ONE ☐ PROPULSION ☐ AUXILIARY ENGINE NO. _____ * Preferred to 30" Barometer

DISREGARD WHEN NOT REQUIRED

TIME	TACHOMETER	GENERATOR					TEMPERATURES										PRESSURES											CLUTCH AND REDUCTION GEAR					
		ELECTRIC LOAD		TEMPERATURE			SALT WATER		FRESH WATER			LUBE OIL		HOTTEST CYLINDER		SCAV. ENG. INC. AIR	SEA WATER AT PUMP	FRESH WATER TO ENG.	LUBE OIL		FUEL OIL		SCAV. ENG. INC AIR	BACK PRESSURE (IN.)	VAC.* UUM (IN.)	CRANK-CASE MANOMETER (IN.)	LUBE-OIL SUMP (GAL.)	L.O. IN CLUTCH (°F)	L.O. OUT CLUTCH (°F)	L.O. IN R. GEAR (°F)	L.O. OUT R. GEAR (°F)	L.O. OR AIR IN CLUTCH (°F)	L.O. IN R. GEAR (P.S.I.)
		AMPS.	VOLTS	AIR TO CLR.	FWD. BRG.	AFT BRG.	INJECTION	OVERBD.	TO ENG.	FROM ENG.	TO OIL CLR.	TO ENG.	FROM ENG.	NO.	TEMP.		AT PUMP	TO ENG.	AT PUMP	AT ENG.	TO FILT.	FROM FILT.											
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ENGINE HOURS	THIS COMMISSION	TOTAL TODAY	BROUGHT FWD.	TOTAL	SINCE OVERHAUL	TOTAL TODAY	BROUGHT FWD.	TOTAL	SNORKEL	TOTAL TODAY	BROUGHT FWD.	TOTAL

0000-0400	0400-0800	0800-1200

A-6826

Figure 11-2.—Diesel engine operating record.

Pressures and Temperatures

You must ensure that all pressures and temperatures are maintained within the normal operating ranges. If this is not possible, secure the engine. You must also check all instruments frequently. The NAVSEA technical manual will provide you with detailed information concerning the proper operating pressures and temperatures. When this information is not available, maintain the temperature of the lubricating oil as it leaves the engine between 160° and 200°F (180° F is preferred), and maintain the temperature of the fresh water as it leaves the engine at not less than 155°F or more than 185°F (170°F is preferred). Do not allow the temperatures in the seawater cooling system to exceed 130°F. Higher temperatures will cause deposits of salt and other solids in the coolers and piping and will aggravate corrosion.

Make frequent checks of the cooling system to detect any leaks. Vent coolers and heat exchangers at least once each watch. Check the level of the fresh water in the expansion tank frequently and add fresh water as necessary. If the freshwater level gets low enough to cause overheating of the engine, NEVER add cold water until after the engine has cooled.

Critical Speeds

The vibrations resulting from operation at destructive critical speeds will cause serious damage to an engine.

All moving parts of machinery have critical speeds. CRITICAL SPEED means there are certain ranges of speed during which excessive vibration in the engine will be created. Every part of the engine has a NATURAL PERIOD OF VIBRATION, or FREQUENCY. When impulses set up a vibration that coincides with the natural frequency of the body, each impulse adds to the magnitude of the previous vibration. Finally, the vibration becomes great enough to damage the engine structure.

Vibration may be set up by linear impulses from reciprocating parts or by torsional impulses from rotating members. The crankshaft is the part that causes torsional vibration, because pressure impulses on the piston cause the crankshaft to twist. When the pressure acting on the piston in each cylinder decreases, the shaft untwists. If pressure impulses, which are timed to the natural period of the shaft, are permitted to continue, the amplitude of vibration will become so great that the shaft can break. If the speed of such an engine is changed, however, the pressure impulses will no longer coincide with the natural period of the shaft and the excessive vibration will stop.

Since each engine has a natural period of vibration (which cannot be changed by the operator), the only control you have is to avoid operating the engine at critical speeds. If critical speeds exist below the normal speed of the engine, you should pass through the critical ranges as quickly as possible when you are changing engine speed. Detailed information concerning critical speed ranges is provided with each installation. Tachometers should be marked to show any critical speed ranges to make it easier for you to keep the engine out of the critical ranges. Remember, tachometers sometimes get out of adjustment. Consequently, you should frequently compare each tachometer with a calibrated mechanical counter.

Fuel

You must maintain an adequate supply of clean fuel. (The importance of clean fuel was discussed in chapter 9.) Check the fuel system frequently for leaks. Clean all fuel strainers at periodic intervals. Replace fuel filter elements whenever necessary. When diesel fuel purifiers are provided, purify all fuel before you transfer it to the service or day tanks. Frequently check the service tanks for water and other settled impurities by sampling through the drain valve at the bottom of the tank. Drain off water and impurities.

Stopping and Securing Procedures

You can stop a diesel engine by shutting off the fuel or air supply. You can shut off the fuel supply by placing the throttle or the throttle control in the STOP position. If the engine installation permits, it is a good idea to allow the engine to idle, without load, for a short time before you stop it. This practice will permit engine temperature to reduce gradually. It is also good practice to operate the manual overspeed trip when you are stopping the engine so that you can check the operating condition of the device. Before tripping the overspeed trip, reduce the engine speed to the specified idling speed. Some overspeed trips reset automatically. In some installations, however, you must reset the overspeed trip manually before the engine can be started again.

In addition to the detailed procedures listed in various EOSS checklists and NAVSEA technical manuals, you should take the following steps after an engine has stopped:

1. Open the drain cocks on the exhaust lines and on the scavenging-air inlet headers (if they are provided).
2. Leave open the specified number of indicator cocks, cylinder test valves, or hand-operated relief valves so you can detect any water accumulation in the cylinders prior to starting the engine.
3. Secure the air pressure. If starting air is left on, the possibility of a serious accident will increase.
4. Close all sea valves.
5. Allow the engine to cool.
6. Clean the engine thoroughly by wiping it down before it cools. Clean the deck plates and see that the bilges are dry.
7. Arrange to have any casualties repaired. No matter how minor casualties may appear, repairs must be made and troubles must be corrected promptly.

PRECAUTIONS IN DIESEL ENGINE OPERATION

You must obtain the specific safety precautions for a given engine from the appropriate NAVSEA technical manual. In addition to the guidelines in the NAVSEA technical manual, you should observe the following precautions when operating or maintaining a diesel engine.

Relief Valves

If a relief valve on an engine cylinder lifts (pops) several times, stop the engine immediately. Determine the cause of the trouble and decide upon the correct solution. Except in an emergency, NEVER lock a relief valve in the closed position. Pressure-relief mechanisms are fitted on enclosures in which excessive pressures may develop.

Fuel

When fuel reaches the injection system, it should be absolutely free of water and foreign matter. You must thoroughly centrifuge the fuel before using it, and you must keep the filters clean and intact. Remember, fuel leakage into the lubricating oil system will cause dilution of the lubricating oil with a consequent reduction in viscosity and lubricating properties.

Cooling Water

Do NOT allow a large amount of cold water, under any circumstances, to enter a hot engine suddenly. Rapid cooling may crack a cylinder liner and head or may cause a piston to seize within a cylinder. Reduce the load or, when ordered to do so, stop the engine when the volume of circulating water cannot be increased and the temperatures are too high. In freezing weather, you must carefully drain all passages and pockets in the engine that contain fresh water and that are subject to freezing, unless an antifreeze solution has been added to the water.

Starting Air

When engines are stopped, you must vent all starting-air lines. Serious accidents may result if pressure is left on. Intake air must be kept as clean as possible. Accordingly, you must keep all air ducts and passages clean.

Cleanliness

Cleanliness is essential to efficient operation and maintenance of diesel engines. You must maintain clean fuel, clean coolants, clean lubricants, and a clear exhaust. You must also keep the engines clean at all times, and take steps to prevent oil or fuel from accumulating in the bilges or in other areas to prevent fire hazards.

EMERGENCY DIESEL GENERATORS

Most naval ships are equipped with diesel-driven emergency generators. (Diesel engines are most suitable for this application because of their quick-starting ability.) Emergency generators furnish power directly to vital electrical auxiliaries, such as the steering gear and the ship's gyro. In addition, emergency generators may serve as a source of power for the casualty power distribution system. All engineering personnel should become familiar with the emergency and casualty power systems aboard their ship.

Emergency diesel generator sets must be ready at all times for immediate use. You should complete the following checks to ensure that the support systems and control system are aligned

and that the emergency generator is ready for operation.

1. Fuel service tank filled, with all water drained.
2. Fuel system valves correctly aligned.
3. Air flask(s) charged
4. Air-starting system valves correctly aligned
5. "Keep warm" system(s) (if used) activated
6. Switchboard set to AUTOMATIC position. (The green light should be on.)

A typical shipboard plant may consist of two emergency diesel generators, one forward (near the bow and above the waterline) and one aft (near the stern), in spaces outside the main machinery spaces. Each emergency generator has its individual switchboard and switching arrangement for control of the generator and for distribution of power to certain vital auxiliaries and to a minimum number of lighting fixtures in vital spaces.

The capacity of the emergency unit varies with the size of the ship in which it is installed. Regardless of the size of the installation, the principle of operation of the engine is basically the same as it is for any diesel engine.

Emergency diesel engines are started either by compressed air or by a starting motor and develop full-rated load power within 10 seconds of starting. In a typical installation, the starting mechanism is actuated when the ship's normal supply voltage on the bus falls to approximately 80 percent. (In a 440-volt system, this would be approximately 350 volts.) The generators are not designed for parallel operation. Therefore, when the ship's supply voltage fails, a transfer switch automatically disconnects the emergency switchboard from the main distribution switchboard and connects the emergency generator to the emergency switchboard. With this arrangement, transfer from the emergency switchboard back to the main distribution switchboard is accomplished manually. Then, the emergency generator must be manually stopped and reset for automatic starting.

Since emergency diesel generators are of limited capacity, only certain circuits can be supplied from the emergency bus. These include such circuits as the steering gear and the interior communications switchboard. If some vital circuit is secured, another circuit may then be cut in, up to the capacity of the generator.

OPERATING INSTRUCTIONS

Normally, the emergency diesel generator will start automatically, but for test purposes and under other conditions it may be started and operated manually. The following guidelines are for testing the operation of an air-started emergency diesel generator set.

The engine is started automatically when the ship's normal supply fails and causes the solenoid air valve (located between the starting-air flask and the engine) to open, admitting starting air to the engine. The engine then turns over on air until firing begins. As the engine speed increases, the air cutoff governor valve closes and shuts off the starting air. As soon as the normal operating speed is reached and the generator develops normal voltage, the solenoid air valve also closes to shut off the starting-air supply. (The starting-air flask is charged from the high-pressure air system, through a reducing valve. The air stored in the starting-air flask varies in pressure from 300 to 600 psi, depending on the installation.)

To start the engine manually, de-energize the solenoid valve. If the ship's supply current is not broken, you must open the switch in the solenoid circuit. Then, admit starting air to the engine by opening the valve manually with the handwheel. After firing begins, turn the handwheel to close the valve and cut off the starting air. (The handwheel must be turned to the open position of the valve whenever you must leave the generator set available for emergency service.)

If the lubricating oil pressure does not build up immediately after the engine starts, shut down the engine and determine the cause of the trouble. NEVER operate the engine without lubricating oil pressure. At regular intervals, check the lube oil pressure, fuel pressure, cooling water temperature, and exhaust temperature. (In addition, clean the fuel and lubricating oil filters regularly.)

To SHUT DOWN or STOP the engine, move the fuel-control lever to the STOP position. After the lever is released, it will automatically return to the running position to permit the engine to be restarted.

OPERATING PRECAUTIONS

You must observe the following operating precautions and inspections:

1. Do NOT operate the engine without lubricating oil pressure; this will cause serious damage.

2. Do NOT operate the engine in an overloaded or unbalanced condition. An overload condition on one or more cylinders may be indicated by an increase in the exhaust temperature or by smoky exhaust.

3. Do NOT operate the engine with an abnormal water outlet temperature.

4. Do NOT operate the engine after an unusual noise develops; the noise might be an indication of pending trouble. Investigate the noise and correct any trouble, particularly if the condition may prove harmful to the engine.

5. If the overspeed device trips and shuts down the engine, investigate the cause of the trouble before you restart the engine.

6. Make certain that the fittings of the ventilation system that serve the compartment in which the engine is located are open. If you start a diesel engine while the vent system is secured, the engine will consume the air in the compartment. Under these conditions, the engine may continue to operate long enough to suffocate you. This precaution applies to installations where the engine does not have a direct air supply from the outside to the intake manifold. THESE PRECAUTIONS ALSO APPLY TO EMERGENCY DIESEL FIRE PUMPS.

FACTORS INFLUENCING ENGINEERING CASUALTY CONTROL

The scope of engineering casualty control is much broader than the immediate actions that are taken at the time of a casualty. Engineering casualty control reaches peak efficiency through a combination of sound design, careful inspection, thorough plant maintenance (including preventive maintenance), and effective personnel organization, management, and training. CASUALTY PREVENTION IS THE MOST EFFECTIVE FORM OF CASUALTY CONTROL.

The primary instructions and guidelines you should use to handle any engineering casualty to your ship are as follows:

1. Engineering Operational Casualty Control (EOCC) procedures
2. Ship's casualty control manual (for ships without EOCC)
3. Ship's damage control manual
4. Ship's damage control bills (part of the ship's Watch, Quarter, and Station Bill)
5. Ship's Organization and Regulations Manual (SORM)

DESIGN

Sound design influences the effectiveness of casualty control in two ways: (1) it eliminates weaknesses which may lead to material failure, and (2) it installs alternate or standby means for supplying vital services in the event of a casualty to the primary means. Both of these factors are considered in the design of naval ships. Individual plants on board ship are equipped with duplicate vital auxiliaries, loop systems, and cross-connections. Complete propulsion plants are also designed to operate as isolated units (split-plant design).

COMMUNICATIONS

Casualty control communication is vitally important to the operation and organization of the ship. Without adequate and proper means of communication, the whole organization of casualty control will fail in its primary objective.

As a provision for. sufficient means of communication to be available, several different systems are installed aboard ship. The normal means of communications are the battle telephone (sound-powered) circuits, interstation 2-way systems (intercoms), ship's service telephones, ship's loudspeaker (l-MC), and voice tubes. Messengers are used in some situations when other methods of communication are not available or when written reports are required.

Transmission of correct information regarding a casualty and the speed with which the report is made are the principal values of any method of communication.

Control of all communication circuits must be established by the control station. The circuits must never be allowed to get out of control from "cross talk" caused by more than one station. Casualty control communications must be incorporated into casualty control training. The control station or engineering control must be promptly notified of a casualty so that other casualties (which could be more serious than the original casualty) can be prevented.

TRAINING

Casualty control training must be a continuous step-by-step procedure with constant refresher drills. Realistic simulation of casualties requires

adequate preparation. The amount of advance preparation required is not always readily apparent. You must carefully visualize the full consequences of any error that could be made in handling simulated casualties that were originally intended to be of a relatively minor nature. There must be a complete analysis and all participants must be carefully instructed before simulation of major casualties and battle damage. A new crew must have an opportunity to become familiar with the ship's piping systems and equipment before simulation of any casualty that may have other than purely local effects.

In the preliminary phases of training, a "dry run" is useful for imparting knowledge of casualty control procedures without endangering the ship's equipment by a too realistic simulation of a casualty. Under this procedure, a casualty is announced, and all individuals are required to report as though action were taken. (An indication must be made that the action is simulated.) Definite corrective actions can be taken, and with careful supervision the timing of individual actions can appear to be very realistic. Regardless of the state of training, dry runs should always be held before actual simulation of any involved casualty. Similar rehearsals should be held before simulation of relatively simple casualties whenever new personnel are involved and particularly after an interruption (such as a naval shipyard overhaul period) of regularly conducted casualty training has occurred.

CORRECTION AND PREVENTION OF CASUALTIES

The speed with which corrective action is taken to control an engineering casualty is of paramount importance. This is particularly true for casualties that affect the ship's propulsion power plant, steering system, and electrical power generation and distribution. If casualties associated with these functions are allowed to accumulate, they may lead to serious damage to the engineering installation—damage that often cannot be repaired without loss of the ship's operating availability. When risk of possible permanent damage exists, the commanding officer has the responsibility of deciding whether to continue operation of the equipment under casualty conditions. Such action can be justified only when the risk of even greater damage, or loss of the ship, may be incurred if the affected unit is immediately secured.

Whenever there is no probability of greater risk, the proper procedure is to secure the malfunctioning unit as quickly as possible even though considerable disturbance to the ship's operations may occur. Although speed in controlling a casualty is essential, action should never be undertaken without accurate information; otherwise, the casualty may be mishandled and cause irreparable damage and possible loss of the ship. War experience has shown that the cross-connecting of intact systems with a partly damaged one must be delayed until it is certain that such action will not jeopardize the intact systems. Speed in handling casualties can be achieved only by thorough knowledge of the equipment and associated systems and by thorough and repeated *practice* in performing the routines required to control specific, predictable casualties.

PHASES OF CASUALTY CONTROL

The handling of any casualty by shipboard personnel can usually be divided into three phases: (1) limiting of the effects of the damage, (2) emergency restoration, and (3) complete repair.

The first phase is concerned with immediate control of a casualty to prevent further damage to the affected unit and to prevent the casualty from spreading through secondary effects, commonly known as "cascading." (One fault leads to another.)

The second phase requires the use of Engineering Operational Procedures (EOPs) and involves restoring, as far as practicable, the services that were interrupted as a result of a casualty. For many casualties, the completion of this phase will eliminate all operational handicaps, except for the temporary loss of standby units, which will lessen the ability of the machinery to withstand additional failure. If no damage to, or failure of, machinery has occurred, this phase usually completes the operation.

The third phase of casualty control consists of making any repairs required to completely restore the installation to its original condition.

SPLIT-PLANT OPERATION

A primary method of casualty prevention and control is use of the split-plant mode of operation. The purpose of the split-plant design is to minimize battle damage that might result from a single hit.

Most naval ships that were built primarily as warships have at least two engineering plants. Larger combatant ships have four individual engineering plants. Split-plant operation means aligning support systems, engines, pumps, and other machinery so that two or more propulsion plans and/or electrical generating plants are available, each complete in itself. Each main engine installation has its own piping systems and other auxiliaries. Each propulsion plant operates its own propeller shaft. If one plant were to be put out of action by explosion, shellfire, or flooding, the other plant could continue to drive the ship ahead, though at somewhat reduced speed.

Split-plant operation is not absolute insurance against damage that might immobilize the entire engineering plant, but it does reduce the chances of such a casualty. It prevents transmission of damage from one plant to another or possible serious effect on the operation of the other plant or plants. It is the first step in the PREVENTION of major engineering casualties.

The fuel system is generally arranged so that fuel transfer pumps can take suction from any fuel tank in the ship and can pump to any other fuel tank. Fuel service pumps supply fuel from the service tanks to the main engines. In split-plant operations, the forward fuel service pumps of a ship are lined up with the forward service tanks, and the after service pumps are lined up with the after service tanks. The cross-connect valves in the fuel transfer line must be closed except when fuel is being transferred.

Diesel propulsion plants are designed for split-plant operation only; however, some of the auxiliary and main systems may be run cross-connected or split. Among these auxiliaries are the starting-air systems, cooling-water systems, firemain systems, and, in some plants, the fuel and lube oil systems.

In diesel-electric installations, the diesel elements are split, but the generator elements can be run split or cross-connected. The advantages of this type of installation will depend on operating procedures as well as design.

LOCKING MAIN SHAFT

An engineering casualty may be such that continued rotation of the main shaft will cause further damage. The main shaft should be locked until necessary repairs can be made since, except at very low speeds, movement of the ship through the water will cause the shaft to turn. Turning of the shaft will occur whether the ship is proceeding on its own power or being towed.

For locking a main shaft, there are no standard procedures applicable to all types of diesel-driven ships. For ships that have main reduction gears, shaft locking of the turning gear is permissible, provided it is designed for this purpose. Some ships have brakes that are used to hold the shaft stationary. On diesel-electric drive ships, no attempt should be made to hold the shaft stationary by energizing the electrical propulsion circuits.

EMERGENCY PROCEDURES

Under certain circumstances, you may be ordered to start additional engines. Time may not permit you to follow the normal, routine procedures. You may have to use emergency procedures. Because emergency procedures will differ, depending on the installation, you must be familiar with the specific procedures established for your ship.

ENGINE-ROOM CASUALTIES

In the event of a casualty to a component of the propulsion plant, the principal objective is to prevent additional or major casualties. Where practicable, the propulsion plant should be kept in operation with standby pumps, auxiliary machinery, and piping systems. The important thing for you to remember is to prevent minor casualties from becoming major casualties, even if it means suspending the operation of the propulsion plant. It is better to stop the main engines for a few minutes than to risk putting them completely out of commission, a condition that will require major repairs.

When a casualty occurs, the engineering officer of the watch (EOOW) and the petty officer of the watch (POOW) must be notified immediately. The watch officer will notify the OOD and the engineer officer. Main engine control must keep the bridge informed as to the nature of the casualty, the ship's ability to answer bells, the maximum speed available, and the probable duration of the casualty.

GENERAL SAFETY PRECAUTIONS

In addition to following the specific safety precautions listed in the operating instructions for an engine, you must continuously exercise good

judgment and common sense when taking steps to prevent damage to material and injury to personnel.

In general, you can help to prevent damage to machinery by operating engines according to prescribed instructions, by using practices such as "bagging and tagging" parts that were removed from an engine during maintenance or overhaul, by having a thorough knowledge of your duties, and by being totally familiar with the parts and functions of the machinery you are operating and maintaining.

By maintaining machinery so that the engines will be ready for full-power service in the event of an emergency and by taking steps to prevent conditions that are likely to constitute fire or explosion hazards, you can also help to prevent any damage that might occur outside of the ship. (This type of damage may take the form of damage to piers or other external structures or to other marine craft whenever a loss of control over the ship occurs.)

Remember, personnel work most safely when they thoroughly know how to perform their duties, how to use their machines, how to take reasonable precautions around moving parts, and when they are consistently careful and thoughtful while performing their duties.

EMERGENCY STARTING AND SECURING PROCEDURES

There may be times when an engine must be started, operated, or secured under emergency conditions. Before this becomes necessary, operating personnel should learn the procedures in the ship's EOCC. These procedures should be posted at the engine control station or operating position. Operators should be drilled in casualty control procedures at regular intervals.

There is a definite hazard to starting a diesel engine under emergency conditions because personnel are rushed and tend to be careless. There is always time for you to ensure that personnel are clear of external moving parts, such as belt drives and shafts, before actuating the starting gear. If emergency repairs have been made, be sure that all tools are accounted for before you close up the engine and that all essential parts have been replaced before you start the engine. An engine can be started and run briefly if it has air and fuel and if the starting system will operate. It will run much longer if it has functional lubrication and cooling systems. With the exception of some boat engines that can be started by towing, there is no backup for the starting system. Usually sufficient spare parts and resources are available for you to restore any casualty to the starting system. Remember, however, if the repair is rushed, the danger resulting from careless work will increase.

In an emergency, you can start an engine by lining up the fuel system and actuating the starter. Before you do this, however, make certain that there is a supply of air to the engine and engine compartment and that the lubricating system will operate. After starting, establish cooling-water flow and review all the normal prestarting checks as quickly as possible.

If an operating engine suffers a casualty, the decision of whether to continue operating or to secure the unit must be made immediately. The condition of the ship's operation is an important factor in this decision. In some instances, when risk of possible permanent damage exists, the commanding officer has responsibility for deciding whether to continue operation of equipment under casualty conditions. Such action can only be justified when the risk of greater damage, or loss of the ship, may be incurred if the affected unit is secured. Risk to the ship is present in actual combat situations, severe weather conditions, narrow channels, and potential collision situations, which include close-formation manuevering with other ships.

Engines can be operated with casualties to vital auxiliaries if the function of the auxiliary unit can be produced by other means. For instance, cooling-water flow can be reestablished from a firemain, and an engine can operate for some time with seawater in its cooling system as long as the cooling system is rinsed well afterward.

If the decision is made to secure an engine that has suffered a casualty, the general rule is to stop the engine as soon as possible. In the case of a propulsion engine, it will usually be necessary to stop the shaft also. This may require slowing the ship until the shaft is stopped and locked with the turning gear, shaft brake, or other means.

You can almost always stop an engine by securing the flow of fuel. Occasionally, this method will not work since a blower seal leak or a similar situation may permit the engine to run on its own lubricating oil. If you cannot brake the engine to stop it or slow it by increasing the load, you must find some means to stop the airflow to it.

To stop the airflow, you can activate engine shutdown devices (such as air intake flappers) to cover the air intake, or you can find some way

of securing the air to the blower intake. If you try to secure the air to the blower intake, make certain that the covering will not be sucked into the blower, as this would cause an additional casualty.

NOTE: Do not attempt to use a *portable* carbon dioxide (CO_2) fire extinguisher to secure a diesel engine. The carbon dioxide (CO_2) in the portable extinguisher will have little or no effect on the diesel engine. This is because the volume of air consumed by the diesel engine will be far greater than the volume of CO_2 contained in the extinguisher bottle.

SUMMARY

In this chapter, we have discussed some basic operating procedures that you may be able to apply to the type of unit to which you will be assigned. Our intent in this chapter was to provide you with general knowledge in regard to engine-room operations and to direct you to the EOSS for specific applications. As you should remember, the EOSS provides detailed operational and casualty control procedures for propulsion and auxiliary evolutions. From the information in this chapter, you should be able to recognize the importance of the EOSS and how it relates to normal operation and casualty control. Remember, casualty control that is performed properly will reduce equipment downtime and needless deterioration of engine components. When casualty control is NOT done properly, losses in terms of equipment, the mission, and even your life or the life of a shipmate can result.

You should also be able to recognize the fundamental starting, operating, and stopping procedures you should use for a diesel engine under normal operating conditions and some of the emergency and casualty prevention procedures you may have to use under adverse circumstances. If you are uncertain concerning any of this information, we suggest you review this chapter before proceeding to chapter 12.

CHAPTER 12

TRANSMISSION OF ENGINE POWER

The main components of an engine have been covered in the preceding chapters of this manual. If the power developed by an engine is to be used to perform useful work, there must be some way to transmit the power from the engine (driving unit) to such loads as the propeller of a ship or boat or the drive shaft of a generator, a compressor, or a pump. This chapter provides general information on how the force available at the crankshaft of an engine is transmitted to a point where it will perform useful work. The combination of devices used to transmit engine power to a driven unit is commonly called a DRIVE MECHANISM.

After reading the information in this chapter, you should be able to identify various components associated with the drive mechanism, such as clutches, gears, couplings, and bearings, in terms of the ways in which they function to transmit the power from the engine to the driven unit. You should also be able to recognize the more common problems associated with these drive mechanisms, some general procedures you should perform for preventive maintenance, and the purpose and content of the Engineer's Bell Book.

FACTORS RELATED TO THE TRANSMISSION OF ENGINE POWER

The basic characteristics of an internal-combustion engine make it necessary, in many cases, for the drive mechanism to change both the speed and the direction of shaft rotation in the driven mechanism. There are various methods for making required changes in speed and direction during the transmission of power from the driving unit to the driven unit. In most of the installations with which you will be working, the power is transmitted by a drive mechanism consisting principally of gears and shafts. You will better understand the way a drive mechanism transmits power if you review chapters 1 through 9 of *Basic Machines*, NAVPERS 10624-A1. Chapter 6 will be especially helpful to you; it describes the basic types of gears and discusses how gears are used to change the direction of rotation and the speed of a shaft.

The process of transmitting engine power to a point where it can be used in performing useful work involves a number of factors. Two of these factors are torque and speed.

TORQUE

Torque, or turning force, is the force that tends to cause rotational movement of an object. The crankshaft of an engine supplies a turning force to the gears and shafts which transmit power to the driven unit. Gears serve to increase or decrease torque. For example, an engine may not produce enough torque to turn the shaft of a driven machine if the connection between the driving and driven units is direct, or solid. If the right combination of gears is installed between the engine and the driven unit, however, torque is increased, and the turning force is then sufficient to operate the driven unit.

SPEED

Another factor related to torque and to the transmission of engine power is engine speed. If maximum efficiency is to be obtained, an engine must operate at a certain speed. To obtain efficient engine operation in some installations, the engine may need to operate at a higher speed than that required for operation of the driven unit. In other installations, the speed of the engine may need to be lower than the speed of the driven unit. Through a combination of gears, the speed of the driven unit can be increased or decreased so that both the driving and the driven units operate at their most efficient speeds; that is, so that the proper speed ratio exists between the units.

SPEED RATIO AND GEAR RATIO

The terms SPEED RATIO and GEAR RATIO are frequently used in descriptions of gear-type mechanisms. Both ratios are determined by dividing the number of teeth on the driven gear by the number of teeth on the driving gear. For example, assume that the crankshaft of a particular engine is fitted with a driving gear that is half as large as the meshing, driven gear. If the driving gear has 10 teeth and the driven gear has 20 teeth, the gear ratio is 2 to 1. Every revolution of the driving gear will cause the driven gear to revolve through only half a turn. Thus, if the engine is operating at 2,000 rpm, the speed of the driven gear will be only 1,000 rpm; the speed ratio is then 2 to 1. This arrangement doubles the torque on the shaft of the driven unit. The speed of the driven unit, however, is only half that of the engine.

On the other hand, if the driving gear has 20 teeth and the driven gear has 10 teeth, the speed ratio is 1 to 2, and the speed of the driven gear is doubled. The rule applies equally well when an odd number of teeth is involved. If the ratio of the teeth is 37 to 15, the speed ratio is slightly less than 2.47 to 1. In other words, the driving gear will turn through almost two and a half revolutions while the driven gear makes one revolution. The gear with the greater number of teeth, which will always revolve more slowly than the gear with the smaller number of teeth, will produce the greater torque. Gear trains that change speed always change torque. When speed increases, the torque decreases proportionally.

NOTE: The mechanical force of any driven unit will always be somewhat LESS than that of the driving unit due to power losses caused by such things as friction and lost motion. Therefore, output horsepower will always be equal to input horsepower minus any losses.

TYPES OF DRIVE MECHANISMS

You have just learned that the torque or the speed of an engine may need to be changed to satisfy the torque and speed requirements of the driven mechanism. The term INDIRECT DRIVE, as used in this chapter, describes a drive mechanism that changes both speed and torque. Drives of this type are common to many marine engine installations.

When the speed and the torque of an engine do NOT need to be changed to drive a machine satisfactorily, the mechanism used is a DIRECT DRIVE. Drives of this type are commonly used when the engine furnishes power for the operation of auxiliaries, such as generators and pumps.

INDIRECT DRIVES

The drive mechanisms of most engine-powered ships and of many boats are the indirect type. With this drive, the power developed by the engine(s) is transmitted to the propeller(s) indirectly, through an intermediate mechanism that reduces the shaft speed. Speed may be reduced mechanically, by a combination of gears, or by electrical means (for example, a diesel electric drive).

Mechanical Drives

The mechanical drives discussed in this chapter include devices that reduce the shaft speed of the driven unit, provide a means for reversing the direction of shaft rotation in the driven unit, and permit quick-disconnect of the driving unit from the driven unit.

Propellers operate most efficiently in a relatively low rpm range. The most efficient designs of diesel engines, however, operate in a relatively high rpm range. In order that both the engine and the propeller may operate efficiently, the drive mechanism in many installations includes a device that permits a speed reduction from engine crankshaft to propeller shaft. The combination of gears that brings about the speed reduction is called a REDUCTION GEAR. In most diesel engine installations, the reduction ratio does not exceed 3 to 1. There are some units, however, that have reductions as high as 6 to 1.

The propelling equipment of a ship or a boat must provide astern power as well as forward power. In some ships, backing down is accomplished by reversing the pitch of the controllable pitch propeller; in other ships and boats, however, backing down is accomplished by reversing the direction of rotation of the propeller shaft. In mechanical drives, the direction of rotation of the propeller shaft is reversed by use of REVERSE GEARS.

The drive mechanism of a ship or boat must do more than reduce speed and change direction of rotation. Most drive mechanisms have a CLUTCH. The clutch disconnects the drive

mechanism from the propeller shaft and permits the engine to be operated without turning the propeller shaft.

The arrangement of the components in an indirect drive varies, depending upon the type and size of the installation. In some small installations, the clutch, the reverse gear, and the reduction gear may be combined into a single unit. In other installations, the clutch and the reverse gear may be in one housing and the reduction gear in a separate housing attached to the reverse-gear housing. Drive mechanisms arranged in either manner are usually called TRANSMISSIONS.

In large engine installations, the clutch and the reverse gear may be combined; they may be separate units, located between the engine and a separate reduction gear; or the clutch may be separate and the reverse gear and the reduction gear may be combined.

In most geared-drive multiple propeller shaft ships, the propulsion units and their drive mechanisms are independent of each other. In others, the drive mechanism is arranged so that two or more engines can drive a single propeller. In one type of installation, the CODOG (combination diesel or gas turbine) system, each propeller is driven by a diesel engine or both propellers are driven by one gas turbine. The diesel engines are used for normal cruising and maneuvering in confined waters. Each diesel drives a propeller shaft independently of the other. The gas turbine is used for high-speed operation. The single gas turbine drives both propeller shafts through the drive mechanism. This combination permits a large cruising range along with high speed whenever it is needed.

Electric Drives

In the propulsion plants of some diesel-driven ships, there are no mechanical connections between the engine(s) and the propeller(s). In such plants, the diesel engines are connected directly to generators. The electricity produced by such an engine-driven generator is transmitted through cables to a motor, which is connected to the propeller shaft directly, or indirectly, through a reduction gear. When a speed reduction gear is included in a diesel-electric drive, the gear is located between the motor and the propeller.

The generator and the motor of a diesel-electric drive may be of the direct current (dc) type or the alternating current (ac) type. Since the speed of a dc motor varies directly with the voltage furnished by the generator, the control system of an electric drive is arranged so that the generator voltage can be changed at any time. An increase or decrease in generator voltage is used to control the speed of the propeller. Generator voltage may be changed electrically, by changes in engine speed, and by a combination of these methods. The controls of an electric drive may be located remotely from the engine, such as in the pilot house.

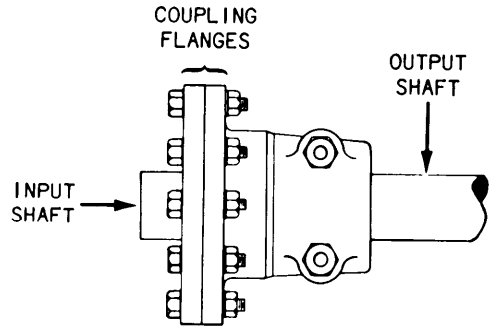
In an electric drive, the direction of rotation of the propeller is not reversed by a reverse gear. The electrical system is arranged so that the flow of current through the motor can be reversed. This reversal of current flow causes the motor to turn in the opposite direction. Thus, the direction of rotation of the motor and of the propeller can be controlled by manipulation of the electrical controls.

DIRECT DRIVES

In some marine engine installations, power from the engine is transmitted to the drive unit without a change in shaft speed; that is, by a direct drive. In a direct drive, the connection between the engine and the driven unit may consist of a solid coupling, a flexible coupling, or a combination of both. There may or may not be a clutch in a direct drive, depending upon the type of installation. Some installations have a reverse gear.

Solid Couplings

Solid couplings vary considerably in design. Some solid couplings consist of two flanges bolted together (fig. 12-1). In other direct drives, the driven unit is attached directly to the engine



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Figure 12-1.—Flange-type solid coupling.

crankshaft by a nut, as in the P-250 centrifugal fire pump.

Solid couplings offer a positive means of transmitting torque from the crankshaft of an engine; however, a solid connection does not allow for any misalignment between the input and output shafts, nor does it absorb any of the torsional vibration transmitted from the engine crankshaft.

Flexible Couplings

Since solid couplings do not absorb vibration and do not permit any misalignment, most direct drives consist of a flexible coupling, which uses a flexible member or element to connect two flanges or hubs together. Connections of the flexible type are common to the drives of many auxiliaries, such as engine-generator sets. Flexible couplings are also used in indirect drives to connect the engine to the drive mechanism.

The two solid halves of a flexible coupling are joined by a flexible element. The flexible element may be made of rubber, neoprene, a steel spring, or gears. An example of a grid-type flexible coupling that uses a steel spring (view A) and a gear-type coupling (view B) are shown in figure 12-2.

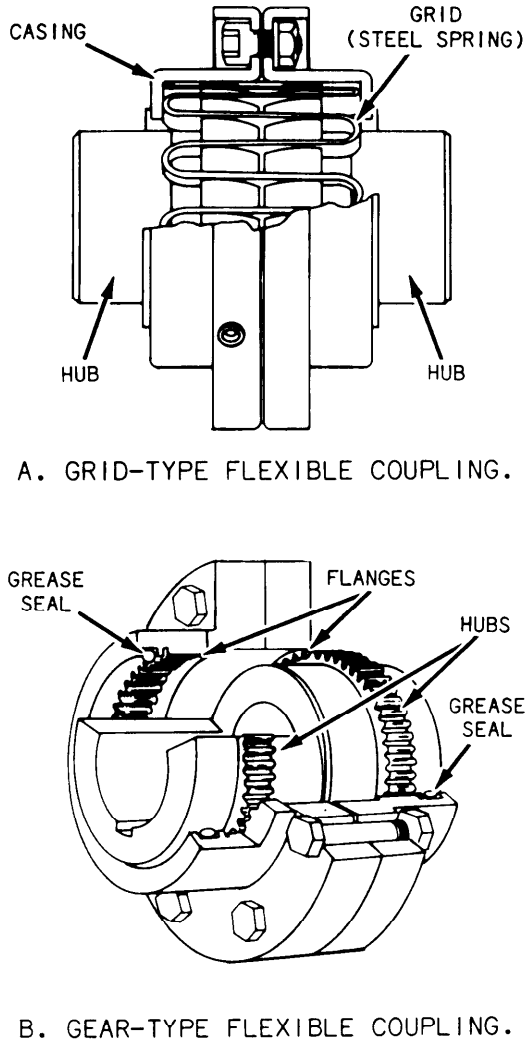


Figure 12-2.—Flexible couplings.

CLUTCHES, REVERSE GEARS, AND REDUCTION GEARS

Clutches may be used on direct-drive propulsion Navy engines to disconnect the engine from the propeller shaft. With small engines, clutches are usually combined with reverse gears and used for maneuvering of boats. In large engines, special types of clutches are used to obtain required coupling or control characteristics and to prevent torsional vibration.

Clutches are used on marine engines to reverse the direction or rotation of the propeller shaft for maneuvering the ship, without changing the direction of rotation of the engine. Reverse gears are used principally with relatively small engines.

Reduction gears are used to obtain low propeller-shaft speed with a high engine speed. Speed reduction gears resolve two conflicting requirements:

1. For minimum weight and size for a given power output, engines must have a relatively high crankshaft speed.
2. For maximum efficiency, propellers must rotate at a relatively low speed, particularly where high thrust capacity is desired.

There are many types of transmissions used by the Navy. This chapter covers, in general, the operation of transmissions that use friction, pneumatic, hydraulic, and electromagnetic clutches, which may be found on Navy marine installations. You will find additional information on a particular unit in the NAVSEA technical manual for that specific installation.

FRICTION CLUTCHES AND GEAR ASSEMBLIES

Friction clutches are most commonly used with smaller high-speed engines. PNEUMATIC clutches, with cylindrical friction surfaces, are used with engines up to 2,000 hp.

There are two general types of friction clutches: DISK and BAND. Disk-type clutches are classified as either MECHANICAL or HYDRAULIC. Because of the wide use of the disk-type clutch on small craft, our discussion in the sections that follow will include both the mechanical and the hydraulic types.

Friction clutches are engaged when two friction surfaces are mechanically forced into contact with each other by toggle-action linkage through stiff springs or through the use of hydraulic or pneumatic pressure.

TWIN-DISK CLUTCH AND GEAR MECHANISM (MECHANICAL)

One of several types of transmissions used by the Navy on small craft is the twin-disk. The twin-disk transmission is equipped with a duplex clutch and a reverse and reduction gear unit, all contained in a housing at the afterend of the engine. (See fig. 12-3.) Parts A, B, and C of the clutch assembly are bolted to the flywheel on the crankshaft of the engine and rotate at the same speed as the engine.

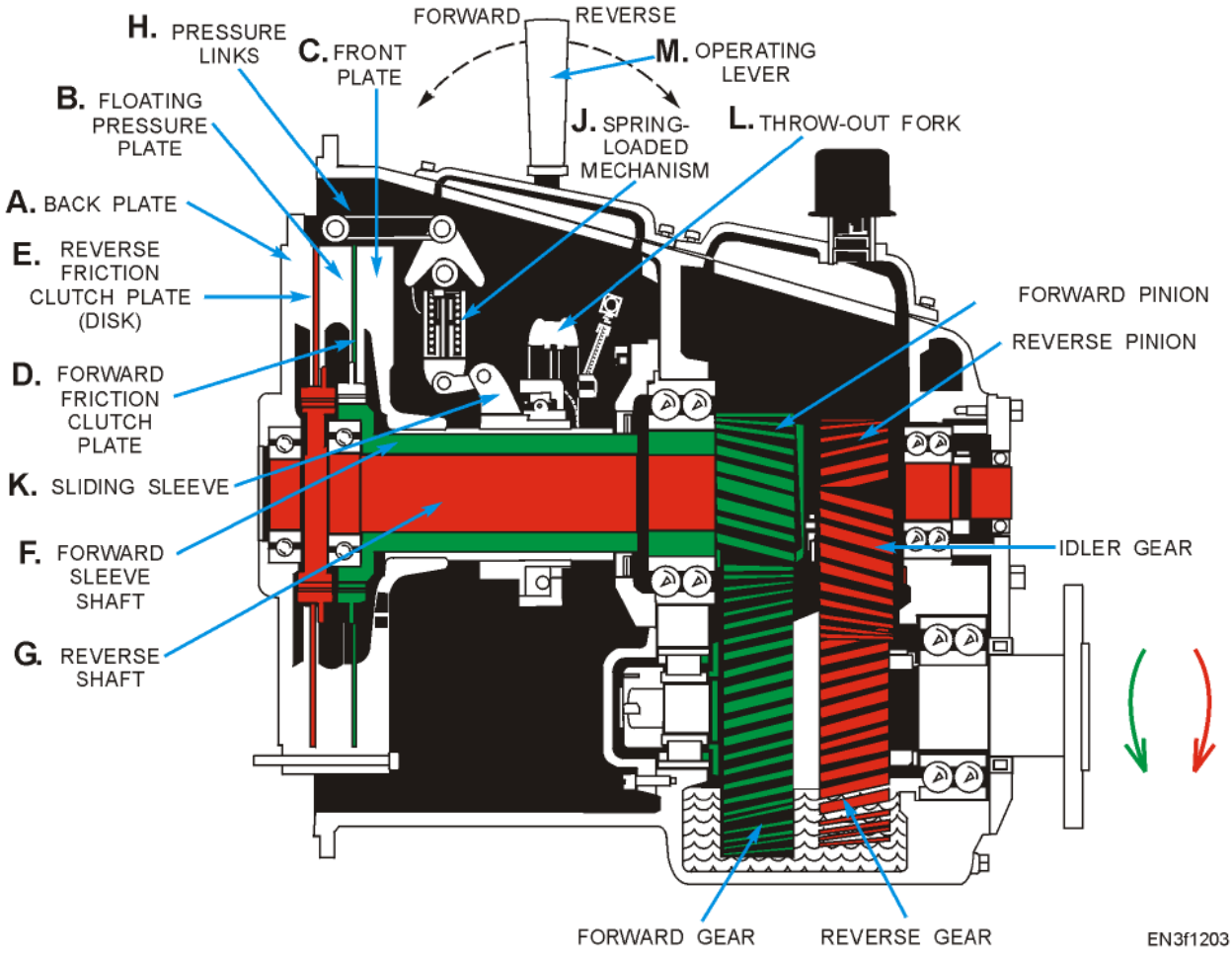


Figure 12-3.—Mechanical transmission (twin-disk).

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The clutch assembly is contained in the part of the housing nearest the engine. It is a dry-type, twin-disk clutch with two friction disks or clutch plates. Each disk is connected to a separate reduction gear train in the afterpart of the housing. The disk (D) and the gear train for forward rotation are **connected** by a hollow shaft (F). The disk (E) and the gear train for reverse rotation are connected by a shaft (G), which runs through the center of shaft (F). Since the gears for forward and reverse rotation of the twin-disk clutch and gear mechanism remain in mesh at all times, there is no shifting of gears. When the mechanism is shifted, only the floating pressure plate, located between the forward and reverse disks, is moved.

OPERATION OF THE TWIN-DISK TRANSMISSION

In figure 12-3, the forward rotating components are color coded green; the reverse rotating components are color coded red. clutch has a positive neutral that is set when the operating lever (M), which operates the throw-out fork (L), is placed in the middle position. Then the sliding sleeve (K) is also in a middle position, and the floating pressure plate (C) rotates freely between the two clutch disks (D and E). The only control the operator has is to cause the floating plate to bear heavily against either the forward disk or the reverse disk, or to put the floating plate in the positive neutral position so that it rotates freely between the two disks.

Forward Rotation

When the operating lever (M) is pushed forward, the sliding sleeve (K) is forced backward. In this position, the pressure link (H) of the spring-loaded mechanism (J) pulls the floating pressure plate (C) against the forward clutch disk (D). (NOTE: Several links must be used around the perimeter of the floating pressure plate to equalize the force against either of the two clutch plates.) The forward clutch friction disk, in turn, is pressed against the front plate (B), which is bolted to and rotates with the engine flywheel. The friction disk immediately begins to rotate with the front plate at engine speed because the forward friction disk has internal teeth that are in mesh with the external gear teeth on the left end of the forward sleeve (F). The forward sleeve shaft (F) transmits the rotation to the propeller shaft through the two-gear train (forward pinion and forward gear). Note the directional arrow for forward rotation.

Reverse Rotation

When the operating lever (M) is pulled back as far as it can go, the sliding sleeve (K) is pushed forward. In this position, the floating pressure plate (C) is forced against the reverse friction clutch plate (E). In turn, the reverse disk is pressed against the backplate (A), which is also bolted to the engine flywheel. At engine speed, the reverse friction clutch plate begins to rotate with the backplate because the reverse friction disk has internal teeth that are in mesh with the external gear teeth on the left end of the inner reverse shaft (G). The reverse shaft transmits the rotation through the three-gear train (reverse pinion gear, idler gear, and reverse gear). Notice the idler gear. This gear transmits motion from the reverse pinion gear to the reverse gear without a change in direction between the two. Note the directional arrow for reverse rotation.

Mechanical Clutch Problems

Malfunctions of friction clutches will vary, depending upon the type of clutch.

The troubles discussed in this section—slippage and wear, freezing, and noise—are common to twin-disk clutches.

SLIPPAGE AND WEAR.—Slippage and wear of mechanical clutches must be considered together, since each can be the cause of the other and each intensifies the other's effect. Slippage generally occurs at a high engine speed when the engine is delivering the greatest torque. Slippage causes lower efficiency, loss of power, and rapid wear of the clutch friction surfaces.

There are several possible causes of clutch slippage: wear, insufficient pressure, overload, and fouling. Over a period of operation, extended engaging and disengaging of the surfaces will cause a normal amount of wear. If the surfaces are rough, wear will be excessive. Do not engage the clutch while the engine is racing. It may cause excessive wear, and it will strain the entire drive system.

When an engine is overloaded, torque may be increased to such an extent that slippage will occur. Obviously, you can prevent this trouble by keeping the load within specified limits. Whenever an engine is fully loaded, watch for symptoms that indicate slippage.

The clutch may slip when the lining surfaces become fouled with oil, grease, or water. Oil or grease on the clutch surfaces is usually the result of careless maintenance practices, such as forcing too much grease into the bearings or overfilling the gear case with oil. When oil in a gear case foams, there will probably be leakage from the shaft bearings. Foaming may result from overfilling. When foaming occurs, check for the proper oil level.

When filling a reduction gear case, add only enough oil to bring the level up to the FULL mark. Do not add or measure oil when the unit is in operation, because you will not get an accurate oil reading.

In a twin-disk clutch installation, an oil leak at the rear main bearing of the engine may cause oil to appear on the clutch surfaces. The leakage may be caused by excessive bearing clearance, overfilling of the engine crankcase, a plugged crankcase breather cap, or excessive crankcase pressure due to piston blowby. The crankcase breather cap must be cleaned periodically so that it will not become clogged.

Another source of fouling is grease that may get on the linings of a dry-type clutch during overhaul. Do not handle the parts with greasy hands, and remove any grease deposits with an approved cleaner. For pneumatically operated friction clutches where rubber parts are used, use only a clean, dry cloth to wipe off clutch faces and linings.

When there is clutch slippage, immediately take steps to correct the trouble. The clutch surfaces are probably worn, so measure the thickness of the clutch linings. When a lining is worn excessively, replace it; tightening the adjusting device (installed on some units) will not correct for excessive wear of the linings. Instead, such adjustments may lead to scoring of the mating clutch surfaces, particularly when the linings are fastened to the clutch faces with rivets.

The spring-loaded clutch-operating mechanism of the twin disk is pressure set at the factory. It should not be necessary to adjust the mechanism, as it is designed to follow up and compensate for wear of the friction surfaces on the clutch plates. The simplest way to determine when the disks need to be replaced is to check the position of the plungers of the spring-loaded mechanisms in the engaged position. The plungers are permitted to travel a specified amount according to the specifications listed in the NAVSEA technical manual.

FROZEN CLUTCH.—When a clutch fails to disengage, it is frozen. Failure of the clutch to disengage may be caused by a defective clutch mechanism or by water absorbed in the material that lines the clutch plates.

When a clutch becomes frozen, inspect the operating mechanism. Check the control rods for obstructions or loose connections, and check for excessive clearances in the throw-out bearing pressure plate, the pivots, and the toggles. In a twin-disk clutch, warped disks will cause the clutch to freeze. (Warped disks are caused by extended running in neutral position.)

If a clutch has molded clutch linings, moisture will cause the linings to swell and become soft. When this occurs, many linings tend to stick to the mating surfaces. Every effort should be made to prevent moisture from getting to the clutch linings. If a molded lining becomes wet, let it dry in the disengaged position. Allowing the linings to dry in the engaged position increases the possibility of sticking.

CLUTCH NOISE.—Dry-type clutches may produce a chattering noise when the clutch is being engaged. Excessive clutch chatter may cause damage to the reverse and reduction gears and may cause the clutch linings to break loose, resulting in complete clutch failure.

The principal cause of clutch chatter is oil, grease, or water on the linings. You should take every possible precaution to keep oil, grease, or water out of the unit, because replacement of the linings is the only satisfactory means of repair. All metal parts of the clutch may be cleaned according to instructions in the appropriate NAVSEA technical manuals.

HYDRAULIC CLUTCH AND GEAR MECHANISM (TRANSMISSION)

Like the twin-disk transmission we have just discussed, the hydraulic transmission uses two friction plates to transfer drive torque to the gear mechanism. However, the hydraulic transmission does not use a floating plate to engage or disengage the clutches. The clutches are engaged or disengaged when either the forward or the reverse clutch disk is locked between a hydraulically operated piston and a drive plate.

Another difference between the two types of transmissions is the use of planetary gears in the

hydraulic transmission, rather than a second shaft and an idler gear, to reverse rotation of the drive shaft. This method of reversing direction will be explained later in detail. One other difference is the method by which the transmissions are lubricated. The twin-disk transmission is splash lubricated by the action of the forward gear and the reverse gear as they pick up oil from the sump and throw the oil as they rotate. The hydraulic transmission is lubricated by both pressure oil and splash oil. A central passage is open to oil pump pressure at all times when the engine is running. All moving parts inside the transmission are lubricated from this source. A nozzle at the top of the housing provides a spray of oil for lubricating the drive (pinion) gear, the driven gear, and the bearings.

The hydraulic transmission consists of a forward drive clutch assembly, a reverse clutch and reduction gear assembly, an oil pump that supplies oil under pressure for operation of the clutches, a control (selector) valve that admits oil to the clutches, and an oil strainer and oil cooler. Although there are several designs of hydraulic transmissions, if you clearly understand the operating principles of the Torqmatic design you should be able to understand the operating principles of other types of hydraulic transmissions.

The hydraulic transmission receives input torque through the forward clutch plate which is bolted to the aft face of the engine flywheel. Torque for forward motion is transferred from the clutch plate to the forward clutch disk. Torque for reverse motion is transferred from the forward clutch disk to the planetary gears by the sun gear. Details of the operating sequences for the neutral, forward, and reverse positions of the selector lever are provided in the sections that follow.

Neutral Operation

We will discuss the neutral operation of the transmission first because the selector valve lever should always be in the neutral position whenever you start the engine.

When the selector valve is in the neutral position, oil flows along one path. No pressure is applied against any of the hydraulic components. Therefore, the forward clutch disk rotates without turning any of the parts inside the transmission. This allows the transmission output shaft to remain stationary.

Forward Operation

When the lever of the selector valve is moved to the forward position, oil is admitted under pressure from the pump to the passage in the transmission and into an orifice in the pinion shaft. Oil then flows through a radial passage in the flywheel to an intersecting horizontal passage leading to the cavity between the flywheel and the forward clutch piston.

A piston-type dump valve, located at the outer diameter of the flywheel, controls the buildup and release of pressure against the piston. When the flywheel is rotating, the force exerted by the piston backup spring tends to push the valve out toward the periphery of the flywheel. When the selector control valve is opened and admits oil to operate the forward piston, the pressurized oil overrides the force of the dump valve spring and pushes the valve in toward the center of the flywheel. When the valve is pushed in, it uncovers a port in the flywheel leading to the piston and admits pressurized oil into the cavity at the front of the piston. The pressurized oil moves the piston toward the backplate, locking the clutch plate between the piston and the backplate and causing the clutch plate to rotate with the backplate. Since the pinion shaft is splined through the center of the clutch plate, the shaft rotates in the same direction and at the same speed as the clutch plate. This is the same speed at which the engine flywheel is rotating because the flywheel and the shaft are locked together hydraulically into one assembly. During this operation, oil has also been flowing along the path to provide lubrication.

Reverse Operation

When the selector control valve lever is moved to the reverse position, oil is admitted from the pump to oil passages. Oil in the piston's passage flows under pressure to the cavity on the face of the rear piston. The oil pressure against the piston moves the piston, causing it to lock the rear clutch plate between the piston and the stationary backplate. This locking action engages the reverse clutch and provides torque to the planetary gear assembly.

Figure 12-4 has been deleted.

The planetary gear assembly (fig. 12-5, view A) is installed in the transmission to provide reverse motion of the output shaft. As shown in figure 12-5, the planetary gear assembly contains the following parts: a sun gear, a ring gear with internal teeth, planet gears, and a planet carrier.

In operation, a planetary gear set (fig. 12-5, view B) resembles the solar system. Planet gears orbit, or circle, the sun gear. Planet gears are held in place by the planet carrier and the ring gear. The ring gear surrounds and meshes with the planet gears. In the planetary gear set in view A of figure 12-5, the teeth of a gear are in mesh with the teeth of at least one other gear at all times. Whenever one part of the gear set is turned, all other parts in the gear set are affected. The planetary gear set can be separated into three major parts, each with its own function.

To transmit power through a gear set, one gear turns as the drive member (SUN GEAR). Another part, called the reaction member (REVERSE RING GEAR), is held and prevented from moving. A third part, which is free to turn inside the reverse ring gear, is the driven member, or the output member (REVERSE PLANET CARRIER).

To understand how the planetary gear set provides reverse motion, you must keep in mind how the major parts are mounted. The sun gear is splined to the drive plate (forward clutch plate), which is bolted to the flywheel. Consequently, when the engine is running, the sun gear is revolving. The carrier to which the planet gears are mounted is attached by splines to the transmission pinion shaft. The ring gear is attached to the reverse clutch disk.

When the selector valve is in the forward position, the reverse clutch is disengaged, allowing the rear clutch disk to rotate freely. As the clutch disk rotates freely, the ring gear attached to the disk offers no resistance to the motion of the planet gears. When the selector valve is put in the reverse position, hydraulic pressure stops and locks the rear clutch disk and the attached ring gear, resulting in the gear motion shown in view B of figure 12-5. As the sun gear rotates clockwise, planet gear A rotates counterclockwise and planet gear B rotates clockwise. Since the ring gear is locked, gear B must move in a counterclockwise direction. The counterclockwise motion of gear B turns the carrier (on which the gear is mounted) and the pinion shaft (to which the carrier is mounted) in a counterclockwise direction. Thus, the planetary gear set has converted the clockwise motion of the input shaft into the counterclockwise motion of the pinion shaft. This change in direction of the pinion shaft also changes the direction of the drive shaft.

General Maintenance Procedures

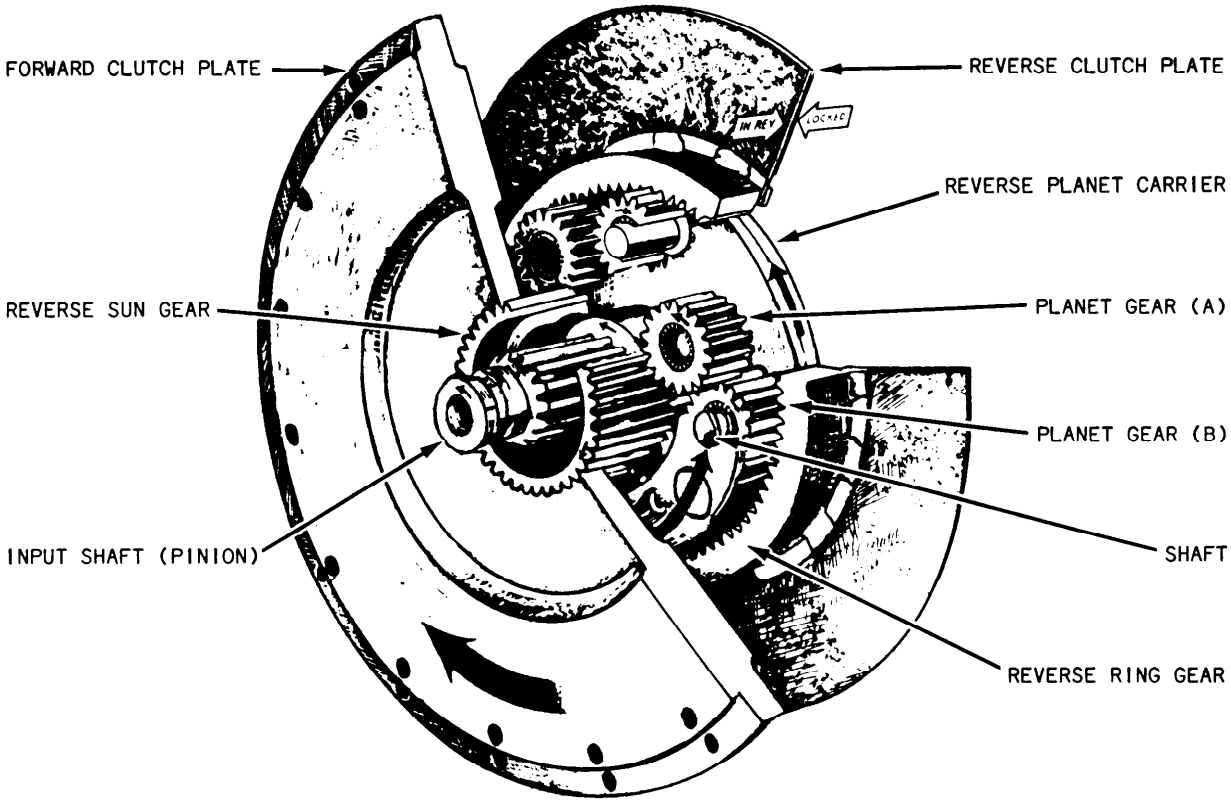
This section describes some routine procedures you can use to maintain the hydraulic transmission in good operating condition and to identify the overall condition of the transmission. These guidelines include the care of the oil system and minor adjustments you can make to the transmission and control linkage.

In the maintenance of the oil system, the proper oil level is very important. The transmission oil serves to apply clutches and lubricant and to cool the components. Consequently, transmission performance will be affected if the oil becomes aerated. The primary cause of aeration or foaming is either low oil or too much oil in the sump. A low oil level can cause the input pump to cavitate. Too much oil in the sump can introduce oil into the gearing and clutches. This condition can cause aeration, which will overheat the transmission. Aeration can also change the viscosity and color of the oil to a thin milky liquid. These conditions will all cause irregular operation of the unit.

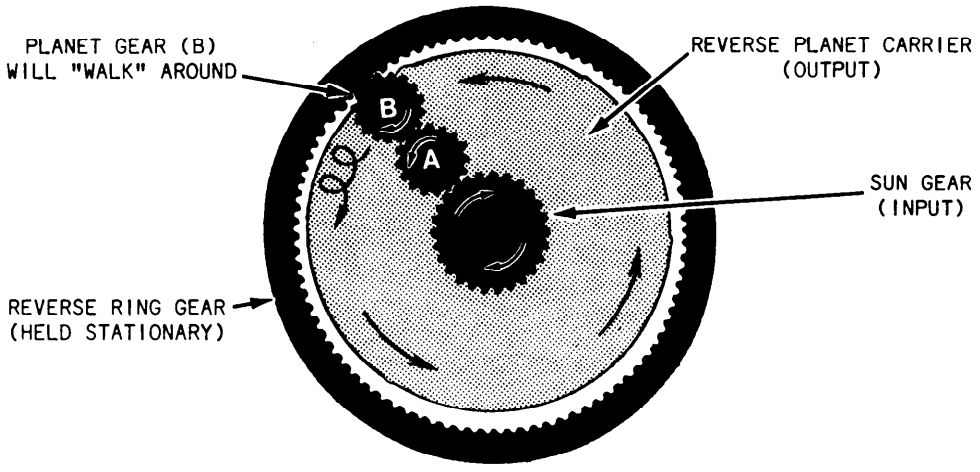
The oil level should be checked daily after the engine has been running for at least 1 hour. The oil level should be maintained at the FULL mark on the dipstick. Every 150 hours (or sooner, depending on the type of duty and environment), the oil and oil filters should be changed. You should refer to the appropriate PMS for the specific procedures and intervals you should use for your unit. Heavy sludge deposits on the oil filter element indicate that the detergency of the oil has been exhausted. When this occurs, the oil change interval should be shortened. The oil filter should always be replaced at the time of the oil change so that any abrasive dust and metal particles can be removed.

When you must change the oil and filter, follow these general procedures:

1. Make sure the transmission has been warmed up to operating temperature.
2. Remove the oil drain plugs from the sump and oil filters and drain the oil. Replace the plugs.
3. Thoroughly clean the transmission strainer assembly. Use a new gasket when you are replacing the cover of the strainer.



A. PLANET AND REVERSE DRIVE (L.H. ROTATION ENGINE).



B. REVERSE OPERATING MODE: OUTPUT SHAFT ROTATION OPPOSITE INPUT SHAFT ROTATION. (FOR CLARITY, ONLY ONE SET OF PLANET GEARS IS SHOWN.)

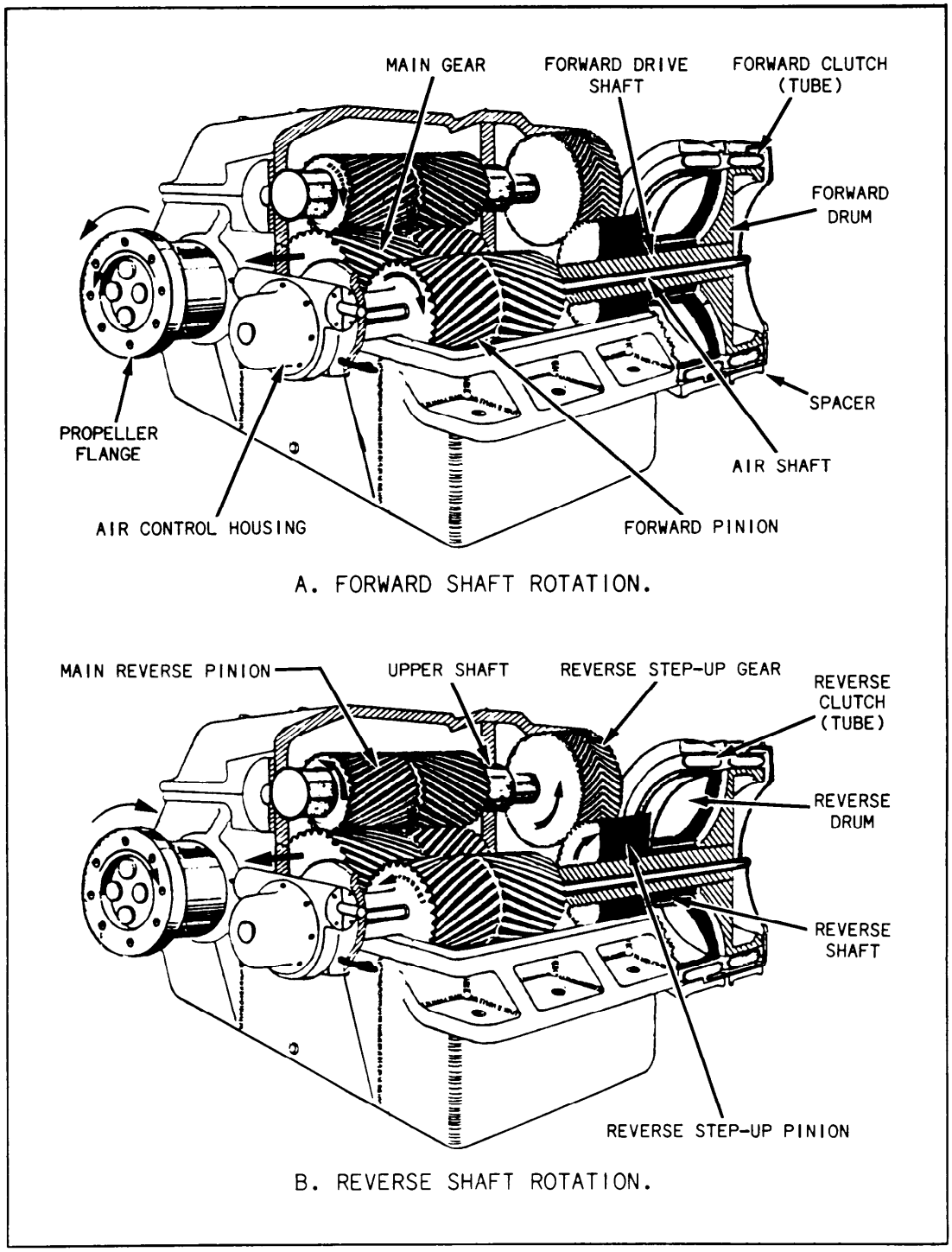
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Figure 12-5.—Operation of planetary gear assembly.

4. Replace the filter elements. Thoroughly clean the filter shells and use new gaskets (seal rings) with the new filter elements.

5. Before starting the engine, remove the breather and refill the transmission with clean oil (from a clean container) to prevent contamination.

6. When refilling the system, pour enough oil into the transmission to bring the oil level up to the FULL mark on the dipstick. Start the engine



75.247

Figure 12-6.—Clutch and reverse-reduction gear assembly.

and let it idle for 2 or 3 minutes with the transmission in neutral. Recheck the oil level and add oil (if necessary) to bring the oil up to the FULL mark on the dipstick. Do not overfill the transmission.

7. Carefully inspect the filter components and cover for oil leakage while the engine is running.

At each oil change, examine the used oil for evidence of dirt or water. If there is evidence of free water, check the cooler for leakage between the water and oil areas. Oil in the water side of the cooler is another sign of leakage. This, however, usually indicates leakage from the engine oil system.

If coolant leaks into the transmission oil system, you must take immediate action to prevent malfunction and possible serious damage. Ethylene glycol antifreeze will attack the material that lines the clutch plates. You must immediately disassemble, inspect, and clean the transmission and flywheel assembly. If antifreeze is present, both forward and reverse friction clutch plates must be replaced. The cooler should be repaired or replaced prior to installation of the new or rebuilt transmission.

Metal particles in the oil (except for the minute particles normally trapped in the oil filter) indicate damage has occurred in the transmission. When these particles are found, the transmission and flywheel assembly should be completely disassembled, and all internal and external oil circuits and all other areas where particles could lodge should be cleaned.

In the selector valve linkage assembly, the manual selector lever should move easily and give a crisp detent feel in the forward, neutral, and reverse positions. You should adjust the linkage so that the stops in the shift tower match the detents in the transmission.

Make periodic inspections for bent or worn parts, loose threaded connections, loose bolts, or accumulations of grease and dirt. All moving joints must be kept clean and well lubricated.

AIRFLEX CLUTCH AND GEAR ASSEMBLY

On large diesel-propelled ships, the clutch, reverse gear, and reduction gear unit has to transmit an enormous amount of power. So that the weight and size of the mechanism can be maintained as small as possible, special clutches have been designed for large diesel installations. One of these is the airflex clutch and gear assembly.

The airflex clutch and gear assembly, shown in views A and B of figure 12-6, consists of two clutches-one for forward rotation (view A) and one for reverse rotation (view B). The basic principles of operation are illustrated in figure 12-7. The clutches are bolted to the engine

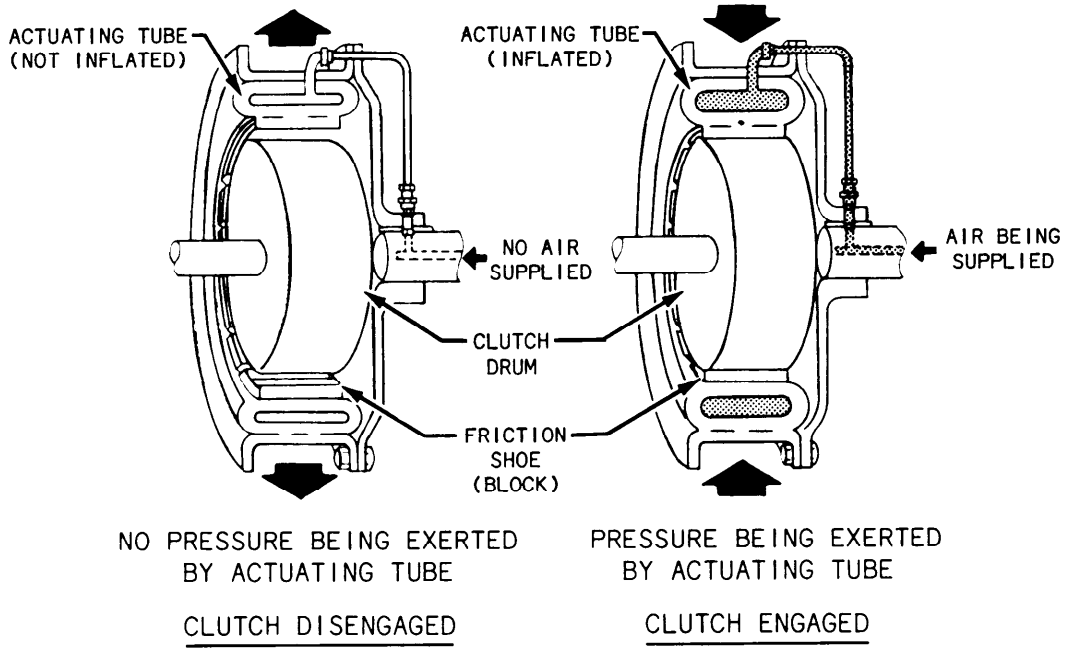


Figure 12-7.—Clutch operation.

flywheel by a steel SPACER, so that they both rotate with the engine at all times at any engine speed. (See view A of fig. 12-6.) Each clutch has a flexible tube (gland) on the inner side of a steel shell. Before the tubes are inflated, they will rotate out of contact with the drums, which are keyed to the forward and reverse drive shafts. When air under pressure (100 psi) is forced into one of the tubes, the inside diameter of the clutch decreases. This causes the friction blocks on the inner tube surface to come in contact with the clutch drum, locking the drive shaft with the engine. (See figure 12-7.)

Forward Rotation

The parts of the airflex clutch that give the propeller shaft ahead rotation are illustrated in view A of figure 12-6. The clutch tube nearest the engine (forward clutch) is inflated to contact and drive the forward drum with the engine. The forward drum is keyed to the forward drive shaft, which carries the double helical forward pinion at the afterend of the gear box. The forward pinion is in constant mesh with the double helical main gear, which is keyed to the propeller shaft. By following through the gear train, you can see that, for ahead motion, the propeller must rotate in a direction opposite to the rotation of the engine. (See the directional arrows.)

Reverse Rotation

The parts of the airflex clutch that give the propeller shaft astern rotation are illustrated in view B of figure 12-6. The reverse clutch is inflated to engage the reverse drum, which is then driven by the engine. The reverse drum is keyed to the short reverse shaft, which surrounds the forward drive shaft. A large reverse step-up pinion transmits the motion to the large reverse step-up gear on the upper shaft. The upper shaft rotation is opposite to the rotation of the engine. (Note the directional arrows in view B.) The main reverse pinion on the upper shaft is in constant mesh with the main gear. By tracing through the gear train, you should see that for reverse rotation the propeller rotates in the same direction as the engine.

The diameter of the main gear of the airflex clutch is approximately 2 1/2 times as great as that of the forward and reverse pinions. Thus, there is a speed reduction of 2 1/2 to 1 from either pinion to the propeller shaft.

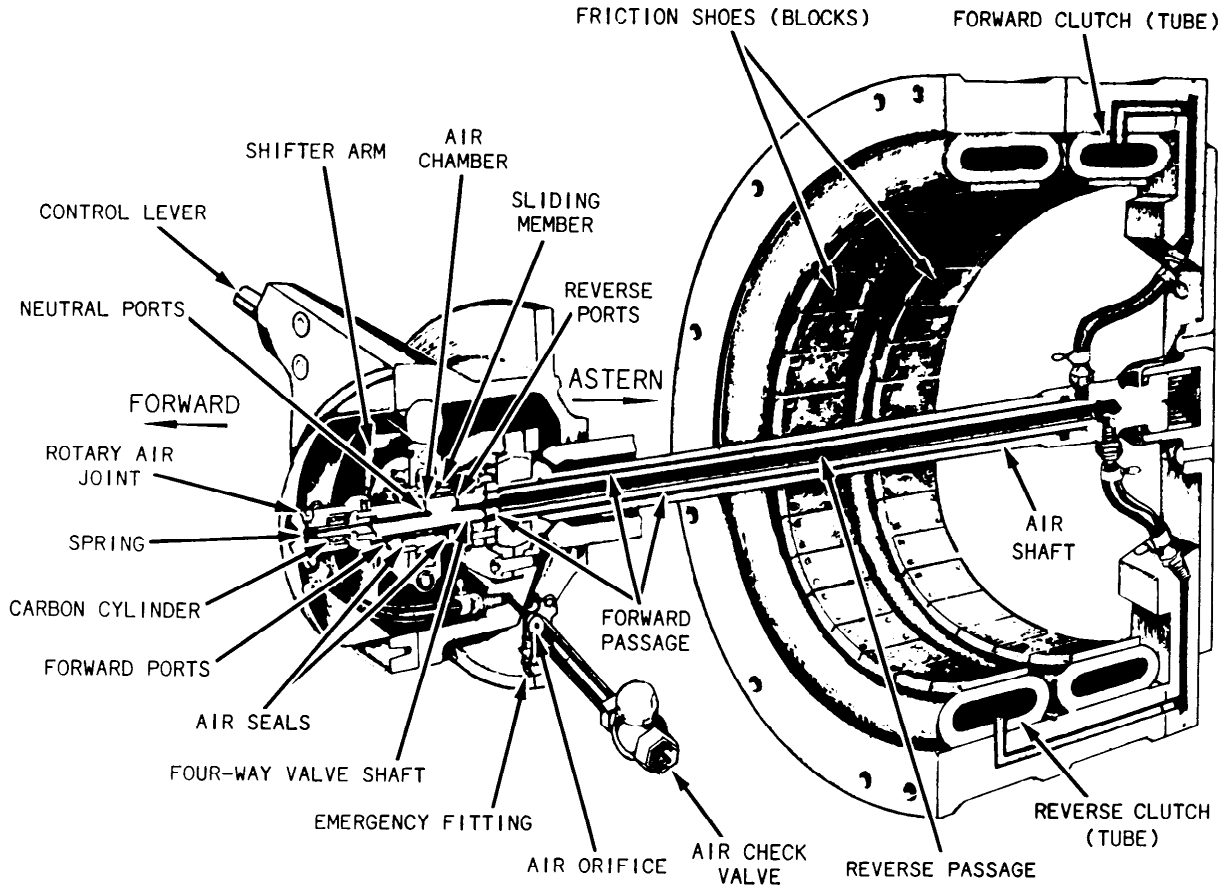
Since the forward and main reverse pinions are in constant mesh with the main gear, the set of gears that is not clutched in will rotate as idlers driven from the main gear. The idling gears rotate in a direction opposite to their rotation when carrying the load. For example, with the forward clutch engaged, the main reverse pinion rotates in a direction opposite to its rotation for astern motion. (Note the dotted arrow in view A of fig. 12-6.) Since the drums rotate in opposite directions, a control mechanism is installed to prevent the engagement of both clutches simultaneously.

Airflex Clutch Control Mechanism

The airflex clutch is controlled by an operating lever that works the air control housing, located at the afterend of the forward pinion shaft. The control mechanism, shown with the airflex clutches in figure 12-8, directs the air into the proper paths to inflate the clutch glands (tubes). The air shaft, which connects the control mechanism to the clutches, passes through the forward drive shaft. The supply air enters the control housing through the air check valve and must pass through the small air orifice. The restricted orifice delays the inflation of the clutch to be engaged during shifting from one direction of rotation to the other. The delay is necessary to allow the other clutch to be fully deflated and out of contact with its drum before the inflating clutch can make contact with its drum.

The supply air goes to the rotary air joints in which a hollow carbon cylinder is held to the valve shaft by spring tension, preventing leakage between the stationary carbon seal and rotating air valve shaft. The air goes from the rotary joint to the four-way air valve. The sliding-sleeve assembly of the four-way valve can be shifted endwise along the valve shaft by operation of the control lever.

When the shifter arm on the control lever slides the valve assembly away from the engine, air is directed to the forward clutch. The four-way valve makes the connection between the air supply and the forward clutch. There are eight neutral ports, which connect the central air supply passage in the valve shaft with the sealed air chamber in the sliding member. In the neutral position of the four-way valve, as shown in figure 12-8, the air chamber is a dead end for the supply air. With the shifter arm in the forward position, the sliding member uncovers eight forward ports, which connect with the forward passages that conduct the air to the forward



75.257

Figure 12-8.—Airflex clutches and control valves.

clutch. The air now flows through the neutral ports, air chamber, forward ports, and forward passages to inflate the forward clutch gland. As long as the shifter arm is in the forward position, the forward clutch will remain inflated, and the entire forward air system will remain at a pressure of 100 psi.

At this point, let us assume that the bridge signals you to reverse the propeller. You should pull the operating lever back to the neutral position and hold it there for 2 or 3 seconds (as a safety factor). Then pull the lever to the reverse idling position and wait about 7 seconds, after which the reverse clutch is fully engaged. Then you can increase the reverse speed to whatever the bridge has ordered.

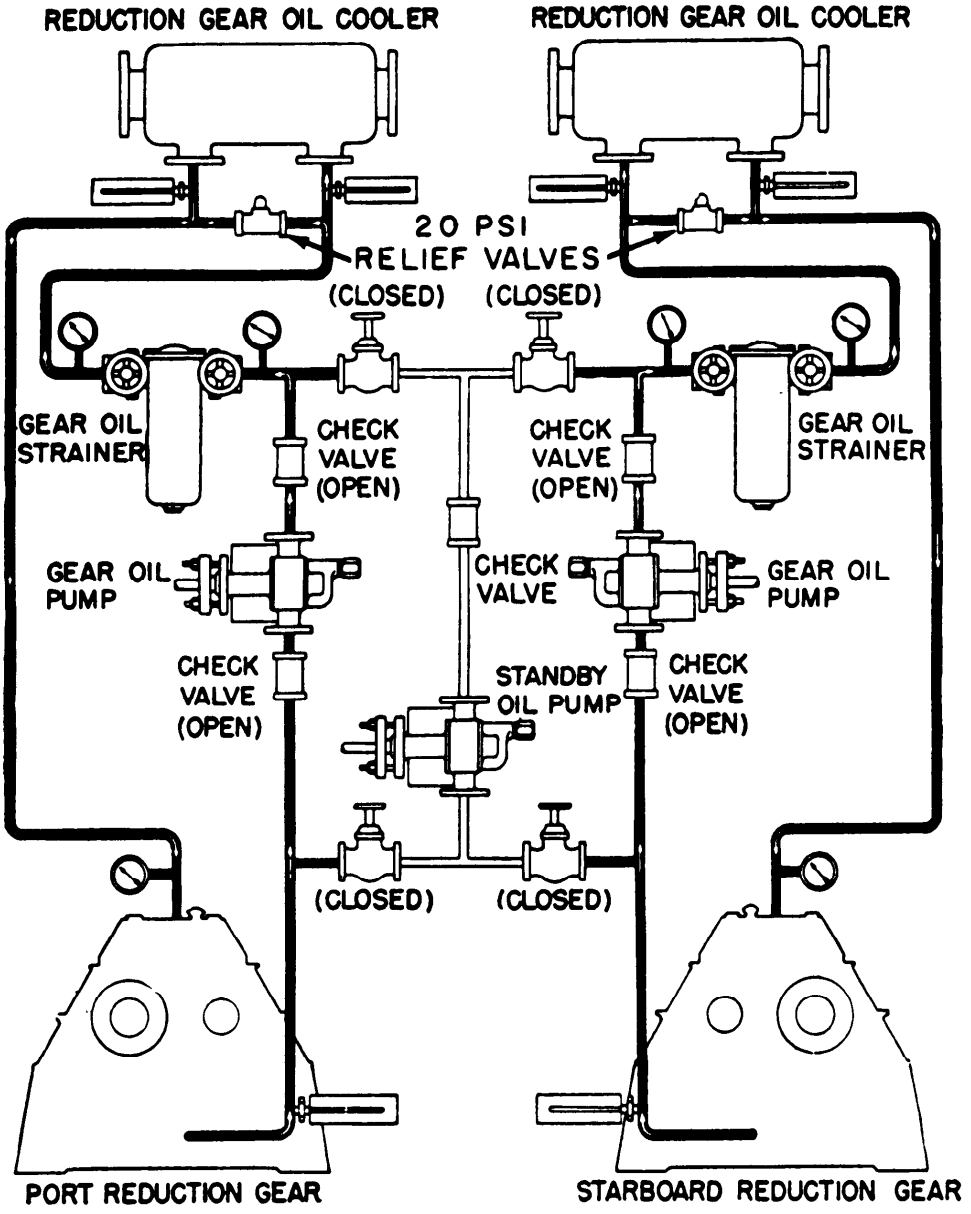
Why was it necessary to pause at the neutral and the reverse idling positions? What has happened in the air control and clutch mechanism? When you shift to neutral, the forward ports are uncovered, and the compressed air from the forward clutch and passage vents to the atmosphere. When you deflate either clutch, the air is vented through eight ports approximately the same size as the air orifice, so that deflating either clutch actually requires 1 to 2 seconds. Pausing for 2 or 3 seconds at neutral allows enough time for the forward clutch to deflate and disengage before you start inflating the reverse clutch.

When you shift to reverse idling, the air chamber comes over the eight reverse ports which open to the central reverse passage in the air shaft. The compressed air begins to inflate the reverse clutch immediately; the inflating air must pass through the single air orifice in the supply line, causing a delay of about 7 seconds to fully inflate a clutch. When the clutch is in the reverse idling position, wait until the reverse clutch is fully engaged before increasing the speed to prevent damaging the clutch (by slippage). It is impossible to have both clutches engaged at the same time.

Unlike the transmissions previously discussed, the gear units on diesel-propelled ships have a separate lubricating system. This type of lubricating system is shown in figure 12-9. The oil is picked up from the gear box by an electric-driven, gear-type lubricating oil pump and is sent through a strainer and cooler. After being cleaned and cooled, the oil is returned to the gear box to cool and lubricate the gears. In a twin installation, such as the one shown in figure 12-9, a separate pump is used for each unit and a standby pump is interconnected for emergency use.

HYDRAULIC CLUTCHES (COUPLINGS)

The fluid clutch (coupling) is used in some Navy ships. A hydraulic coupling eliminates the need for a mechanical connection between the



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Figure 12-9.—Schematic diagram of reverse gear lubrication system.

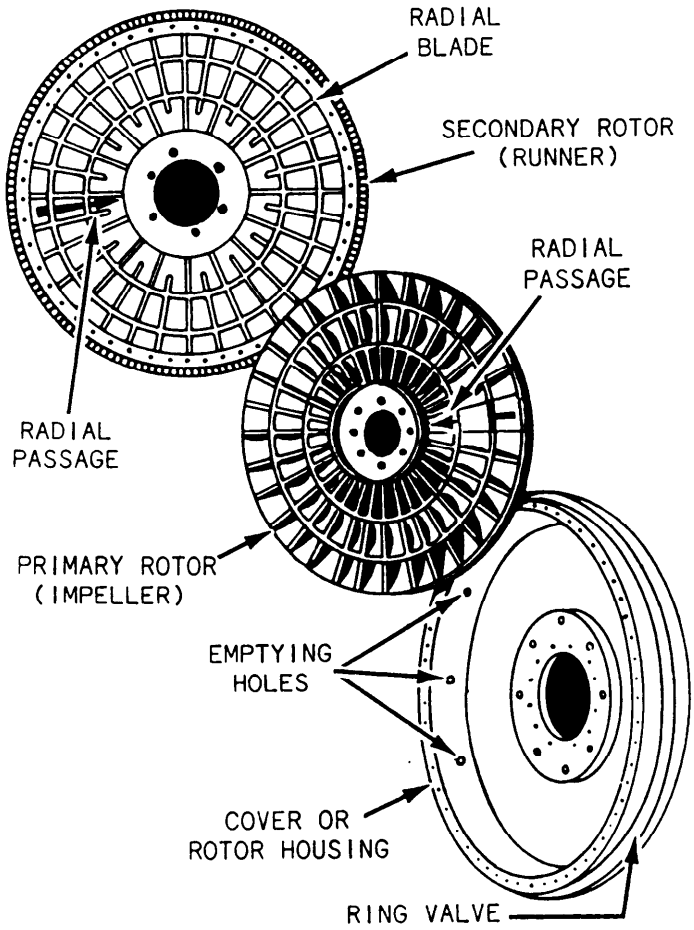
engine and the reduction gears. Power is transmitted through hydraulic couplings very efficiently (97 percent) without the transmission of torsional vibrations or load shocks from the engine to the reduction gear. The power loss from the small amount of slippage is transformed into heat, which is absorbed by the oil in the system. Some slippage is necessary for operation of the hydraulic coupling, since torque transmission depends on relative motion between the two rotors.

Hydraulic Coupling Assemblies

The two rotors and the oil-sealing cover of a typical hydraulic coupling for a large propulsion unit is shown in figure 12-10. The primary rotor (impeller) is attached to the engine crankshaft. The secondary rotor (runner) is attached to the reduction gear pinion shaft. The cover is bolted to the secondary rotor and surrounds the primary rotor.

Before proceeding with the assembly of the rotors and the shafts in the coupling housing, study the structure of the rotors themselves. Each rotor has a concave shape with radial partitions. A shallow trough is welded into the partitions around the inner surface of the rotor. The radial passages tunnel under this trough (as indicated by the arrows in fig. 12-10).

When the coupling halves are assembled, the two rotors are placed facing each other to form



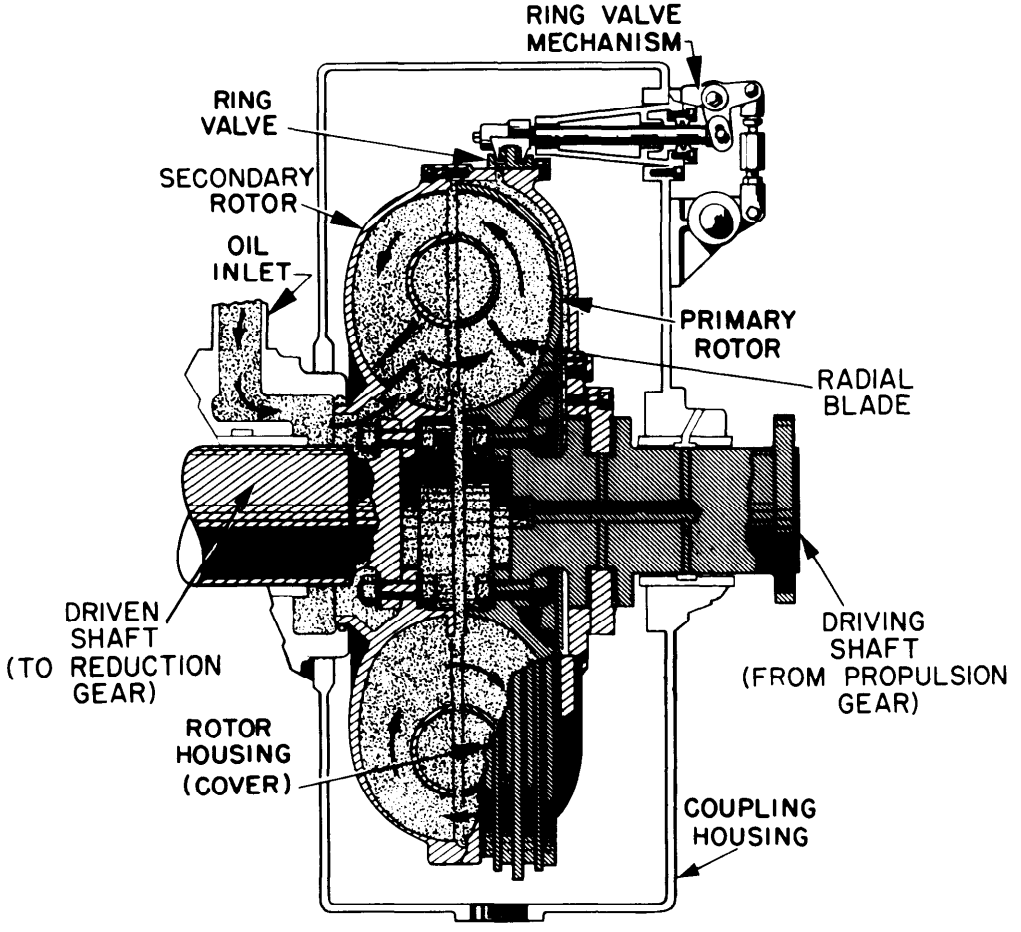
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Figure 12-10.—Runner, impeller, and cover of hydraulic coupling.

a series of circular chambers. (See fig. 12-11.) The rotors do not quite touch each other; the clearance between them is 1/4 to 5/8 inch, depending on the size of the coupling. The curved radial passages of the two rotors are opposite each other, so that the outer passages combine to make a circular passage except for the small gaps between the rotors.

In the hydraulic coupling assembly shown in figure 12-11, the driving shaft is secured to the engine crankshaft and the driven shaft goes to the reduction gear box. The oil inlet admits oil directly to the rotor cavities, which become completely filled. The rotor housing is bolted to the secondary rotor and has an oil-sealed joint with the driving shaft. A ring valve, going entirely around the rotor housing, can be operated by the ring valve mechanism to open or close a series of emptying holes in the rotor housing. When the ring valve is opened, the oil will fly out the rotor housing into the coupling housing, draining the coupling completely in 2 or 3 seconds. Even when the ring valve is closed, some oil leaks out into the coupling housing, and additional oil enters through the inlet. From the coupling housing, the oil is drawn by a pump to a cooler, then sent back to the coupling.

Another coupling assembly used in Navy ships is the hydraulic coupling with PISTON-TYPE quick-dumping valves. The operation of this coupling is similar to the one previously described. A series of piston valves are located around the periphery of the rotor housing. The piston valves are normally held in the closed position by springs. When air or oil pressure is admitted to the valves, the pistons are moved axially to uncover drain ports, allowing the coupling to empty. A hydraulic coupling with piston-type quick-dumping valves is used when extremely rapid declutching is not required. It offers greater simplicity and lower



75.260

Figure 12-11.—Hydraulic coupling assembly.

cost than a hydraulic coupling with a ring valve mechanism.

Another type of self-contained unit for certain diesel-engine drives is the SCOOP CONTROL COUPLING, shown in figure 12-12. In couplings of this type, the oil is picked up by one of two scoop tubes (one tube for each direction of rotation), mounted on the external manifold. Each scoop tube contains two passages: a smaller one (outermost), which handles the normal flow of oil for cooling and lubrication, and a larger one, which rapidly transfers oil from the reservoir directly to the working circuit.

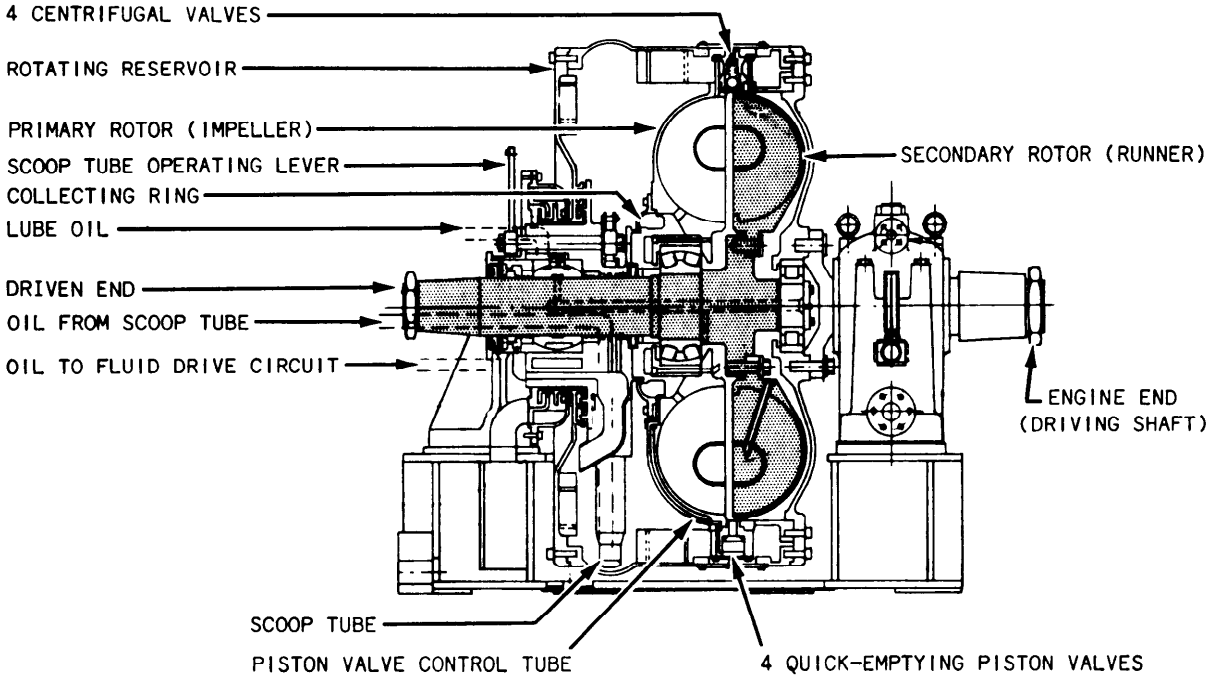
The scoop tubes are mechanically operated from the control station through a system of linkages. As one tube moves outward from the shaft center line and into the oil annulus, the other tube is being retracted.

Four spring-loaded valves are mounted on the primary rotor. These valves, which are operated by centrifugal force, are arranged to open progressively as the speed of the primary rotor decreases. The arrangement provides the necessary oil flow for cooling as it is required. Quick-emptying piston valves are provided to empty the circuit rapidly when the scoop tube is withdrawn from contact with the rotating oil annulus.

Under normal circulating conditions, oil fed into the collector ring passes into the piston valve control tubes. These tubes and connecting passages conduct oil to the outer end of the pistons. The centrifugal force of the oil in the control tube holds the piston against the valve port, thus sealing off the circuit. When the scoop tube is withdrawn from the oil annulus in the reservoir, the circulation of oil will be interrupted, and the oil in the control tubes will be discharged through the orifice in the outer end of the piston housing. This releases the pressure on the piston and allows it to move outward, thus opening the port for rapid discharge of oil. Resumption of oil flow from the scoop tube will fill the control tubes, and the pressure will move the piston to the closed position.

Principles of Operation

Now you can see what happens in the coupling when the engine is started and the coupling is filled with oil. The primary rotor turns with the engine crankshaft. (Refer to fig. 12-11.) As the primary rotor turns, the oil in the radial passages is forced to flow outward by centrifugal force. (See the arrows in fig. 12-11.) This forces oil across the gap at the outer edge of the rotor



75.262

Figure 12-12.—Scoop control hydraulic coupling.

and into the radial passages of the secondary rotor, where the oil flows inward. The oil in the primary rotor not only is flowing outward, but also is rotating. As the oil flows over and into the secondary rotor, it strikes the radial blades in the rotor.

The secondary rotor soon begins to rotate and pick up speed, but it will always rotate more slowly than the primary rotor because of drag on the secondary rotor. Therefore, the centrifugal force of the oil in the primary rotor will always be greater than that of the oil in the secondary rotor. This causes a constant flow from the primary rotor to the secondary rotor at the outer ends of the radial passages and from the secondary rotor to the primary rotor at the inner ends.

Hydraulic Coupling Problems

With the quick-dumping hydraulic coupling, you may encounter the problem of DUMPING WHILE UNDER LOAD or EXCESSIVE SLIPPAGE. Either of these malfunctions may be caused by plugging of the pressure relief nozzles located in the periphery of the secondary (piston-type) rotors. These nozzles consist of drilled allen setscrews, mounted in the secondary rotor at the ends of the radial tubes that feed air or oil to the dumping valves. The nozzles permit the feeder tubes to drain when the air or oil supply valve is closed, thus allowing the dumping valve to return to the closed position. The nozzles also permit the draining of any oil that has leaked past the control valve when shut.

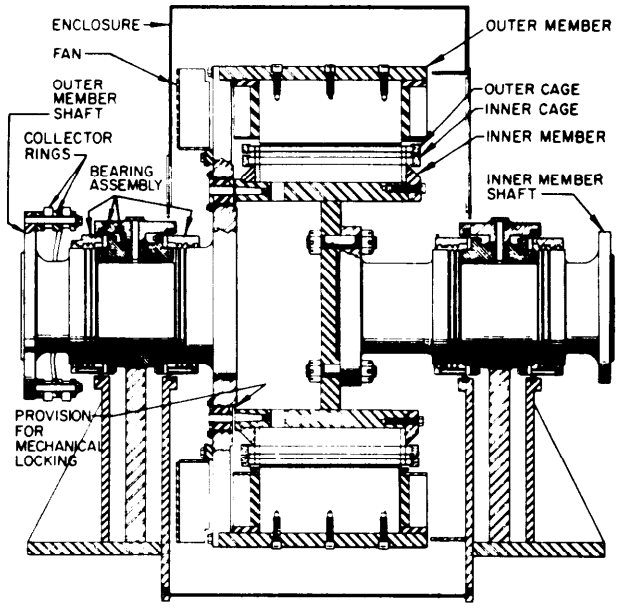
There are also leak-off nozzles in the periphery of the secondary rotor at the base of the dumping valves. The leak-off nozzles serve as flushing exits for the valves and allow a continual flow of oil past the inlet port of the dumping valves. The oil washes away any particles of foreign matter that may collect as a result of the centrifugal force acting on the oil.

The best way to prevent a hydraulic coupling from dumping while under load is to keep the oil system free from foreign matter. Gasket compound and shreds of copper from oil tube packings often cause trouble. Every possible precaution must be taken to keep the oil system clean from foreign material. To aid in this, the system has a strainer that effectively catches, or traps, most of the foreign matter that may reach the nozzles. All nozzles must be blown out during each overhaul.

If nozzles become clogged during operation, it is possible to clear them by operating the dumping control several times. This action may blow the obstruction through the nozzle opening. If this method fails, it will be necessary for you to secure the engine and remove and clean the nozzles.

INDUCTION COUPLINGS

Couplings of the induction type are used in some ships in the Navy. (See fig. 12-13.) These couplings use the force of magnetism to "couple" the outer shaft to the input shaft. The inner cage is very similar in construction to the rotor of an electric motor. When the outer member is energized through the collector rings, a magnetic field is produced which will "lock in" the inner rotor. An instant disconnect of the driver from the driven shaft is accomplished by de-energizing the coupling excitation circuit. The induction coupling limits maximum torque by pulling out of step when excessive torque is applied. The induction coupling also allows for a small amount of misalignment.



75.263

Figure 12-13.—Induction coupling.

In operating equipment that has induction couplings, observe the following directions and precautions:

1. Do NOT attempt to alter plant performance by changing control settings to settings other than those recommended in the NAVSEA technical manual for the equipment.
2. Ensure the coupling does not overheat because of insufficient ventilation when the fields rotate at slow speeds.
3. Ensure proper alignment is maintained (although most clutches of this type are capable of operating satisfactorily with a limited amount of misalignment).
4. Be thoroughly familiar with the means to permit the rotating members to be mechanically coupled in the event of total failure of the coupling excitation system.
5. Be thoroughly familiar with any interlocks that serve to PREVENT the following:
   a. Operation at reduced excitation EXCEPT when the prime mover is operating at specified reduced speeds.
   b. Excitation of the field windings UNLESS the throttle control is in the proper position.
   c. Excitation of the field windings UNLESS the shaft turning gear and shaft-locking devices are disengaged.
   d. Excitation of the field windings at a time when the clutch would turn the driven gear counter to the direction in which it is already being driven by another coupling or clutch.

BEARINGS

Bearings in main propulsion units vary in size, composition, and lubrication requirements, but their purposes are the same. Bearings guide and support rotating elements, prevent free radial movement, and limit the axial movement of these elements. Radial or journal bearings carry loads applied in a plane that is at a right angle to the axis of the shaft. Thrust bearings carry loads applied in the same direction as the axis of the shaft and restrict axial movement.

Lubrication of bearings differs according to type. Babbitt-lined bearings are lubricated by a constant flow of lubricating oil. Stern tube and strut bearings, which are lined with hardwood, phenolic, or a rubber composition, are lubricated by a constant flow of seawater. Bearings operate with a small lubricant clearance. (The lubricant clearance is the difference between the outside diameter of the journal and the inside diameter of the bearing.) This clearance must always be maintained within specified limits. With proper clearances and proper lubrication, bearings will last for many years.

The information in this training manual is of a general nature. You can find additional information in chapters 244, 9420, and 9430 of the *Naval Ships' Technical Manual.* For details concerning a particular unit, consult the applicable NAVSEA technical manual and current MRCs.

MAIN REDUCTION GEAR BEARINGS

Reduction gear bearings must support the weight of the gears and their shafts. They must also hold the shafts in place against tremendous mechanical forces. These forces are exerted by the shafts and gears when they are transmitting power to the propeller shaft. (NOTE: It takes a lot of horsepower to move a 5,000-ton ship through the water at 15 knots.) Like other radial bearings in main engine installations, these bearings are of the babbitt-lined split type. However, the bearings are not spherically seated and self-aligning. Instead, they are rigidly mounted into the bearing housings by dowels or by locking screws and washers. The angular direction of the forces acting upon a main reduction gear bearing changes with the amount of propulsion power being transmitted by the gear.

To avoid wiping, reduction gear bearings must be positioned so that the heavy shaft load is not brought against the area where the bearing halves meet (the split). For this reason, most bearings in reduction gears are placed so that the split is at an angle to the horizontal plane.

MAIN THRUST BEARINGS

The main thrust bearing is usually located in the reduction gear casing. It absorbs the axial thrust transmitted through the shaft from the propeller. In fact, in the main thrust bearing for a propeller shaft, the only thing that prevents metal-to-metal contact between the fixed and moving parts of the bearing is a thin, wedge-shaped film of oil!

Kingsbury bearings, also called segmental pivoted-shoe thrust bearings (fig. 12-14), are commonly used for main thrust bearings. This bearing consists of pivoted segments or shoes (usually six or eight) against which the thrust collar revolves. The action of the thrust shoes against the thrust collar restrains the ahead or astern axial motion of the shaft to which the thrust collar is secured. These bearings operate on the principle that a wedge-shaped film of oil is more readily formed and maintained than a flat film, and that it can, therefore, carry a heavier load for any given size.

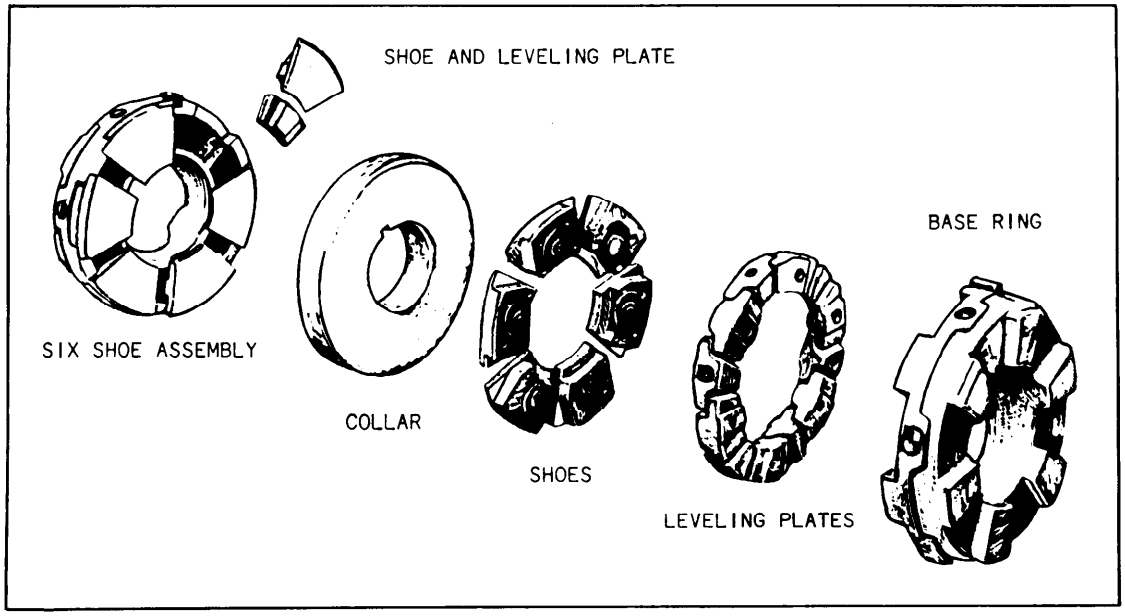
The upper leveling plates upon which the shoes rest and the lower leveling plates equalize the thrust load among the shoes (fig. 12-15). The base ring, which supports the lower leveling plates, holds the plates in place. This ring transmits the thrust on the plates to the ship's structure via housing members that are bolted to the foundation. Shoe supports (hardened steel buttons or pivots) located in the shoes separate the shoes and the upper leveling plates. This separation enables the shoe segments to assume the angle required to pivot the shoes against the upper leveling plates. Pins and dowels hold the upper and lower leveling plates in position. This design allows for ample play between the base ring and the plates and ensures freedom of movement (oscillation only) of the leveling plates. The base ring is prevented from turning by its keyed construction, which secures the ring to its housing.

MAIN PROPULSION SHAFT BEARINGS

You will be required to monitor the operation of the propeller shaft bearings and to maintain them in good condition. These bearings support and hold the propulsion shafting in alignment. Three kinds of bearings are used for a main propulsion shaft: LINE SHAFT BEARINGS (or SPRING BEARINGS), STERN TUBE BEARINGS, and STRUT BEARINGS. We will briefly discuss each of these bearings. Refer to figure 12-16, which illustrates the general location of the bearings on main shafting.

Line Shaft Bearings or Spring Bearings

Most of the line shaft bearings or spring bearings are the ring- or disc-oiled, babbitt-faced, spherical seat, or shell type. This type of



96.53

Figure 12-14.—Kingsbury pivoted-shoe thrust bearing.

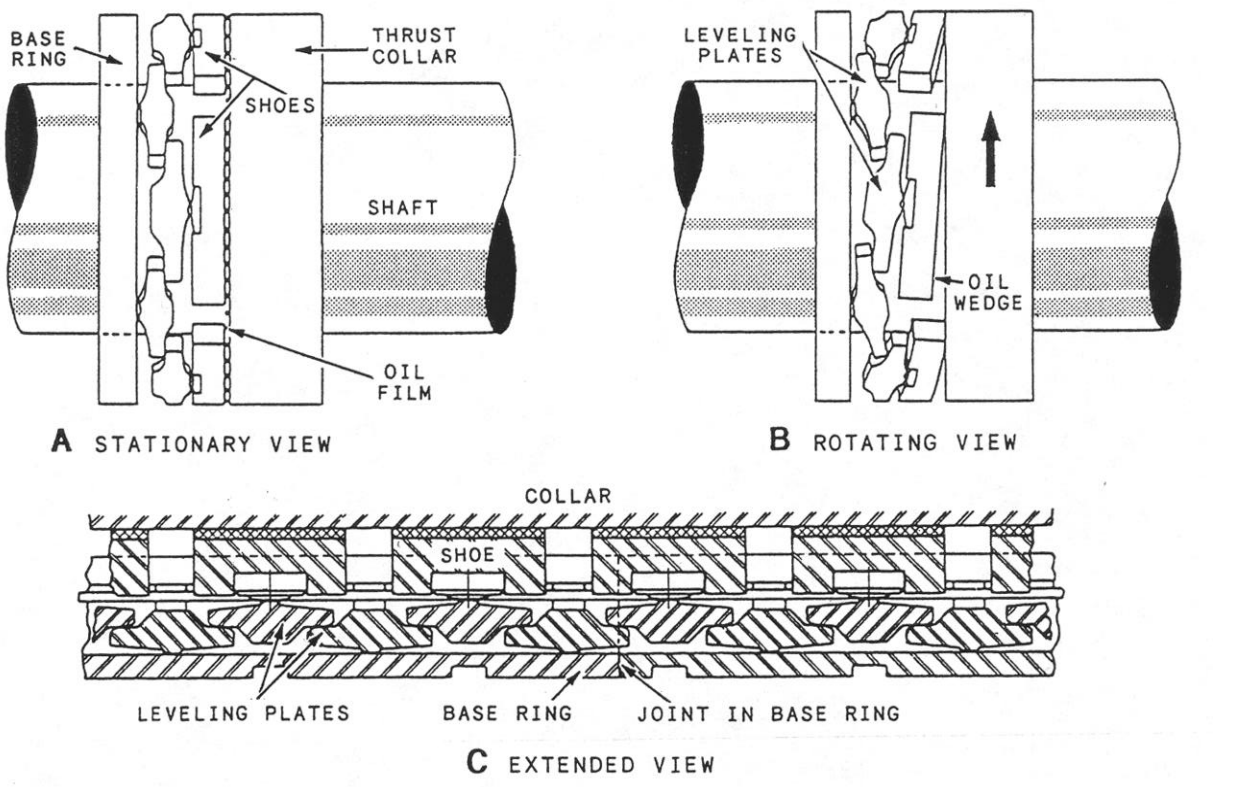
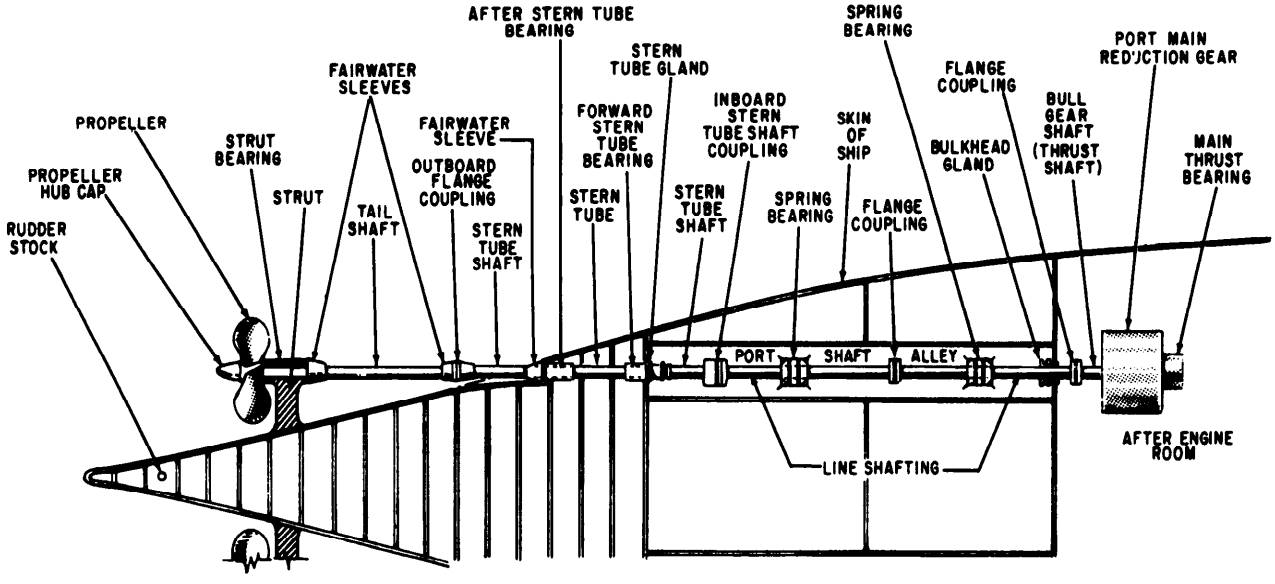


Figure 12-15.—Diagrammatic arrangement of a typical thrust bearing.



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Figure 12-16.—Main shafting.

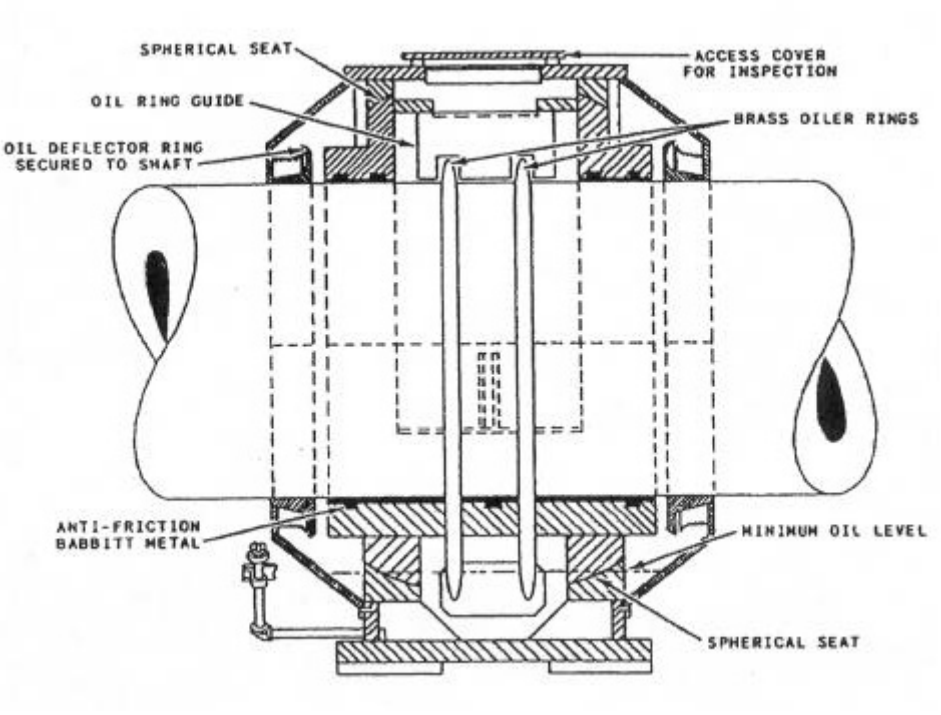
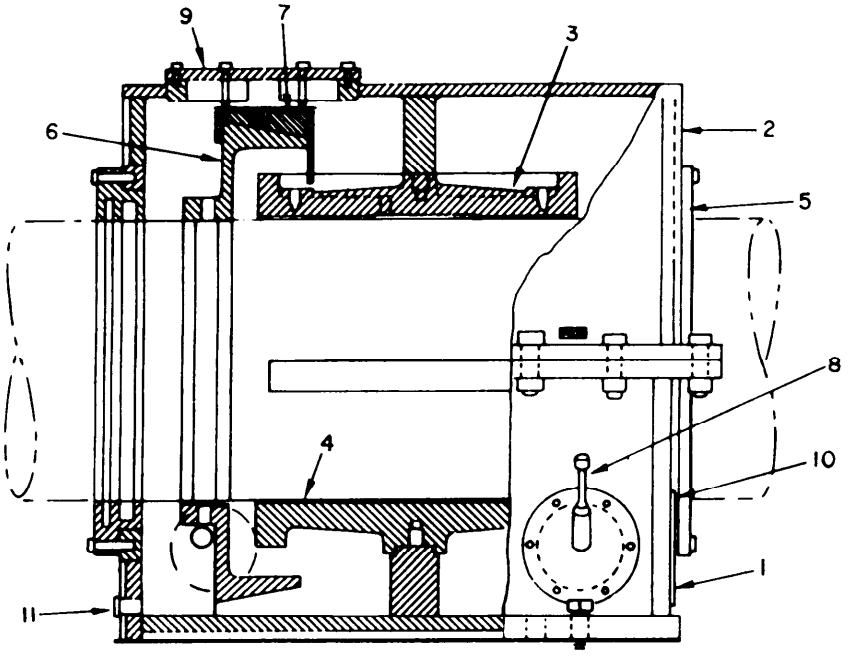


Figure 12-17.—Main line shaft bearing (ring oiled).



1. BEARING PEDESTAL
2. BEARING CAP
3. UPPER BEARING SHELL
4. LOWER BEARING SHELL
5. OIL RETAINING END COVER
6. OIL DISC
7. OIL SCRAPER
8. OIL GAUGE
9. SIGHT HOLE
10. HAND HOLE
11. PIPE PLUG

47.240

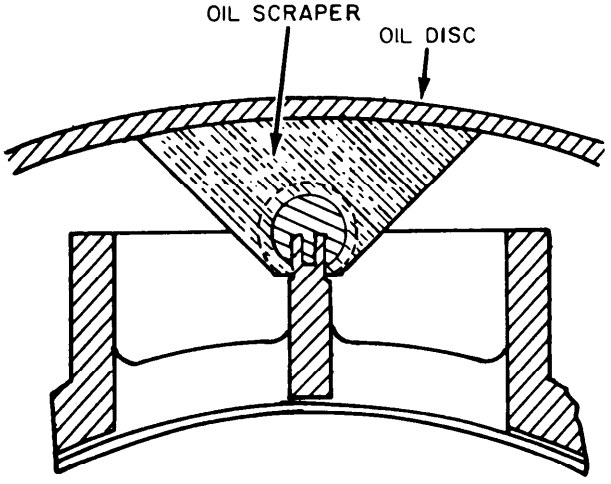
Figure 12-18.—Line shaft bearing (disc oiled).

bearing (fig. 12-17) is designed primarily to align itself to support the weight of the shafting.

The brass oiler rings, shown in figure 12-17, are a loose fit. The rings are retained in an axial position by guides or grooves in the outer bearing shell. As the shaft rotates, friction between the rings and the shaft is enough to cause the rings to rotate with the shaft. The rings dip into the oil in the sump. Oil is retained on the inside diameter of the rings and is carried to the upper bearings by the rings. The action of the oil ring guides and the contact of the rings on the upper shaft cause the oil to be removed from the rings and to lubricate the bearings.

The disc-oiled spring bearing (fig. 12-18) is basically the same as the ring-oil type except it uses an oil disc to lubricate the bearing. The oil disc is attached to, and rotates with, the shaft. Oil is removed from the disc by a scraper, located at the top of the bearing. The oil then runs into a pocket at the top of the upper bearing shell. (Fig. 12-19 shows the scraper arrangement .) From here, the oil enters the bearing through drilled holes.

Tests have shown that the disc delivers more oil at all speeds than the ring discussed earlier, especially at turning gear speeds. The disc is also more reliable than the ring. Some ships have line shaft bearings that are force lubricated by a pump.



47.241

Figure 12-19.—Disc-oiled line shaft bearing scraper arrangement.

You should check the line shaft bearing temperatures and oil levels at least once an hour. Inspection and maintenance should be done according to PMS requirements.

Stern Tubes and Stern Tube Bearings

The stem tube is located where the shaft passes through the hull of the ship. The shaft is supported within the stern tube by two stern tube bearings; one on the inner side, and one on the outer side of the hull. The construction of the stern tube bearing is basically the same as that of the strut bearing, which is described later in this chapter.

The point where the shaft passes through the hull must be sealed to prevent seawater from entering the ship. This is accomplished primarily by use of either packing or mechanical seals. Stem tube packing (fig. 12-20) is used only on older ships as a primary sealer.

This packing method uses a stuffing box that is flanged and bolted to the stern tube. The afterspace contains a flushing connection to provide a constant flow of water through the stem tube (from inside the ship to outside the ship) to lubricate, cool, and flush the bearings. This flushing connection is supplied by the firemain. A drain connection is provided both to test the presence of cooling water in the bearing and to allow seawater to flow through the stern tube to lubricate the packing when the ship is underway. This is done where natural seawater circulation is used.

The gland for the stuffing box is divided longitudinally into two parts. The packing

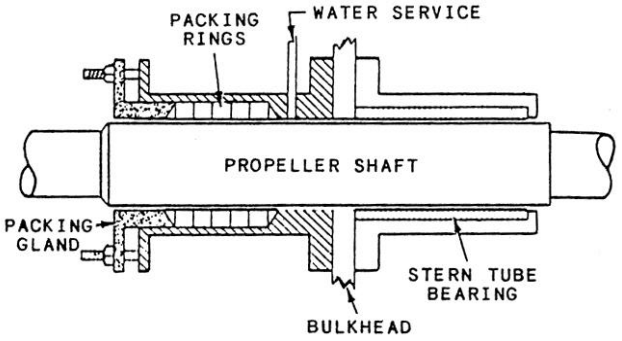


Figure 12-20.—Stern tube stuffing box and gland.

material used, Teflon-impregnated asbestos (PTE), is according to MIL-P-24377 and has replaced all previously used packing material.

Gland leakage is required to prevent packing from heating up, crystallizing, and scoring the shaft sealing surface within the gland. Usually, the gland is tightened and the flushing connection is closed to eliminate leakage when the ship is in port. It is loosened just enough to permit a slight trickle of water for cooling purposes when the ship is underway. Whenever packing is added to a stern tube, be sure that the gland is drawn up evenly by using a rule to measure the distance between the gland and the stuffing box.

In some installations, mechanical seals are used to seal the stern tube. Two of the major advances of these seals are (1) they will operate maintenance free for extended periods, and (2) there is no leakage into the shaft alley.

Inflatable Sealing Ring

The split inflatable rubber seal ring is widely used in Navy ships. It is installed aft of the prime seal assembly rig (packing box or mechanical seal). It is used when it is necessary to repair or replace the prime sealing elements when the ship is waterborne.

When the seal is needed, it is inflated with nitrogen and expands against the shaft to form a watertight seal. Nitrogen is used because it is dry and will not deteriorate the seal as rapidly as compressed air, which often contains moisture, oil, and dirt.

The operation and testing of the split inflatable ring seal should be done according to ship's instructions and the applicable MRC. Never exceed the maximum pressure designated for inflating the seal. You can find the specified pressure designations in the *Naval Ships' Technical Manual,* chapter 9430 (243). Over-pressurization can rupture the seal.

Strut Bearings

Strut bearings, as well as the stern tube bearings, are equipped with composition bushings that are split longitudinally into two halves. (See fig. 12-21.) The outer surface of the bushing is machined with steps to bear on matching lands

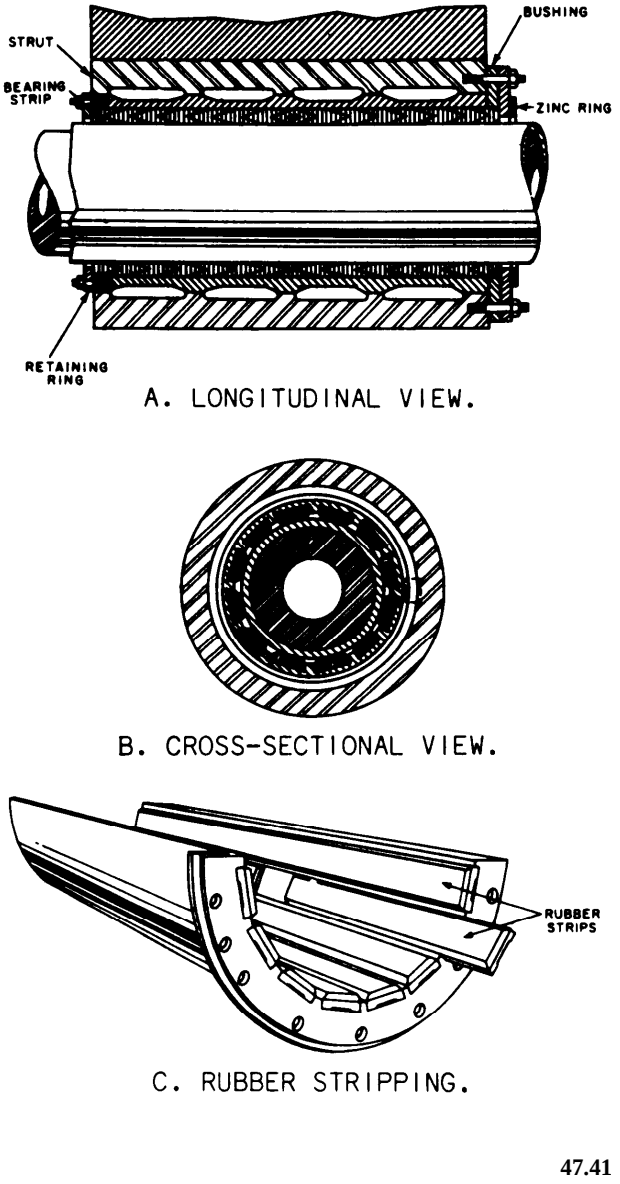
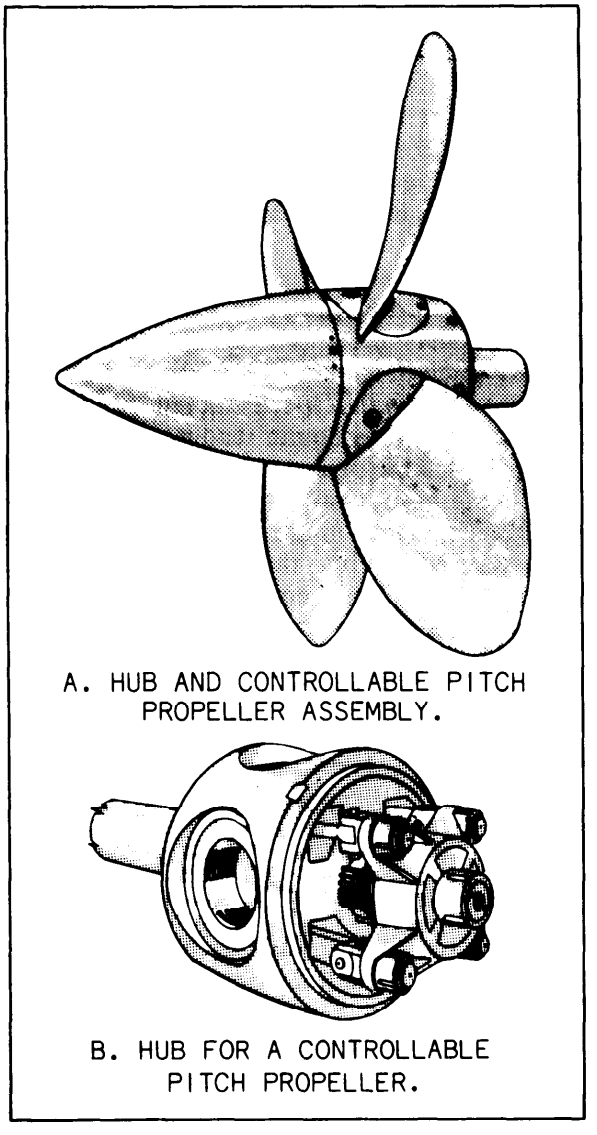


Figure 12-21.—Details of a strut bearing.

in the bore of the strut. One end is bolted to the strut.

Since it is usually not practical to use oil or grease as a lubricant for underwater bearings, some other frictionless material must be used. There are certain materials that become slippery when wet. They include synthetic rubber; lignum vitae, a hard tropical wood with excellent wearing qualities; and laminated phenolic material consisting of layers of cotton fabric impregnated and bonded with phenolic resin. Strips made from any of these materials are fitted inside the bearing. Most Navy installations use rubber composition strips (view C of fig. 12-21).



147.48

Figure 12-22.—Controllable pitch propeller components.

CONTROLLABLE PITCH PROPELLERS

Controllable pitch propellers (fig. 12-22) are used in some naval ships. Controllable pitch propellers give a ship excellent maneuverability and allow the propellers to develop maximum thrust at any given shaft rpm. Ships with controllable pitch propellers require no reversing gear since the direction of the propeller thrust can be changed without changing the direction of shaft rotation. Controllable pitch systems are widely used on diesel-driven ships,. while gas turbine powered ships use controllable pitch as the only means available for providing reverse thrust.

Controllable pitch propeller systems may be controlled from the bridge or from the engineroom through piping inside a hollow propulsion shaft to the propeller hub. Hydraulic or mechanical controls are used to apply the actuating force required to change the position, or angle of the pitch, of the propeller blades.

A hydraulic system is the most widely used means of providing the force required to change the pitch of a controllable pitch propeller. In this type of system, a valve-positioning mechanism actuates an oil control valve. The oil control valve permits hydraulic oil, under pressure, to be introduced to either side of a piston (which is connected to the propeller blade) and at the same time allows for the controlled discharge of hydraulic oil from the other side of the piston. This action repositions the piston and thus changes the pitch of the propeller blades.

Some controllable pitch propellers have mechanical means for providing the blade actuating force necessary to change the pitch of the blades. In these designs, a worm screw and crosshead nut are used instead of the hydraulic devices for transmitting the actuating force. The torque required for rotating the worm screw is supplied either by an electric motor or by the main propulsion plant through pneumatic brakes.

In most installations, propeller pitch and engine power are controlled through a single lever. Movement of the lever causes both engine speed and pitch to change to suit the powering condition ordered. In emergencies, and in ships without single lever control, the propeller pitch may be changed independently of the engine power setting. Under this condition, overspeeding of the engine can result if the pitch is set too low, or overtorquing of the engine can result if the pitch is set too high.

Instructions regarding the limitations of engine speeds at different propeller pitches have been issued to all ships equipped with controllable pitch propellers. In addition, the special operating and maintenance instructions for these propellers should be consulted before any overhaul or repairs are undertaken.

ENGINEER'S BELL BOOK

The Engineer's Bell Book, NAVSHIPS 3120/1 (fig. 12-23), is a record of all bells, signals, and other orders received by the throttleman to change the speed and direction of the ship's propellers. Entries are made in the Bell Book by the throttleman (or an assistant) as soon as an order is received. Entries are usually made by the assistant when the ship is entering or leaving port, or engaging in any maneuver that is likely to involve numerous or rapid speed changes. This procedure allows the throttleman to devote his undivided attention to answering the signals.

The Bell Book is maintained in the following manner:

1. A separate bell sheet is used for each shaft each day, except where more than one shaft is controlled by the same throttle station. In that case, the same bell sheet is used to record the orders for all shafts controlled by the station. All sheets for the same date are filed together as a single record.

2. The time of receipt of the order is recorded in column 1.

3. The order received is recorded in column 2. Minor speed changes (generally received via the revolution indicator) are recorded in column 2 as the number of rpm ordered. Major speed changes (normally received via the engine order telegraph) are recorded by use of the following symbols:

1/3 - Ahead 1/3

2/3 - Ahead 2/3

I - Standard

II - Full

III - Flank

Z - stop

BEM - Back Emergency

BF1 - Back Full

B2/3 - Back 2/3

B1/3 - Back 1/3

4. The number of revolutions corresponding to the major speed change ordered is entered in column 3. When the order received is recorded as rpm in column 2 (minor speed changes), no entry is made in column 3.

5. The shaft revolution counter reading (total revolutions) at the time of the speed change is recorded in column 4. The shaft revolution counter reading-as taken hourly on the hour while the ship is underway-is also entered in column 4.

Ships and craft equipped with controllable pitch propellers must record in column 4 the propeller pitch in feet and fractions of feet set in response to a signaled speed change, rather than the shaft revolution counter readings. The entries for astern pitch are preceded by the letter B. Each hour on the hour, entries are made of counter readings. This helps in the calculation of engine miles steamed during those hours when the propeller pitch remains constant at the last value set in response to a signaled order.

On ships with gas turbine propulsion plants, a bell logger provides an automatic printout each hour. This printout is also provided whenever propeller rpm or pitch is changed by more than 5 percent, when the engine order telegraph is changed, or the controlling station is shifted. Provision must be made for manual logging of data in the event the bell logger is out of commission (OOC).

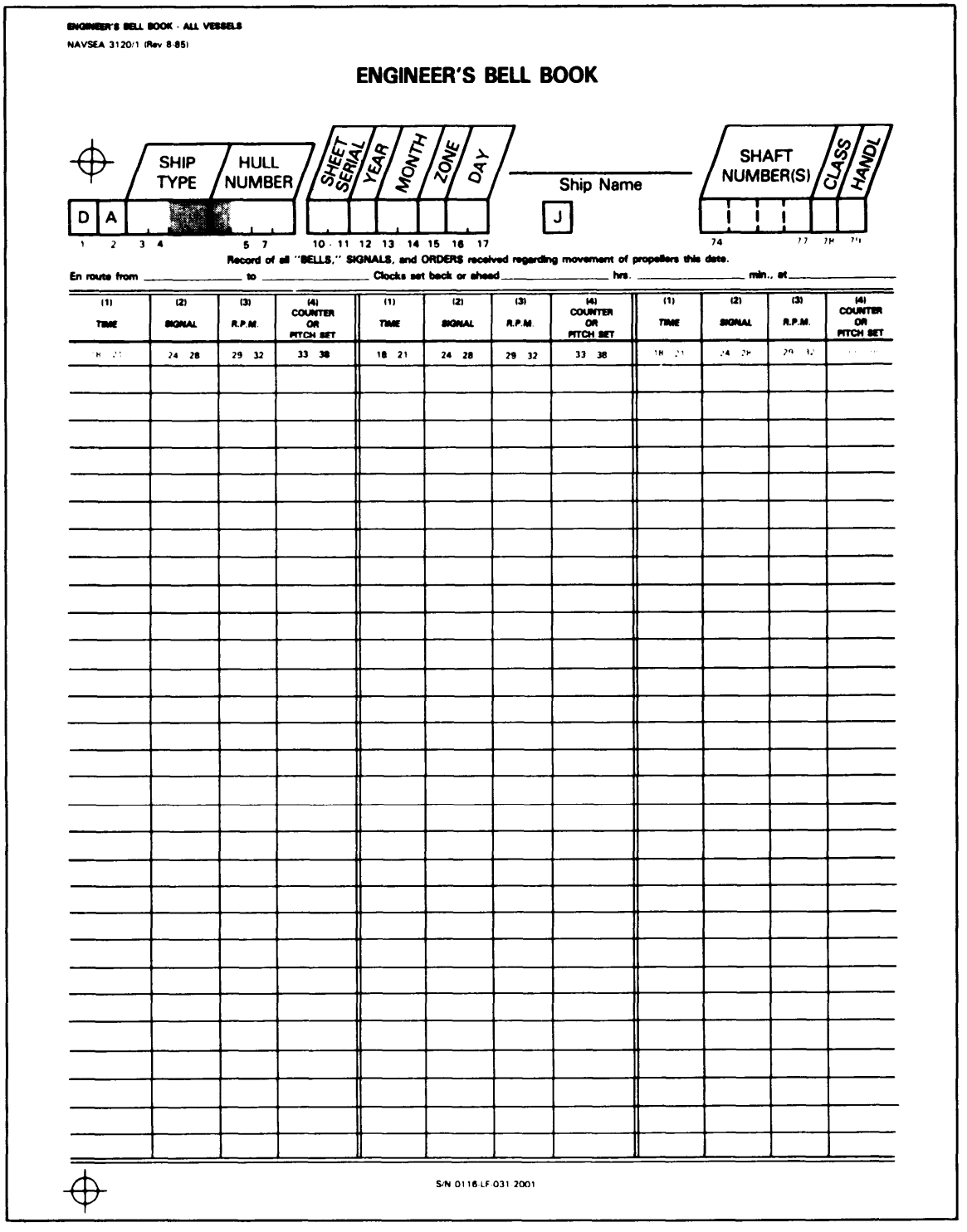
Before going off watch, the EOOW signs the Bell Book on the line following the last entry for that watch. The next officer of the watch continues the record immediately thereafter. In machinery spaces where an EOOW is not stationed, the watch supervisor signs the bell sheet.

NOTE: A common practice is also to have the throttleman sign the Bell Book before it is signed by the EOOW or the EOOW's relief.

The Bell Book is maintained by bridge personnel in ships and craft equipped with controllable pitch propellers and those in which the engines are directly controlled from the bridge. When control is shifted to the engineroom, however, the Bell Book is maintained by the engineroom personnel. The last entry made in the Bell Book on the bridge shows the time that control was shifted. The first entry made in the Bell Book in the engineroom shows the time that control was taken by the engineroom. Similarly, the last entry made by engineroom personnel shows the time that control was shifted to the bridge. When

the Bell Book is maintained by bridge personnel, it is signed by the officer of the deck (OOD) in the same manner as prescribed for the EOOW.

Alterations or erasures are not permitted in the Bell Book. A single line should be drawn through the incorrect entry and the correct entry should be recorded on the following line. Deleted entries are initialed by the EOOW, the OOD, or the watch supervisor, as appropriate.



ENGINEER'S BELL BOOK - ALL VESSELS
NAVSEA 3120/1 (Rev 8-85)

ENGINEER'S BELL BOOK

SHIP TYPE | HULL NUMBER | SHEET SERIAL | YEAR | MONTH | ZONE | DAY | Ship Name | SHAFT NUMBER(S) | CLASS | HANDL

D A J

1 2 3 4 5 7 10 11 12 13 14 15 16 17 74 77 78 79

Record of all "BELLS," SIGNALS, and ORDERS received regarding movement of propellers this date.

En route from _____ to _____ Clocks set back or ahead _____ hrs. _____ min., at _____

(1) TIME	(2) SIGNAL	(3) R.P.M.	(4) COUNTER OR PITCH SET	(1) TIME	(2) SIGNAL	(3) R.P.M.	(4) COUNTER OR PITCH SET	(1) TIME	(2) SIGNAL	(3) R.P.M.	(4) COUNTER OR PITCH SET
H 21	24 28	29 32	33 38	18 21	24 28	29 32	33 38	18 21	24 28	29 32	

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Figure 12-23.—Engineer's Bell Book.

SUMMARY

In this chapter, we have discussed the various devices that transmit the power developed by the engine to the propeller of a vessel. In general, these devices consist of clutches, reverse gears, reduction gears, and the related shafting and bearings. A transmission requires an activating force to engage or disengage the clutch. This force may be in the form of mechanical, hydraulic, pneumatic, or electromagnetic energy. Some vessels are provided with controllable pitch propellers. With this arrangement, no reversing gear is required because the direction of propeller thrust can be changed without changing the direction of shaft rotation.

Learning to recognize various symptoms will help you to identify the abnormal conditions that may occur in clutches, couplings, and various associated gears. You should become familiar with the causes of gear, clutch, and coupling problems. By recognizing the causes of these problems, you can learn to prevent their reoccurrence through the application of correct operating procedures and proper upkeep and maintenance.

If you are uncertain as to any of the information in this chapter, we recommend you reread the sections in question before continuing to chapter 13.

CHAPTER 13

PUMPS AND VALVES

As an Engineman, you will operate various types of pumps and valves. You will also be responsible for routine maintenance of this equipment in your spaces and possibly throughout the ship. The machinery of a system cannot work properly unless the pumps and valves are in good working order. In this chapter, we will discuss basic types of pumps and valves. Our discussion will also include the need for flange safety shields and the purpose of equipment tag-out. The information in this chapter is general. You should refer to the appropriate NAVSEA technical manual for specific information about various pumps and valves used on your ship.

TYPES OF PUMPS

Pumps are by far the most numerous units of auxiliary machinery aboard ship. The types or classes of pumps used aboard ship include (1) rotary pumps, (2) centrifugal pumps, (3) variable-stroke reciprocating pumps, and (4) jet pumps. You can find straightforward explanations and illustrations of the basic principles of each type of pump in *Fireman,* NAVEDTRA 14104. This manual also discusses how the characteristics of each pump make it adaptable to a particular service in various engineering systems. We recommend that you review the information on pumps in *Fireman,* NAVEDTRA 14104, before you begin to study the information in this chapter.

ROTARY PUMPS

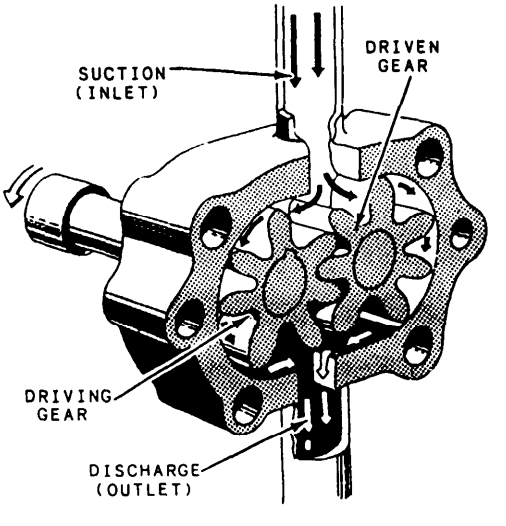
The operation of a positive-displacement rotary pump depends upon the principle that rotating gears, vanes, screws, or lobes trap liquid in the inlet side of the pump casing and move it to the outlet connection—thus producing flow. (POSITIVE DISPLACEMENT means that a definite quantity of liquid is moved from the inlet to the outlet side on each revolution.) In a positive displacement pump, pressure is the result of RESISTANCE TO FLOW in the system to which it discharges. Pressure is limited only by the bursting strength and available power of the pump. For this reason, relief valves are always fitted on the pump discharge. Positive-displacement rotary pumps have largely replaced reciprocating pumps for pumping viscous liquids in naval ships, as they have a greater capacity for their weight and occupy less space.

Rotary pumps have very small clearances between rotating parts to minimize slippage (leakage) from the discharge side back to the inlet of the pump. With close clearances, these pumps must be operated at relatively low speeds to obtain reliable operation and maintain capacity over an extended period of time.

Types of Rotary Pumps

There are several types of positive-displacement rotary pumps, including the simple gear, herringbone gear, helical gear, vane, lobe, and screw types. The main features of gear and screw pumps will be discussed briefly in the following paragraphs.

SIMPLE GEAR PUMP.—The simple gear pump (fig. 13-1) has two spur gears which mesh



194-112

Figure 13-1.—Simple gear rotary pump.

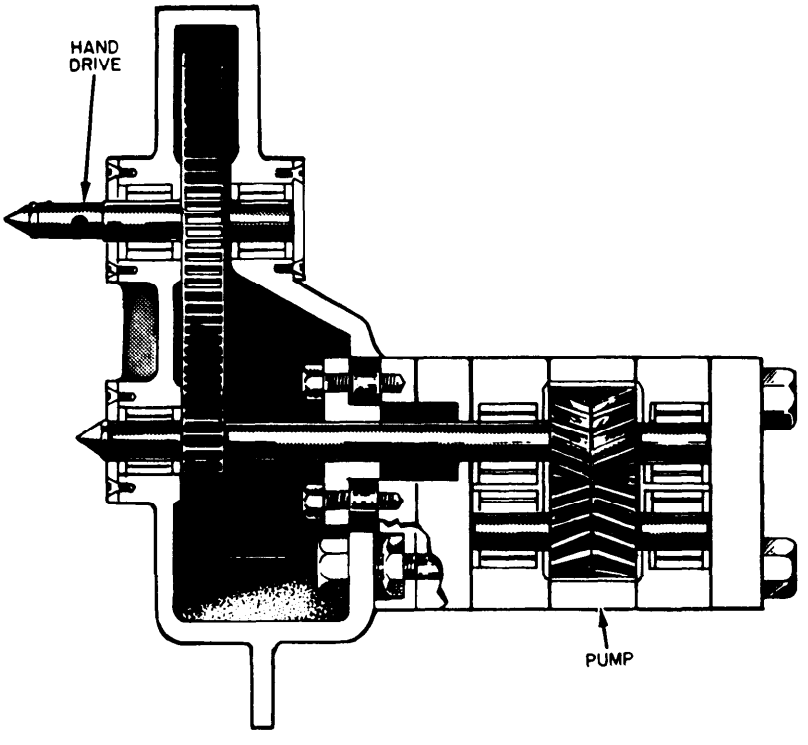
together and revolve in opposite directions. One is the DRIVING GEAR, and the other is the DRIVEN GEAR. Clearances between the gear teeth (the outside diameter of the gear) and the casing, and between the end face and the casing are only a few thousandths of an inch. As they turn, the gears unmesh and liquid flows into the pockets which are vacated by the meshing gear teeth. This creates the suction that draws the liquid into the pump. The liquid is then carried around in the pockets formed by the gear teeth and the casing. At the outlet, or discharge side, the liquid is pushed out (displaced) by the meshing of the gear teeth and is forced to flow through the outlet connection of the pump.

HERRINGBONE GEAR PUMP.—In the herringbone gear pump (fig. 13-2), a modification of the simple gear pump, one discharge phase begins before the previous discharge phase is entirely complete. This overlapping tends to give a steadier discharge pressure than is found in the simple gear pump. Power-driven pumps of this type are sometimes used for low-pressure lubricating oil service and fuel service.

HELICAL GEAR PUMP.—The helical gear pump (fig. 13-3) is still another modification of the simple gear pump. Because of the helical gear design, the overlapping of successive discharges from spaces between the teeth is even greater than it is in the herringbone gear pump. The discharge flow is, accordingly, even smoother. Since the discharge flow is smooth in the helical gear pump, the gears can be designed with a small number of large teeth. This design allows for increased capacity without sacrificing smoothness of flow.

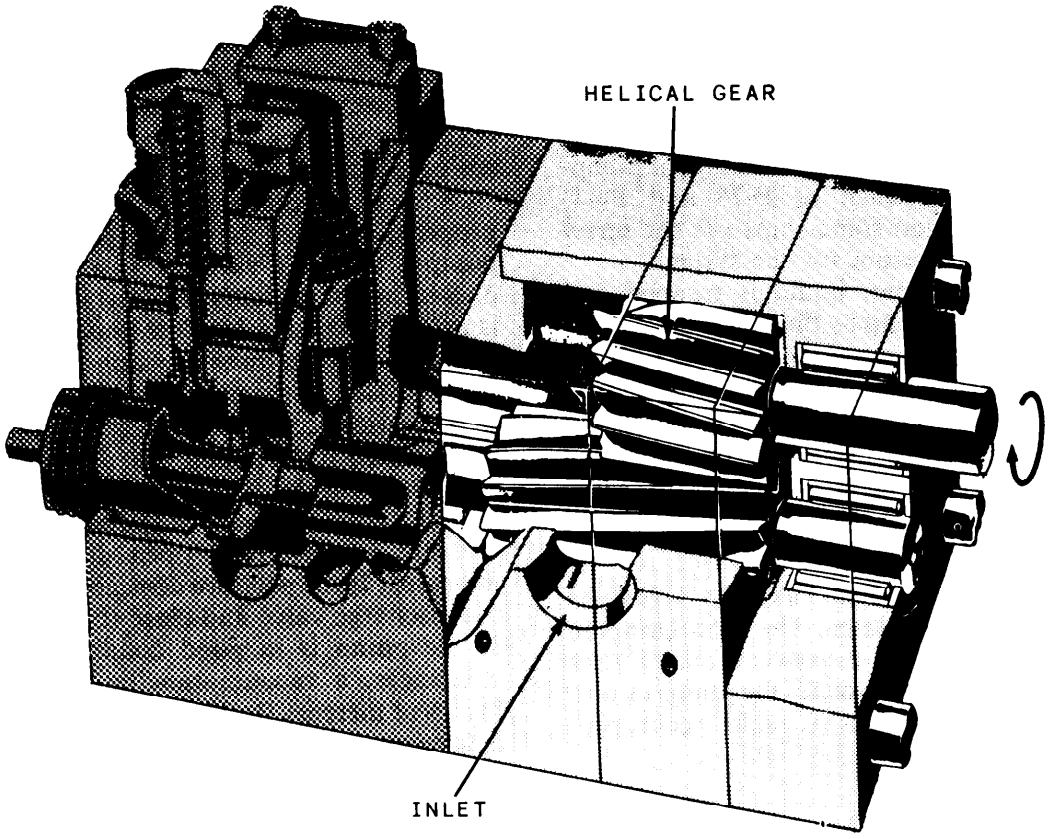
The pumping gears in this type of pump are driven by a set of timing and driving gears, which also function to maintain the required close clearances while preventing actual metal-to-metal contact between the pumping gears. Metallic contact between the teeth of the pumping gears would provide a tighter seal against leakage; however, it would cause rapid wear of the teeth because foreign matter in the pumped liquid would act like an abrasive on the contact surfaces.

Roller bearings at both ends of the gear shafts maintain proper alignment, thereby minimizing the friction loss in the transmission of power. Stuffing boxes prevent leakage at the shafts. The helical gear pump can pump nonviscous liquids



194.113

Figure 13-2.—Herringbone gear pump.

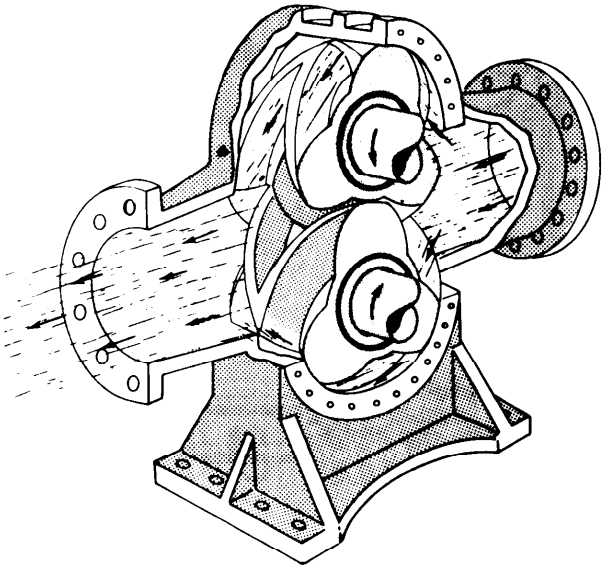


147.114

Figure 13-3.—Helical gear pump.

and light oils at high speed. At lower speed, it can pump heavy viscous materials.

LOBE PUMP.—The lobe pump is still another variation of the simple gear pump. A lobe pump (heliquad type) is illustrated in figure 13-4. The lobes are considerably larger than gear teeth, but there are only two or three lobes on each rotor. The rotors are driven by external spur gears on the rotor shafts. Some lobe pumps are made with replaceable inserts (gibs) at the extremities of the lobes. These inserts take up the wear that would otherwise be sustained by the ends of the lobes. In addition, they maintain a tight seal between the lobe ends and the casing. The inserts are usually seated on a spring. In this way, they automatically compensate for considerable wear of both the gibs and the casing. Replaceable cover plates (liner plates) are fitted at each end of the casing where the lobe faces cause heavy wear.



147.115

Figure 13-4.—Lobe pump (heliquad type).

SCREW PUMP.—There are several types of screw pumps. The main differences are the number of intermeshing screws and the pitch

of the screws. Figure 13-5 shows a positive-displacement, double-screw, low-pitch pump. (In a low-pitch pump, the threads form a small angle with respect to the center line of the pumping element.) Screw pumps are used primarily for pumping viscous fluids, such as F-76 and F-44. Hydraulic systems on some ships use the screw pump to supply pressure for the system.

In the screw pump, liquid is trapped and forced through the pump by the action of rotating screws. As the rotor turns, the liquid is trapped between the threads at the outer end of each pair of screws. The threads carry the liquid along within the housing to the center of the pump casing where it is discharged.

Operating Troubles

From time to time you are likely to have some troubles with rotary pumps. The most common causes of trouble are (1) the system fails to build up the required pressure, or (2) the pump fails to discharge fluid. When these troubles occur, proceed as follows:

1. Stop the unit.
2. See that all valves in the pump suction lines are open.
3. Check the packing of all inlet valves and manifold valve stems to ensure that no air is being drawn into the suction piping.

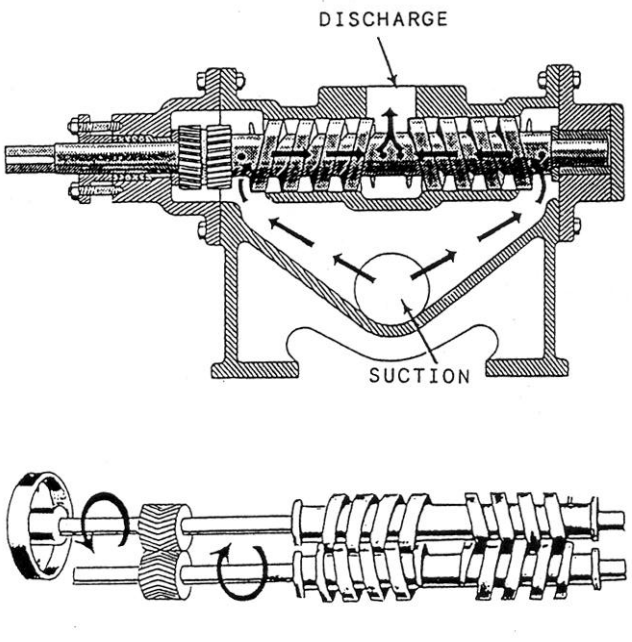


Figure 13-5.—Positive-displacement, double-screw, low-pitch pump.

4. Check the pump shaft packing for air leakage into the pump.
5. Check the spring case and the inlet and outlet connections of the discharge relief valve to ensure that no air is leaking into the pump suction.
6. Start the pump again. When it is up to the proper speed, read the suction gauge to see if the pump is pulling a vacuum. If a low vacuum (5 or 6 inches of mercury, or less) is indicated, air is probably leaking into the pump casing. If no vacuum is shown on the suction pressure gauge, it is possible that the pump is not "primed." (This should rarely occur once the pump casing has once been filled.) If the system still does not build up pressure, close the discharge valve gradually, and note the pressure gauge at the same time. If the pressure increases, an open discharge line is indicated. If the pressure does not increase, open the discharge valve and close the suction valve. If the pump is in good condition with close clearances, a vacuum ranging from 15 to 25 inches of mercury (in.Hg) should be indicated by a vacuum gauge connected to the inlet of the pump.

CAUTION

Do not operate the pump any longer than necessary to get a gauge reading; the pumping elements depend on a constant flow for lubrication.

If a higher than normal vacuum is indicated, there may be an obstruction in the inlet piping or the suction strainer may be clogged. If the pump is noisy, mechanical defects such as misalignment or a bent shaft may be indicated.

CENTRIFUGAL PUMPS

Ships use centrifugal pumps for fire and flushing systems. Internal-combustion engines use centrifugal pumps to circulate cooling water. There are many types of centrifugal pumps, but all operate on the same principle.

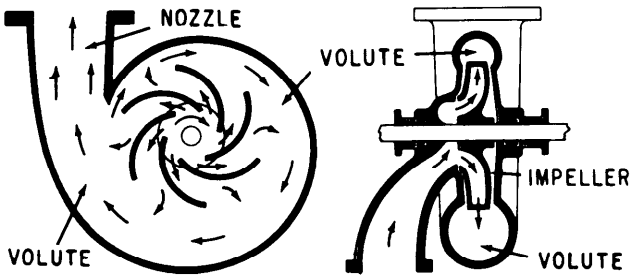
The centrifugal pump uses the throwing force of a rapidly revolving IMPELLER. The rotating impeller creates an empty space at the center hole (eye). The pressure at this point is less than atmospheric pressure (because of the mechanically displaced liquid). This causes atmospheric pressure to act on the surface of the liquid being

pumped, forcing it into the pump casing and through the hole in the center of the impeller. It is then discharged from the outer rim of the impeller.

By the time the liquid reaches the outer rim of the impeller, it has acquired considerable velocity (kinetic energy). The flow of liquid then slows down as it moves through a volute or series of diffusing passages. As the velocity of the liquid decreases, its pressure increases; and thus its kinetic energy is transformed into potential energy.

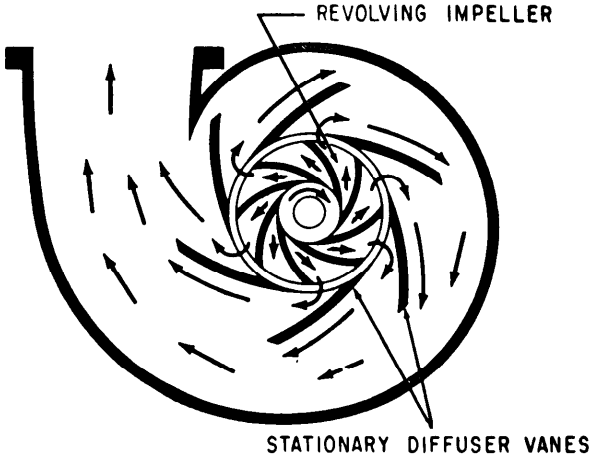
Types of Centrifugal Pumps

There are many different types of centrifugal pumps, but the two you are most likely to encounter onboard ship are the volute pump and the diffuser pump.



23.18.0

Figure 13-6.—Simple volute pump.



23.19

Figure 13-7.—Diffuser pump.

VOLUTE PUMP.—In the volute pump, shown in figure 13-6, the impeller discharges into a volute (a gradually widening spiral channel in the pump casing). As the liquid passes through the volute and into the discharge nozzle, a great part of its kinetic energy (velocity head) is converted into potential energy (pressure head).

DIFFUSER PUMP.—In the diffuser pump, shown in figure 13-7, the liquid leaving the impeller is first slowed down by the stationary diffuser vanes that surround the impeller. The liquid is forced through gradually widening passages in the diffuser ring and into the volute (casing). Since both the diffuser vanes and the volute reduce the velocity of the liquid, there is an almost complete conversion of kinetic energy to potential energy.

Classification of Centrifugal Pumps

Centrifugal pumps may be classified in several ways. For example, they may be either SINGLE STAGE or MULTISTAGE. A single-stage pump has only one impeller. A multistage pump has two or more impellers housed together in one casing. **As** a rule, each impeller acts separately, discharging to the suction of the next stage impeller. This arrangement is called series staging. Centrifugal pumps are also classified as HORIZONTAL or VERTICAL, depending upon the position of the pump shaft.

The impellers used on centrifugal pumps may be classified as SINGLE SUCTION or DOUBLE SUCTION. The single-suction impeller allows liquid to enter the eye from one side only. The double-suction impeller allows liquid to enter the eye from two directions.

Impellers are also classified as CLOSED or OPEN. Closed impellers have side walls that extend from the eye to the outer edge of the vane tips. Open impellers do not have these side walls. Most centrifugal pumps used in the Navy have closed impellers.

Construction of Centrifugal Pumps

The following information applies in general to most of the centrifugal pumps used in naval

service. Figure 13-8 shows the parts of a centrifugal pump that is used for the cooling water system on a diesel engine. Figure 13-9 shows a cutaway view of a fire and flushing pump. For the relative location of components, refer to figure 13-9 as we continue our discussion of the construction of centrifugal pumps.

The shaft is protected from excessive wear and corrosion by a Monel or corrosion-resistant steel sleeve wherever the shaft comes in contact with the liquid being pumped or with the shaft packing. The advantage of using a shaft sleeve is that it can be replaced more economically than the entire shaft.

The impellers are carefully machined and balanced to reduce vibration and wear since they rotate at very high speeds. To prevent corrosion of pumps that handle seawater, the components of these pumps are made of nonferrous materials such as bronze or Monel.

A close radial clearance must be maintained between the outer hub of the impeller and that part of the pump casing in which the hub rotates to minimize leakage from the discharge side of the pump casing to the inlet side. Because of the close clearances at the hub and the high rotational speed of the impeller, the running surfaces of both the impeller hub and the casing at that point are subject to wear. Wear results from erosion as the liquid passes between the close spacing (clearance) of the wearing rings, from the high-pressure side of the impeller, and back to the low-pressure side of the pump. (See the insert in fig. 13-10.)

Centrifugal pumps are provided with replaceable wearing rings to eliminate the need for renewing an entire impeller and pump casing because of wear. One ring is attached to each outer hub of the impeller. This ring is called the IMPELLER WEARING RING. The other ring, which is stationary and attached to the casing, is called the CASING WEARING RING.

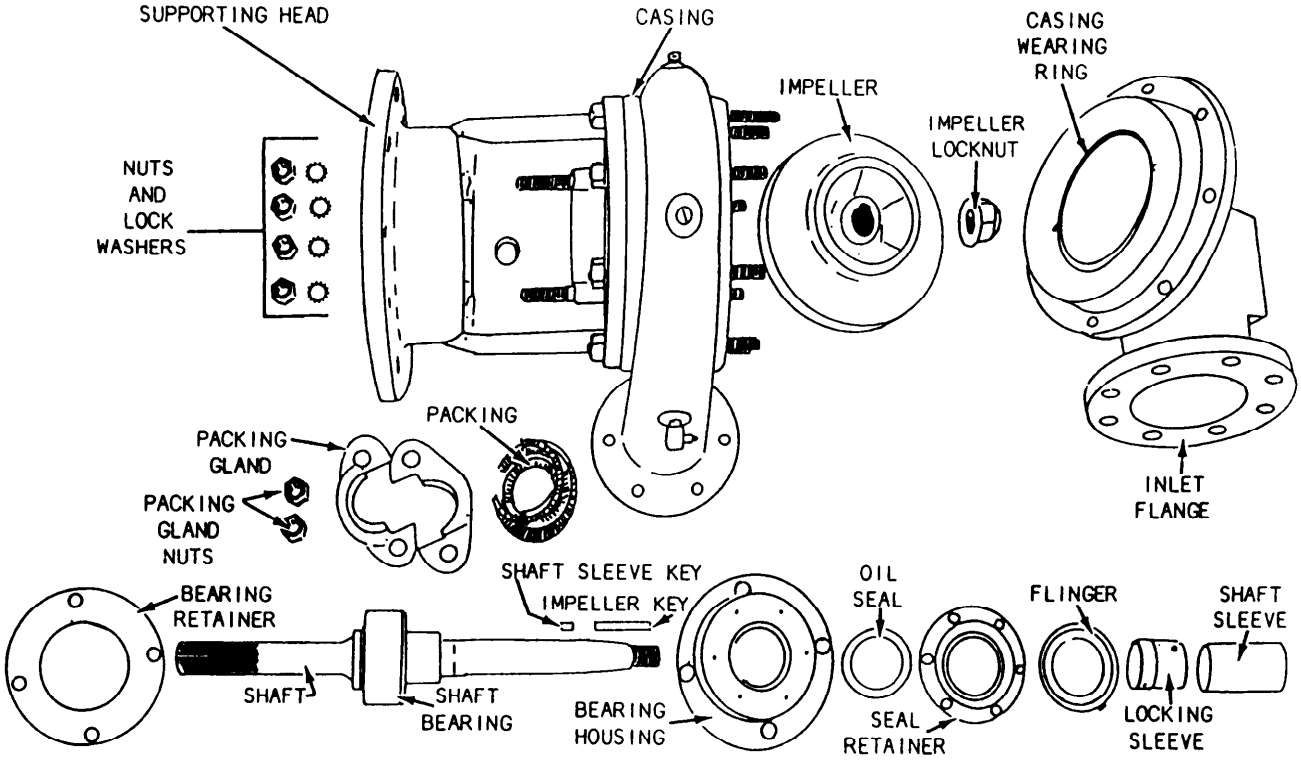
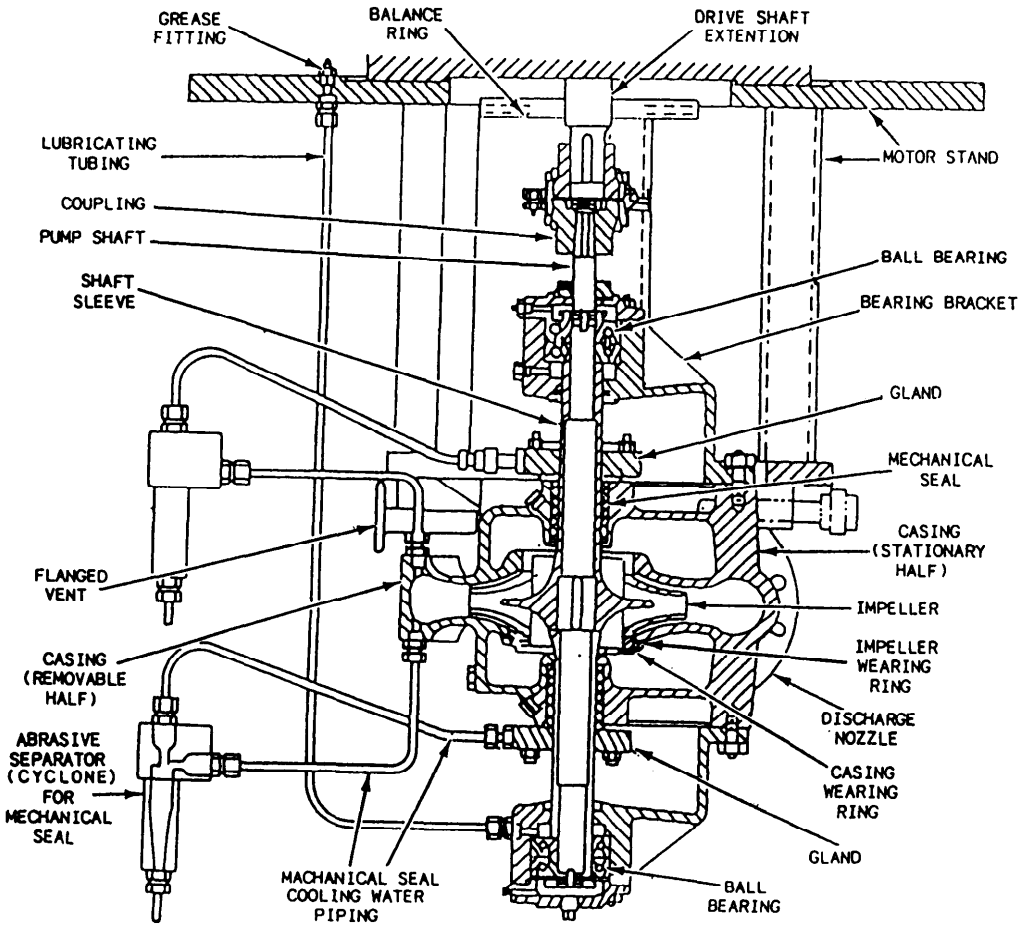
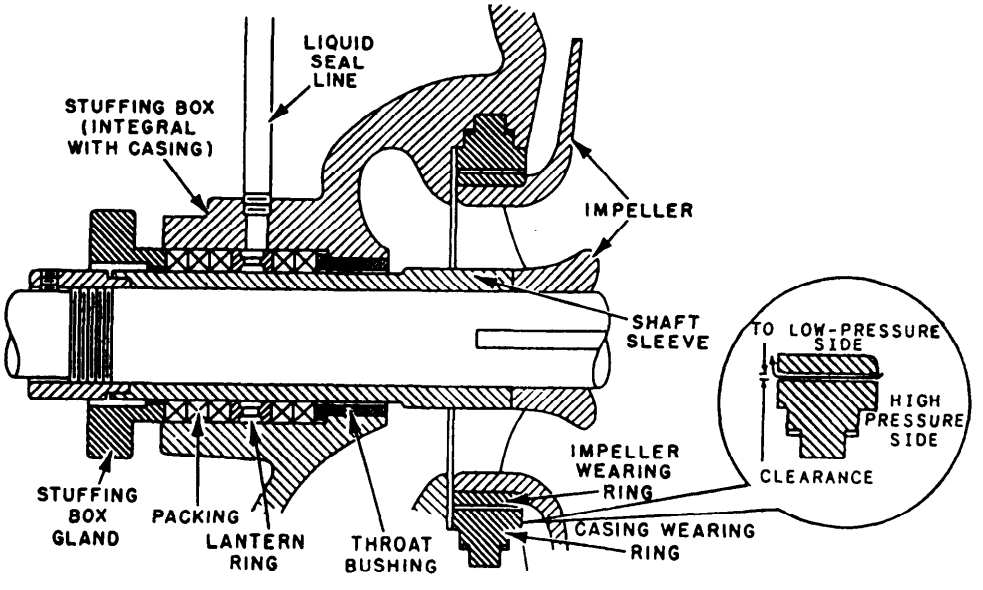


Figure 13-8.—Exploded view of a centrifugal water pump.



75.403

Figure 13-9.—Fire pump (vertical, double-suction impeller).



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Figure 13-10.—Stuffing box on a centrifugal pump.

Figure 13-11 illustrates an impeller and casing wearing rings.

Some small pumps with single-suction impellers have only a casing wearing ring and no impeller ring. In this type of pump, the casing wearing ring is fitted into the end plate.

Recirculating lines are installed on some centrifugal pumps to prevent the pumps from overheating and becoming vapor bound in case the discharge is entirely shut off or the flow of fluid is stopped for extended periods. Seal piping is installed to cool the shaft and the packing, to lubricate the packing, and to seal the rotating joint between the shaft and the packing against air leakage. A lantern ring spacer is inserted between the rings of the packing in the stuffing box. Seal piping (fig. 13-10) leads the liquid from the discharge side of the pump to the annular space formed by the lantern ring. The web of the ring is perforated so that the water can flow in either direction along the shaft (between the shaft and the packing). Water flinger rings are fitted on the shaft between the packing gland and the pump bearing housing. These flingers prevent water from the stuffing box from flowing along the shaft and entering the bearing housing.

During pump operation, a certain amount of leakage around the shafts and casings normally takes place. This leakage must be controlled for two reasons: (1) to prevent excessive fluid loss from the pump, and (2) to prevent air from entering the area where the pump suction pressure is below atmospheric pressure. The amount of leakage that can occur without limiting pump efficiency determines the type of shaft sealing selected. Shaft sealing systems are found in every pump. They can vary from simple packing to complicated sealing systems.

Packing is the most common and oldest method of sealing. Leakage is checked by the compression of packing rings that causes the rings to deform and seal around the pump shaft and casing. The packing is lubricated by liquid moving through a lantern ring in the center of the packing. The sealing slows down the rate of leakage. It does not stop it completely since a certain amount of leakage is necessary during operation.

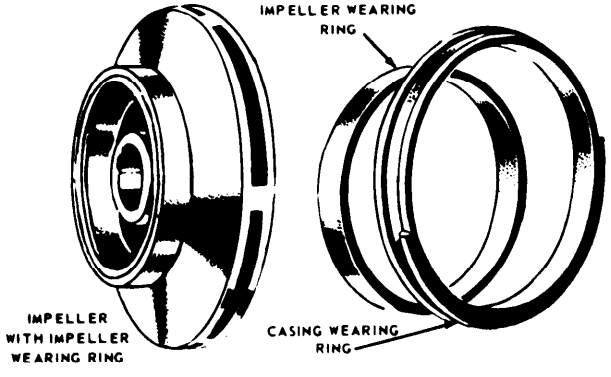
Mechanical seals are rapidly replacing conventional packing on centrifugal pumps. A typical mechanical seal is shown in figure 13-12. Some of the reasons for the use of mechanical seals are as follows:

1. Leaking causes bearing failure by contaminating the oil with water. This is a major problem in engine-mounted water pumps.

2. Properly installed mechanical seals eliminate leakoff on idle (vertical) pumps. This design prevents the leak (water) from bypassing the water flinger and entering the lower bearings. Leakoff causes two types of seal leakage:

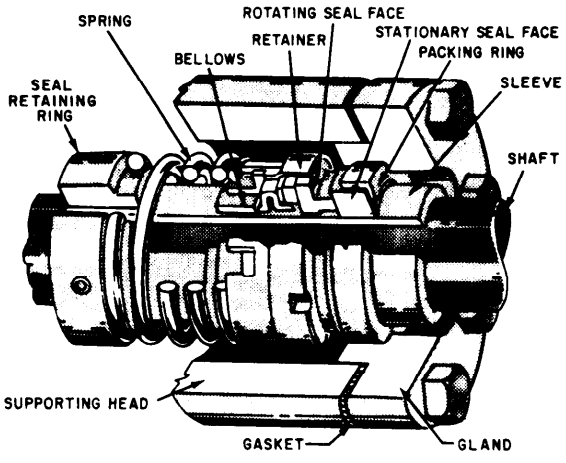
a. Water contamination of the engine lubrication oil.

b. Loss of treated fresh water which causes scale buildup in the cooling system.



75.281

Figure 13-11.—Impeller and wearing rings for a centrifugal pump.



47.192

Figure 13-12.—Type-1 mechanical seal.

In regard to the use of mechanical seals, there are two important safety considerations:

1. Flammable liquids must be contained in the system.
2. Pumps in the vicinity of electrical or electronic gear where moisture can be a major problem must have zero leakoff.

Fire pumps and seawater pumps that are provided with mechanical shaft seals may also have cyclone separators. These separators use centrifugal force to prevent abrasive material (such as sand) in the seawater from passing between the sealing surfaces of the mechanical seal. (Refer to fig. 13-9.)

As figure 13-9 shows, this abrasive separator has no moving parts. Liquid from the high-pressure side of a pump is directed through tubing to the opening in the sides of the separator device, which is offset from the center line. As the liquid enters, it is given a swirling motion (cyclone effect) which causes heavier abrasive materials to be forced to the walls of the center tube, which is shaped to form a venturi. There is an opening at each end of the separator. The opening at the top is for "clean" water, which is directed through tubing to the mechanical seals in the pump. The high-velocity "dirty" water is directed through the bottom of the separator, back to the inlet piping for the pump.

Shaft and thrust bearings support the weight of the impeller and maintain the position of the rotor, both radially and axially. (Radial bearings may be sleeve or ball type. Thrust bearings may be ball or pivoted segmental type.)

The power end of a centrifugal pump may be a steam turbine, an electric motor, or a diesel engine. Pumps used for continuous service can be either turbine or motor driven. Smaller pumps, such as those used for in-port or cruising operations, are generally motor driven. Pumps used for emergency firemain service are generally diesel driven.

Operating Troubles

Some of the operating troubles you, as an Engineman, may encounter with centrifugal pumps, together with the probable causes are discussed in the following paragraphs.

If a centrifugal pump DOES NOT DELIVER ANY LIQUID, the trouble may be caused by (1) insufficient priming; (2) insufficient speed of the pump; (3) excessive discharge pressure, such as might be caused by a partially closed valve or some other obstruction in the discharge line; (4) excessive suction lift; (5) clogged impeller passages; (6) the wrong direction of rotation (this may occur after motor overhaul); (7) clogged suction screen (if used); (8) ruptured suction line; or (9) loss of suction pressure.

If a centrifugal pump delivers some liquid but operates at INSUFFICIENT CAPACITY, the trouble may be caused by (1) air leakage into the suction line; (2) air leakage into the stuffing boxes in pumps operating at less than atmospheric pressure; (3) insufficient pump speed; (4) excessive suction lift; (5) insufficient liquid on the suction side; (6) clogged impeller passages; (7) excessive discharge pressure; or (8) mechanical defects, such as worn wearing rings, impellers, stuffing box packing, or sleeves.

If a pump DOES NOT DEVELOP DESIGN DISCHARGE PRESSURE, the trouble may be caused by (1) insufficient pump speed; (2) air or gas in the liquid being pumped; (3) mechanical defects, such as worn wearing rings, impellers, stuffing box packing, or sleeves; or (4) reversed rotation of the impeller (3-phase electric motor-driven pumps).

If a pump WORKS FOR A WHILE AND THEN FAILS TO DELIVER LIQUID, the trouble may be caused by (1) air leakage into the suction line; (2) air leakage in the stuffing boxes; (3) clogged water seal passages; (4) insufficient liquid on the suction side; or (5) excessive heat in the liquid being pumped.

If a motor-driven centrifugal pump DRAWS TOO MUCH POWER, the trouble will probably be indicated by overheating of the motor. The basic causes may be (1) operation of the pump to excess capacity and insufficient discharge pressure; (2) too high viscosity or specific gravity of the liquid being pumped; or (3) misalignment, a bent shaft, excessively tight stuffing box packing, worn wearing rings, or other mechanical defects.

VIBRATION of a centrifugal pump is often caused by (1) misalignment; (2) a bent shaft; (3) a clogged, eroded, or otherwise unbalanced impeller; or (4) lack of rigidity in the foundation. Insufficient suction pressure may also cause vibration, as well as noisy operation and fluctuating discharge pressure, particularly in pumps that handle hot or volatile liquids.

If the pump fails to build up pressure when the discharge valve is opened and the pump comes up to normal operating speed, proceed as follows:

1. Shut the pump discharge valve.
2. Secure the pump.
3. Open all valves in the pump suction line.
4. Prime the pump (fill casing with the liquid being pumped) and be sure that all air is expelled through the air cocks on the pump casing.
5. Restart the pump. If the pump is electrically driven, be sure the pump is rotating in the correct direction.
6. Open the discharge valve to "load" the pump. If the discharge pressure is not normal when the pump is up to its proper speed, the suction line may be clogged, or an impeller may be broken. It is also possible that air is being drawn into the suction line or into the casing. If any of these conditions exist, stop the pump and continue troubleshooting according to the technical manual for that unit.

Maintenance of Centrifugal Pumps

When properly installed, maintained (by use of PMS), and operated, centrifugal pumps are usually trouble-free. Some of the most common corrective maintenance actions that you may be required to perform are discussed in the following sections.

REPACKING.—Lubrication of the pump packing is extremely important. The quickest way to wear out the packing is to forget to open the water piping to the seals or stuffing boxes. If the packing is allowed to dry out, it will score the shaft. When operating a centrifugal pump, be sure there is always a slight trickle of water coming out of the stuffing box or seal.

How often the packing in a centrifugal pump should be renewed depends on several facts-such as the type of pump, condition of the shaft sleeve, and hours in use.

To ensure the longest possible service from pump packing, make certain the shaft or sleeve is smooth when the packing is removed from a gland. Rapid wear of the packing will be caused by roughness of the shaft sleeve (or shaft where no sleeve is installed). If the shaft is rough, it should be sent to the machine shop for a finishing cut to smooth the surface. If it is very rough, or has deep ridges in it, it will have to be renewed. It is absolutely necessary to use the correct packing. Navy packing is identified by symbol numbers, as explained later in this manual.

When replacing packing, be sure the packing fits uniformly around the stuffing box. If you have to flatten the packing with a hammer to make it fit, YOU ARE NOT USING THE RIGHT SIZE.

Pack the box loosely, and set up the packing gland lightly. Allow a liberal leak-off for stuffing boxes that operate above atmospheric pressure. Next, start the pump. Let it operate for about 30 minutes before you adjust the packing gland for the desired amount of leak-off. This gives the packing time to run-in and swell. You may then begin to adjust the packing gland. Tighten the adjusting nuts one flat at a time. Wait about 30 minutes between adjustments. Be sure to tighten the same amount on both adjusting nuts. If you pull up the packing gland unevenly (or cocked), it will cause the packing to overheat and score the shaft sleeves. Once you have the desired leak-off, check it regularly to make certain that sufficient flow is maintained.

MECHANICAL SEALS.—Mechanical seals are rapidly replacing conventional packing as the means of controlling leakage on rotary and positive-displacement pumps. Mechanical seals eliminate the problem of excessive stuffing box leakage, which causes failure of pump and motor bearings and motor windings. Mechanical seals are ideal for pumps that operate in closed systems (such as fuel service and air-conditioning, chilled-water, and various sonar, radar, and other electronic cooling systems). They not only conserve the fluid being pumped but also improve system operation.

The type of material used for the seal faces will depend upon the service of the pump. Most water service pumps use a carbon material for one of the seal faces and ceramic (tungsten carbide) for the other. When the seals wear out, they are simply replaced.

You should replace a mechanical seal whenever the seal is removed from the shaft for any reason or whenever leakage causes undesirable effects on equipment or surrounding spaces. Do not touch a new seal on the sealing face because body acid and grease or dirt will cause the seal to pit prematurely and leak.

Mechanical shaft seals are positioned on the shaft by stub or step sleeves. Mechanical shaft seals must not be positioned by setscrews. Shaft sleeves are chamfered (beveled) on outboard ends for easy mechanical seal mounting.

Mechanical shaft seals serve to ensure that postion liquid pressure is supplied to the seal faces under all conditions of operation. They also

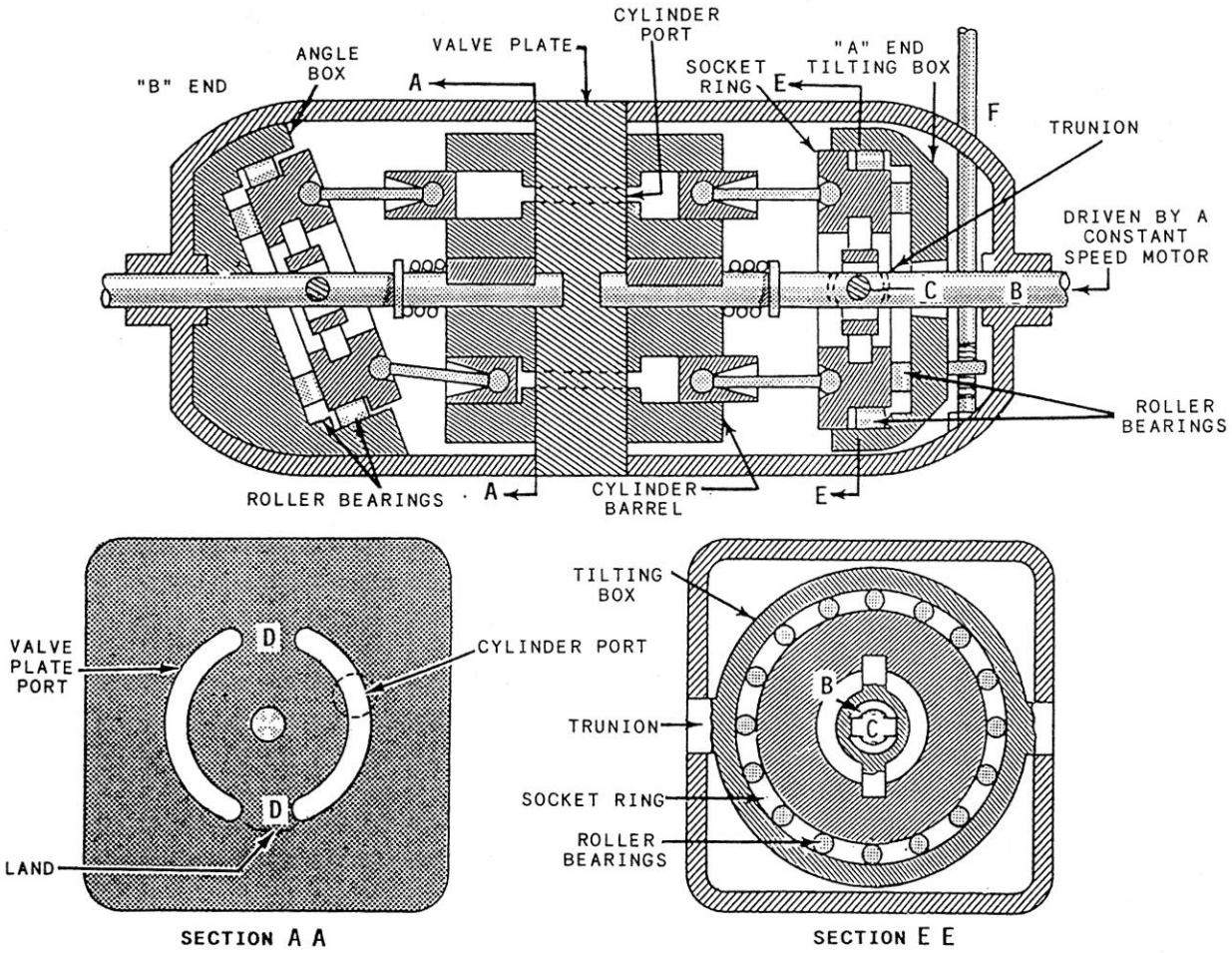


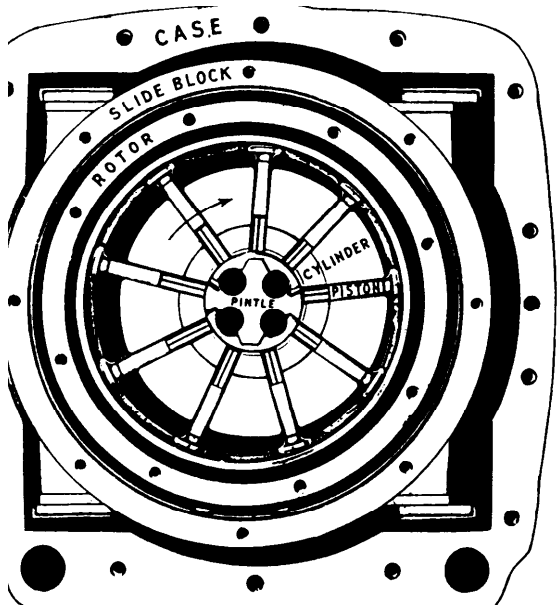
Figure 13-13.—Axial-piston hydraulic speed gear.

ensure adequate circulation of the liquid at the seal faces to minimize the deposit of foreign matter on the seal parts.

VARIABLE-STROKE PUMPS

Variable-stroke reciprocating pumps (also called variable-displacement pumps) are most commonly used on naval ships as part of an electrohydraulic transmission system. They are used on anchor windlasses, cranes, winches, steering engines, and other equipment. You will have to maintain and make minor repairs to hydraulic and related equipment outside your ship's engineering spaces. The information that follows is in addition to that found in *Fireman,* NAVEDTRA 10520-H.

Two general types of variable-stroke pumps are in common use: the axial-piston pump and the radial-piston pump. In the axial-piston pump (fig. 13-13), the pistons are arranged parallel to each other and to the pump shaft. In the radial-piston pump (fig. 13-14), the pistons are arranged radially from the shaft.



194.123

Figure 13-14.—Nine-piston (radial-piston) pump.

Variable-Stroke Axial-Piston Pump

The variable-stroke axial-piston pump usually has either seven or nine single-acting pistons which are evenly spaced around a cylinder barrel. (Note that the term CYLINDER BARREL, as used here, actually refers to a cylinder block that holds all the cylinders.) An uneven number of pistons is always used so that pulsations in the discharge flow can be avoided. The piston rods make a ball-and-socket connection with a socket ring. The socket ring rides on a thrust bearing carried by a casting called the TILTING BOX or TILTING BLOCK.

When the tilting box is at a right angle to the shaft, and the pump is rotating, the pistons do not reciprocate; therefore, no pumping takes place. When the box is tilted away from a right angle, however, the pistons reciprocate and the liquid is pumped.

The variable-stroke axial-piston pump is often used as a part of a variable-speed gear, for forward and reverse rotation, such as electrohydraulic anchor windlasses, cranes, winches, and the power transmitting unit in electrohydraulic steering engines. In those cases, the tilting box is arranged so that it may be tilted in either direction. Thus it may be used to transmit power hydraulically to pistons or rams, or it may be used to drive a hydraulic motor. In the latter use, the pump is driven by a constant-speed electric motor and is called the A-end of the variable-speed gear. The hydraulic motor is called the B-end.

The B-end unit of the hydraulic speed gear is exactly the same as the A-end of the variable-stroke pump mentioned previously. However, it generally does not have a variable-stroke feature. The tilting box is installed at a permanently fixed angle. Thus, the B-end becomes a fixed-stroke axial-piston pump. Figure 13-13 illustrates an axial-piston hydraulic gear with the A-end and B-end as a single unit. It is used in gun turrets for horizontal and vertical drive and for elevation driving units. For electrohydraulic winches and cranes, the A-end and B-end are in separate housings connected by hydraulic piping.

Hydraulic fluid introduced under pressure to a cylinder causes the piston to be pushed out. In being pushed out, the piston, through its connecting rod, will seek the point of greatest distance between the cylinder barrel and the socket ring. The resultant pressure of the piston against the socket ring will cause the cylinder barrel and the socket ring to rotate. This action occurs during the half revolution while the piston is passing the intake port of the motor (which is connected to the pressure port of the pump). After the cylinder of the motor has taken all the hydraulic fluid it can from the pump, the piston passes the valve plate land and starts to discharge oil through the outlet ports of the motor to the suction inlet of the pump, and from there to suction pistons of the pump. The pump is constantly putting pressure on one side of the motor while it is constantly receiving hydraulic fluid from the other side. The fluid is merely circulated from pump to motor and back again.

Variable-Stroke Radial-Piston Pump

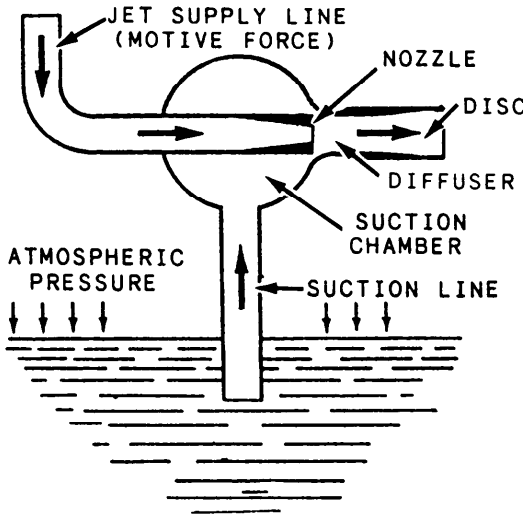
The variable-stroke radial-piston pump (fig. 13-14) is similar in general principle to the axial-piston pump, but the arrangement of components is different. In the radial-piston pump, the cylinders are arranged radially in a cylinder body which rotates around a nonrotating central cylindrical valve. Each cylinder communicates with horizontal ports in the central cylindrical valve. Plungers or pistons, which extend outward from each cylinder, are pinned at their outer ends to slippers which slide around the inside of a rotating floating ring or housing.

The floating ring is constructed so that it can be shifted off-center from the pump shaft. When it is centered, or in the neutral position, the pistons do not reciprocate and the pump does not function, even though the electric motor is still causing the pump shaft to rotate. When the floating ring is forced off-center to one side of the pump shaft, the pistons reciprocate and the pump operates. If the floating ring is forced off-center to the other side, the pump also operates but the direction of the flow is reversed. Therefore, the direction of flow and the amount of flow are both determined by the position of the cylinder body relative to the position of the floating ring.

For further information, refer to *Naval Ships' Technical Manual,* chapter 556, and the NAVSEA technical manual for your unit.

JET PUMPS (EDUCTORS)

An eductor is a type of jet pump. Unlike other pumps, a jet pump has no moving parts. A simple jet pump, illustrated in figure 13-15, consists of a jet supply line, a jet or nozzle, a suction line, a suction chamber, a diffuser, and a discharge line.



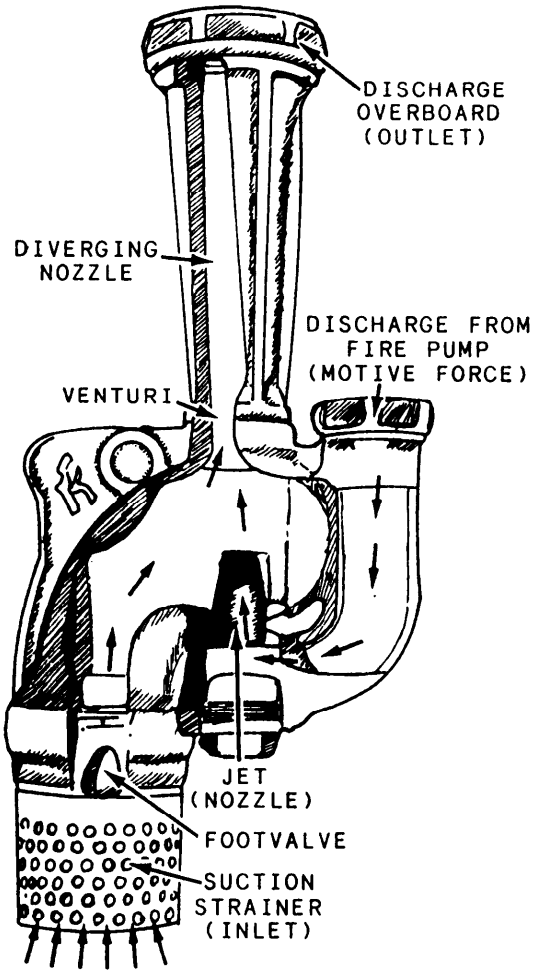
75-283

Figure 13-15.—Simple jet pump.

In a jet pump, pumping action is created as a fluid (water, steam, or air) passes at a high pressure and velocity through a nozzle and into a chamber that has an inlet and outlet opening.

The operating principle of a jet pump is as follows: Upon starting up, the rapidly moving jet fluid pushes on and gives sufficient motion to the air (or whatever substance may be in the suction chamber) to carry it out through the discharge line. Displacement of the air from the suction chamber creates a partial vacuum within the suction chamber, causing fluid to flow through the suction line. The fluid entering the chamber from the suction line is picked up by the high-velocity fluid, thus providing continuous pumping action.

Eductors are designed to pump large volumes of water. Figure 13-16 illustrates a portable eductor used for emergency dewatering of a flooded compartment. In modern ships, fixed eductors have replaced fire and bilge pumps as a primary means for pumping bilges, deballasting, and dewatering compartments. Eductors allow centrifugal fire pumps to serve indirectly as drainage pumps without the risk of becoming fouled with debris from the bilges. The centrifugal pumps pressurize the firemain, and water from the firemain actuates the eductors. The eductors in modern combat ships have a much larger pumping capacity than fire and bilge pumps. They are installed as part of the piping in the drainage system and are flanged to permit easy removal and disassembly when repairs are necessary.



47.48.1

Figure 13-16.—Portable eductor.

Because of their simplicity, jet pumps generally require very little maintenance. Since there are no moving parts, only the nozzles will show wear. The erosion action will cause the nozzles to become enlarged; in this case they are generally renewed. Occasionally the nozzles are removed; the strainers, if fitted, are cleaned; and a special reamer is inserted in the nozzles to clean out any rust or scale that may have accumulated.

CAUTION: Improper starting or securing of an eductor can cause rapid flooding of the space being pumped. Always follow the procedure on the posted operating card.

PUMP CARE AND OPERATION

You should carry out pump operation and safety precautions according to the Engineering

Operational Procedures (EOP), a subsystem of the Engineering Operational Sequencing System (EOSS), if your ship has EOSS, or the *Naval Ships' Technical Manual* and the instructions posted on or near each individual pump. Follow the NAVSEA technical manual or MRCs (for PMS related maintenance) for all maintenance work.

VALVES

Every piping system must have some means to control the amount and direction of the flow of a liquid or a gas through the lines. This is accomplished by the use of valves, which can be opened or closed as required. All valves can be grouped in two general classifications: (1) manually operated valves and (2) automatic valves.

Manually operated valves include all valves that are adjusted by hand. Automatic valves include check valves, thermostatic valves, and pressure-regulating valves. (Thermostatic valves were discussed in chapter 7 of this training manual.) This section contains general information only. You should refer to the appropriate NAVSEA valve manuals if you should require more specific information.

Valves are usually made of bronze or steel. Steel valves are either cast or forged and are made of either plain steel or alloy steel. Alloy steel valves are used in high-pressure, high-temperature systems. The disks and seats (internal sealing surfaces) of valves used in steam piping systems are usually coated with a chromium-cobalt alloy known as Stellite, which is an extremely hard metal.

Bronze valves are never used in systems where temperatures exceed 550°F. Steel valves are used for all services above 550°F. Bronze valves are used almost exclusively in systems that carry salt water. The seats and disks of these valves are usually made of Monel, a metal that has excellent corrosion- and erosion-resistant qualities.

STOP VALVES

Stop valves are used to shut off or, in some cases, control the flow of fluid. They are controlled by the movement of the valve stem. Stop valves can be divided into four general categories: globe, gate, butterfly, and ball. (Plug valves and needle valves are also considered to be stop valves, but they are covered in more detail in *Fireman,* NAVEDTRA 10520-H.)

Globe Valves

Globe valves are probably the most common valves in existence. They are used throughout the engineering plant and other parts of the ship. The globe valve gets its name from the globular shape of the valve body. However, you have to look inside the valve for a positive identification because other valve types may also have globular bodies. Globe valve inlet and outlet openings are arranged in several ways to suit varying requirements of flow. Figure 13-17 shows the common types; straight flow, angle flow, and cross flow. Figure 13-18 shows a cutaway view of a straight-flow globe valve.

Gate Valves

Gate valves are used when a straight line flow of fluid and minimum flow restriction are needed, such as in the inlet piping for a centrifugal pump. Gate valves are so named because the part that either stops or allows flow through the valve acts somewhat like the opening or closing of a gate and is called, appropriately, the gate. The gate is usually wedge-shaped. When the valve is wide open the gate is fully drawn up into the valve bonnet. This leaves an opening for flow through the valve the same size as the pipe in which the valve is installed. Therefore, there is little pressure drop or flow restriction through the valve. Gate valves are not suitable for throttling purposes. The control of flow would be difficult because of valve design, and the flow of fluid slapping against a

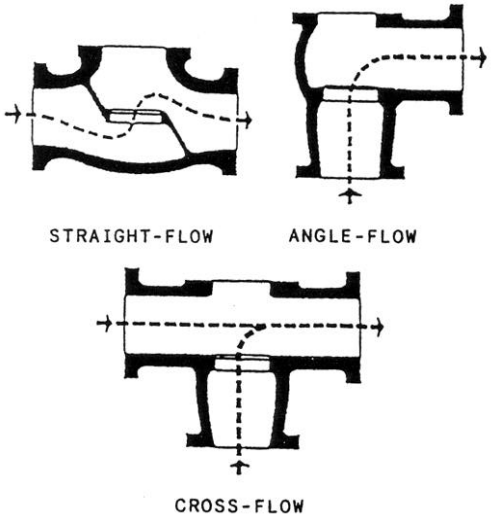
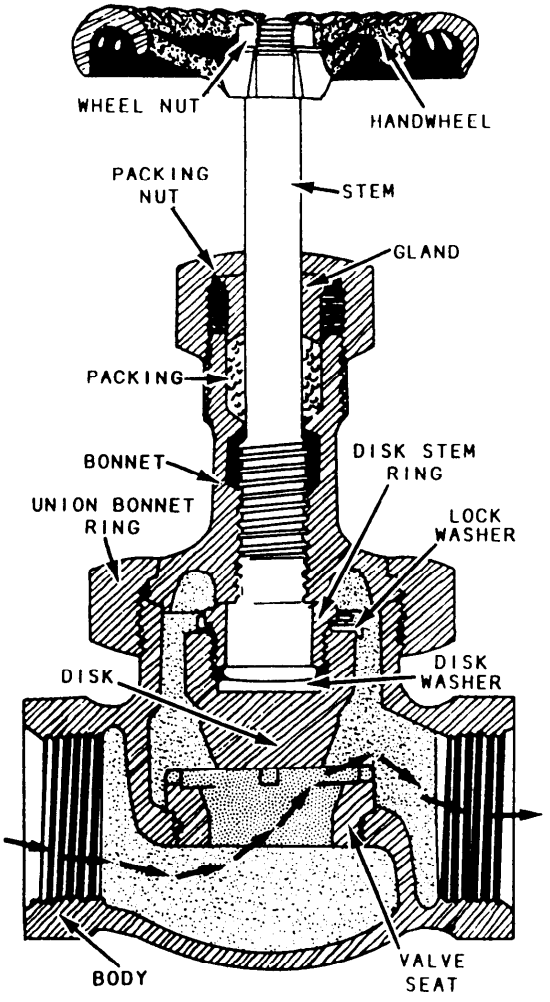


Figure 13-17.—Types of globe valve bodies.



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Figure 13-18.—Cutaway view of a straight-flow globe valve.

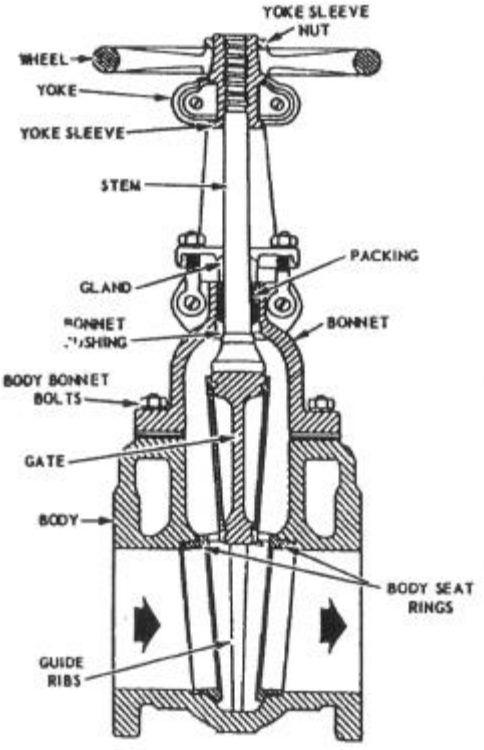


Figure 13-19.—Cutaway view of a gate stop valve (rising stem).

partially open gate can cause extensive damage to the valve. Except as specifically authorized, gate valves should not be used for throttling.

Gate valves are classified as either rising-stem or nonrising-stem valves. The rising-stem valve is shown in figure 13-19. In the design of the rising-stem valve, the stem is attached to the gate. The gate and stem rise and lower together as the valve is operated.

In the design of the nonrising-stem gate valve, the stem is threaded on the lower end into the gate. As the handwheel on the stem is rotated, the gate travels up or down the stem on the threads while the stem remains vertically stationary. This type of valve will almost always have a pointer type of indicator threaded onto the upper end of the stem to indicate the position of the gate inside the valve.

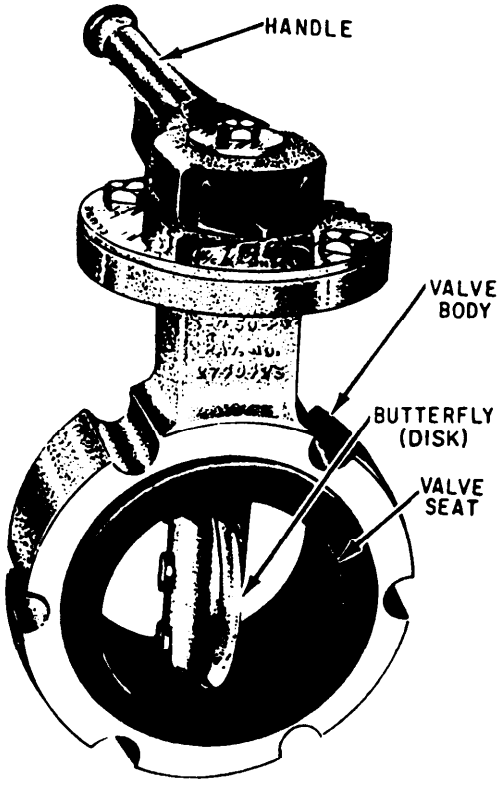
Butterfly Valves

The butterfly valve is light in weight and is relatively small and quick acting. Butterfly valves are used in freshwater, fuel, lube oil, and chilled water systems where quick action and positive flow control are required.

Butterfly valves operate in the same manner as the throttle valves and the choke valves in carburetors. A disk attached to a shaft pivots between the open and closed positions as the shaft is turned.

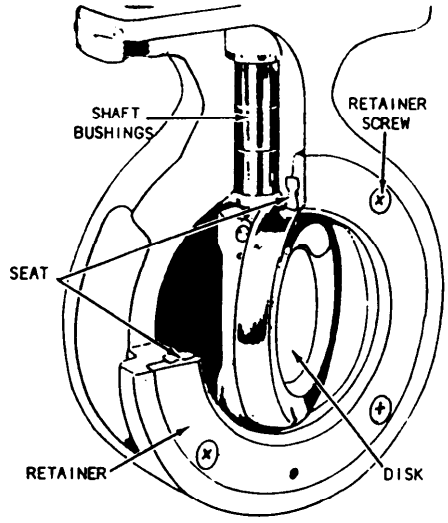
Figure 13-20 shows an older design of butterfly valve that is still widely used. This valve provides for positive shutoff, but it should not be used for throttling as standard practice. It consists of a body, a resilient seat, a butterfly-type disk, a stem, packing, a notched positioning plate, and a handle. The seat is under compression when it is installed in the valve body. This design provides a seal for the disk and the upper and lower points where the stem passes through the seat. The packing provides a positive seal around the stem for added protection in case the seal formed by the seat becomes damaged. To gain access to the seat for replacement, you must first remove the stem and valve disk.

Figure 13-21 shows a high-performance butterfly valve. This improved design has higher pressure capabilities and allows for a full range of throttling positions not offered in the older design of butterfly valve shown in figure 13-20. The newer design of butterfly valve has been introduced into the fleet and is gradually replacing the older design. Unlike the older style of butterfly valve, the new style has a removable retaining ring that holds the seat in place. To change the seat,



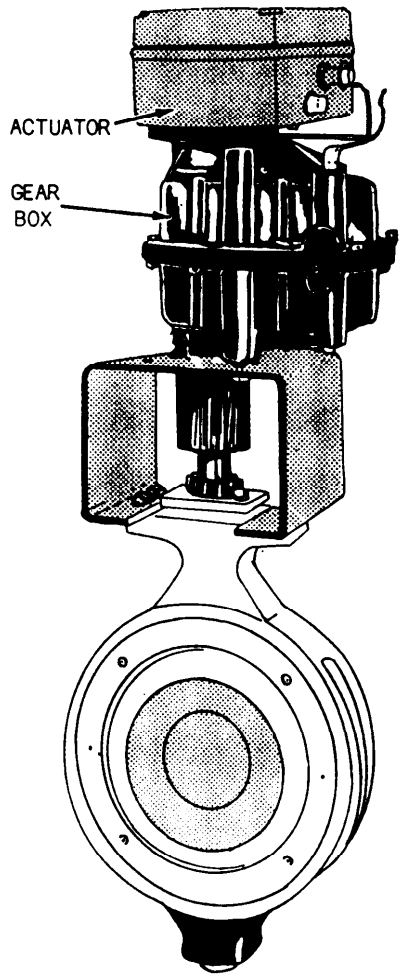
11.318

Figure 13-20.—Butterfly valve.



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Figure 13-21.—Cutaway view of a high-performance butterfly valve.



75.405

Figure 13-22.—Automatically operated butterfly valve.

all you must do is remove the retaining ring, remove the old seat, place a new seat into its groove, and reinstall the retainer ring.

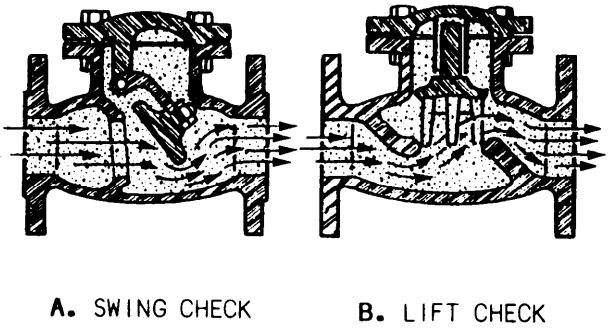
To open or close a butterfly valve, turn the handle only one quarter of a turn to rotate the disk 90 degrees. Some larger butterfly valves may have handwheels or actuators that are driven by pneumatic, electric, or hydraulic means through a gearing arrangement. (See fig. 13-22.)

Ball Valves

Ball valves, as the name implies, are stop valves that use a ball to stop or start the flow of fluid. Most ball valves are the quick-acting type. They require only a 90-degree turn to operate the valve either completely open or closed. The ball, shown in figure 13-23, performs the same function as the disk in the globe valve. When the valve handle is operated to open the valve, the ball rotates to a point where the hole through the ball is in line with the valve body inlet and outlet. When the ball is rotated so the hole is perpendicular to the openings of the valve body, flow is stopped.

CHECK VALVES

Check valves allow fluid to flow in a system in only one direction. They are operated by the flow of fluid in the piping. A check valve may be of the swing type, lift type, or ball type. Figure 13-24 shows a swing check valve and a lift check valve. Check valves may also be built into globe valves or ball valves.



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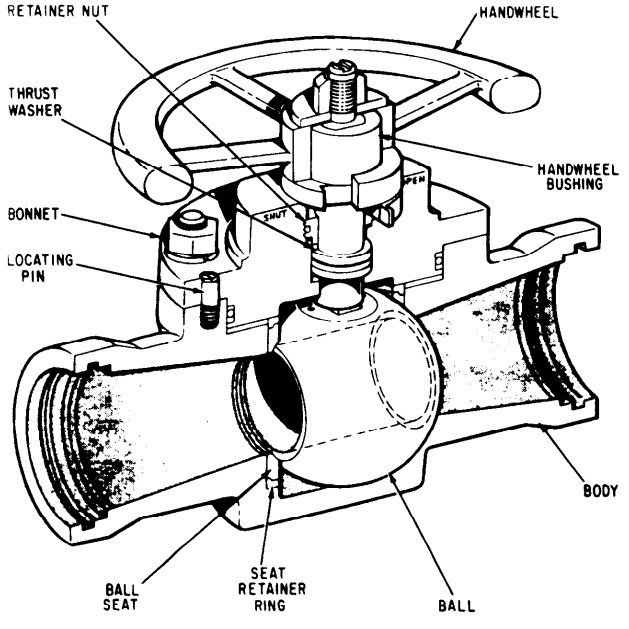
Figure 13-24.—Check valves.

SPECIAL-PURPOSE VALVES

There are many types of automatic pressure control valves. Some of them merely provide an escape for excessive pressures. Others reduce or regulate fluid pressure.

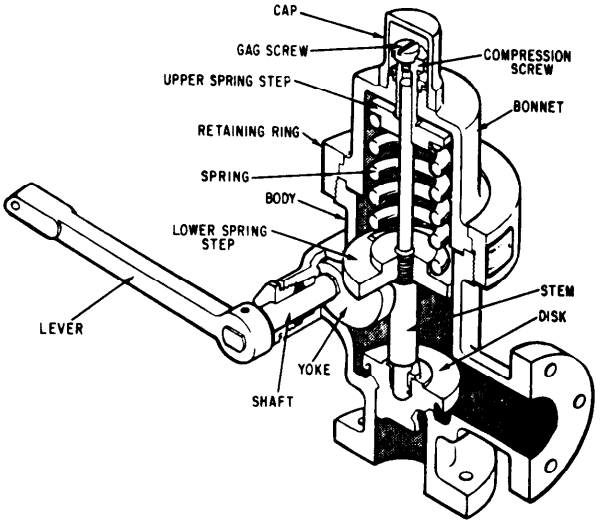
Relief Valves

Relief valves are installed in piping systems to protect them from excessive pressure. These valves have an adjusting screw, a spring, and a disk. The force exerted on the disk by the spring sets the relieving pressure. Most relief valves simply open when the preset pressure is reached and close when the pressure drops slightly below the lifting pressure. Many relief valves will also have a lever so the valve can be opened by hand for test purposes. Figure 13-25 shows a relief valve of this type.



47.196

Figure 13-23.—Typical seawater ball valve.



47.198

Figure 13-25.—Relief valve.

Sentinel Valves

Sentinel valves are simply small relief valves installed in some systems to warn of impending overpressurization. Sentinel valves do not relieve the pressure of the system. If the situation causing the sentinel valve to lift is not corrected, a relief valve (if installed) will lift to protect the system or component. If a relief valve is not installed, action must be taken quickly to secure the piece of equipment or system to reduce the pressure.

Pressure-Reducing Valves

Reducing valves are automatic valves that provide a steady pressure into a system that is at a lower pressure than the supply system. Reducing valves of one type or another are found in steam, air, lube oil, seawater, and other systems. A reducing valve can normally be set for any desired downstream pressure within the design limits of the valve. Once the valve is set, the reduced pressure will be maintained. This is true regardless of changes in the supply pressure; however, the supply pressure must be at least as high as the reduced pressure desired. It is also true regardless of the amount of reduced pressure fluid that is used.

Pressure-reducing valves for piping systems are usually installed in reducing stations, like the one shown in schematic form in figure 13-26. In addition to a pressure-reducing valve, a reducing station should contain at least four other valves. Two of these are stop valves, located in the inlet piping and outlet piping for the reducing valve. These valves (V1 and V2) are shut to isolate the pressure-reducting valve from the piping system, in the event the valve needs repair. Some reducing valves may also have a stop valve in the downstream sensing line (V3). There should be a bypass valve (V4), used for throttling service, to manually control downstream pressure when the reducing valve is inoperative. The bypass valve is normally shut. (NOTE: When a pressure-reducing station is lined up in the manual mode, the operator should use the indication on the outlet pressure gauge to adjust the bypass valve for the proper setting. The watch stander must check this setting periodically to ensure that the downstream pressure setting is within the specified value.) Finally, there should be a relief valve (V5) to prevent overpressurization of the piping system downstream of the reducing station in the event the reducing valve fails open (or the manual bypass valve is misadjusted).

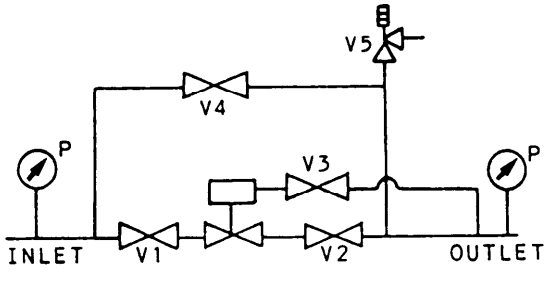
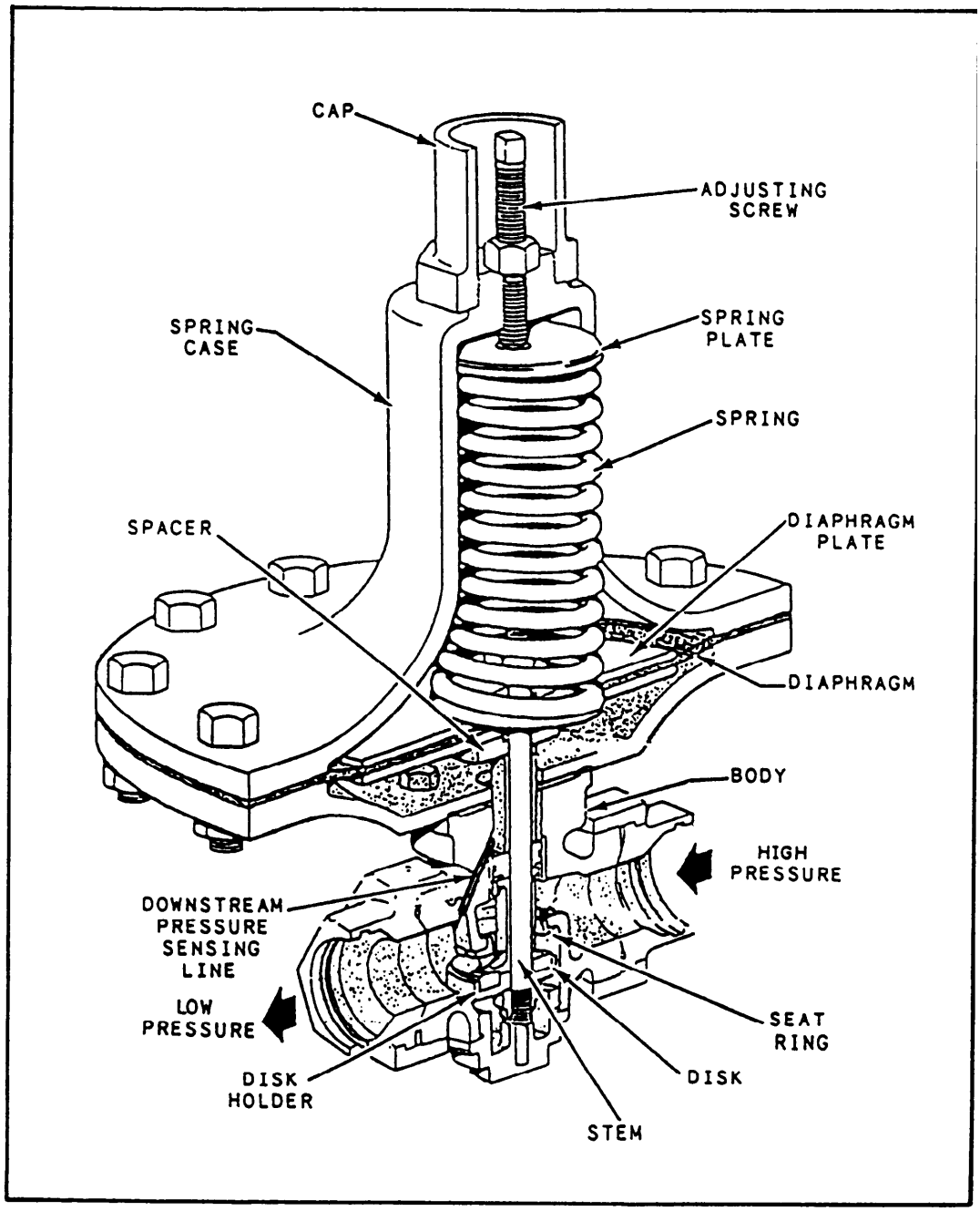


Figure 13-26.—Pressure-reducing station.

There are three basic designs of pressure-reducing valves in use. They are spring-loaded reducing valves, pneumatic-pressure-controlled (gas-loaded) reducing valves, and air-pilot-operated diaphragm-type reducing valves. There are many different styles within these three types. We will discuss a few of these variations.

SPRING-LOADED REDUCING VALVES.—One type of spring-loaded reducing valve is shown in figure 13-27. These valves are used in a wide variety of applications. Low-pressure air reducers, auxiliary machinery cooling-water reducing stations, and some reduced-steam system reducers are of this type. The valve simply uses spring pressure against a diaphragm to open the valve. On the bottom of the diaphragm, the outlet pressure (the pressure in the reduced-pressure system) of the valve forces the disk upward to shut the valve. When the outlet pressure drops below the set point of the valve, spring pressure overcomes the outlet pressure and forces the valve stem downward, opening the valve. As outlet pressure increases, approaching the desired value, the pressure under the diaphragm begins to overcome



47.199

Figure 13-27.—Pressure-reducing (spring-loaded) valve.

spring pressure. This forces the valve stem upward, shutting the valve. Downstream pressure can be adjusted by removing the valve cap and turning the adjusting screw, which varies the spring pressure against the diaphragm. This particular spring-loaded valve will fail in the open position in the case of a diaphragm rupture.

INTERNAL PILOT-ACTUATED PRESSURE-REDUCING VALVES.—The internal pilot-actuated pressure-reducing valve, shown in

figure 13-28, uses a pilot valve to control the main valve. The pilot valve controls the flow of upstream fluid, which is ported to the pilot valve, to the operating piston, which operates the main valve. The main valve is opened by the operating piston and closed by the main valve spring. The pilot valve opens when the adjusting spring pushes downward on the pilot diaphragm. It closes when downstream pressure exerts a force that exceeds the force of the adjusting spring. When the pilot valve shuts off or throttles the flow of upstream fluid to the operating piston, the main valve then pushes the valve and stem upward to throttle or close the main valve. When downstream pressure falls below the set point, the adjusting spring force acts downward on the diaphragm. This action overcomes the force of the downstream system pressure, which is acting upward on the diaphragm. This opens the pilot valve, allowing upstream pressure to the top of the operating piston to open the main valve.

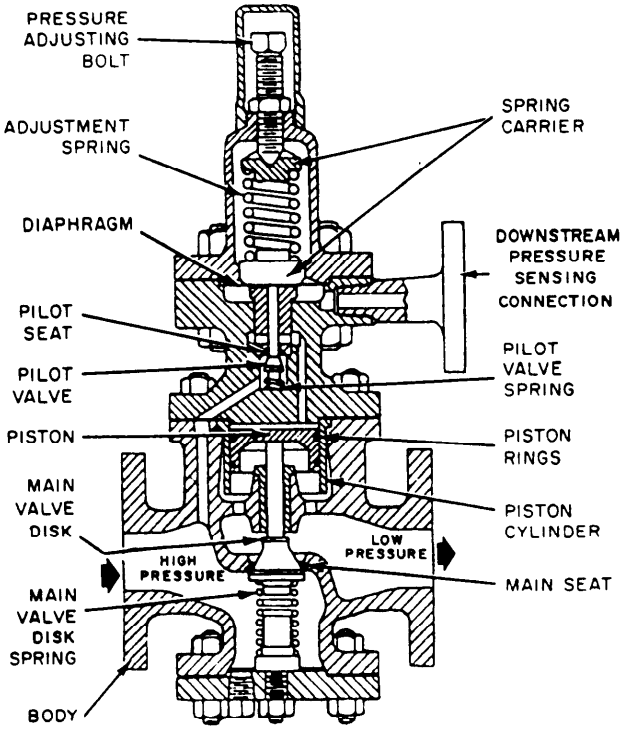


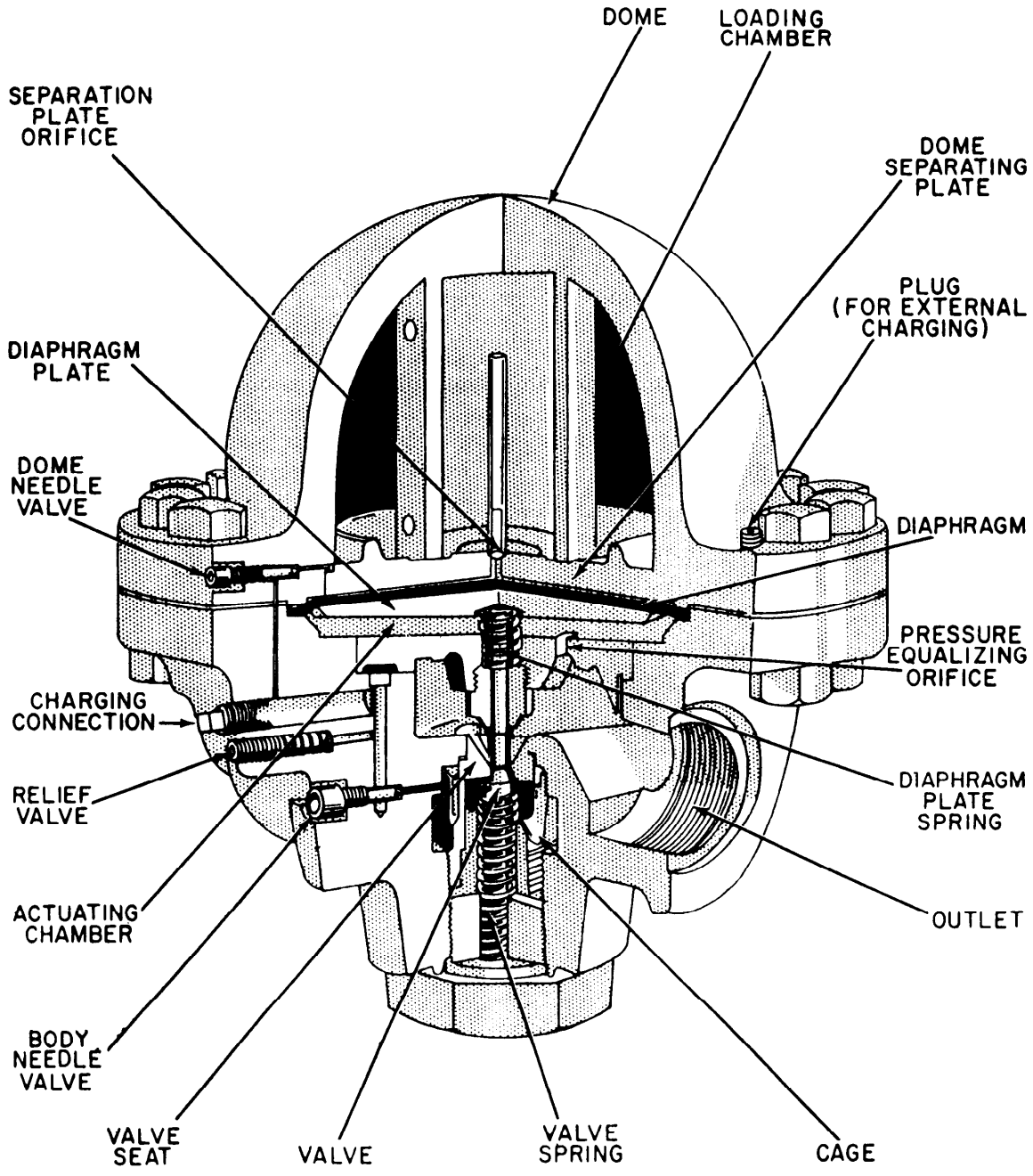
Figure 13-28.—Internal pilot-actuated pressure-reducing valve.

PNEUMATIC-PRESSURE-CONTROLLED REDUCING VALVES.—For engines that use compressed air as a power source, starting air comes directly from the ship's medium- or high-pressure air service line or from starting air flasks, which are included in some systems for the purpose of storing starting air. From either source, the air, on its way to the engine, must pass through a pressure-reducing valve, which reduces the higher pressure to the operating pressure required to start a particular engine.

One type of pressure-reducing valve is the regulator shown in figure 13-29, in which compressed air, sealed in a dome, furnishes the regulating pressure that actuates the valve. The compressed air in the dome performs the same function as a spring used in a more common type of regulating valve.

The dome is tightly secured to the valve body, which is separated into an upper (low-pressure outlet) and a lower (high-pressure inlet) chamber by the main valve. At the top of the valve stem is another chamber, which contains a rubber diaphragm and a metal diaphragm plate. This chamber has an opening leading to the low-pressure outlet chamber. When the outlet pressure drops below the pressure in the dome, air in the dome forces the diaphragm and the diaphragm plate down on the valve stem. This partially opens the valve and permits high-pressure air to pass the valve seat into the low-pressure outlet and into the space under the diaphragm. As soon as the pressure under the diaphragm is equal to that in the dome, the diaphragm returns to its normal position, and the valve is forced shut by the high-pressure air acting on the valve head.

When the dome-type regulator is used in the air start system for a diesel engine during the starting event, the regulator valve continuously and rapidly adjusts for changes in air pressure by partially opening and partially closing to maintain a safe, constant starting pressure. When the engine starts and there is no longer a demand for air, pressure builds up in a low-pressure chamber to equal the pressure in the dome, and the valve closes completely.



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Figure 13-29.—Pressure-reducing (regulator) valve.

Air-Pilot-Operated Diaphragm Control Valves

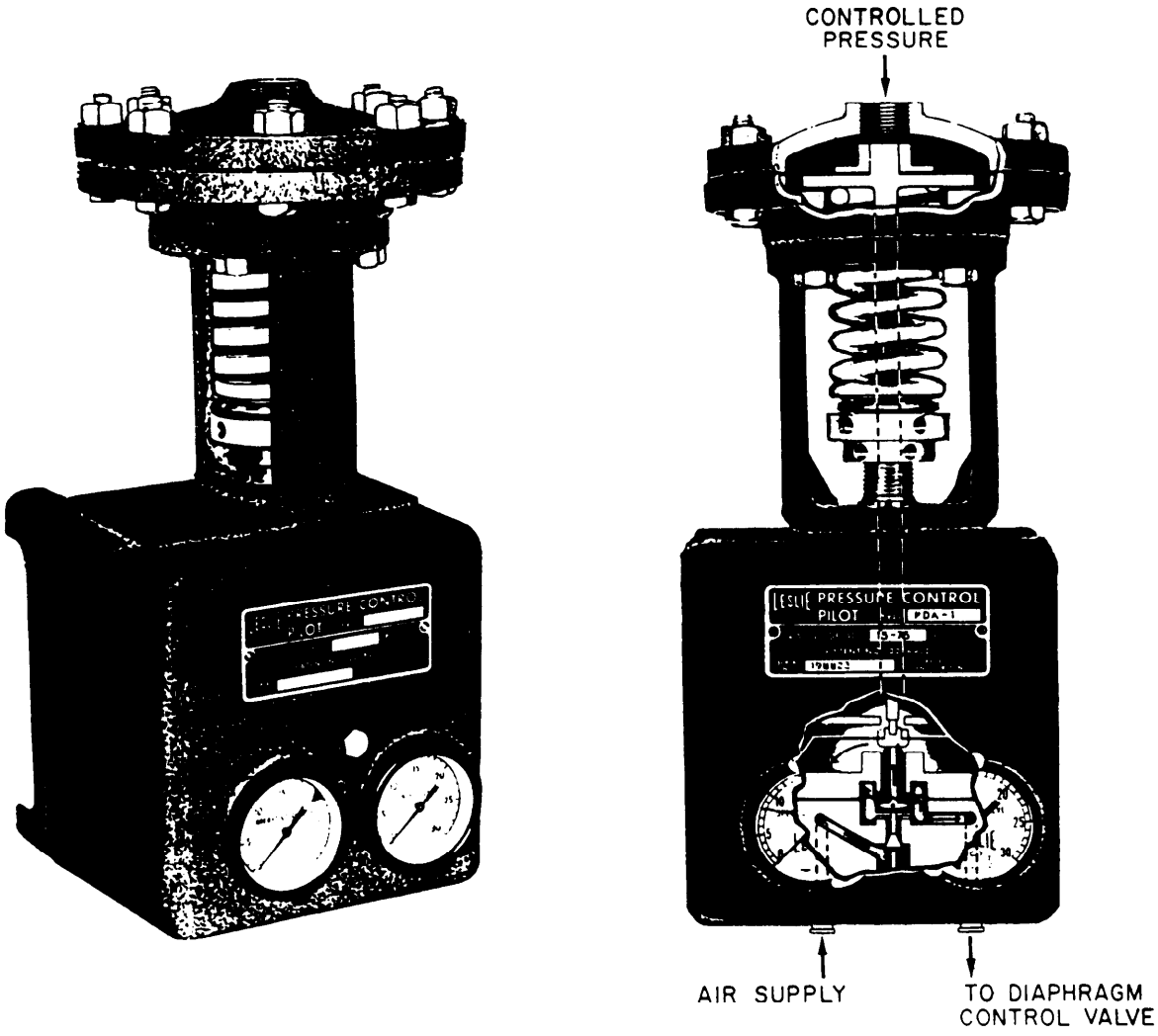
These valves are used extensively on naval ships. The valves and their control pilots are available in several designs to meet different requirements. They may be used as unloading valves to reduce pressure or to provide continuous regulation of pressure and temperature. They may also be used for the control of liquid levels.

The air-operated control pilot may be either direct acting or reverse acting. A direct-acting pilot

is shown in figure 13-30. In this type of pilot, the controlled pressure—that is, the pressure from the discharge side of the diaphragm control valve—acts on top of a diaphragm in the control pilot. This pressure is balanced by the pressure exerted by the pilot adjusting spring. When the controlled pressure increases and overcomes the pressure exerted by the pilot adjusting spring, the pilot valve stem is forced downward. This action opens the pilot valve to increase the amount of operating air pressure going from the pilot to the diaphragm control valve. A reverse-acting pilot has a lever that reverses the pilot action. In a reverse-acting pilot, therefore, an increase in controlled pressure produces a decrease in operating air pressure.

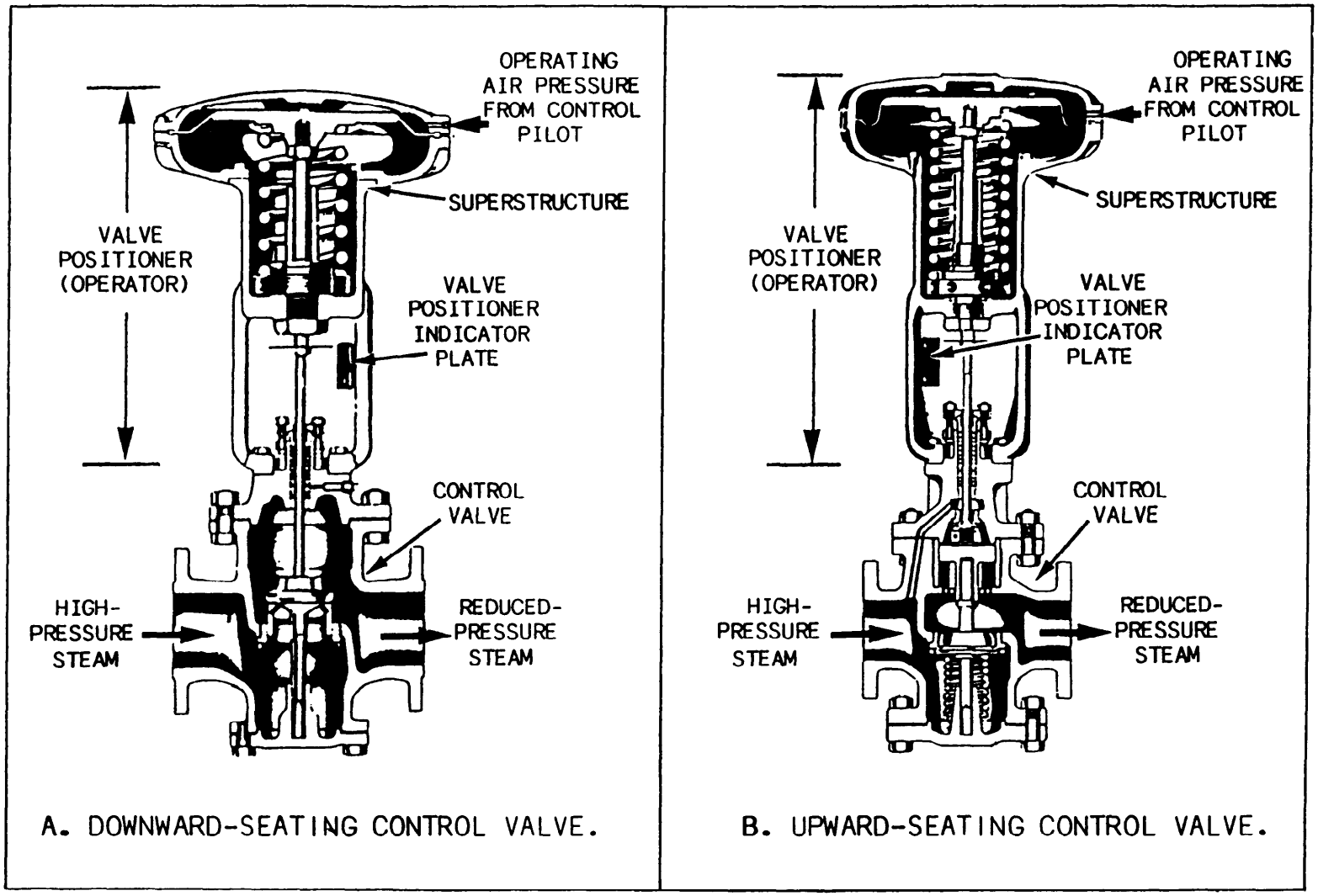
In the diaphragm control valve, operating air from the pilot acts on a diaphragm contained in the superstructure of the valve operator or positioner. (See fig. 13-31.) It is direct-acting in some valves and reverse-acting in others. If the valve operator is direct-acting, the operating air pressure from the control pilot is applied to the TOP of the valve diaphragm. When the valve operator is reverse-acting, the operating air pressure from the pilot is applied to the UNDERSIDE of the valve diaphragm.

View A in figure 13-31 shows a very simple type of direct-acting diaphragm control valve. The operating air pressure from the control pilot is applied to the top of the valve diaphragm. The valve in the figure is a downward-seating valve. Therefore, any increase in operating air pressure



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Figure 13-30.—Air-operated control pilot.



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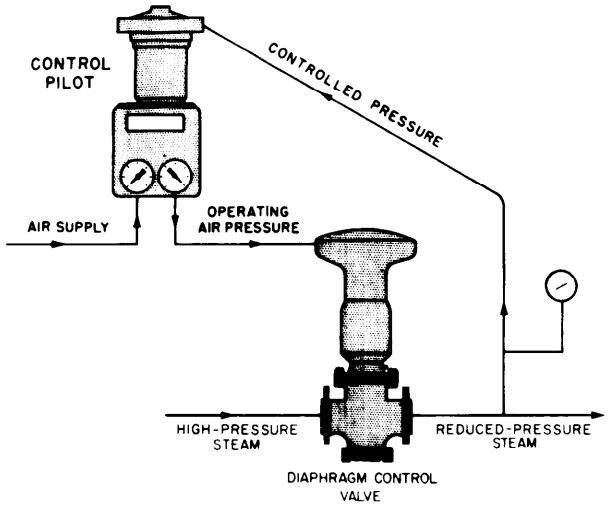
Figure 13-31.—Diaphragm control valves.

pushes the valve stem downward. This tends to close the valve.

Now look at view B. This is also a direct-acting valve. The operating air pressure from the control pilot is applied to the top of the valve diaphragm. But the valve shown in view B is more complicated than the one shown in view A. The valve shown in view B is an upward-seating valve rather than a downward-seating valve. Therefore, any increase in operating air pressure from the control pilot tends to OPEN this valve rather than to close it.

As we have seen, the air-operated control pilot and the positioner of the diaphragm control valve may be either direct-acting or reverse-acting. In addition, the diaphragm control valve may be either upward-seating or downward-seating. These factors, as well as the purpose of the installation, determine how the diaphragm control valve and its air-operated control pilot are installed in relation to each other.

To see how these factors are related, let's consider an installation; a diaphragm control valve and its air-operated control pilot are used to supply reduced steam pressure. Figure 13-32 shows one arrangement that we might use. We will assume that the service requirements indicate the need for a direct-acting, upward-seating, diaphragm control valve. Can you figure out which kind of a control pilot—direct-acting or reverse-acting— should be used in this installation?



38.125

Figure 13-32.—Arrangement of control pilot and diaphragm control valve for supplying reduced steam pressure.

Let's try it first with a direct-acting control pilot. The controlled pressure (discharge pressure from the diaphragm control valve) increases. When that happens, increased pressure is applied to the diaphragm of the direct-acting control pilot. The valve stem is pushed downward and the valve in the control pilot is opened. This sends an increased amount of operating air pressure from the control pilot to the top of the diaphragm control valve. The increased operating air pressure acting on the diaphragm of the valve pushes the stem downward. Since this is an upward-seating valve, this action OPENS the diaphragm control valve still wider. Obviously, this won't work—for this application, an INCREASE in controlled pressure must result in a DECREASE in operating air pressure. Therefore, we made a mistake in choosing the direct-acting control pilot. For this particular pressure-reducing application, we should choose a REVERSE-ACTING control pilot.

You will probably not need to decide which type of control pilot and diaphragm control valve are needed in any particular installation. But you must know how and why they are selected so that you will not make mistakes in repairing or replacing these units.

REMOTE-OPERATED VALVES

Remote-operating gear provides a means of operating certain valves from distant stations. Remote-operating gear may be mechanical, hydraulic, pneumatic, or electric. A reach rod or series of reach rods and gears may be used to operate engine-room valves in instances where valves are difficult to reach.

Other remote-operating gear is installed as emergency equipment. Some split-plant valves, main drainage system valves, and overboard valves are equipped with remote-operating gear. These valves can be operated normally or, in an emergency, they may be operated from remote stations. Remote-operating gear also includes a valve position indicator to show whether the valve is open or closed.

STEAM TRAPS

Steam traps in steam lines drain condensate from the lines without allowing steam to escape. There are many different kinds of steam traps. They all consist essentially of a valve and some temperature or liquid level sensing device or an arrangement that will cause the valve to open

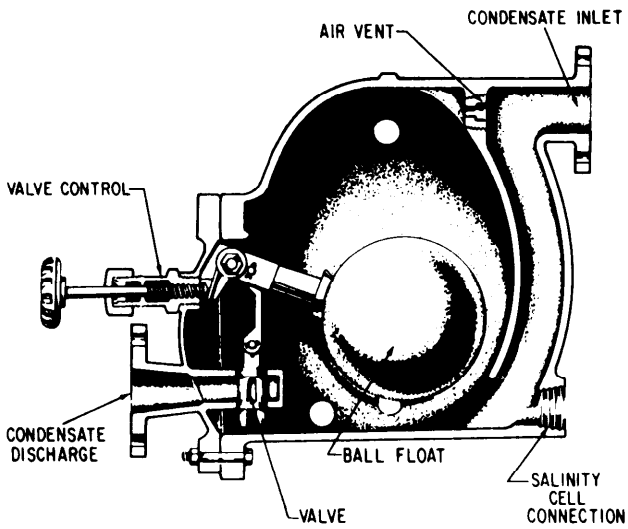
and close as necessary to drain the condensate without allowing the escape of steam. Some designs are suitable for low pressures and low temperatures, others for high pressures and high temperatures. Some examples of common types of steam traps are the mechanical, thermostatic, and orifice.

MECHANICAL STEAM TRAPS

Mechanical steam traps may be of the ball-float type or the bucket type.

Ball-Float Trap

In a ball-float steam trap, such as the one shown in figure 13-33, the valve of the trap is connected to the float in such a way that the valve opens when the float rises. The operating principle of the trap is quite simple. When steam cools, it condenses (changes state) back to water. The liquid water, called condensate, flows by gravity into the chamber around the ball valve. As the water level rises, the float is lifted, thereby lifting the valve plug and opening the valve. The condensate drains out and the float settles to a lower position, closing the valve. The condensate that passes out of the trap is returned to the feed system. In figure 13-33, the two white circles directly above and below the ball float are connections (holes) for a gauge glass, which the operator checks to set the desired liquid level in the steam trap.



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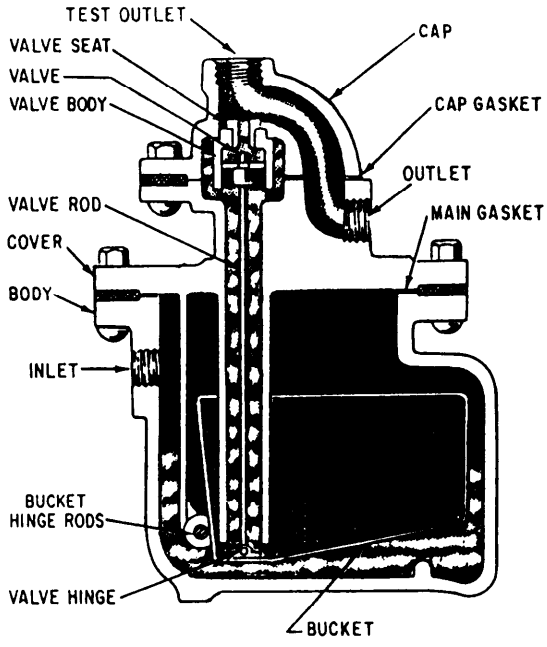
Figure 13-33.—Ball-float steam trap.

Bucket-Type Trap

Figure 13-34 shows a common bucket trap which is suitable for high pressures and temperatures and has a large capacity. Its operation may be described as follows: As soon as sufficient water enters the trap, the bucket, being buoyant, floats and closes the valve. As condensation increases, the body of the trap fills and water enters the bucket, causing it to sink. The bucket being attached to the discharge valve, opens the discharge valve and the trap begins to discharge, continuing to do so until the condensation is blown out of the body to the edge of the bucket. At this point, the water in the bucket continues to be forced out until the bucket again becomes buoyant and rises, closing the valve.

THERMOSTATIC STEAM TRAPS

There are several types of thermostatic steam traps. In general, these traps are more compact and have fewer moving parts than most mechanical steam traps. The operation of a bellows-type thermostatic trap is controlled by expansion of the vapor of a volatile liquid enclosed in a bellows-type element. Steam enters the trap body and heats the volatile liquid in the sealed bellows, thus causing expansion of the bellows. The valve is



11.325

Figure 13-34.—Bucket-type steam trap.

attached to the bellows in such a way that the valve closes when the bellows expands. The valve remains closed, trapping steam in the trap body. As the steam cools and condenses, the bellows cools and contracts, opening the valve and allowing the condensate to drain.

The impulse and bimetallic steam traps are two examples of those that use the thermostatic principle.

Impulse Steam Traps

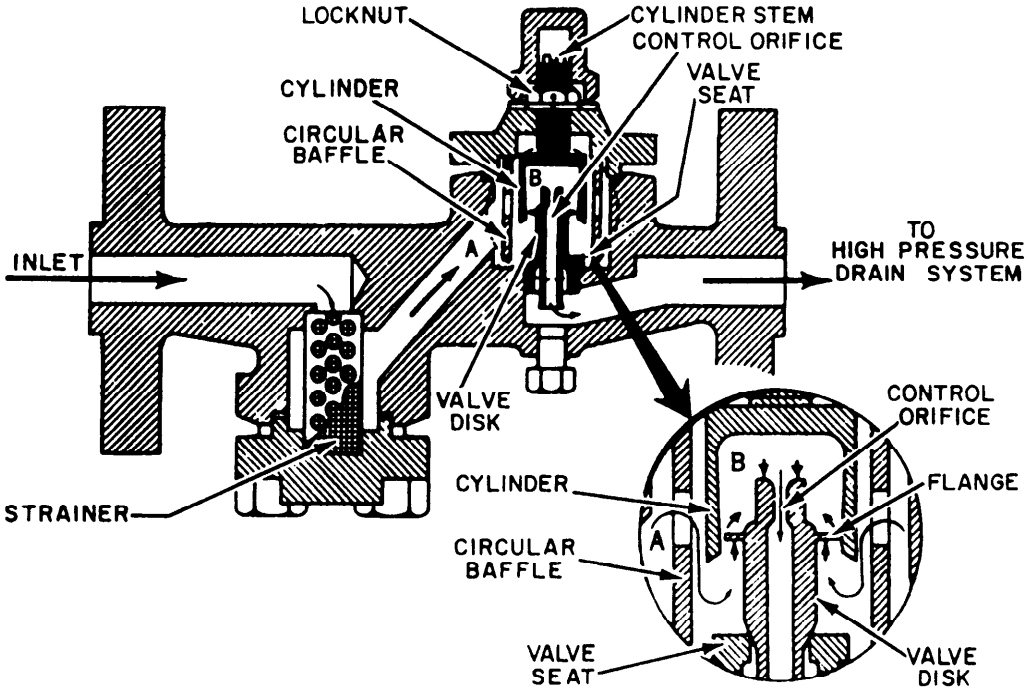
Impulse steam traps of the type shown in figure 13-35 are commonly used in steam drain collecting systems onboard ship. Steam and condensate pass through a strainer before entering the trap. A circular baffle keeps the entering steam and condensate from striking on the cylinder or on the disk.

The impulse trap operates on the principle that hot water under pressure tends to flash into steam when the pressure is reduced. So that you understand how this principle is used, let's consider the arrangement of parts shown in figure 13-35 and see what happens to the flow of condensate under various conditions.

The only moving part in the steam trap is the disk, which is rather unusual in design. Near the top of the disk is a flange that acts as a piston. As you can see in the insert, the working surface above the flange is larger than the working surface below the flange. The importance of having this larger effective area above the flange is brought out later in this discussion.

A control orifice runs through the disk from top to bottom and is considerably smaller at the top than at the bottom. The bottom part of the disk extends through and beyond the orifice in the seat. The upper part of the disk (including the flange) is inside a cylinder. The cylinder tapers inward, so the amount of clearance between the flange and the cylinder varies according to the position of the valve. When the valve is open, the clearance is greater than when the valve is closed.

When the trap is first cut in (put in service), pressure from the inlet (chamber A) acts against the underside of the flange and lifts the disk off the valve seat. Condensate is thus allowed to pass out through the orifice in the seat. At the same time, a small amount of condensate (CONTROL FLOW) flows up past the flange and into chamber B. The control flow discharges through the control orifice, into the outlet side of the trap.



38.126

Figure 13-35.—Impulse steam trap.

The pressure in chamber B remains lower than the pressure in chamber A.

As the line warms up, the temperature of the condensate flowing through the trap increases. The reverse taper of the cylinder varies the amount of flow around the flange. This continues until a balanced position is reached in which the total force exerted above the flange is equal to the total force exerted below the flange. It is important to note that there is still a PRESSURE DIFFERENCE between chamber A and chamber B. The FORCE is equalized because the effective area above the flange is larger than the effective area below the flange.

As the temperature of the condensate approaches its boiling point, some of the control flow going to chamber B flashes into steam as it enters the low-pressure area. The steam has a much larger volume than the water from which it is generated. Therefore, pressure is built up in the space above the flange (chamber B). The force exerted on the top of the flange pushes the disk downward and closes the valve.

With the valve closed, the only flow through the trap is past the flange and through the control orifice. When the temperature of the condensate entering the trap drops slightly, condensate enters chamber B without flashing into steam. Pressure in chamber B is thus reduced to the point that the valve opens and allows condensate to flow through the orifice in the valve seat. Thus the entire cycle is repeated.

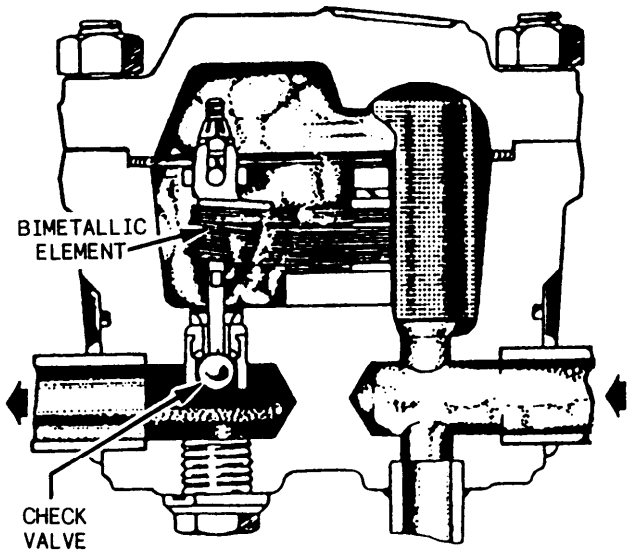
With a normal condensate load, the valve opens and closes at frequent intervals. This discharges a small amount of condensate at each opening. With a heavy condensate load, the valve remains wide open and allows a heavy, continuous discharge of condensate. (You can tell if this valve is working properly by listening to it with an engineer's stethoscope. A clicking sound indicates the valve disk is moving up and down on its seat.)

Bimetallic Steam Traps

Bimetallic steam traps are used in many ships to drain condensate from main steam lines, auxiliary steam lines, and other steam components. The main working parts of this type of steam trap are a segmented bimetallic element and a ball-type check valve (fig. 13-36).

The bimetallic element consists of several bimetallic strips fastened together in a segmented fashion. One end of the bimetallic element is fastened rigidly to a part of the valve body. The other end, which is free to move, is fastened to the top of the stem of the ball-type check valve.

Line pressure acting on the check valve tends to keep the valve open. When steam enters the trap body, the bimetallic element expands unequally because of the different response to the temperature of the two metals. The bimetallic element deflects upward at its free end. This moves the valve stem upward and closes the valve. As the steam cools and condenses, the bimetallic element moves downward toward the horizontal position. This opens the valve and allows some condensate to flow out through the valve. As the flow of condensate begins, an unbalance of line pressure across the valve is created. Since the line pressure is greater on the upper side of the ball of the check valve, the valve now opens wide and allows a full capacity flow of condensate.



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Figure 13-36.—Bimetallic steam trap.

ORIFICE-TYPE STEAM TRAPS

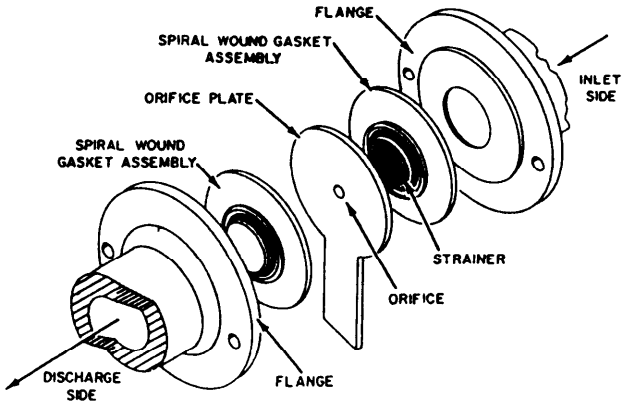
Figure 13-37 shows the assembly of an orifice-type steam trap. Constant-flow drain orifices may be used in systems of 150 psi and above where condensate load and pressure remain near constant.

The constant-flow drain orifice operates on a thermodynamic principle—the variable density of condensate. The density of any fluid changes with temperature. As the temperature of the condensate decreases, its density will increase, as will the flow of condensate through the orifice. The reverse is also true. As the temperature of the condensate increases, its density will decrease, as will the flow of the condensate through the orifice.

Because of the difference in densities between the steam and the condensate, the condensate will flow through the orifice at a faster rate.

PACKING AND GASKET MATERIALS

You will use gasket materials to seal fixed joints in steam, water, fuel, air, lube oil, and other piping systems. You will use packing materials to seal joints that slide or rotate under operating conditions (moving joints). There are many commercial types and forms of packing and gasket material. The Navy has simplified the selection of packing and gasket materials commonly used in naval service. The Naval Sea Systems Command has prepared a packing and gasket chart (Mechanical Standard Drawing B0153). This chart shows the symbol numbers and the recommended applications of all types and kinds of packing and gasket materials. A copy of the chart should be located in all engineering spaces.



38.303

Figure 13-37.—Orifice-type steam trap assembly.

A four-digit symbol number identifies each type of packing and gasket. The first digit indicates the class of service with respect to fixed and moving joints. For example, if the first digit is 1, it indicates a moving joint (moving rods, shafts, valve stems, and so forth). If the first digit is 2, it indicates a fixed joint (such as a flange or a bonnet). The second digit indicates the material of which the packing or gasket is primarily composed. This may be vegetable fiber, rubber, metal, and so on. The third and fourth digits indicate the different styles or forms of the packing or gaskets made from the material. To find the right packing material, check the maintenance requirement card (MRC) or the NAVSEA packing and gasket chart. The MRC lists the symbol numbers and the size and number or rings required. The NAVSEA packing and gasket chart lists symbol numbers and includes a list of materials. For additional information concerning packing and gasket material, refer to *Naval Ships' Technical Manual,* chapter 078.

FLANGE SAFETY SHIELDS

A fire in the engine room can be caused by a leak at a fuel or lube-oil pipe-flange connection. Even the smallest leak can spray fine droplets of lube oil or fuel on nearby hot surfaces, such as the exhaust manifold of a diesel engine. To reduce this possibility, spray shields (flange safety shields) are installed on piping flanges of flammable liquid systems, especially in areas where the fire hazard is apparent. (See fig. 13-38.) The spray shields are usually made of aluminized glass cloth and are simply wrapped and wired around the flange. Additional information concerning the use and installation of flange safety shields is provided in *Naval Ships' Technical Manual,* chapter 9480.

EQUIPMENT AND INSTRUMENT TAG-OUT

Whenever you make repairs to equipment, you will be required to isolate and tag-out the equipment of that section of the system. The tag-out program provides procedures to be used when a component, a piece of equipment, a system, or a portion of a system must be isolated for preventive or corrective maintenance. The tag-out

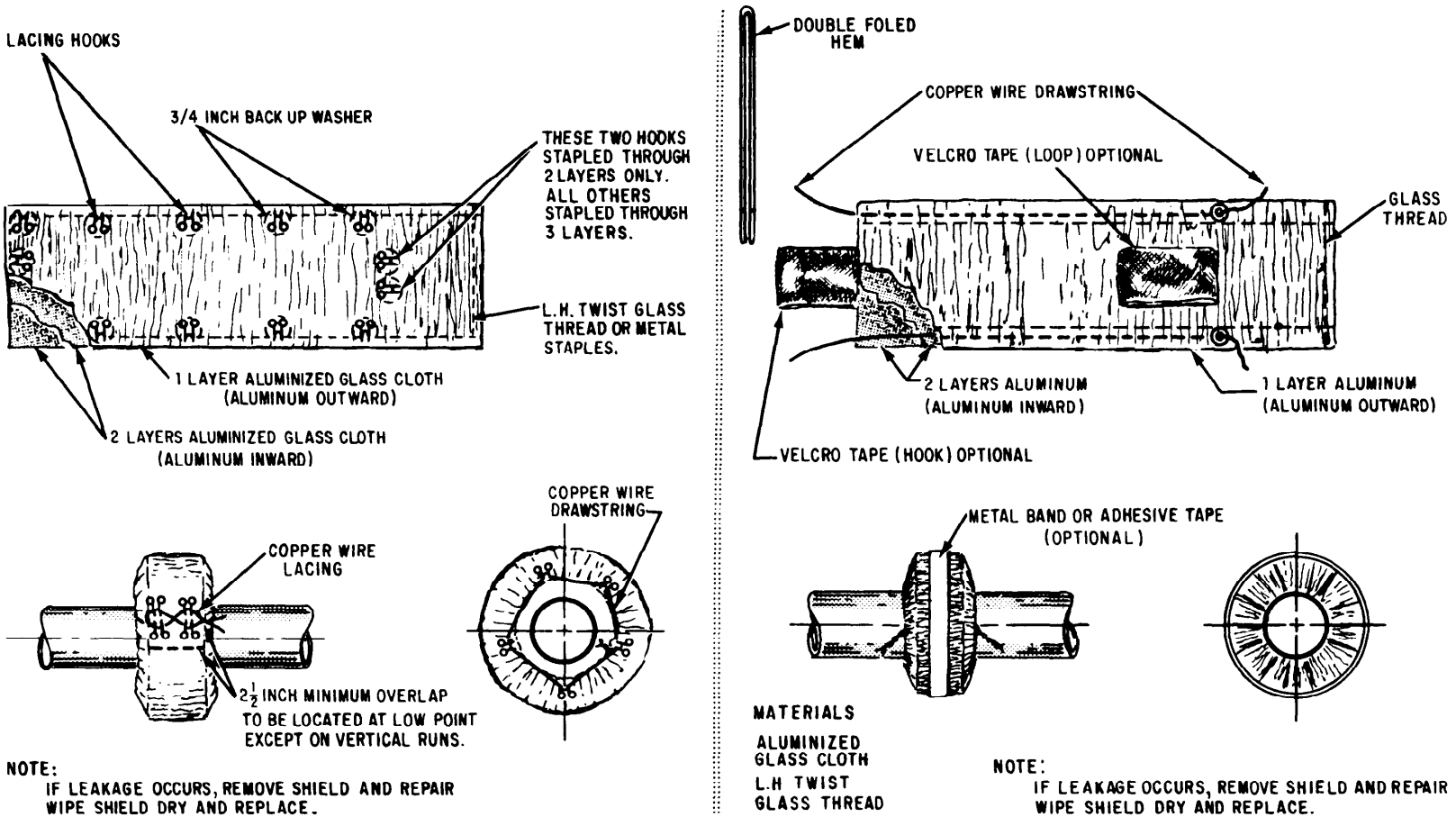


Figure 13-38.—Flange safety shields.

program also provides procedures to be used when an instrument becomes unreliable or is not operating properly. The major difference between equipment tag-out and instrument tag-out is that labels are used for instrument tag-out and tags are used for equipment tag-out.

Tag-out procedures are described in OPNAVINST 3120.32B and represent the MINIMUM requirements for tag-out. These procedures are MANDATORY and are standardized aboard ship and repair activities through local written instructions.

SUMMARY

This chapter has provided you with an overview of the pumps and valves you will be required to operate and maintain. Now that you have read the information in this chapter, you should understand the relationship of a pump or a valve to the system it serves. You should readily understand the necessity for keeping these components operating at top efficiency through proper maintenance. If you are uncertain concerning any areas of this chapter, go back and review the sections with which you are having trouble before you go on to chapter 14.

CHAPTER 14

COMPRESSED AIR SYSTEMS

As an Engineman, you should have a thorough knowledge of air compressors. After studying the information in this chapter, you should understand that compressed air serves many different purposes aboard ship. These purposes include, but are not limited to, the operation of pneumatic tools and equipment, prairie-masker systems, diesel engine starting and speed control systems, and propulsion control systems. In this chapter, we will discuss how compressed air is supplied to the various systems by high-, medium-, or low-pressure air compressors, depending on the needs of the ship.

After studying the information in this chapter, you should be able to identify the common types of air compressors used in Navy ships in terms of their design and classification, purpose, function, principles of operation, and associated equipment. You should also be able to identify the components of a compressed air system. You should be able to recognize how compressed air is prepared and delivered for use aboard ship. You should also be able to identify some of the operational and safety procedures you must use when you are working with compressed air systems.

AIR COMPRESSORS

The compressor is the heart of any compressed air system. It takes in atmospheric air, compresses it to the pressure desired, and moves it into supply lines or into storage tanks for later use. Air compressors come in different designs and configurations and have different methods of compression. Some of the most common types in use on Navy ships will be discussed in this chapter.

Before we describe the various types of air compressors used on Navy ships, let's talk about the composition of air and some of the things air may contain. This discussion should help you to understand why air compressors have special features that prevent water, dirt, and oil vapor from getting into compressed air piping systems.

Air is mostly composed of nitrogen and oxygen. At atmospheric pressure (within the range of temperatures for the earth's atmosphere), air is in a gaseous form. The earth's atmosphere, of course, also contains varying amounts of water. Depending upon weather conditions, water will appear in a variety of forms, such as rain (liquid water), snow crystals, ice (solid water), and vapor. Vapor is composed of tiny drops of water that are light enough to stay airborne. Clouds are an example of the existence of water vapor.

Since air is a gas, it will expand when it is heated. Consequently, the heating of air will cause a given amount of air to expand, take up more space (volume), and hold more water vapor. When a given amount of air at a given temperature and pressure is no longer able to soak up water vapor. the air is saturated, and the humidity is 100 percent.

When air cools its density increases; however, its volume and ability to hold water decrease. When temperature and pressure conditions cause air to cool and to reach the dew point, any water vapor in the air will condense into a liquid state (water). In other words, one method of drying air out is to cool it until it reaches the dew point.

In addition to nitrogen, oxygen, and water vapor, air contains particles of dust and dirt that are so tiny and lightweight that they remain suspended in the air. You may wonder how the composition of air directly affects the work of an air compressor. Although one cubic foot of air will not hold a tremendous amount of water or dirt, you should realize that air compressors have capacities that are rated in hundreds of standard cubic feet per minute (cfm). This is a very high rate of flow. When a high flow rate of dirty, moisture-laden air is allowed to enter and pass through an air compressor, the result is rapid wear of the seals and load-bearing parts, internal corrosion (rust), and early failure of the unit. The

reliability and useful life of any air compressor is extended by the installation of filters. Filters will remove most of the dirt and dust from the air before it enters the equipment. On the other hand, most of the water vapor in the air at the intake will pass directly through the filter material and will be compressed with the air. When air is compressed, it becomes very hot. As we mentioned earlier, hot air is capable of holding great amounts of water. The water is removed as the compressed air is routed through coolers. The coolers remove the heat from the airstream and cause some of the water vapor to condense into liquid (condensate). The condensate must be periodically drained from the compressor.

Although the coolers will remove some of the water from the air, simple cooling between the stages of compression (intercooling) and cooling of the airstream after it leaves the compressor (aftercooling) will not make the air dry. When there is a requirement to provide clean dry air that is suitable for pneumatic control and other shipboard systems, air from the compressor is routed through air-drying units. Many air-drying units are capable of removing enough water vapor from the airstream to cause the dew point to be as low as –60°F. Several of the more common devices used to remove water and oil vapor from the air-stream will be explained later in this chapter.

CLASSIFICATION AND DESIGN

An air compressor may be classified according to pressure (high, medium, or low), type of compressing element, and whether the discharged air is oil free.

Because of our increasing need for oil-free air aboard ship, the oil-free air compressor is gradually replacing most of the standard low-pressure and high-pressure air compressors. For this reason, we will focus most of our discussion on the features of oil-free air compressors.

According to the *Naval Ships' Technical Manual,* chapter 551, compressors are classified as low, medium, or high pressure. Low-pressure compressors have a discharge pressure of 150 psi or less. Medium-pressure compressors have a discharge pressure of 151 psi to 1,000 psi. Compressors that have a discharge pressure above 1,000 psi are classified as high-pressure compressors.

SOURCES OF POWER

Compressors may be driven by electric motors, steam turbines, or gas turbines. Aboard ship, most low-, medium-, and high-pressure air compressors that supply the ship's service air are driven by electric motors.

The driving unit may be coupled to the compressor by one of several methods. When the compressor and the driving unit are mounted on the

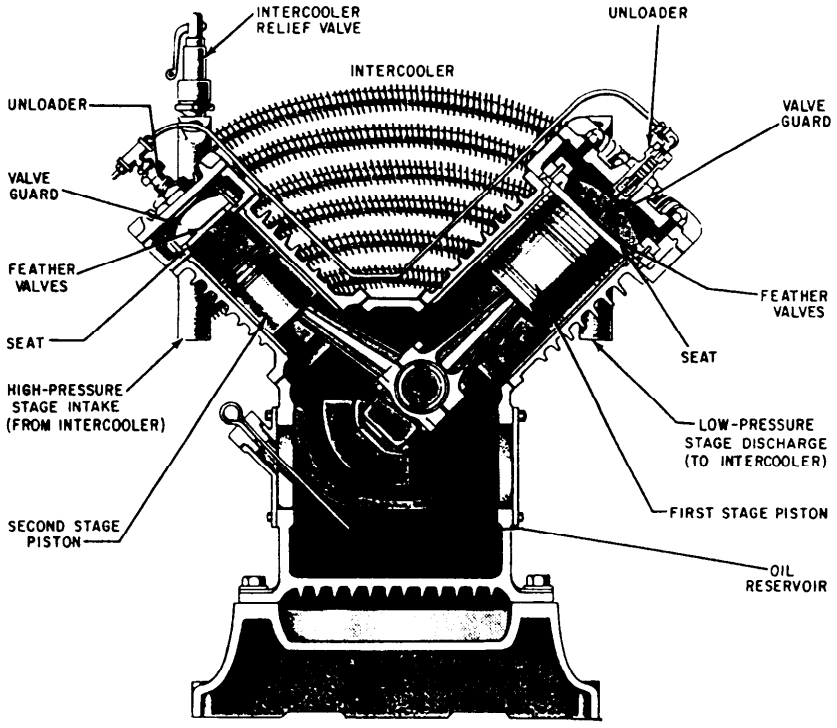


Figure 14-1.—A simple two-stage reciprocating low-pressure air compressor (vertical V configuration).

same shaft, they are close-coupled. This method is usually restricted to small-capacity air compressors driven by electric motors. When the speed of the compressor and the speed of the driving unit are the same, flexible couplings are used to mount the driving unit to the compressor. This is called a direct-coupled drive.

V-belt drives are commonly used with small, low-pressure, motor-driven compressors and with some medium-pressure and high-pressure compressors. In a few installations, a rigid coupling is used between the compressor and the electric motor of a motor-driven compressor. In a steam-turbine drive, the compressors are usually (but not always) driven through reduction gears. Centrifugal high-speed compressors are usually driven through speed increasing gears.

COMPRESSING ELEMENTS

Shipboard air compressors may be centrifugal, rotary, axial flow screw, or reciprocating. The more common reciprocating type of air compressor is generally selected for capacities from 100 to 800 cfm with outlet pressure ratings of 125, 600, and 3,000 psi, up to 5,000 psi. The rotary lobe type of air compressor is selected for capacities up to 8,800 cfm and for pressures of no more than 20 psi. The centrifugal type of air compressor is selected for capacities of 800 cfm or greater (up to 2,100 cfm in a single unit) and for pressures up to 125 psi. The axial flow screw type of air compressor is selected for capacities up to 100 cfm and for pressures of no more than 125 psi.

Most general-service air compressors aboard ship are the reciprocating type. In the reciprocating air compressor, the air pressure is increased by the use of one or more cylinders. This is very much like the compression that takes place in an internal-combustion engine.

RECIPROCATING AIR COMPRESSORS

All reciprocating air compressors are similar in design and operation. The following discussion describes the basic components and principles of operation of low-, medium-, and high-pressure reciprocating air compressors.

CYLINDER ARRANGEMENT

Most low-pressure reciprocating air compressors are of the two-stage type. They have either a vertical V (fig. 14-1), a vertical W (fig. 14-2), or a vertical in-line arrangement

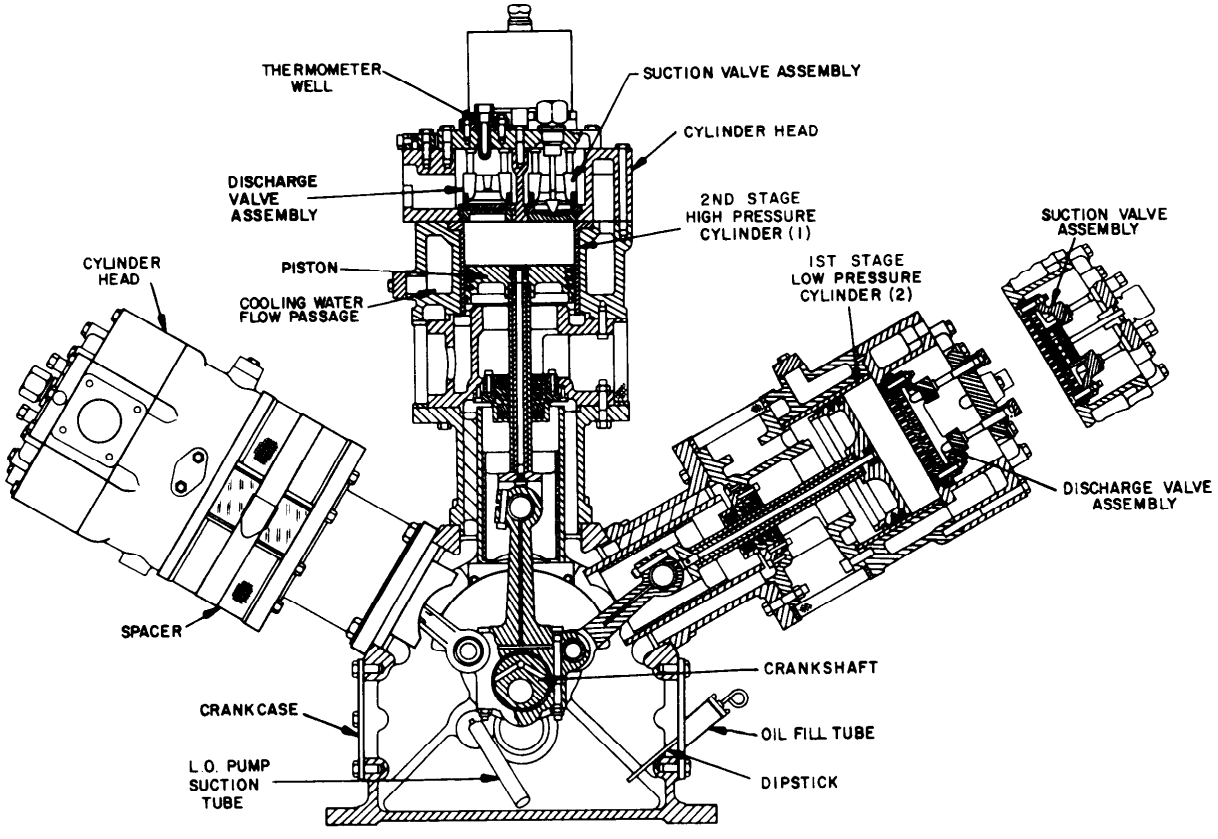


Figure 14-2.—Low-pressure reciprocating air compressor (vertical W configuration).

of cylinders. The V-type and in-line compressors have one cylinder for the first (lower pressure) stage of compression and one cylinder for the second (higher pressure) stage of compression. The W-type compressor has two cylinders for the first stage of compression and one cylinder for the second stage. The vertical W cylinder arrangement is shown in view A of figure 14-3. Notice that the pistons in the lower-pressure stage (1) have larger diameters than the pistons in the higher-pressure stage (2).

Medium-pressure air compressors are generally the two-stage, vertical, duplex, single-acting type. Many medium-pressure compressors have differential pistons. This type of piston is used in machines designed for more than one stage of compression during each stroke of the piston. (See view A of fig. 14-3.)

Most high-pressure compressors are motor-driven, liquid-cooled, four-stage, single-acting units with vertical cylinders. View B of figure 14-3 shows the cylinder arrangements for the high-pressure air compressors installed in Navy ships. Small-capacity, high-pressure air systems may have three-stage compressors. Large-capacity, high-pressure air systems may be equipped with four-, five-, or six-stage compressors.

OPERATING CYCLE

As our example of the operating cycle, we will describe one stage of compression in a single-stage, single-acting compressor. The cycle of operation, or compression cycle, within an air compressor cylinder includes two strokes of the piston: an intake stroke and a compression stroke. (Refer to fig. 14-4.) The intake stroke (view A) begins when the piston moves away from top dead center (TDC). The air remaining in the clearance space above the piston expands rapidly (view B) until the pressure in the cylinder falls below the pressure on the opposite side of the inlet valve, which is at atmospheric pressure. At this point (view C), the difference in pressure causes the inlet valve to open, and air is admitted to the cylinder. Air continues

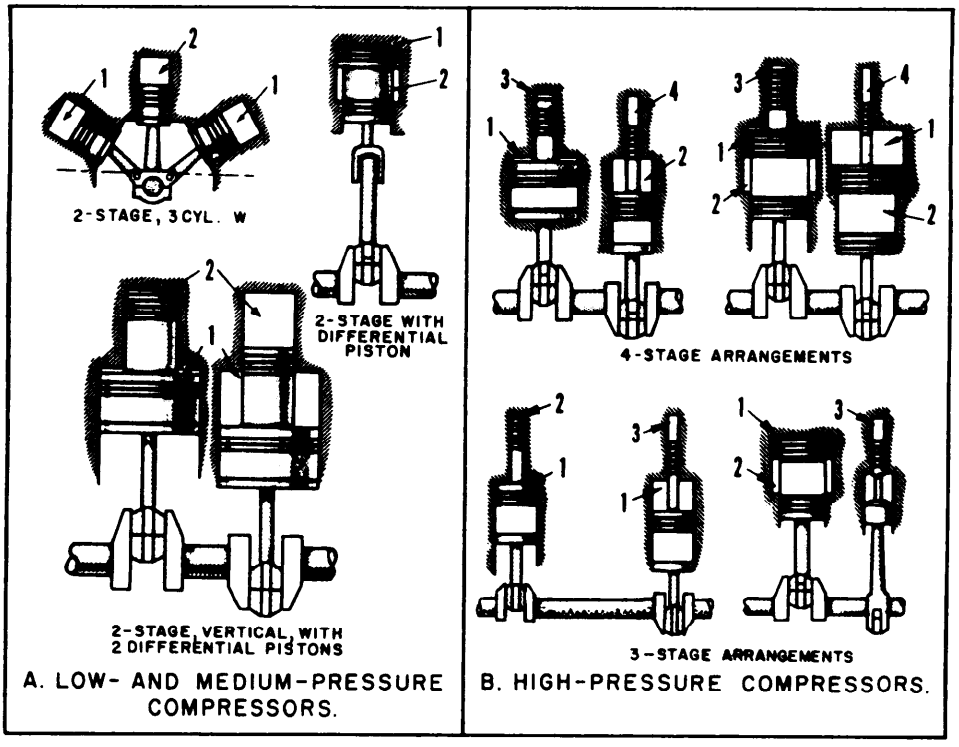


Figure 14-3.—Air compressor cylinder arrangements.

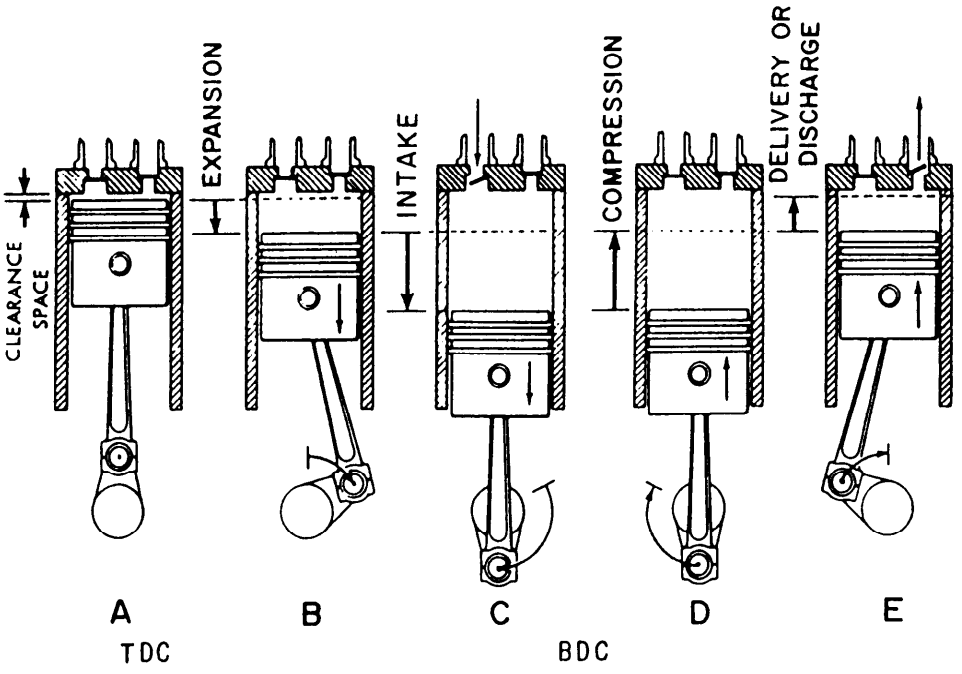


Figure 14-4.—The compression cycle.

to flow into the cylinder until the piston reaches bottom dead center (BDC).

The compression stroke (view D) starts as the piston moves away from BDC and continues until the piston reaches TDC again. When the pressure in the cylinder equals the pressure on the opposite side of the air inlet valve, the inlet valve closes. The air trapped in the cylinder continues to be compressed as the piston moves toward TDC. When the pressure in the cylinder (view E) becomes great enough, it will force the discharge valve to open against the discharge line pressure and the force of the valve springs. (The discharge valve opens shortly before the piston reaches TDC.) During the remainder of the compression stroke, the air that has been compressed in the cylinder is discharged at almost constant pressure through the open discharge valve.

The basic operating cycle just described is completed twice for each revolution of the crankshaft in double-acting compressors, once on the down stroke and once on the up stroke.

COMPONENTS AND SYSTEMS

Reciprocating air compressors consist of a system of connecting rods, a crankshaft, and a flywheel. These parts transmit power developed by the driving unit to the pistons as well as to the lubrication systems, cooling systems, control systems, and unloading systems.

Compressing Element

The compressing element of a reciprocating air compressor consists of the cylinders, pistons, and air valves.

CYLINDERS.—The design of the cylinders depends mostly upon the number of stages of compression required to produce the maximum discharge pressure. Several common cylinder arrangements for low- and medium-pressure air compressors are shown in view A of figure 14-3. Several arrangements for the cylinders and pistons of high-pressure air compressors are shown in view B of figure 14-3. The stages are numbered 1 through 4. Notice that a three-stage arrangement and a four-stage arrangement are both shown. The basic stage arrangement is similar for the five- and six-stage compressors.

PISTONS.—The pistons may be either of two types: trunk or differential. (See fig. 14-5.) TRUNK PISTONS are driven directly by the connecting rods (view A). The upper end of a connecting rod is fitted directly to the piston by a wrist pin. This design produces a tendency for the piston to develop a side pressure against the cylinder walls. For the side pressure to be distributed over a wide area of the cylinder walls or liners, pistons with long skirts are used. The design of the trunk piston helps minimize cylinder wall wear. DIFFERENTIAL PISTONS, shown in view B of figure 14-5, are modified trunk pistons with two or more different diameters. These pistons are fitted into special cylinders, arranged so that more than one stage of compression is achieved by a single upward stroke of the piston. The compression for one stage takes place over the piston crown; compression for the other stage(s) takes place in the annular space between the large and small diameters of the piston.

VALVES.—The valves are made of special steel and come in a number of different types. The opening and closing of the valves is caused by the difference between (1) the pressure of the air in the cylinder and (2) the pressure of the external air on the intake valve or the pressure of the discharged air on the discharge valve.

Two types of valves commonly used in high-pressure air compressors are shown in figure 14-6. The strip- or feather-type valve is shown in view A. It is used for the suction and discharge valves of the lower-pressure stages (1 and 2). The valve shown in view A is a suction valve; the discharge valve assembly (not shown) is identical except that the positions of the valve seat and the guard are reversed. At rest, the thin strips lie flat against the seat. They cover the slots and form a seal when pressure is applied to the guard side of the valve. The following action works in either a suction or a discharge operation (depending on the valve service). As soon as pressure on the seat side of the valve exceeds the pressure on the guard side, the strips flex against the contoured recesses in the guard. As soon as the pressure equalizes or reverses, the strips unflex and return to their original position, flat against the seat.

The disk-type valve in view B of figure 14-6 is used for the suction and discharge valves of the higher-pressure stages (3 and 4). The fourth stage assembly is shown in view B. The valves shown are the spring-loaded, dished-disk type. At rest, the disk is held against the seat by the spring. It forms a seal when pressure is applied to the keeper

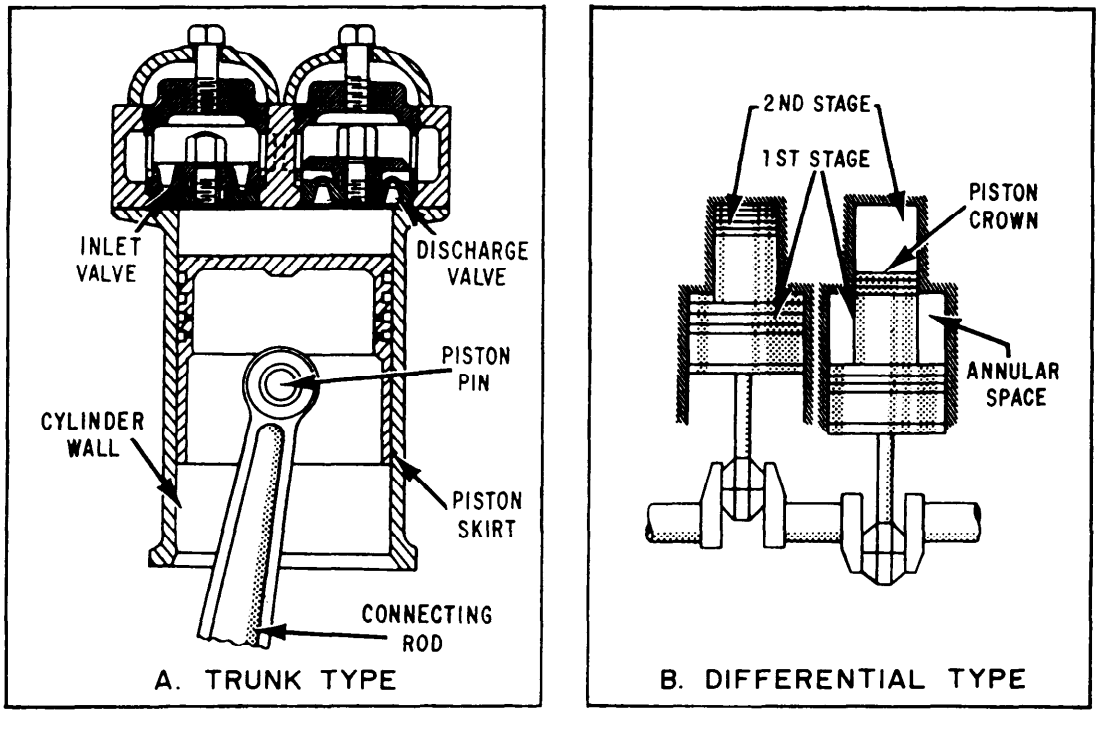


Figure 14-5.—Air compressor pistons.

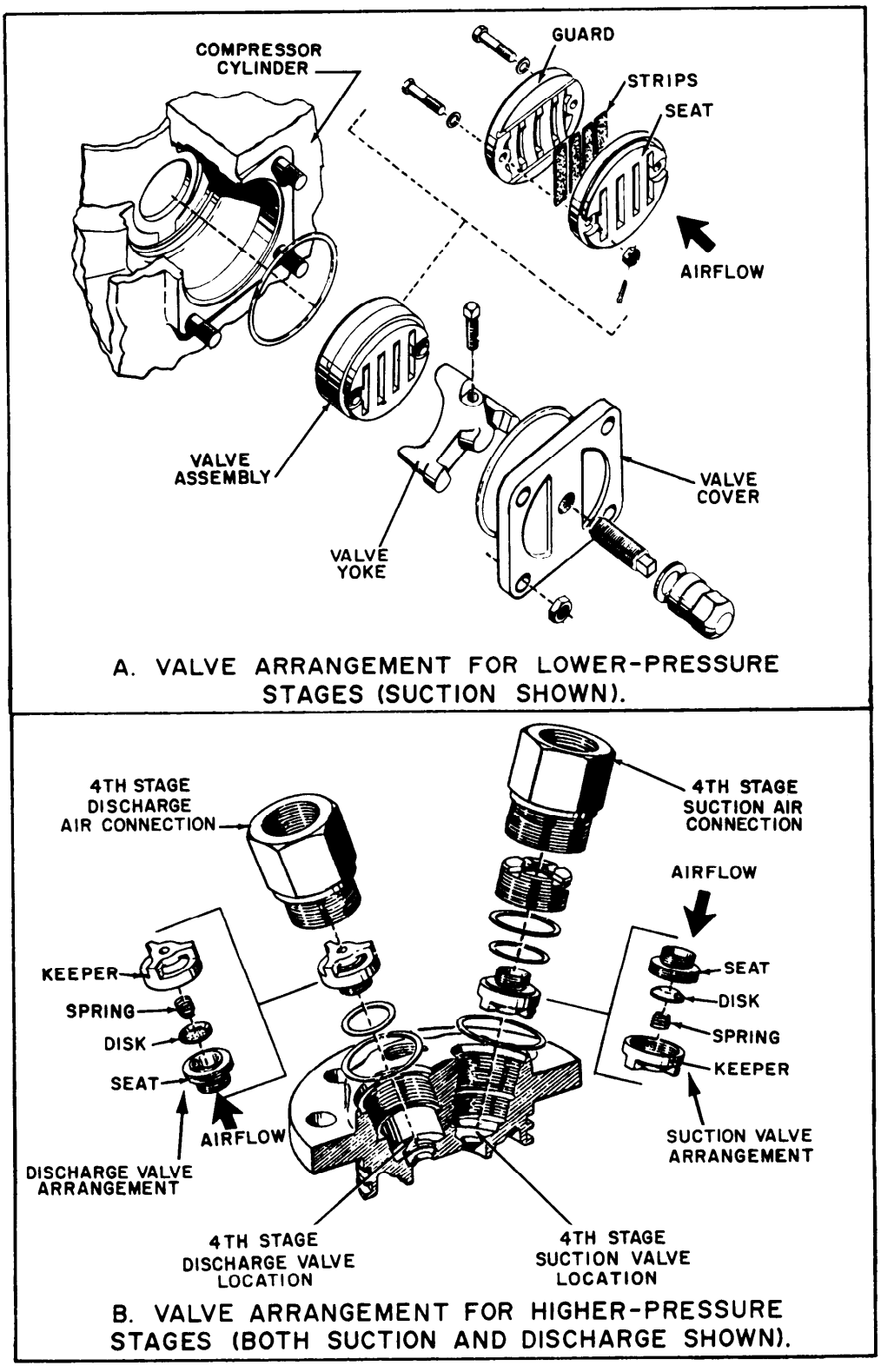


Figure 14-6.—High-pressure air compressor valves.

side of the valve. The following action works in either a suction or a discharge operation (depending on the valve service). When the pressure on the seat side of the valve exceeds the pressure on the keeper side, the disk lifts against the stop in the keeper. This action compresses the spring and permits air to pass through the seat, around the disk, and through the openings in the sides of the keeper. As soon as the pressure equalizes or reverses, the spring forces the disk back onto the seat.

Lubrication Systems

There are generally three types of lubrication systems in reciprocating compressors. They are for high-pressure, low-pressure, and oil-free air compressors.

High-pressure air compressor cylinders (except for nonlubricated compressors) are generally lubricated by an adjustable mechanical force-feed lubricator. This unit is driven from a reciprocating or rotary part of the compressor. Oil is fed from the cylinder lubricator by separate lines to each cylinder. A check valve at the end of each feedline keeps the compressed air from forcing the oil back into the lubricator. Each feedline has a sight-glass oil flow indicator. Lubrication begins automatically as the compressor starts up. Figure 14-7 shows the lubrication connections for the cylinders. The type and grade of oil used in

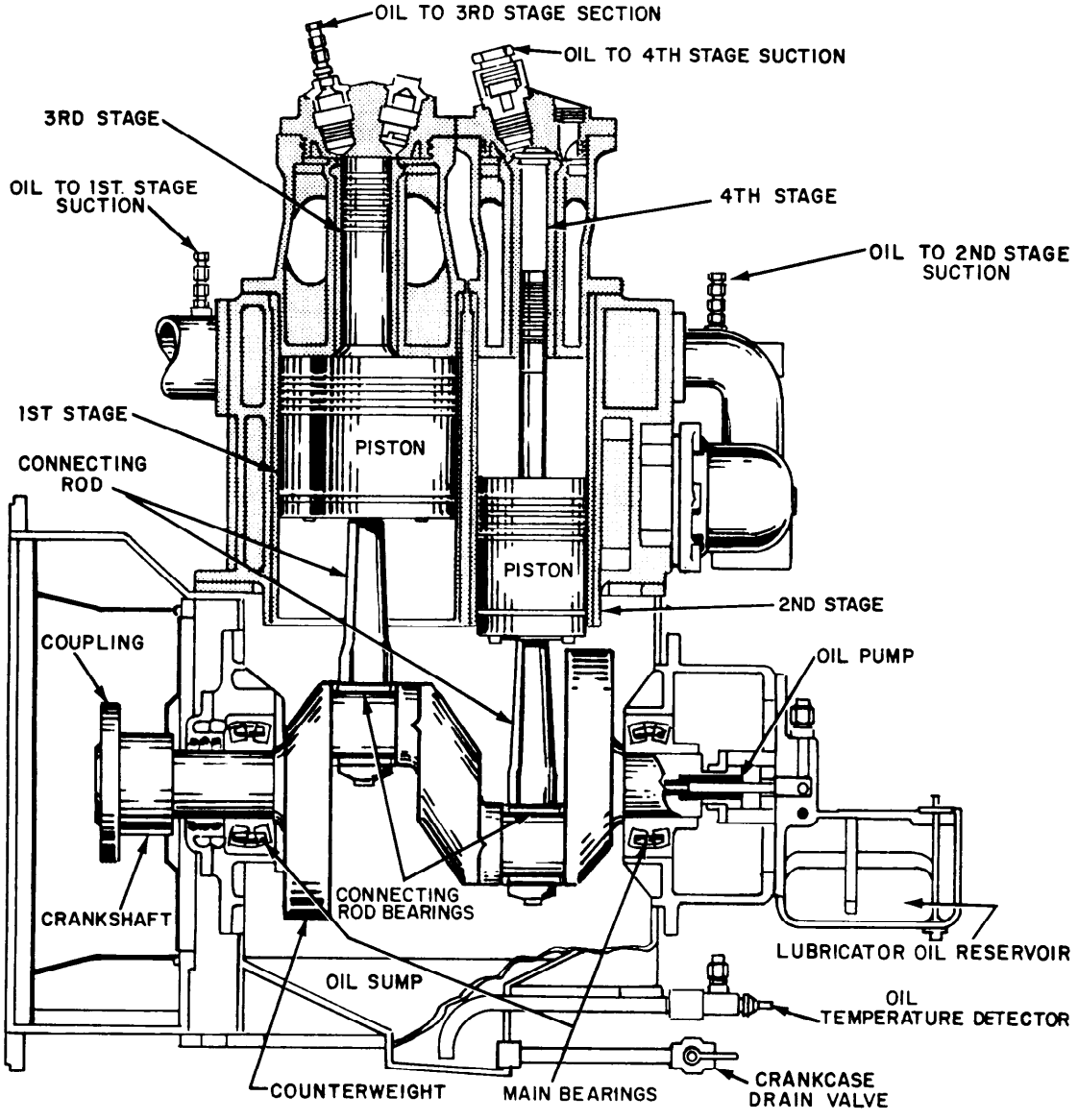


Figure 14-7.—High-pressure air compressor showing the lubrication system.

compressors is specified in the applicable NAVSEA technical manual. The correct type is vital to the operation and reliability of the compressor.

The running gear is lubricated by an oil pump that is attached to the compressor and driven from the compressor shaft. This pump is usually a gear type. It moves oil from the reservoir (oil sump) in the compressor base and delivers it through a filter to an oil cooler (if installed). From the cooler, the oil is distributed to the top of each main bearing, to the spray nozzles for the reduction gears, and to the outboard bearings. The crankshaft is drilled so that oil fed to the main bearings is picked up at the main bearing journals and carried to the crank journals. The connecting rods contain passages that conduct lubricating oil from the crank bearings up to the piston pin bushings. As oil is forced out from the various bearings, it drips back into the oil sump (in the base of the compressor) and is recirculated. Oil from the outboard bearings is carried back to the sump by drain lines.

A low-pressure air compressor lubrication system is shown in figure 14-8. This system is similar to that of the running gear lubrication system for the high-pressure air compressor.

Nonlubricated reciprocating compressors have lubricated running gear (shaft and bearings) but no lubrication for the pistons and valves. This design produces oil-free air.

Cooling Systems

The power input to the compressor is converted to heat in the compression process. This heat is removed by a cooling system for two primary reasons: (1) to prevent the compressed air and various compressor parts from reaching excessively high temperatures, and (2) to improve the efficiency of multistage compressors by increasing the density of air between stages of compressions.

In reciprocating compressors, the compression cylinders are cooled by fresh water or seawater, which is circulated through cooling water passages in the cylinder block. When removable cylinder

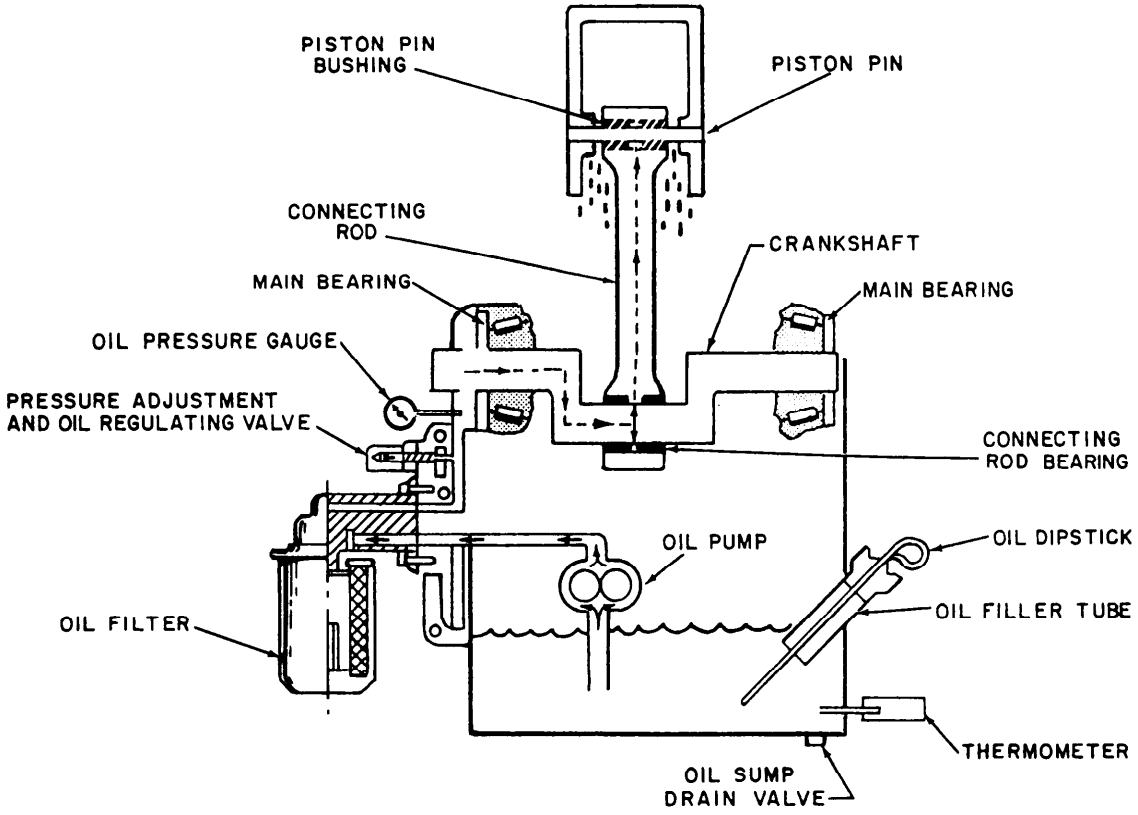


Figure 14-8.—Lubricating oil system of a low-pressure air compressor.

liners or cylinder sleeves are used, the cylinder block may incorporate wells or bores for the liners so that the cooling water does not come into direct contact with the cylinder liners (dry liners). In another design, the liner may be held in shoulders with O-ring seals within the cylinder block so that the cylinder liners are "wetted" by the cooling water (wet liners). Cylinder jackets are fitted with handholes and covers so that the water spaces may be inspected and cleaned. On many compressors, water passes directly through the joint between the cylinder and the head. On such designs, extreme care must be taken so that the joint is properly gasketed to prevent leakage. If allowed to continue, water leakage would cause corrosion problems or more severe damage.

In addition to cylinder cooling, each stage of a reciprocating compressor has an air cooler in which the discharge air is cooled before it enters the next stage. The coolers are usually of the shell and tube design. Compressed air is directed through the tubes of the cooler, with the cooling water flowing through the shell and over the tubes. On some compressors, this design may be reversed on the low-pressure stages (first and second) so that the cooling water flows through the tubes and the air through the shell. The coolers between stages are called INTERCOOLERS. The last cooler is the AFTERCOOLER. (Intercoolers and aftercoolers will be discussed in greater detail later in this chapter.)

You may encounter several different types of cooling systems, depending, of course, on the ship to which you are assigned. On older air compressors, cooling is provided by a seawater system that serves the compression cylinders as well as the intercoolers and aftercooler. (See fig. 14-9.) In these systems, the seawater flows essentially in a series arrangement—first through the intercoolers and aftercooler, and then through the compression cylinders. This process ensures that the air entering the cylinders is always cooler than the valve chambers and cylinders. Therefore, moisture from condensation is minimized. However, with seawater temperatures substantially lower than 85°F, condensation may occur within the cylinders and discharge valve chambers (or cylinder heads) on the compression stroke. Also,

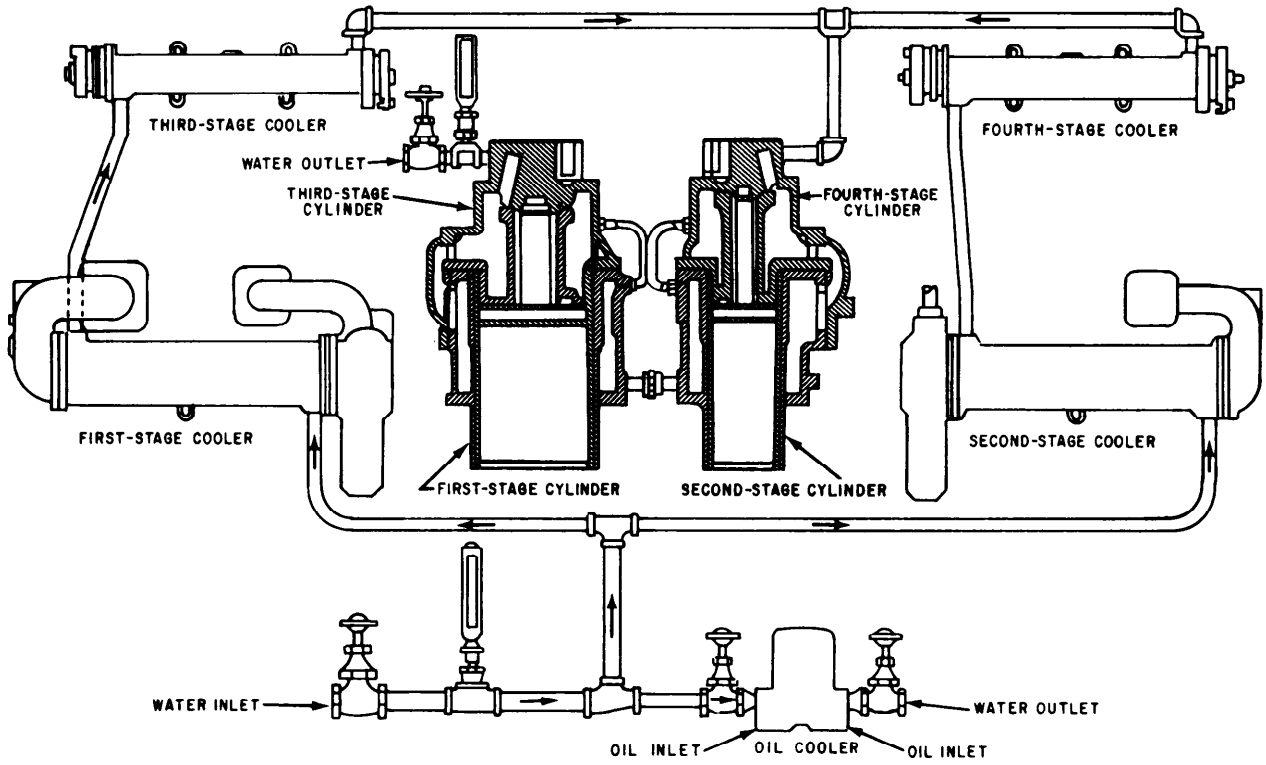


Figure 14-9.—Seawater cooling (open) system of a multistage air compressor.

because of the compact design of some air compressors, low seawater temperatures can cause the compressor frame and oil sump to reach temperatures that are sufficiently low to cause condensation within the oil sump. This condition can cause rapid water buildup and subsequent bearing failure. For protection against the overcooling of compressors that are cooled entirely by seawater, it is recommended that cooling water be throttled. This action will reduce the cooling effect in the compression cylinders. However, excessive reduction in cooling water flow can result in hot spots in the cylinder areas where flow under normal conditions becomes marginal. In this regard, you must follow the recommendations in the NAVSEA technical manual for any specific compressor.

The majority of compressors, including oil-free compressors on surface ships, employ seawater cooling systems for the intercoolers and aftercoolers and a secondary freshwater system for cylinder cooling. (See fig. 14-10.) The closed freshwater cooling system consists of a pump, a surge tank, a thermostatic valve, and a heat exchanger. The pressurized coolant is moved from the surge tank by the water pump and is directed to each cylinder assembly. A high-water-temperature shutdown switch downstream from the cylinder assemblies monitors the coolant temperature. Coolant at the thermostatic valve flows either directly to the cylinders or through the heat exchanger if the cylinder water requires cooling. The design provides a constant rate of flow and thermostatic temperature control in the cylinder cooling system. This type of control ensures uniform operating conditions for the compression stages and helps the system avoid the harmful excessive cooling of cylinders. As we mentioned earlier, excessive cooling causes condensation on cylinder walls—a condition that results in early catastrophic seal failure.

The intercoolers and aftercoolers act to remove heat that is generated whenever air is compressed. They also cause any water vapor that may be present in the airstream

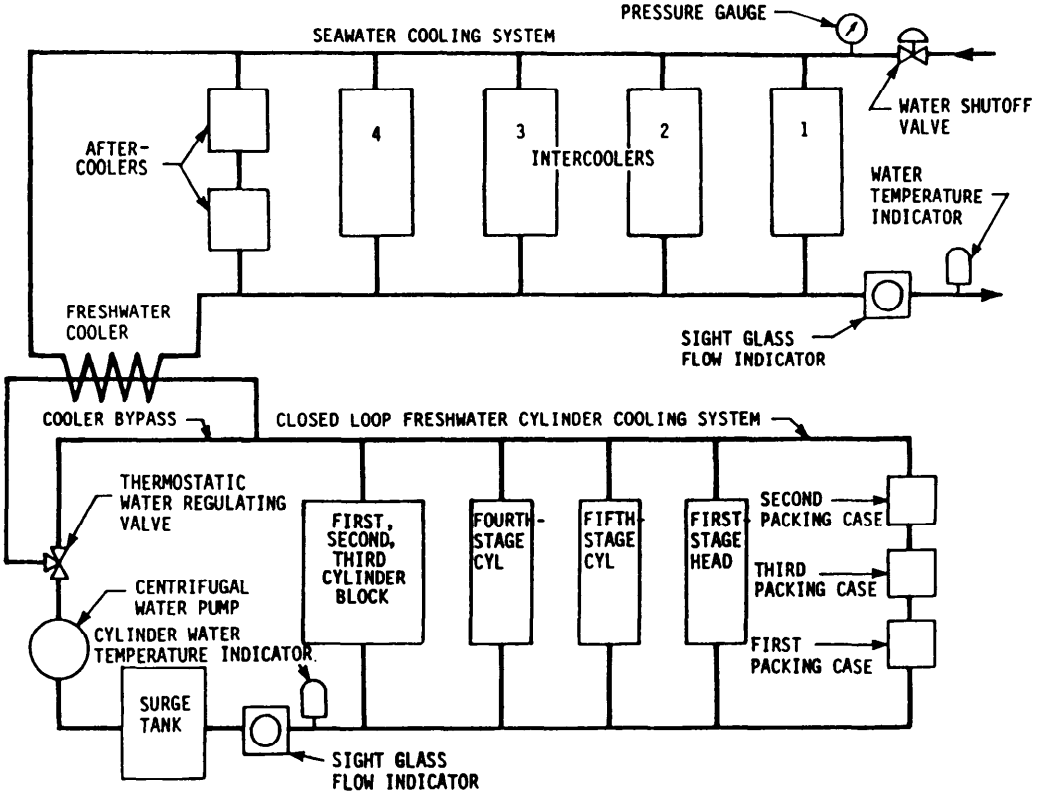


Figure 14-10.—Cooling water flow diagram showing seawater and freshwater systems.

to condense into a liquid. Figure 14-11 is a diagram of a basic cooler and separator unit. Intercoolers and aftercoolers are normally fitted with moisture separators. Moisture separators, which come in a variety of designs, serve to remove the condensed moisture and oil vapor from the airstream. The liquid is removed by centrifugal force, impact, or sudden changes in velocity of the airstream. Notice that the condensate collects in the lower section of the outlet header. Drains on each separator serve to remove the water and oil. The condensate must be drained at regular intervals to prevent carryover into the next stage of compression. When the condensate accumulates at low points, it may cause water hammer or freezing and bursting of pipes in exposed locations. It may also cause faulty operation of pneumatic tools and diesel engine air start systems, and possible damage to electrical apparatus when air is used for cleaning. The removal of heat is also necessary for efficient compression. During compression, the temperature of the air increases. As we explained earlier, heated air expands to a larger volume. The larger volume of air requires a corresponding increase of work to compress it. Multistaging, therefore, with interstage cooling of the air, reduces the power requirement for a given capacity.

Interstage cooling reduces the maximum temperature in each cylinder. This temperature reduction, of course, reduces the amount of heat that must be removed by the water jacket at the cylinder. Figure 14-12 illustrates the pressures and temperatures through a four-stage compressor. The intercoolers and the aftercoolers (on the output of the final stage) are of the same general construction. The exception is that the aftercoolers are designed to withstand a higher working pressure than that of the intercoolers. Both intercoolers and aftercoolers are generally fitted with relief valves on both the air and the water sides. The relief valves must be set according to PMS.

In all compressors fitted with thermostatically controlled freshwater cooling systems, such as the one shown in figure 14-10, the possibility of overcooling the cylinders occurs only when the thermostat is malfunctioning. The air cannot be cooled too much in the intercoolers and aftercoolers. There are no detrimental effects for low air discharge temperatures from the coolers. The more the air is cooled in the intercoolers, the lower the brake horsepower will be. When more water is condensed within the cooler, fewer chances exist for the water to condense during the subsequent compression stroke.

Oil coolers may be of the coil type, shell and tube type, or a variety of commercial designs. Although external oil coolers are generally used, some compressors are fitted with a base-type oil cooler. In this design, cooling water circulates through a coil placed in the oil sump. On most compressors, the circulating water system is arranged so that the amount of cooling water passing through the oil cooler can be regulated without disturbing the quantity of water passing through the cylinder jackets, intercoolers, or aftercoolers. Thermometers are fitted to the circulating water inlet and outlet connections, the intake

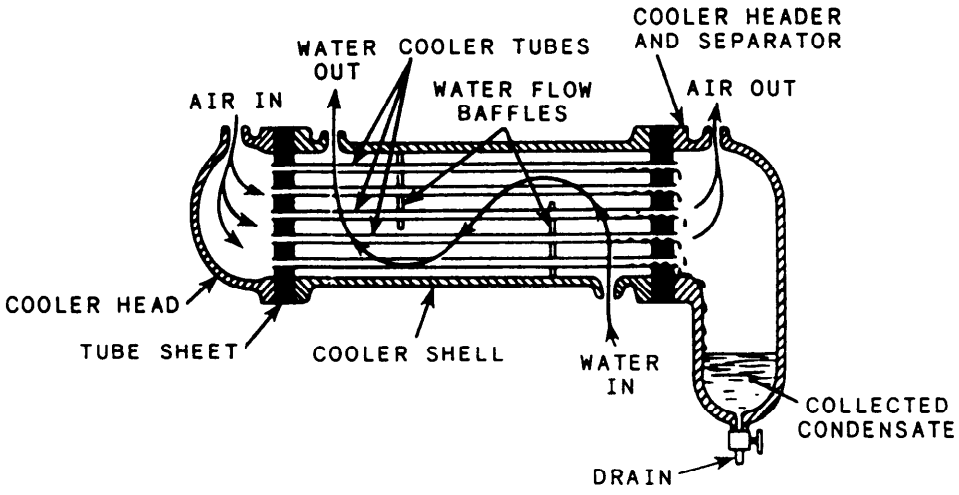


Figure 14-11.—Basic cooler and separator.

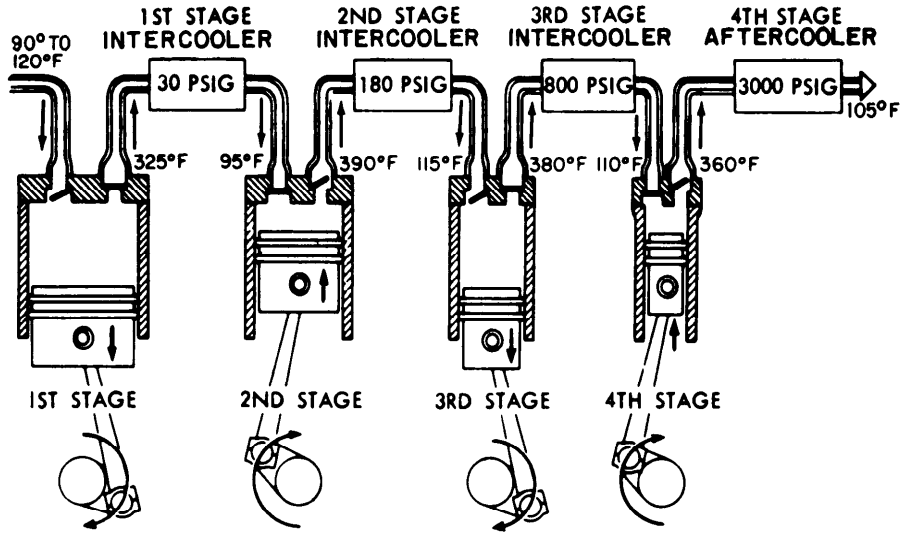


Figure 14-12.—Pressure and temperature resulting from multistaging and interstage cooling.

and discharge of each stage of compression, the final air discharge, and the oil sump.

Control Systems

The control system of a reciprocating air compressor may include one or more control devices. These control mechanisms may include start-stop control, constant-speed control, cooling water failure switches, and automatic high-temperature shutdown devices.

Control or regulating systems for air compressors in use by the Navy are largely of the start-stop type. In the start-stop design, the compressor starts and stops automatically as the receiver pressure falls or rises within predetermined set points. On electrically driven compressors, the system is very simple. As air pressure in the receiver increases, it actuates a pressure switch that opens the electrical control circuit when the pressure acting upon the switch reaches a given value, commonly called a SET POINT. The switch closes the control circuit when the pressure drops a predetermined amount. Because of their high horsepower rating, centrifugal compressors do not have automatic start-stop controls. Instead, an automatic load and unload control system is used.

Some electrically driven units, such as the medium-pressure system, are required to start at either of two pressures. In these units, there are two pressure switches. One of these switches has a three-way valve that admits pressure from the air accumulator to the selected pressure switch. In other electrically driven units, the air is directed from the receiver through a three-way valve to either of two control valves adjusted for the required range of pressure settings. A line connects each control valve to a single pressure switch. This switch may be set to any convenient pressure. The setting of the control valve selected will determine the operation of the switch.

The CONSTANT-SPEED CONTROL regulates the pressure in the air receiver by controlling the output of the compressor. This control works without stopping or changing the speed of the unit. The constant-speed control prevents frequent starting and stopping of compressors when there is a fairly constant but low demand for air. Control is provided when air is directed to unloading devices through a control valve that is set to operate at a predetermined pressure.

AUTOMATIC HIGH-TEMPERATURE SHUTDOWN DEVICES are fitted on almost all high-pressure air compressors. If the cooling water temperature rises above a safe limit, the compressor will stop and will not restart automatically. Some compressors are equipped with a device that will shut down the compressor if the temperature of the air leaving any stage exceeds a preset value.

Unloading Systems

Most of the compressors used on board ship use electric motors as prime movers. You need to understand that, at the instant of starting, an electric motor demands maximum power from the electrical distribution system. Therefore, when any motor is to be started, it is necessary to have the motor unloaded as much as possible. Any attempt to start any motor-driven pump, such as an air compressor, when it is loaded will cause the circuit breaker on the power distribution panel (and even the main breaker on a switchboard) to trip the unit off the line. Upon starting, the drive motor for a reciprocating air compressor is lightly loaded (only due to friction in bearings and piston rings against the cylinder walls) because of the unloader system of the air compressor. The unloader may use a combination of pneumatic, electropneumatic (solenoid), or hydraulic-actuated valves to control the unloading function. The unloader for an air compressor has the following two primary functions:

1. When the unit stops, the unloader releases any air trapped in the cylinders. (You should hear the unit go "PSSsshhhhh" when it shuts down.)
2. When the drive motor starts, the unloader prevents air from being compressed in any stage until the motor has reached operating speed.

Units with start-stop control devices will have an unloading system that is separate from the control system. Compressors with constant-speed control devices will have the unloading and control systems as integral parts of each other.

We cannot give you a detailed explanation for every type of unloading device that unloads the cylinders of an air compressor. Still, you should know something about the common methods used to unload an air compressor. These methods include closing or throttling the compressor intake, forcing intake valves off their seats, relieving intercoolers to the atmosphere, relieving the final discharge to the atmosphere (or opening a bypass from the discharge to the intake), or opening cylinder clearance pockets.

We will discuss one example of a typical compressor unloading device—the MAGNETIC-TYPE UNLOADER. Refer to figure 14-13 and study the unloader valve arrangement. The magnetic unloader consists of a solenoid-operated valve actuated by the controller for the motor. When the compressor is at rest, the solenoid valve is de-energized, and the two ball valves are in the position shown. Air pressure is routed from the receiver to the unloading mechanism. When the compressor drive motor reaches operating speed, the solenoid valve is energized. The two ball valves will be forced downward. The upper ball will block the inlet from the receiver and the lower ball will block the exhaust port, which allows the compressor to load and build up air pressure.

For details about the unloading devices used with the compressors aboard your ship, you should consult the specific NAVSEA technical manual for each unit.

OIL-FREE, LOW-PRESSURE AIR COMPRESSORS

The most common method of providing oil-free air aboard Navy ships is to use low- or high-pressure reciprocating oil-free air compressors. For the purpose of our discussion of the oil-free design, we will use the reciprocating low-pressure, oil-free air compressor as our example.

RECIPROCATING OIL-FREE LOW-PRESSURE AIR COMPRESSORS

For many years, the reciprocating types of air compressors had to use lubricating oil to reduce the friction and wear of piston rings sliding on the walls of the cylinders. Some of the oil, in the form of vapor, would be picked up by the airstream and carried to the outlet of the compressor. Like water vapor, oil vapor tends to collect in low places. When oil vapor mixes with water vapor, the resulting emulsion may deposit itself on machined surfaces, which generally become collecting points for dirt and particles of rust. This sludge formation can foul pneumatic valves, which must have very close clearances and operating tolerances. However, fouling of machine parts is minor compared to the potentially hazardous condition that results when oil vapor is entrained in the airstream of a high-pressure air compressor.

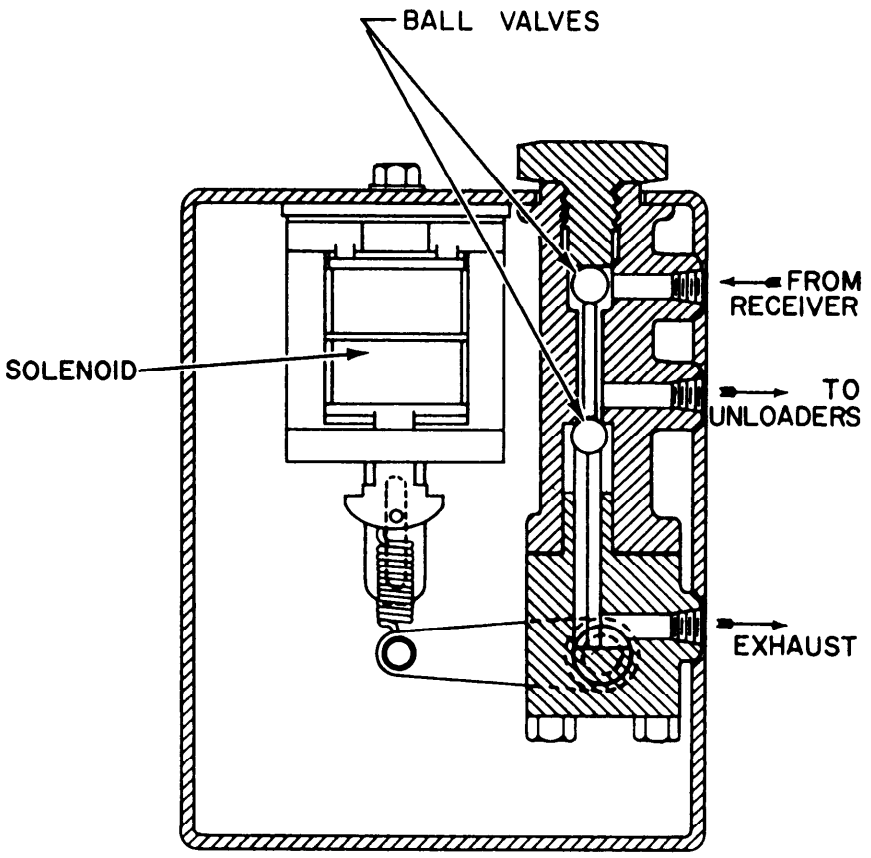


Figure 14-13.—Magnetic-type unloader.

From our earlier discussion, you should remember that air is mostly nitrogen (about 78 percent) and oxygen (about 21 percent). Nitrogen is an inert gas. When mixed with oil vapor, nitrogen is not hazardous. On the other hand, when oil vapor is mixed with oxygen in the air, two of the three elements needed for an explosion or fire have been combined. All that is needed to trigger this combination is heat. Where could the heat possibly come from? Think about it. When air is compressed, a lot of heat is produced. Now, let's consider what could happen when a careless operator quickly opens a valve in a high-pressure air system. The air and oil vapor mixture will flow rapidly into the next part of the system until it reaches the next obstruction, which will cause the air to be compressed. At this point, all three elements needed for an explosion are present—oxygen, fuel, and heat.

The danger associated with the use of lubricated air compressors has caused the Navy to replace low-pressure and high-pressure reciprocating air compressors with the oil-free type. Oil-free air compressors are designed to prevent any oil vapor from getting into the airstream in the compressor. (Navy standard oil-free compressors have not been developed for the medium-pressure range.) The design of oil-free air compressors was made possible by the development of new materials for piston rings. These materials do not require lubrication, only cooling by water. The design of the oil-free air compressor makes it possible for the compression stages to be separated from the running gear, which still uses oil for lubrication.

COMPONENTS

Oil-free reciprocating air compressors use a crosshead arrangement consisting of a guide piston and cylinder and guide piston seal assembly. The design separates the compressor

section from the running gear section and still transfers mechanical power from the lubricated crankshaft to the piston and connecting rod assemblies of the nonlubricated compressor stages. Refer to figures 14-14 and 14-15 as we continue.

The compression piston is hollow and is connected to the guide piston by the guide piston seal assembly. (Refer to fig. 14-14.) The piston rings are made from a Teflon-bronze material that will become damaged upon contact with lube oil.

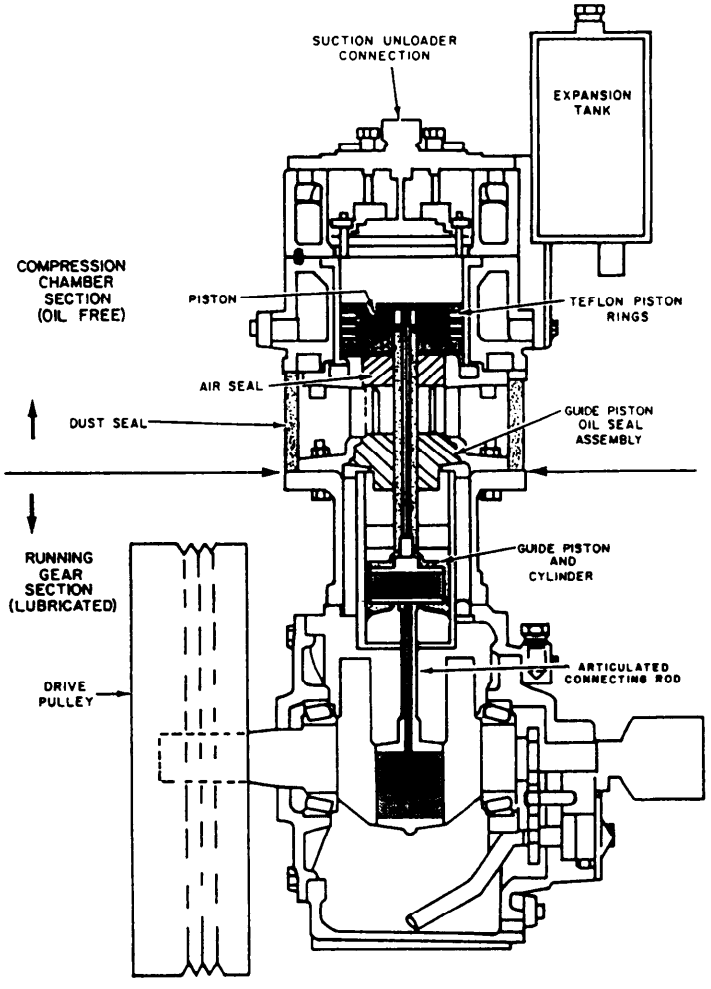
The guide piston seal assembly contains oil control rings and seal rings, retainer rings, a cup, and a cover. (See fig. 14-15.) The seal assembly prevents oil from entering the compression chamber by scraping the oil from the piston connecting rod as it moves up and down in the seal assembly.

The running gear chamber consists of a system of connecting rods, a crankshaft, and a flywheel. (NOTE: The connecting rods are connected to the guide piston in the oil-free air compressor.)

The valve assemblies are of the strip/feather type previously discussed in this chapter.

UNLOADER SYSTEM

The Worthington oil-free, low-pressure air compressor unloader system consists of three suction valve unloaders, one for each cylinder, connected to each suction valve assembly. (See figs. 14-16 and 14-17.) The major components of



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Figure 14-14.—Cutaway view of an oil-free, low-pressure air compressor.

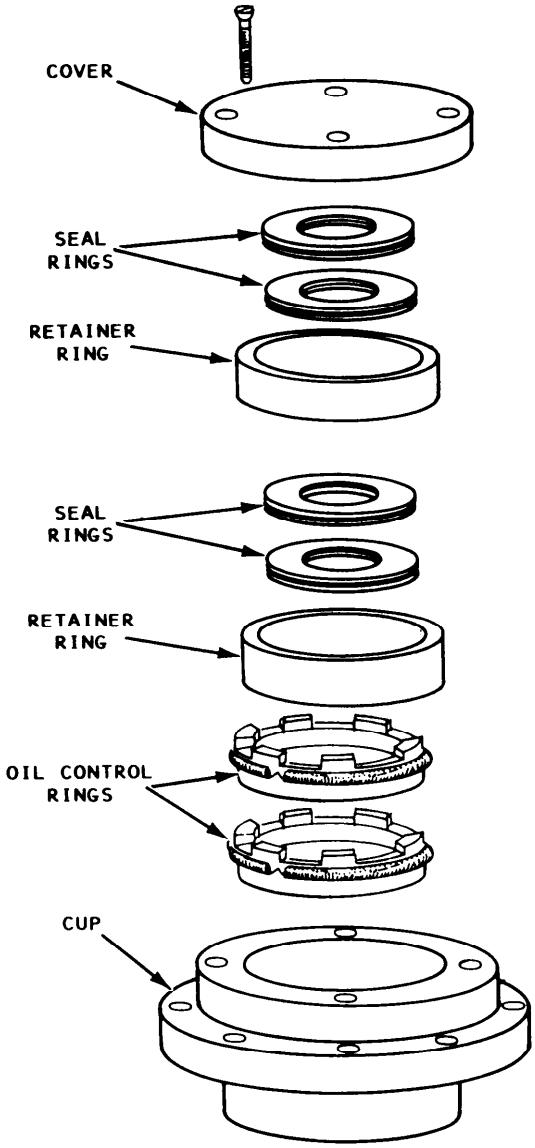


Figure 14-15.—Guide piston seal assembly.

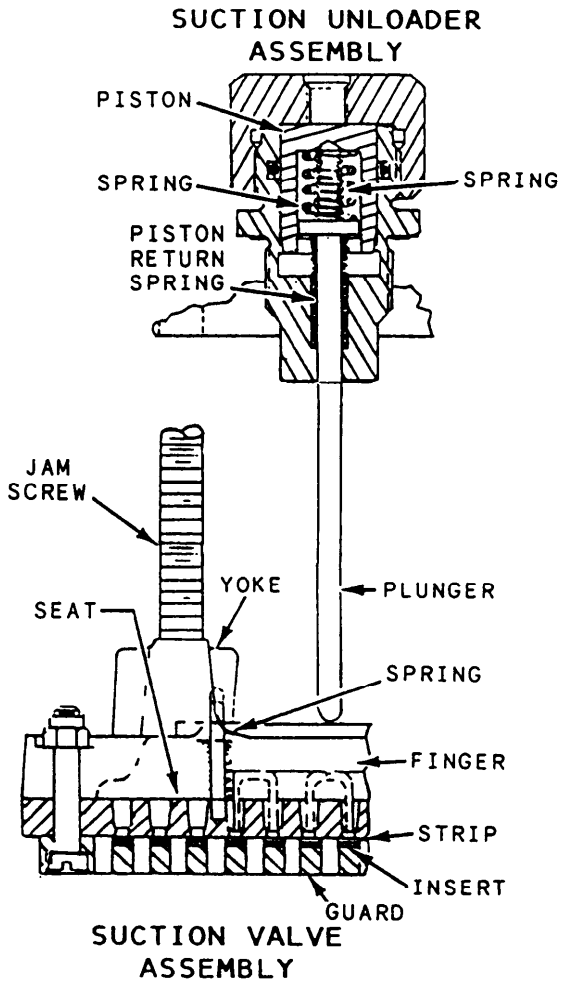


Figure 14-16.—Suction unloader and valve assembly.

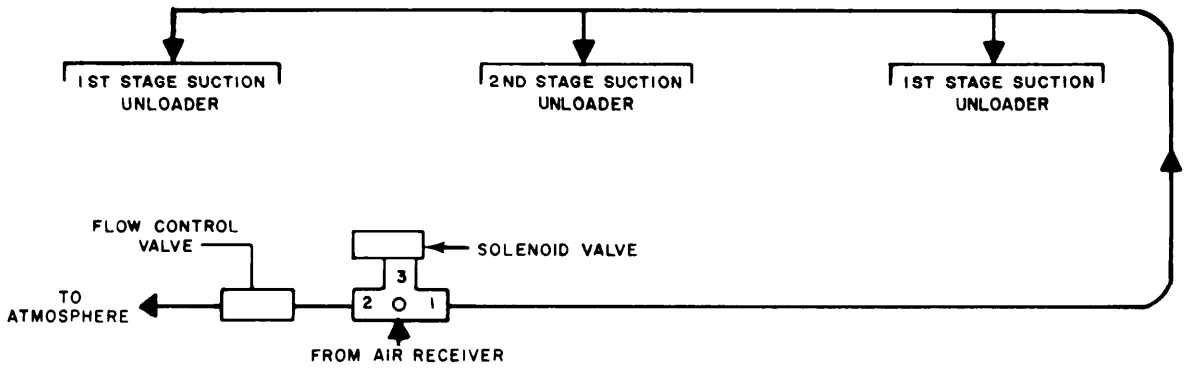


Figure 14-17.—Unloader system of an oil-free, low-pressure air compressor.

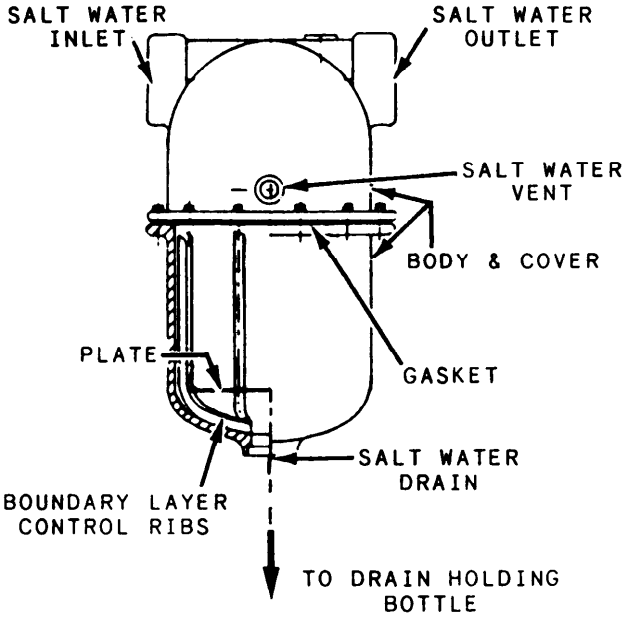


Figure 14-18.—Moisture separator.

the unloader assembly are the piston, springs, and plunger. (See fig. 14-16.) The unloader assemblies are actuated by a single solenoid-operated valve that routes the air from the receiver to the top of the piston in the suction unloader assembly. Air pressure forces the piston down, thereby forcing the finger down against the strip valves and unseating the suction valves. This action causes the air compressor to be in an unloaded condition when the drive motor starts. The compressor becomes loaded when the solenoid-operated valve bleeds the air off the top of the piston in the unloader assemblies through the flow control valve. The pistons and fingers are forced upward by the piston return spring, causing the suction valves to seat. The flow control valve prevents instant full loading of the compressor by controlling the amount of airflow from the unloader assemblies through the solenoid-operated valve.

The oil-free air compressor has a moisture separator that receives air from an air cooler. (See fig. 14-18.) The separator drains the collected

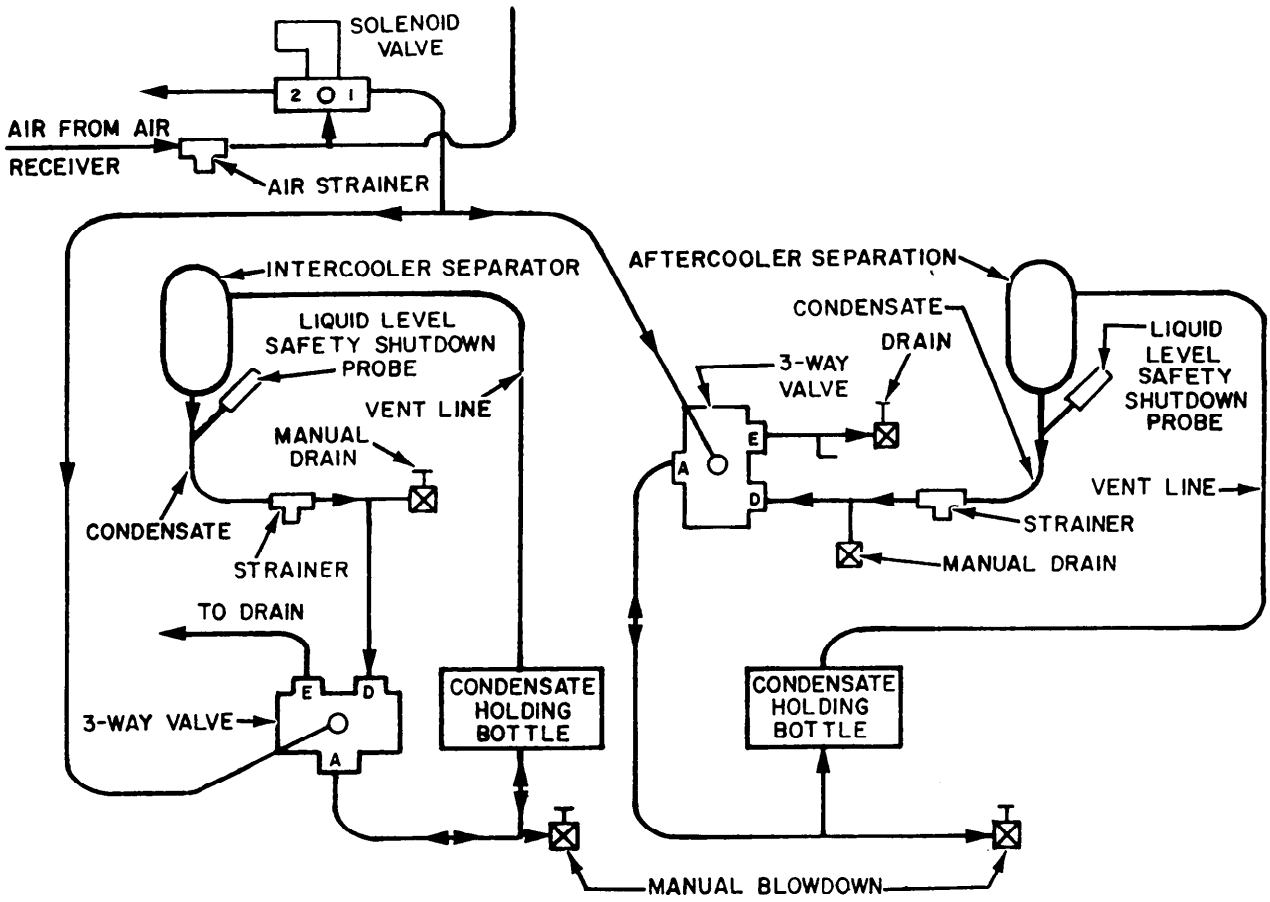


Figure 14-19.—Condensate drain system.

moisture into a drain holding bottle where the moisture is then removed by either the automatic drain system or the manual drain valves. The separator has a level probe that shuts off the air compressor in the event that the drains are backed up because of a malfunction of the automatic drain system.

The automatic drain system uses a solenoid-operated valve and a three-way air-operated valve. (See fig. 14-19.) The solenoid-operated valve is energized by a time relay device in the motor controller. The solenoid-operated valve admits air to the three-way air-operated valve, which allows for drainage of the moisture separator and the holding bottle.

Helical Screw Compressor

A relatively new design of oil-free air compressor is being installed aboard some of our newer ships, such as the FFG-7 class and CG-47 class ships. This low-pressure air compressor is a single-stage, positive-displacement, axial-flow, helical-screw type of compressor. It is often referred to as a screw-type compressor. (Refer to figs. 14-20 and 14-21.) Compression is caused by the meshing of two helical rotors (male and female) located on parallel shafts and enclosed in a casing. Air inlet and outlet ports are located on opposite sides of the casing. Atmospheric air is drawn into the compressor through the filter-silencer. The air passes through the air cylinder-operated unloader (butterfly) valve and into the inlet part of the compressor when the valve is in the open (load) position. Fresh water is injected into the airstream as it passes through the inlet port of the compressor casing.

The injected fresh water serves two purposes: (1) it reduces the air discharge temperature caused by compression, and (2) it seals the running clearances to minimize air leakage. Most of the injected water is entrained into the airstream as it moves through the compressor.

The compression cycle starts as the rotors unmesh at the inlet port. As rotation continues, air is drawn into the cavity between the male rotor lobes and into the grooves of the female rotor. The air is trapped in these grooves, or pockets, and follows the rotative direction of each rotor. As soon as the inlet port is closed, the compression cycle begins as the air is directed to the opposite (discharge) end of the compressor. The rotors mesh, and the normal free volume is

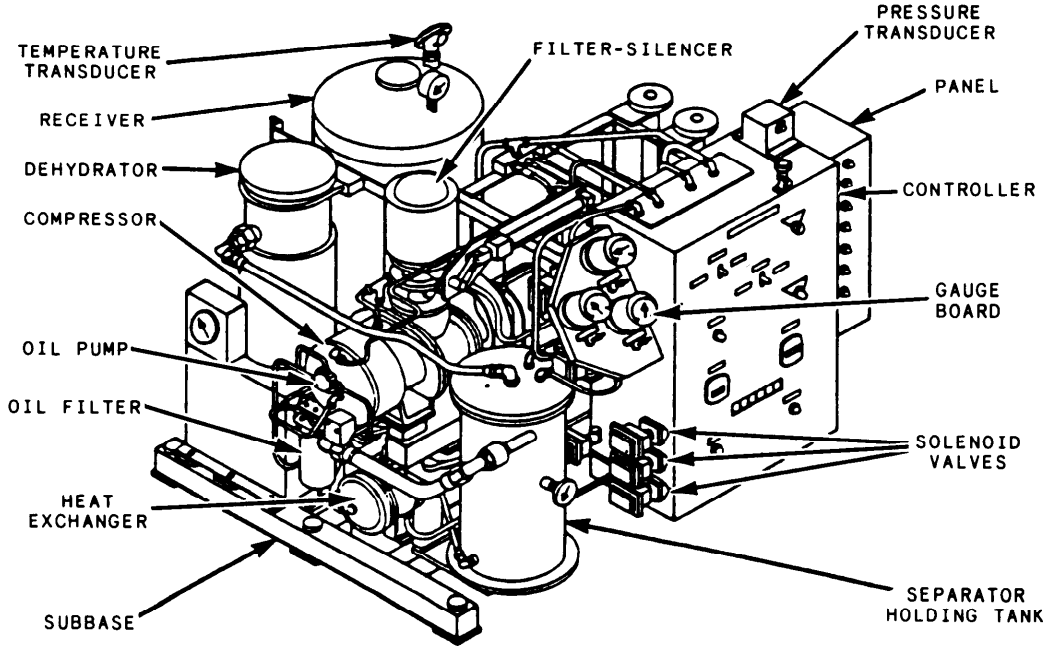


Figure 14-20.—Low pressure, oil-free rotary helical screw compressor.

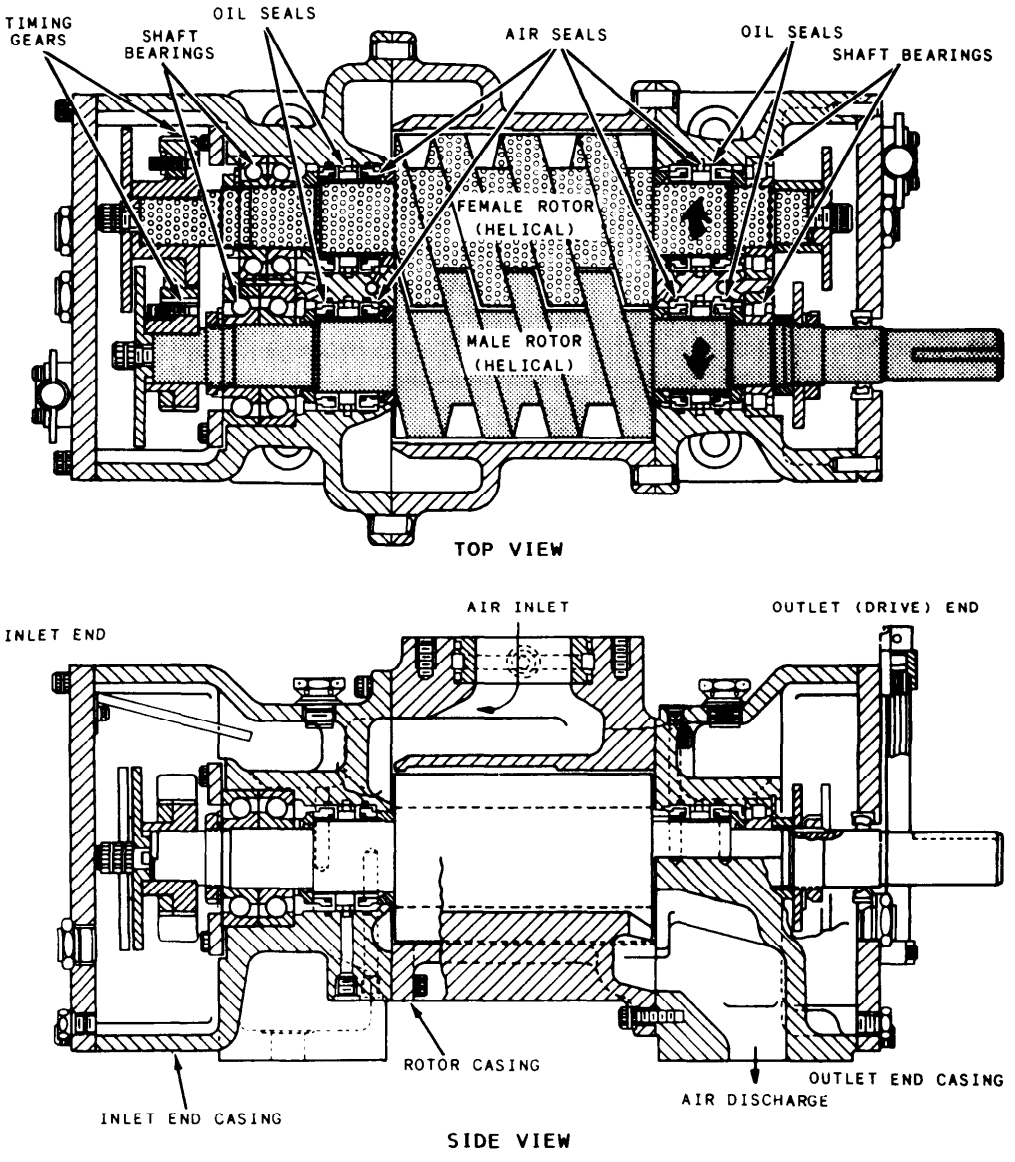


Figure 14-21.—Helical screw compressor.

reduced. The reduction in volume (compression) continues with a resulting increase in pressure, until the closing pocket reaches the discharge port.

The entrained water is removed from the discharged air by a combined separator and water holding tank. The water in the tank passes through a seawater-cooled heat exchanger. The cooled water then recirculates to the compressor for reinjection.

During rotation and throughout the meshing cycle, the timing gears maintain the correct clearances between the rotors. Since there is no contact between the rotor lobes and grooves, between the rotor lobes and casing, or between the rotor faces and end walls, no internal oil lubrication is required. This design allows the compressor to discharge oil-free air.

For gear and bearing lubrication, lubricating oil from a force-feed system is supplied to each end of the compressor. Mechanical seals serve to keep the oil isolated from the compression chamber.

Centrifugal Compressors

The newer large ships, such as aircraft carriers, require large amounts of oil-free, low-pressure

compressed air. Centrifugal ship's service air compressors were introduced into the fleet to meet this demand. These compressors are driven by 350-horsepower, constant-speed electric motors, and have a typical output capacity of 1,250 cubic feet of air per minute at a pressure of 125 psi.

The basic operating principles of the centrifugal air compressor are similar to those of a multistage centrifugal water pump, in that pressure of the air is increased as the air passes from one stage impeller to the next.

Air enters the compressor through a filter-silencer, where it undergoes an initial pressure drop. The air then flows through an inlet nozzle to the first-stage impeller. After the pressure is raised, the air leaves the first-stage compressor and passes through an intercooler on its way to the second-stage compressor. The function of this intercooler is similar to that of the intercooler between the second- and third-stage compressors. This intercooler lowers the temperature of the air, increasing its density before it passes from stage to stage. Increasing the density of air requires fewer compression stages to raise the pressure of the air to the desired pressure of 125 psi. The compressed air passes through the second and third compression stages in a similar manner. After the compressed air leaves the third-stage compressor, it passes through a shell and tube type of aftercooler that uses seawater as the cooling medium. The air then usually passes through an additional aftercooler that uses chilled fresh water from the ship's air conditioning chilled water system. In this aftercooler, the air cools to 60°F. The cooling action condenses the moisture from the hot compressed air and allows cool, dry air to be supplied to the low-pressure air distribution system.

Mechanically, centrifugal air compressors have a unique design feature not available in the other compressors we have discussed. Each compression stage impeller is driven by its own shaft through a bull gear and pinion system. Therefore, the impellers, acting together as a compressor, provide the required outlet air pressure. Typical shaft speeds for a three-stage centrifugal compressor are 32,088 rpm for the first stage; 43,854 rpm for the second stage; and 52,624 rpm for the third stage. For additional information on centrifugal air compressors, refer to the *Naval Ships' Technical Manual,* chapter 551.

COMPRESSED AIR RECEIVERS

An air receiver is installed in each space that houses air compressors (except centrifugal and rotary lobe types of air compressors). A COMPRESSED AIR RECEIVER is an air storage tank. If demand is greater than the compressor capacity, some of the stored air is supplied to the system. If demand is less than the compressor capacity, the excess is stored in the receiver or accumulator until the pressure is raised to its maximum setting. At that time, the compressor unloads or stops. Thus, in a compressed air system, the receiver minimizes pressure variations in the system and supplies air during peak demand. This capability serves to minimize the start-stop cycling of air compressors.

Air receivers may be mounted horizontally or vertically. Vertically mounted receivers have convex bottoms that permit proper draining of accumulated moisture, oil, and foreign matter. All receivers have fittings, such as inlet and outlet connections and drain connections and valves. They have connections for an operating line to compressor regulators, pressure gauges, and relief valves (set at approximately 12 percent above the normal working pressure of the receiver). They also have manhole plates (depending on the size of the receiver). The discharge line between the compressor and the receiver is as short and straight as possible. This design eliminates vibrations caused by pulsations of air and reduces pressure losses caused by friction.

In high-pressure air systems, air receivers are called AIR FLASKS. Air flasks are usually cylindrical in shape, with belled ends and female-threaded necks. The flasks are constructed in shapes that will conform to the hull curvature for installation between hull frames. One or more air flasks connected together constitute an AIR BANK.

COMPRESSED AIR SUPPLY SYSTEMS

The remainder of the compressed air system is the piping and valves that distribute the compressed air to the points of use.

HIGH-PRESSURE AIR

Refer to figure 14-22. View A shows the first part of a high-pressure air system aboard a surface ship. The 3,000/150-psi reducing station is used for emergencies or abnormal situations to provide air to the low-pressure air system.

LOW-PRESSURE AIR

Low-pressure air (sometimes referred to as LP ship's service air) is the most widely used air system aboard the ship. View B of figure 14-22 shows the first part of a low-pressure air system. Many of the low-pressure air systems are divided into subsystems, referred to as VITAL and NON-VITAL air.

Vital air is used primarily for engineering purposes, such as automatic boiler controls, water level controls, and air pilot-operated control valves. Vital air is also supplied to electronics systems. Vital air systems are split between all main machinery groups with cross-connect capability.

Nonvital air has many different purposes, such as laundry equipment, tank-level indicating systems, and air hose connections. Air for a nonvital air system is supplied through a PRIORITY VALVE. This valve will shut automatically to secure air to nonvital components when the pressure in the air system drops to a specified set point. It will reopen to restore non-vital air when pressure in the system returns to normal This system gives the vital air first priority on all the air in the low-pressure system.

PRAIRIE-MASKER AIR SYSTEMS

A special-purpose air system installed in many surface ships is the prairie-masker air system. This two-part system supplies a high volume of low-pressure air to a system of emitter rings or belts surrounding the hull and to the propeller blades through the hollow propulsion shafts.

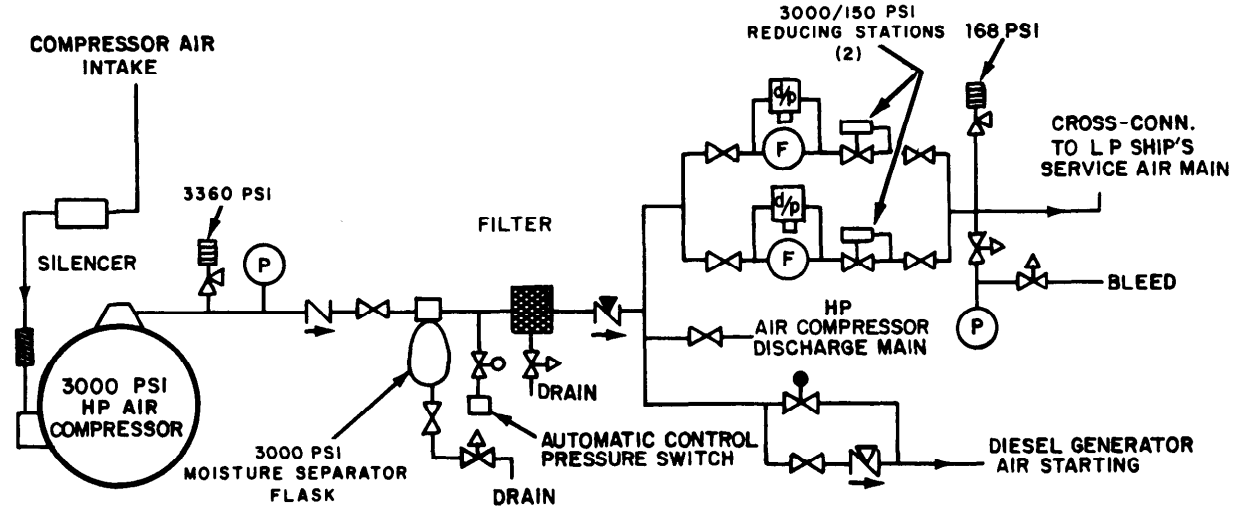
The EMITTER RINGS, often referred to as MASKER BELTS, contain small holes which release the masker air into the sea, coating the hull with air bubbles. The bubbles disguise the shape of the ship so that it cannot be seen accurately by enemy sonar. The prairie air passing through the propulsion shafts is emitted to sea by small holes in the propeller blades.

The air supply for the prairie-masker system is provided by a turbocompressor. On ships with steam propulsion plants, the turbocompressor is composed of five major parts contained in one compact unit. They are the turbine-driven compressor, lube water tanks, air inlet silencer, lube water system, and control system.

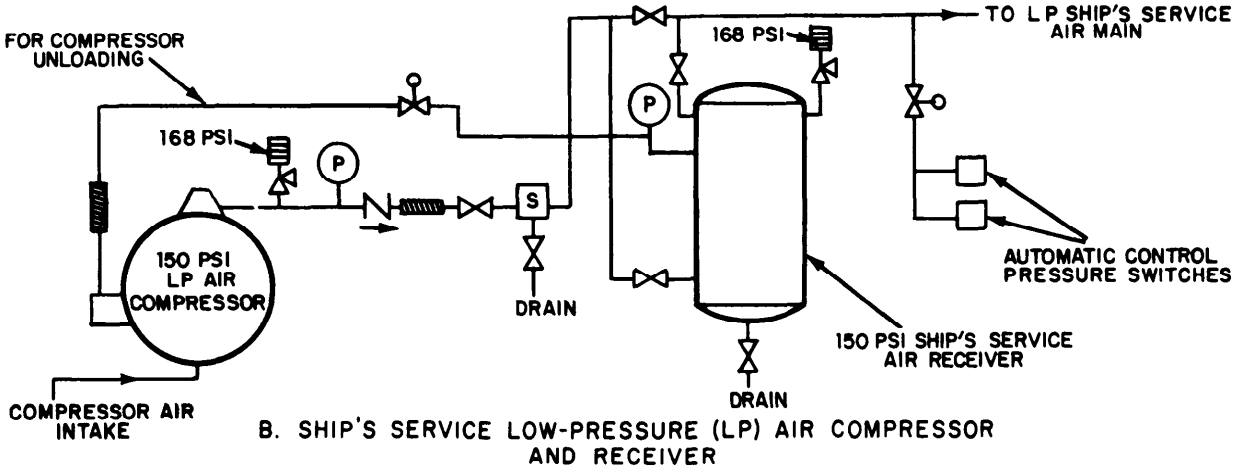
The turbine-driven compressor consists of a single-stage centrifugal compressor driven by a single-stage impulse turbine. The compressor impeller and the turbine wheel are mounted at opposite ends of the same shaft. Two water-lubricated bearings support the rotor assembly. The compressor runs at speeds approaching 40,000 rpm. A control system for the unit provides constant steam admission, overspeed trip, overspeed alarm, low lube pressure trip and alarm, and a high lube water temperature alarm. On ships with gas turbine propulsion plants, air from the prairie-masker system is taken from the bleed air system of an on-line gas turbine.

MOISTURE REMOVAL

The removal of moisture from compressed air is an important feature of compressed air systems. Some moisture is removed by the intercoolers and aftercoolers, as explained earlier in this chapter. Air flasks and receivers are provided with low point drains so that any collected moisture may drain periodically. However, many shipboard uses for compressed air require air with an even smaller moisture content than is obtained through these methods. Water vapor in air lines can create other problems which are potentially hazardous, such as the freezing of valves and controls. These conditions can occur when air at very high pressure is throttled to a low pressure area at a high flow rate. The venturi effect of the throttled air produces very low temperatures, which will cause any moisture in the air to freeze into ice. Under these conditions, a valve (especially an automatic valve) may become very difficult or impossible to operate. Also, liquid water in any air system can cause serious water hammer within the system. For these reasons, air dryers or dehydrators are used to remove most of the water vapor from compressed air.



A. HIGH-PRESSURE (HP) AIR COMPRESSOR AND CROSS CONNECTION REDUCING STATION



B. SHIP'S SERVICE LOW-PRESSURE (LP) AIR COMPRESSOR AND RECEIVER

LEGEND		
PRESSURE REDUCING VALVE	GLOBE VALVE	DIFFERENTIAL PRESSURE INDICATOR
PRESSURE SWITCH	NEEDLE VALVE	LP AIR PURIFIER
GLOBE VALVE LOCKED SHUT	SWING CHECK VALVE	FILTER
GLOBE VALVE LOCKED OPEN	LIFT CHECK VALVE	ANGLE RELIEF VALVE
PRESSURE GAGE	FLEXIBLE CONNECTOR	

Figure 14-22.—High-pressure and low-pressure air systems.

The Navy uses two basic types of air dryers and a combination of the two. These air dryers are classified as follows:

Type I—Refrigeration

Type II—Heater, self-activating desiccant

Type III—Refrigeration, self-reactivating desiccant

Each of these types is designed to meet the requirements specified for the quality of the compressed air to be used in pneumatic control systems or for clean, dry air used for shipboard electronic systems. Specific requirements usually involve operating pressure, flow rate, dew point, and purity (percentage of aerosols and size of particles). We will briefly discuss each of the types of air dryers (dehydrators).

Refrigeration Type of Air Dehydrator (Type I)

Refrigeration is one method of removing moisture from compressed air. The dehydrator

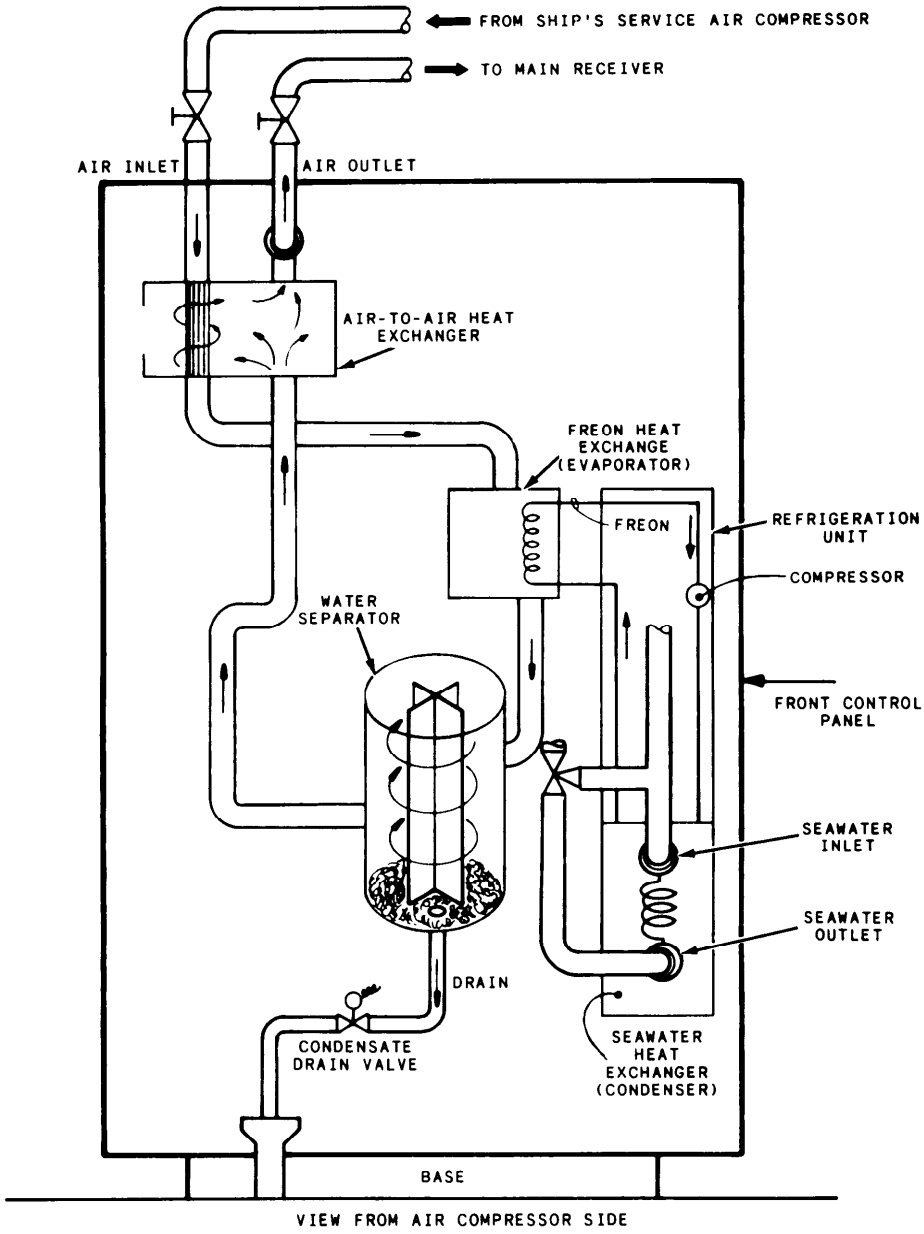


Figure 14-23.—Refrigeration dehydrator.

in figure 14-23 is a REFRIGERATED AIR DRYER or REFRIGERATION DEHYDRATOR. This unit removes water vapor entrained in the stream of compressed air by causing the water to condense into a liquid that is heavier than air. Air flowing from the separator/holding tank first passes through the air-to-air heat exchanger, where some of the heat of compression is removed from the airstream. The air then moves through the evaporator section of the dehydrator, where the air is chilled by circulating refrigerant. In this unit, the airstream is cooled to a temperature that is below the dew point. This will cause the water vapor in the air to condense so it can be removed by the condensate drain system. After leaving the evaporator section, the dehydrated air moves upward through the cold air side of the air-to-air heat exchanger. In the air-to-air heat exchanger, the dehydrated air is raised in temperature by the warm air entering the dehydrator. The heating of the air serves to reduce thermal shock as the air enters the system. The exiting dry air flows into the receiver for availability to the ship's air system.

Desiccant Type of Air Dehydrator (Type II)

A desiccant is a drying agent. More practically, a desiccant is a substance with a high capacity to remove (adsorb) water or moisture. It also has a high capacity to give off that moisture so that the desiccant can be reused. DESICCANT-TYPE DEHYDRATORS are basically composed of cylindrical flasks filled with desiccant.

Compressed air system dehydrators use a pair of desiccant towers. One tower is in service dehydrating the compressed air while the other is being reactivated. A desiccant tower is normally reactivated when dry, heated air is routed through the tower in the direction opposite to that of the normal dehydration airflow. The hot air evaporates the collected moisture and carries it out of the tower to the atmosphere. The air for the purge cycle is heated by electrical heaters. When the tower that is reactivating has completed the reactivation cycle, it is placed in service to dehydrate air, and the other tower is reactivated.

Another type of desiccant dehydrator in use is the Heat-Less dryer. These units require no electrical heaters or external sources of purge air. Figure 14-24 shows the compressed air entering at the bottom of the left tower (view A). The compressed air then passes upward through the desiccant, where it is dried to a very low moisture content. The dry air passes through the check valve to the dry air outlet. Simultaneously, a small percentage of the dry air passes through the orifice between the towers and flows down through the right tower. This dry air reactivates the desiccant

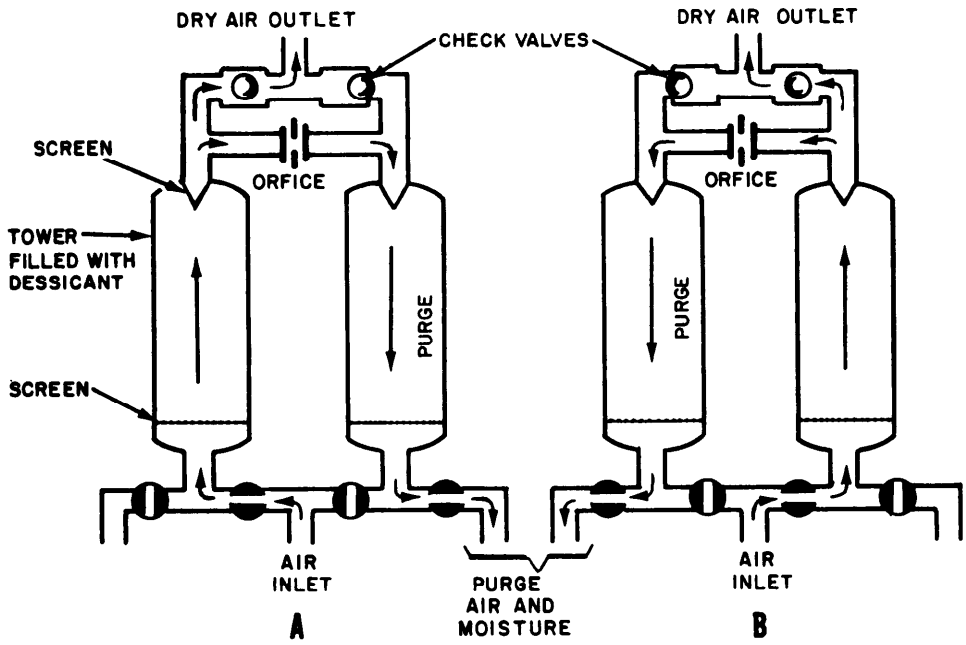


Figure 14-24.—Heat-Less desiccant dehydrator.

and passes out through the purge exhaust. At the end of the cycle, the towers are automatically reversed, as shown in view B.

Refrigeration and Desiccant Type of Air Dehydrator (Type III)

Some installations may use a combination of refrigeration and absorption for moisture removal. Hot wet air from the compressor first enters a refrigeration-type dehydrator where low-temperature R-12 removes heat from the airstream and condenses water vapor from the air. The cold, partially-dried air then flows into a desiccant-type dehydrator, where the desiccant absorbs additional moisture from the air.

COMPRESSED AIR PLANT OPERATION AND MAINTENANCE

As an Engineman, you must be thoroughly aware of the operational and safety procedures you must use when you are operating or maintaining a compressed air system. You must operate any air compressor or air system in strict compliance with approved operating procedures. Compressed air is potentially very dangerous. Keep in mind that cleanliness is of greatest importance in all maintenance that requires the opening of compressed air systems.

SAFETY PRECAUTIONS

There are many hazards associated with pressurized air, particularly air under high pressure. Dangerous explosions have occurred in high-pressure air systems because of DIESEL EFFECT. If a portion of an unpressurized system or component is suddenly and rapidly pressurized with high-pressure air, a large amount of heat is produced. If the heat is excessive, the air may reach the ignition temperature of the impurities present in the air and piping (oil, dust, and so forth). When the ignition temperature is reached, a violent explosion will occur as these impurities ignite. Ignition temperatures may also result from other causes. Some are rapid pressurization of a low-pressure dead end portion of the piping system, malfunctioning of compressor after-coolers, and leaky or dirty valves. Use every precaution to have only clean, dry air at the compressor inlet.

Air compressor accidents have also been caused by improper maintenance procedures. These accidents can happen when you disconnect parts under pressure, replace parts with units designed for lower pressures, and install stop valves or check valves in improper locations. Improper operating procedures have resulted in air compressor accidents with serious injury to personnel and damage to equipment.

You must take every possible step to minimize the hazards inherent in the process of compression and in the use of compressed air. Strictly follow all safety precautions outlined in the NAVSEA technical manuals and in the *Naval Ships' Technical Manual*, chapter 551. Some of these hazards and precautions are as follows:

1. Explosions can be caused by dust-laden air or by oil vapor in the compressor or receiver. These explosions are triggered by abnormally high temperatures, which may be caused by leaky or dirty valves, excessive pressurization rates, and faulty cooling systems.
2. NEVER use distillate fuel or gasoline as a degreaser to clean compressor intake filters, cylinders, or air passages. These oils vaporize easily and will form a highly explosive mixture with the air under compression.
3. Secure a compressor immediately if you observe that the temperature of the air being discharged from any stage exceeds the maximum temperature specified.
4. NEVER leave the compressor station after starting the compressor unless you are sure that the control, unloading, and governing devices are operating properly.
5. If the compressor is to remain idle for any length of time or is in an exposed position in freezing weather, thoroughly drain the compressor circulating water system.
6. Before working on a compressor, be sure the compressor is secured and cannot start automatically or accidentally. Completely blow down the compressor, and then secure all valves (including the control or unloading valves) between the compressor and the receiver. Follow the appropriate tag-out procedures for the compressor control valves and the isolation valves. When the gauges are in place, leave the pressure gauge cutout valves open at all times.
7. When cutting air into the whistle, the siren, or a piece of machinery, be sure the supply line to the equipment has been properly drained of moisture. When securing the supply of air to the

affected equipment, be sure all drains are left open.

8. Before disconnecting any part of an air system, be sure the part is not under pressure. Always leave the pressure gauge cutout valves open to the sections to which they are attached.

9. Avoid rapid operation of manual valves. The heat of compression caused by a sudden flow of high pressure into an empty line or vessel can cause an explosion if oil or other impurities are present. Slowly crack open the valves until flow is noted, and keep the valves in this position until pressure on both sides has equalized. Keep the rate of pressure rise under 200 psi per second.

SUMMARY

In this chapter, we have covered the various types of air compressors you will be required to operate. We have discussed how the air is compressed and the requirements and methods of producing oil-free air as well as how moisture is removed from the compressed air. We have also discussed some of the safety precautions you must use whenever you are operating or working on a compressed air plant or system. If you are unclear as to any of this information, go back and review this chapter before proceeding to chapter 15.

CHAPTER 15

DISTILLING PLANTS

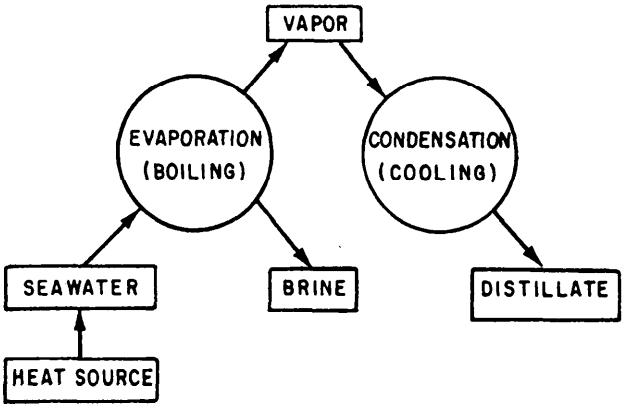
Fresh water is needed aboard ship for boiler/steam generator feed, drinking, cooking, bathing, washing, and cleaning. Therefore, a naval ship must be self-sufficient in producing fresh water. Space limitations permit only enough storage tank capacity for a couple of days' supply. The ship, therefore, depends on distilling plants to produce fresh water of high purity from seawater. As an EN3, you will be required to operate and to maintain various types of distilling plants.

PRINCIPLES OF DISTILLATION

The principle by which distilling plants produce fresh water from seawater is quite simple. There are several different types of distilling plants. Each may appear very complicated at first, but they all work on the same basic principles. When water is boiled, it gives off steam vapor that is relatively free of sea salts and minerals. The distillation process heats seawater to the boiling point and condenses the vapor (steam) into fresh water. This leaves behind the impurities of the seawater. The process for a shipboard plant is illustrated very simply in figure 15-1. Notice that the seawater after boiling is identified as brine.

Seawater is a solution of water and various minerals and salts. Seawater also contains suspended matter, such as marine vegetable growths, tiny marine animals, bacteria, and other microorganisms. When properly operated, naval distilling plants produce fresh water that contains only slight traces of chemical salts and no biological contaminants (bacteria that is harmful to humans).

Distilling plants are not effective, however, in removing volatile gases or liquids that have a lower boiling point than water. These dissolved gases and liquids will simply boil into the vapor and be combined with the fresh water (distillate).



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Figure 15-1.—Simplified diagram of the shipboard distillation process.

COMMON TERMS

Before getting into the discussion of the process of distillation, you should familiarize yourself with the terms defined in the following paragraphs. These terms apply basically to all types of distilling plants now in naval service.

DISTILLATION—The process of boiling seawater and then cooling and condensing the resulting vapor to produce fresh water.

EVAPORATION—The process of boiling seawater to separate it into freshwater vapor and brine. Note that evaporation is the first half of the process of distillation.

CONDENSATION—The process of cooling the freshwater vapor produced by evaporation to produce usable fresh water. Note that condensation is the second half of the process of distillation.

FEED—Seawater, which is the raw material of the distilling unit; also called SEAWATER FEED or EVAPORATOR FEED. Be careful how you use these terms. Do not confuse the feed (water) for the distilling plants with the feed

(water) for the boilers. Feed for a distilling plant is nothing but raw seawater. Feed for the boilers or steam generators is distilled water of very high purity.

VAPOR—The product of the evaporation of seawater feed.

DISTILLATE—The product (also called fresh water) that results from the condensation of the steam (vapor) produced by the evaporation of seawater.

POTABLE WATER—Water that is safe for human consumption. Potable water is fresh water (distillate) that has been treated with a chemical disinfectant to kill harmful bacteria while the water is in the storage tanks.

BRINE—As seawater feed is evaporated in the distilling plant, the concentration of chemical salts in the remaining seawater feed becomes greater. Any water in which the concentration of chemical salts is higher than it is in seawater is called brine.

SALINITY—The concentration of chemical salts in water is called salinity, which increases the ability of water to conduct electrical current. This conductivity is measured by electrical devices, called salinity cells; salinity is indicated in units of either epm (equivalents per million), ppm (parts per million), or micromhos/cm.

EFFECT—In a distilling plant, an effect is that part of a unit where a distillation process occurs. For example, the first place where boiling (or evaporation) of feed into vapor occurs is in the first effect. Distilling plants may be of the single effect design or the multiple effect types (two, three, four, or five effects). This means that the feed is boiled more than once within the plant. An effect may also be referred to as a STAGE.

SATURATED STEAM—Water in a gaseous state that is in contact with the liquid from which it was boiled at a given pressure and temperature. The properties of saturated steam are defined in table 15-1 according to pressure and temperature.

SUPERHEATED STEAM—Vapor that is not adjacent or next to its liquid source and that has been heated to a temperature above its saturation temperature.

DEGREE OF SUPERHEAT—The temperature difference of a superheated vapor between its saturation temperature and its existing temperature for a given value of pressure.

Let's take an example where the steam pressure at the outlet of an orifice in the auxiliary exhaust steam piping system is 16 in.Hg and the temperature of the steam is 240°F (116°C). Table 15-1 gives the properties of saturated steam. Look in the column labeled Vacuum Inches of Hg Gauge and find 16.69 and 15.67. By interpolation (estimation), we find the saturation temperature (at the right) to be 176°F (80°C). However, the auxiliary exhaust steam is approximately 240°F (116°C). In this case, then, there is about 64°F (36°C) of superheat in the incoming steam (240°F – 176°F = 64°F).

TYPES OF DISTILLING PLANTS

Distilling plants installed in naval ships are of three general types: (1) vapor compression, (2) low-pressure steam, and (3) heat recovery. The major differences between the three types are the kinds of energy used to operate the units and the pressure under which distillation takes place. (NOTE: Another process of producing potable water from seawater is being installed on several naval ships. The reverse osmosis (RO) unit uses a completely different operating principle that does not require the heating of seawater. In the RO unit, reciprocating pumps force the seawater at high pressure against a membrane, where the liquid is permitted to pass but the salts are pumped back to the sea as brine. At the present time, RO units are not capable of producing water of a purity that is safe to use in boilers without additional processing. The information contained in this chapter is general in nature; for specific information for your ship's RO units, refer to your ship's technical manual.)

VAPOR COMPRESSION UNITS use electrical energy for heaters (the heat source) and a compressor. In addition, vapor compression units boil the feedwater at a pressure that is slightly above atmospheric pressure. Although used on submarines, the vapor compression type of distilling plant has all but been replaced on surface craft by the heat recovery distilling units. For this reason, vapor compression distilling units will not be covered in this manual. Chapter 9580, section II (53 1) of the *Naval Ships' Technical Manual* contains information on these plants.

LOW-PRESSURE STEAM UNITS use lowpressure steam from either the auxiliary exhaust systems or the auxiliary steam system. Lowpressure steam distilling units are so called for two reasons. First, they use low-pressure steam as the heat source. Second, their operating shell pressure is less than atmospheric pressure (vacuum).

HEAT RECOVERY DISTILLING UNITS use low-pressure hot water from the diesel jacket-water system as a heat source. Heat recovery units

Table 15-1.—Properties of Saturated Steam

Absolute Pressure			Temperature	
Lb. per Sq. In.	Inches of Hg	Vacuum Inches of Hg Gauge	°C	°F
0.20	0.41	29.51	11.74	53.14
0.25	0.51	29.41	15.17	59.30
0.30	0.61	29.31	18.04	64.47
0.35	0.71	29.21	20.52	68.93
0.40	0.81	29.11	22.70	72.86
0.45	0.92	29.00	24.66	76.38
0.50	1.02	28.90	26.43	79.58
0.60	1.22	28.70	29.56	85.21
0.70	1.43	28.49	32.27	90.08
0.80	1.63	28.29	34.66	94.38
0.90	1.83	28.09	36.80	98.24
1.0	2.04	27.88	38.74	101.74
1.2	2.44	27.48	42.18	107.92
1.4	2.85	27.06	45.14	113.26
1.6	3.26	26.66	47.77	117.99
1.8	3.66	26.26	50.13	122.23
2.0	4.07	25.85	52.27	126.08
2.2	4.48	25.44	54.23	129.62
2.4	4.89	25.03	56.05	132.89
2.6	5.29	24.63	57.74	135.94
2.8	5.70	24.22	59.33	138.79
3.0	6.11	23.81	60.82	141.48
3.5	7.13	22.79	64.21	147.57
4.0	8.14	21.78	67.21	152.97
4.5	9.16	20.76	69.91	157.83
5.0	10.18	19.74	72.36	162.24
5.5	11.20	18.72	74.61	166.30
6.0	12.22	17.70	76.70	170.06
6.5	13.23	16.69	78.64	173.56
7.0	14.25	15.67	80.47	176.85
7.5	15.27	14.65	80.52	176.94
8.0	16.29	13.63	83.81	182.86
8.5	17.31	12.61	85.36	185.64
9.0	18.32	11.60	86.82	188.28
9.5	19.34	10.58	88.22	190.80
10.0	20.36	9.56	89.57	193.21
11.0	22.40	7.52	92.08	197.75
12.0	24.43	5.49	94.42	201.96
13.0	26.47	3.45	96.60	205.88
14.0	28.50	1.42	98.64	209.56

are also of the low-pressure design in that they also operate with a relatively high vacuum like the low-pressure steam distilling plants.

There are two reasons why naval distilling plants are designed to operate at low pressures and low boiling temperatures. One is that low temperature operation helps to prevent the formation of harmful scale on heat transfer surfaces. Scale is formed when sea salts precipitate out of seawater at high temperatures. The other reason is that heated seawater will flash into steam when the pressure is lower than the saturation pressure corresponding to the temperature.

HEAT RECOVERY DISTILLING PLANTS

Heat recovery units are used in some vessels with propulsion diesel engines or auxiliary diesel engines. Two variations of the recovery type are used; both use the heat from one or more engines as a source of heat to evaporate seawater. Supplemental water heaters may also be used to provide an additional heat source as needed.

In one model of a heat recovery plant, the heat of the diesel engine jacket water is transferred to the seawater in a feedwater heat exchanger. When it enters the distilling plant, the heated seawater "flashes" into steam, hence the name flash-type distilling unit. In another design, the hot diesel engine jacket water is circulated through a tube bundle that is submerged in seawater. The seawater is boiled in a chamber that is under vacuum, hence the name submerged-tube distilling plant.

SUBMERGED-TUBE DISTILLING PLANT

The unit shown in figure 15-2 is a submerged-tube heat recovery distilling plant. Figure 15-2

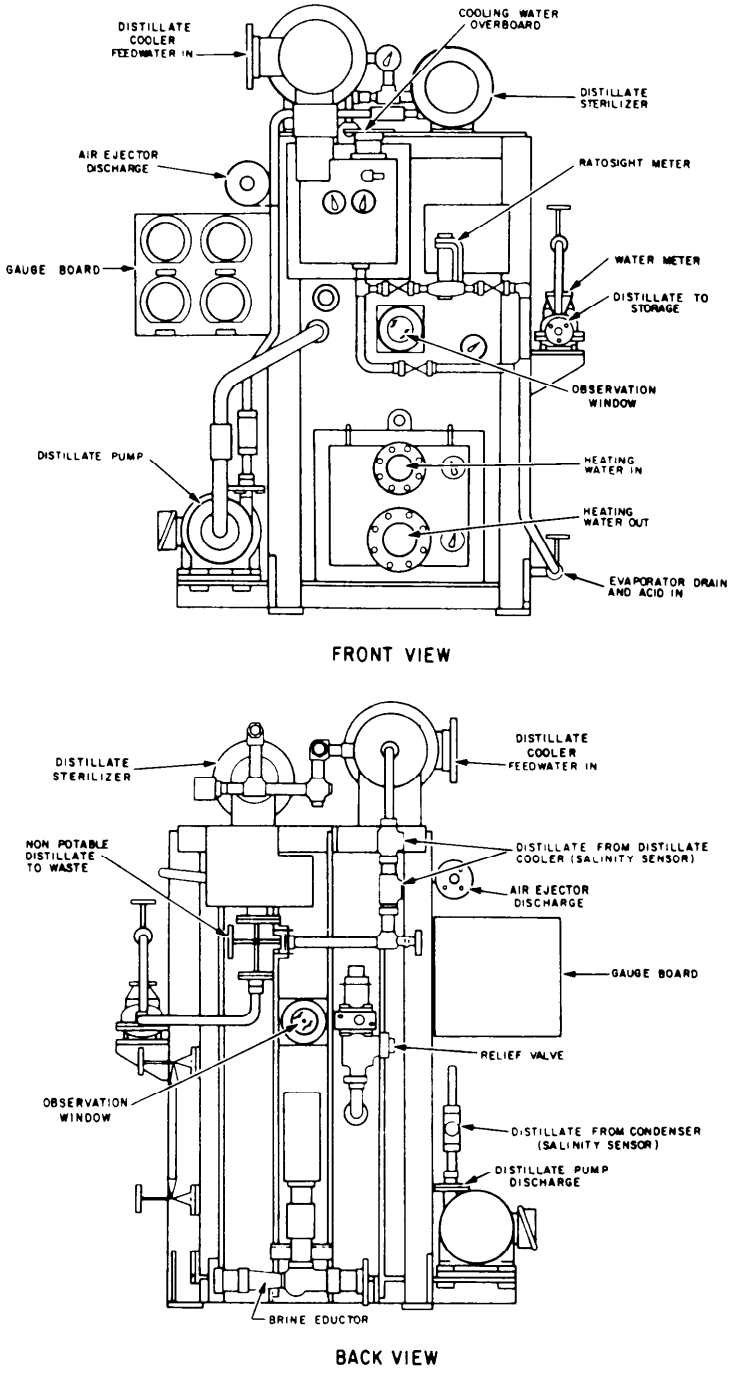


Figure 15-2.—Model S167ST heat recovery (submerged-tube) distilling plant.

shows the major components that we are going to discuss. The main source of heat for the feedwater is a continuous flow of diesel jacket water. The hot jacket water flows through the heating tube bundle and transfers its heat to the feedwater. In the event that the heat of the jacket water is not sufficient to maintain the temperature through the tube bundle between 168° and 172°F, supplemental heaters (electric or steam) are provided in the system and are energized to provide additional heat as required.

When properly operated, this unit is capable of producing 4,000 gallons of distillate per day with a purity of 0.065 epm chloride, 2.3 ppm chloride, or 9.43 micromhos/cm.

Design and Components

The submerged-tube distilling plant in figure 15-2 contains a single evaporating stage in a shell, an air ejector assembly, a brine eductor assembly, a ratosight meter, a distillate pump, a distillate sterilizer, a distillate sterilizer temperature control system, and a distillate cooler. For the operation and monitoring of the distilling plant, the salinity indicating system, a three-way solenoid trip valve, a water meter, pressure gauges, thermometers, and associated piping, valves, and fittings are all provided. All the components, except the evaporator feed pump and the feedwater strainer, are mounted on a common base. As we discuss the main components of the submerged-tube heat recovery distilling plant, refer to figure 15-2. You may also find it helpful to refer to figure 15-9 (at the end of this chapter), which shows the major flow paths and relative location of the components within each flow path.

EVAPORATOR ASSEMBLY.—The evaporator assembly is an evaporator-condenser effect contained within a single shell mounted on the distiller base. The distilling process is shown by the large arrows in figure 15-3. Feedwater (seawater) that is pumped into the bottom of the evaporator will eventually be converted into steam.

Jacket water from the diesel engine(s) is pumped through the heating tube bundle and serves as a source of heat for the tube bundle.

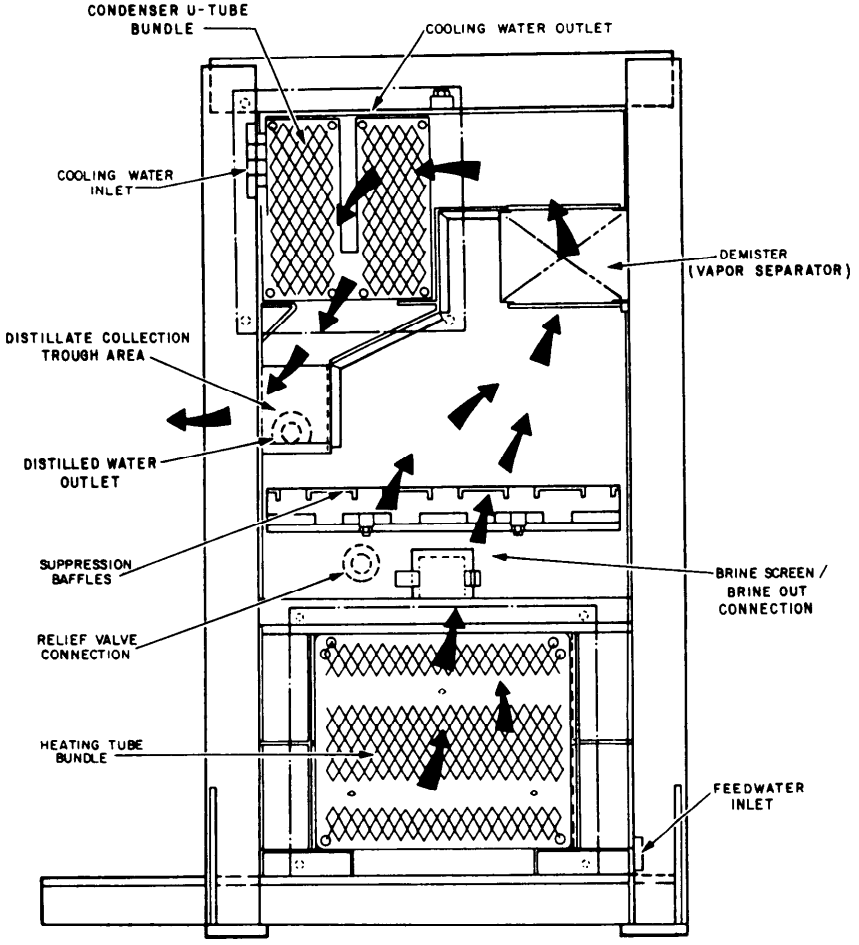


Figure 15-3.—Evaporator feed/distillate assembly.

Submerged in the feedwater, the heating tube bundle transfers the heat by conduction from the hot jacket water to the feedwater. The heat from the jacket water causes the feedwater to boil and give off steam. (Because of the low pressure created by a vacuum inside the evaporator, the feedwater boils at a lower temperature.) As the steam rises, it first passes through the suppression baffles. While the suppression baffles allow the steam to pass through to the demister, they also block the larger moisture-laden droplets of steam from entering the demister.

The steam then passes through the demister (vapor separator). The demister consists of staggered layers (or pads) of densely woven Monel mesh. By virtue of its design, the demister causes the vapor to change its direction of motion many times as it passes through. The demister works by separating the moisture from the vapor, thereby producing a dry saturated steam. The separated moisture, which may contain salt particles, drips back to the feedwater as brine.

As the saturated steam leaves the demister, it is drawn to the condenser tube bundle. Seawater pumped through the condenser tubes cools the tubes. As the steam passes over the condenser tube bundle, vapor condenses on the tubes as distillate (fresh water). The distillate falls from the condenser tubes into a collection trough located under the condenser and is then channeled to the distillate water outlet.

A pressure relief valve located on the back of the evaporator shell prevents the shell from being damaged by high internal pressure that may result from improper operation of the unit. A brine-out connection, installed in the lower section of the shell, maintains the proper level of feedwater while drawing off the brine. The connection is located at a height that allows it to maintain the feedwater level slightly above the heating tube bundle. This design assures adequate and continued submersion of the heating tube bundle. A screen in the brine-out connection blocks any debris that might foul the brine eductor.

Observation windows are installed in the evaporator shell. These windows will allow you to monitor the system by viewing water level conditions in the vapor and distillate collection areas.

AIR EJECTOR.—The air ejector is mounted on the upper side of the evaporator shell near the top of the distillate condensing area.

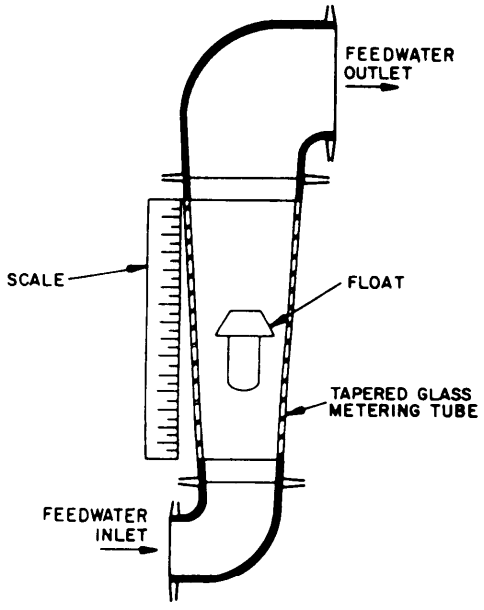


Figure 15-5.—Ratosight meter functional diagram.

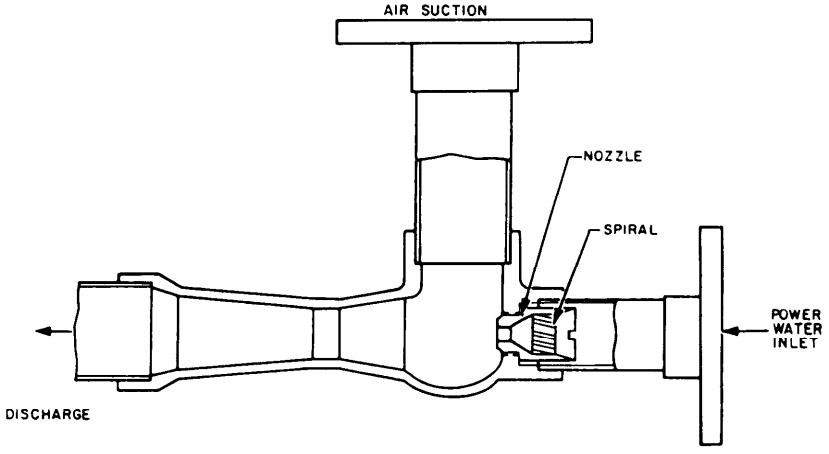


Figure 15-4.—Air ejector.

(Refer to fig. 15-4.) The air ejector is a single-stage, seawater-driven jet pump. Firemain pressure is applied to the pressure side of the ejector and flows through the constricted nozzle, creating a high vacuum at the vent connection of the evaporator shell. This method creates the initial vacuum in the evaporator. Once the initial vacuum is drawn, the main function of the ejector is to remove noncondensable gases such as air and carbon dioxide from the evaporator. If allowed to accumulate, noncondensable gases would insulate the heat transfer surfaces. The accumulation of gases would also raise the pressure and upset the temperature and pressure operating conditions of the distilling plant.

BRINE EDUCTOR.—The brine eductor is mounted on the lower back of the evaporator shell. It is also a single-stage, seawater-driven jet pump that serves to draw off the brine from the overflow duct of the evaporator and discharge it overboard. Seawater from the firemain is supplied to the pressure side of the eductor. This water flows through the constricted nozzle, creating a high vacuum at the brine suction connection. This pressure differential causes the brine to be drawn from the evaporator shell assembly. (NOTE: In this unit, the air ejector and brine eductor are both jet pumps. The difference in terminology is due to the application of the pump. In the ejector application, the pump moves air and noncondensable gases; in the eductor application, the pump moves liquid.

RATOSIGHT METER—The ratosight meter is attached to the front of the evaporator shell in the feed inlet line. (Refer to fig. 15-5.) It is used to measure the flow rate of the feedwater entering the evaporator shell. The ratosight meter is a variable-area meter of the tapered tube and float type. A metal float is suspended in a vertically tapered glass tube and moves axially with the water flow. (The flow is vertically upward.) The weight of the float, minus its buoyancy in the fluid, is balanced by the drag force of the fluid upon the float. The float rides at a height that will maintain the balance of forces and permit stable operation while the ratosight measures the liquid flow rate. To prevent excessive scale buildup, the feedwater flow rate through the meter should be set at three times the distillate flow rate as measured by the water meter.

DISTILLATE PUMP.—The distillate pump moves distillate formed within the evaporator to storage tanks or to waste water tanks. It is an electric motor-driven, centrifugal pump with connections for a seal cooling water line, vent, and pressure gauges. The distillate pump is mounted on a plate that is attached to the evaporator assembly. If the distillate pump should stop during normal evaporator operation, the distillate sterilizer heater will be automatically de-energized to prevent burnout due to lack of distillate flow through the sterilizer.

DISTILLATE STERILIZER—The distillate sterilizer is mounted above the evaporator assembly. (Refer to fig. 15-6.) The sterilizer consists of a shell fitted with inlet, outlet, and vent connections. A six-element, 440-volt electric immersion heater is located within the sterilizer shell. The heater heats the distillate flowing through the shell to the required 170°F outlet temperature, which is high enough to kill harmful bacteria.

DISTILLATE COOLER.—A distillate cooler is mounted above the evaporator assembly. The distillate cooler is a shell and tube type of heat

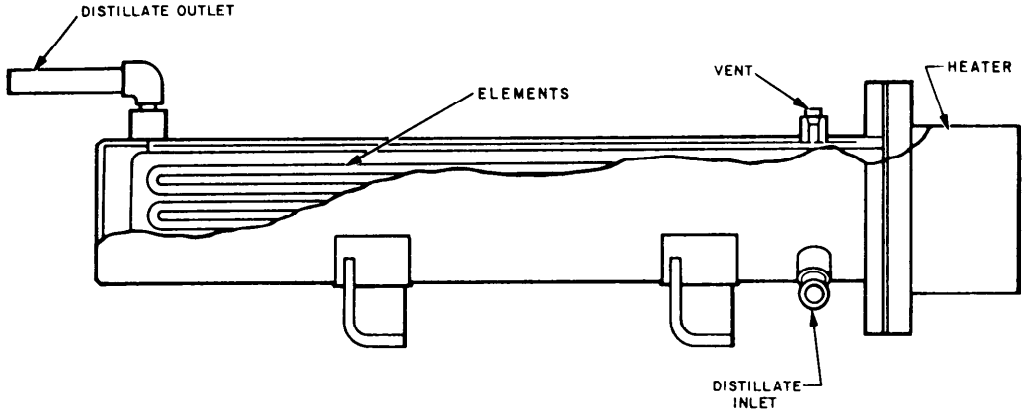


Figure 15-6.—Distillate sterilizer.

exchanger containing a vent and a drain fitting. (The shell and tube heat exchanger was discussed in chapter 7, "Engine Cooling Systems. ") Hot distillate from the sterilizer is piped through the distillate cooler shell and is cooled by cold seawater flowing through the tube bundle.

SALINITY CELLS.—Three SALINITY CELLS in the plant continuously monitor the purity of the distillate. One cell is located in the discharge line of the distillate pump, and the other two cells are located in the distillate cooler outlet line. All of the salinity cells are read on a salinity indicating panel. Two of the cells—one located in the discharge line of the distillate pump and the other in the distillate cooler outlet line—also control the three-way solenoid-operated trip valve. Additional information on salinity monitoring and indicating will be provided later in this chapter.

THREE-WAY SOLENOID VALVE.—The three-way trip valve (dump valve) is located on the back of the evaporator shell. Its function is to direct the flow of distillate to either the distilled water collecting tank or to waste. (See fig. 15-7.) During normal operating conditions, when acceptable distillate is being produced, the solenoid is energized and the valve lever is in the raised position.

When tripped, either by a salinity cell or from loss of electrical power, this valve will automatically divert the flow of distillate to waste when the salinity reaches a predetermined set point

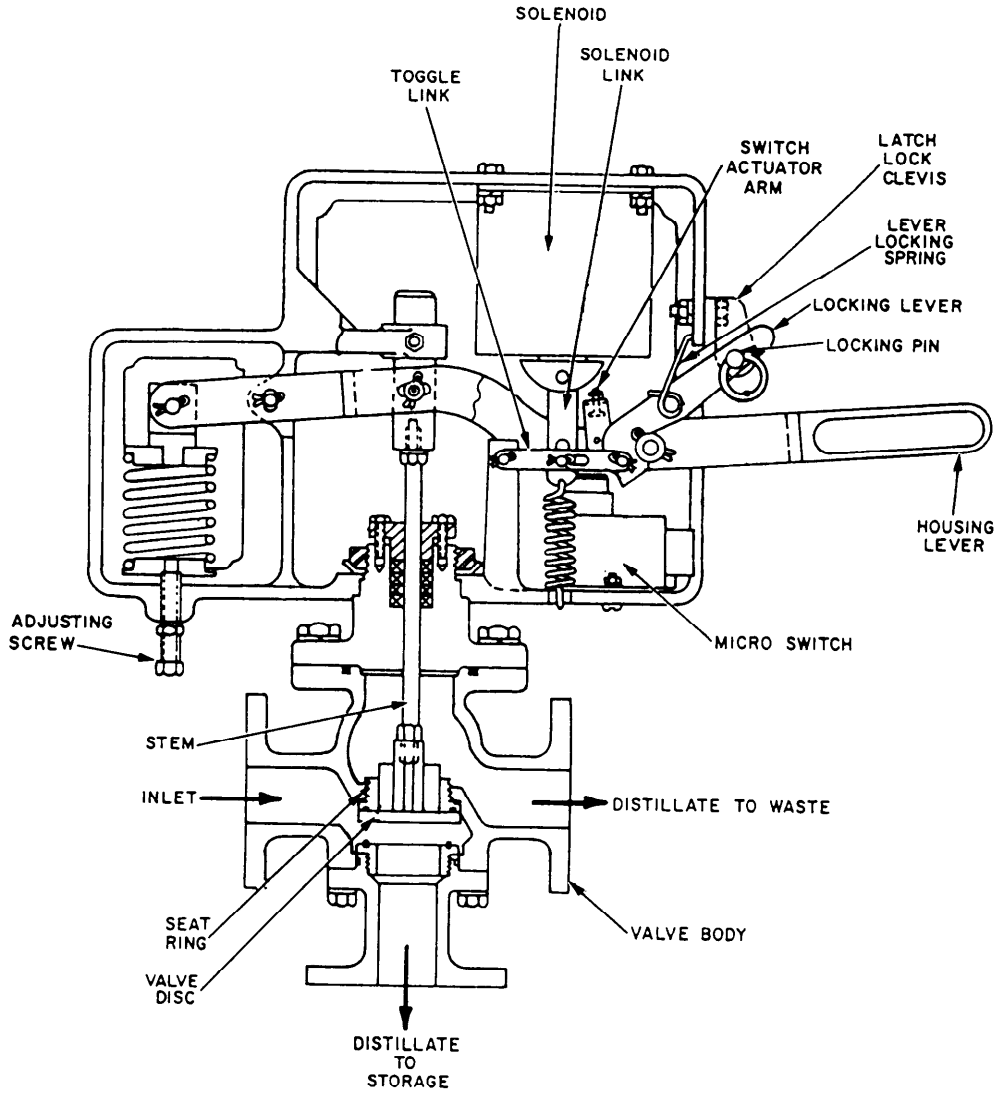


Figure 15-7.—Solenoid trip valve (dump valve).

(usually 0.065 epm). When the cause of the salinity alarm is corrected, or on restoration of electrical power, the dump valve must be manually reset by raising the lever.

WATER METER.—A water meter is located in the evaporator distillate line immediately downstream of the three-way solenoid trip valve. This direct-reading meter measures the production in gallons of acceptable distillate that is produced by the evaporator.

EVAPORATOR FEED PUMP.—The evaporator feed pump supplies feedwater to the distilling plant. This close-coupled, electric motor-driven pump is a horizontal, single-stage water pump with connections for seal cooling water lines and pressure gauges. Its discharge flow rate is controlled by the cooling water overboard valve and the feed rate control valve. The pump is located beneath the evaporator and is isolated from its mounting plate with vibration pads.

DUPLEX STRAINER.—A duplex strainer is provided in the feed pump discharge line to remove marine organisms and other particulate matter in the feedwater that may foul the evaporator unit. This basket strainer is of the duplex type (fig. 15-8) to permit continuous operation. If one basket becomes clogged, the feed flow can be shifted to the other clean basket,

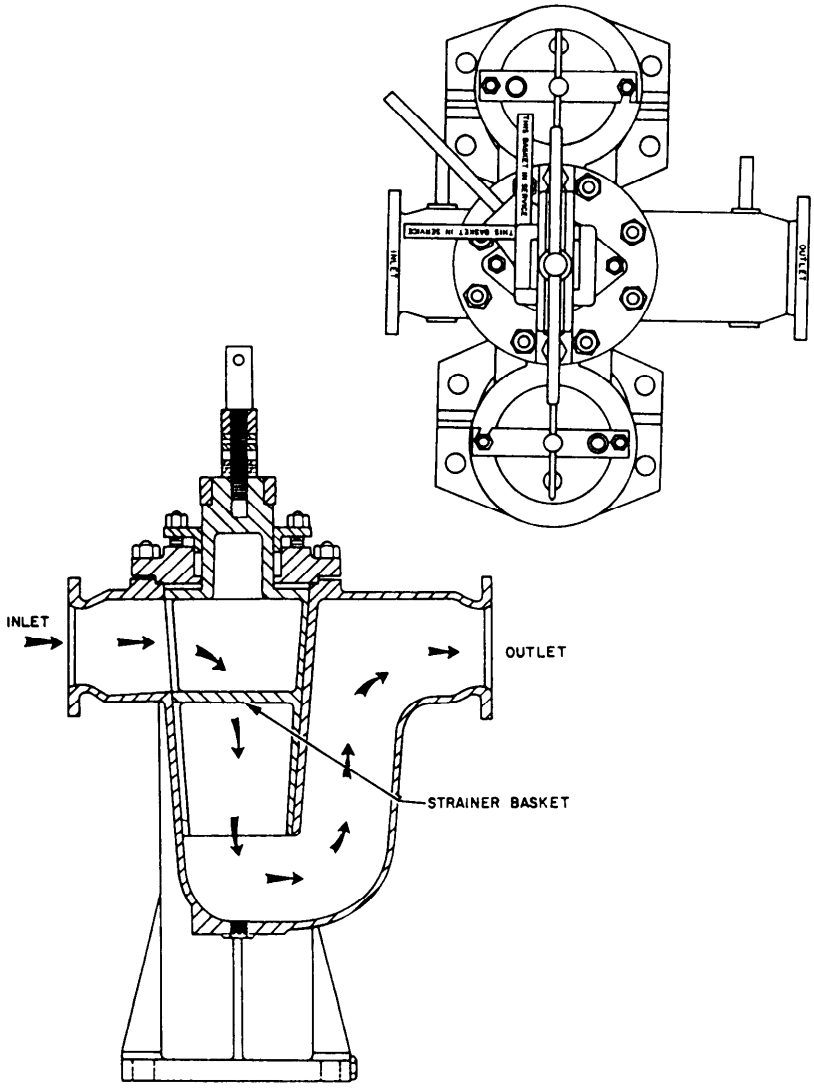


Figure 15-8.—Feedwater duplex strainer.

and then the clogged basket can be opened, cleaned, and prepared for service.

Theory of Operation

Now that you have read about the major components and their respected functions and locations within the system, you should be able to study and understand the flow diagram in figure 15-9 . The diagram illustrates the operation of a submerged-tube plant.

FEEDWATER CIRCUIT.—Feedwater is piped to the suction of the feedwater pump. This pump discharges the feedwater through a duplex feedwater strainer, through the tube side of the distillate cooler, and through the tubes of the condenser tube bundle. The major portion of the feedwater is piped overboard. A portion is piped through the ratosight meter and into the shell of the evaporator. The heating water, flowing through the heating tube bundle, heats the feedwater to boiling, causing water vapor to be released. The vapor is drawn up and passes through demister pads in the condensing area. The demisters aid in purifying the resultant distillate by mechanically blocking out salt-entrained drops of feedwater, thus allowing only pure water vapor to pass through.

BRINE CIRCUIT.—The feedwater fills the evaporator to a level above the heating tube bundle. Because there is less distillate produced than feedwater introduced, the overflow is piped to the suction of the brine eductor. The brine eductor draws this brine out of the evaporator and discharges it overboard.

DISTILLATE CIRCUIT.—The water vapor condenses on the condensing tube bundle into fresh water (distillate). This condensing action maintains the vacuum in the effect, which was established initially by the air ejector. The distillate collects in the distillate trough, and flows to the suction of the distillate pump. The distillate pump moves the distillate through the shell side of the distillate sterilizer. The distillate sterilizer heats the distillate to 170°F. (The temperature must be high enough to kill all harmful bacteria and other organisms.) The distillate then flows through the shell side of the distillate cooler, where it is cooled to 95°F. From the cooler, the distillate flows through a three-way solenoid trip valve. If it is pure, the distillate flows through a water meter to storage or to the brominator for treatment (disinfection), which serves to maintain purity, and then to the potable water system. If it is impure, it flows to waste.

Operational Procedures

As an Engineman, you will be required to operate a submerged-tube distilling plant. Some basic operational practices are as follows:

1. Check the flow rate of the feedwater through the ratosight meter and the flow rate of the distillate through the water meter. Adjust the feed inlet control valve to maintain a feedwater to distillate flow ratio of 3 to 1. (For example, you should have 3 gallons of feedwater to 1 gallon of distillate.) This procedure will help you prevent excessive scale buildup in the unit.

2. When you are operating the unit in seawater temperatures below 85°F, adjust the cooling water control overboard valve (using the indication on the ratosight meter) to maintain the evaporator shell temperature at 130°F.

3. Maintain the distillate level below the top of the observation windows on the evaporator by adjusting the water meter shutoff valve.

4. Make frequent inspections through the distillate observation windows. Watch for a rise in the feedwater level. (The rise may be caused by an insufficient brine discharge rate.) Check for a malfunctioning brine eductor supply pump or brine eductor. Air leaks in the suction piping will impair (or prevent entirely) the operation of the unit pumps and will be indicated by a consequent rise in brine or distillate levels.

5. Do not operate the unit beyond its rated capacity or above the limit specified for shell temperature. Operation of the unit at higher than rated temperatures will cause rapid scale formation on the heat transfer surfaces.

For additional information, consult the NAVSEA technical manual for your unit.

FLASH-TYPE DISTILLING PLANTS

The flash-type distilling plant is widely used throughout the Navy. Flash-type plants have some unique features when they are compared to the submerged-tube type of plant. One is that the flash-type flashes the feed into vapor (steam)

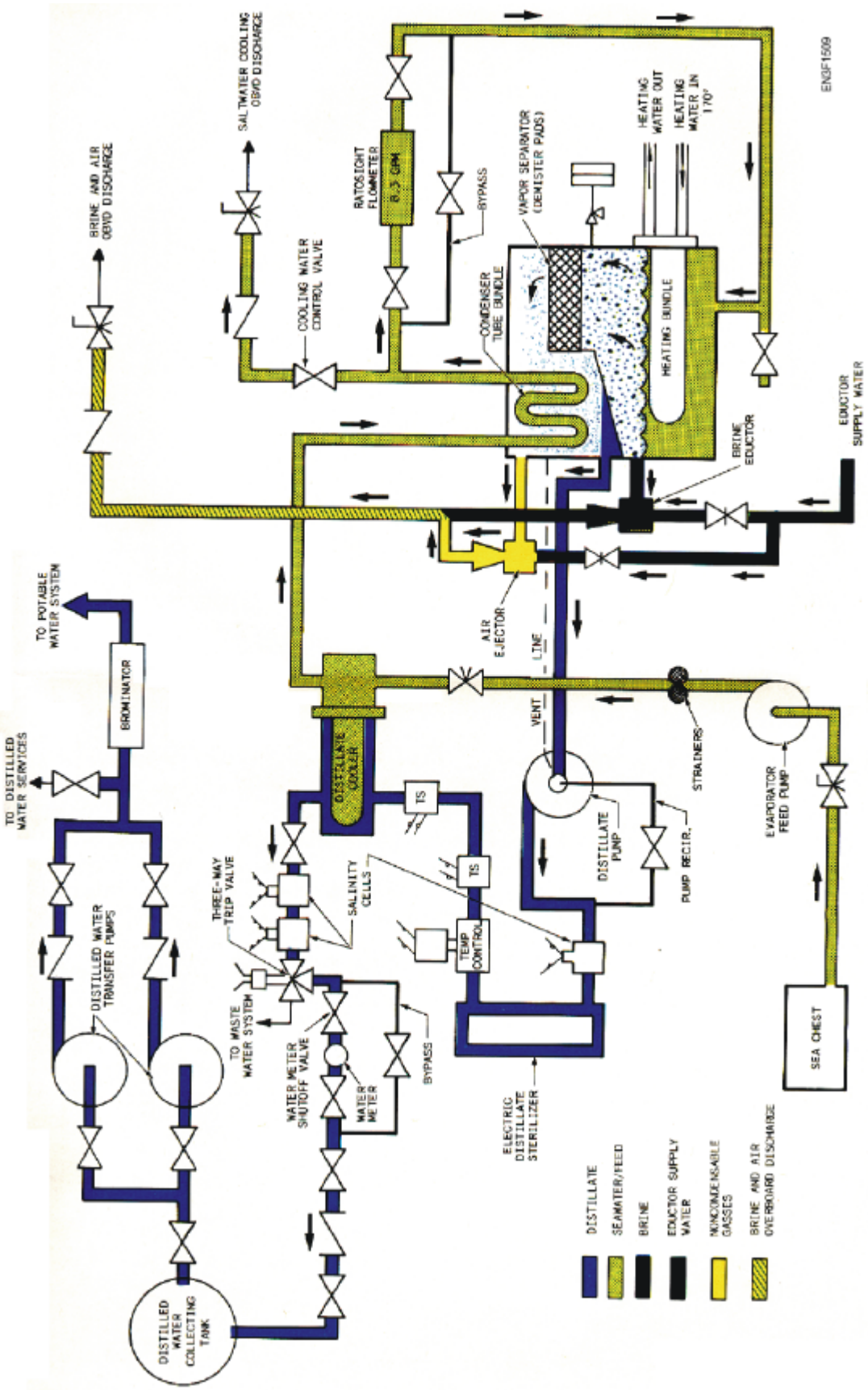


Figure 15-9.—Submerged tube, heat recovery distilling plant, 4,000 gpd capacity.

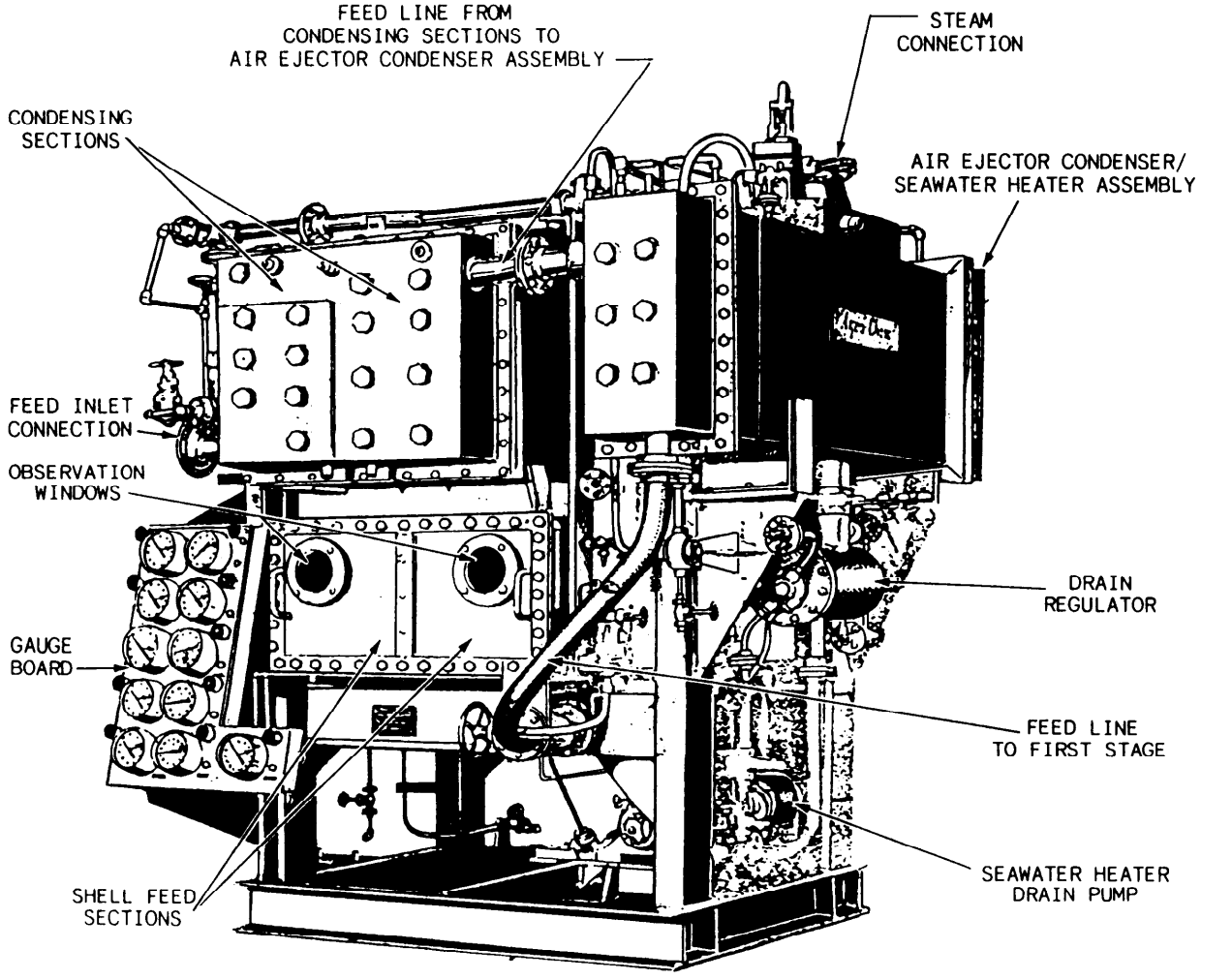
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rather than boiling it inside the evaporator shell. The flashing process involves heating the feed before it enters the evaporator shell. The shell is under a relatively high vacuum. The feed is heated to a temperature at which it will flash into vapor when it enters the first stage, which is maintained at a high vacuum. With this design, there are no submerged heat transfer surfaces within the evaporator shell, such as the tubes in the submerged-tube unit. The elimination of these surfaces greatly reduces the scale formation problem of evaporators and allows prolonged operation at maximum efficiency. Any scale that may form on heat transfer surfaces of a flash-type plant is composed mainly of soft calcium carbonate compounds that are relatively easy to remove by a chemical cleaning process.

Two-Stage Flash

Figure 15-10 is an illustration showing the major components of the two-stage flash distilling plant that we are going to discuss. Figure 15-11 shows the major flow paths through a two-stage, 12,000 gpd flash distilling plant. Follow along on the diagram as we discuss the operation of this plant. Notice the color coding as we continue this discussion.

SEAWATER FEED CIRCUIT.—The seawater feed pump (upper left of fig. 15-11) takes a suction through a sea chest and strainer and discharges seawater (light green) into the tubes of the condensing section of the second stage of the evaporator. The seawater feed then flows through



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Figure 15-10.—Two-stage, 12,000 gpd flash-type distilling plant.

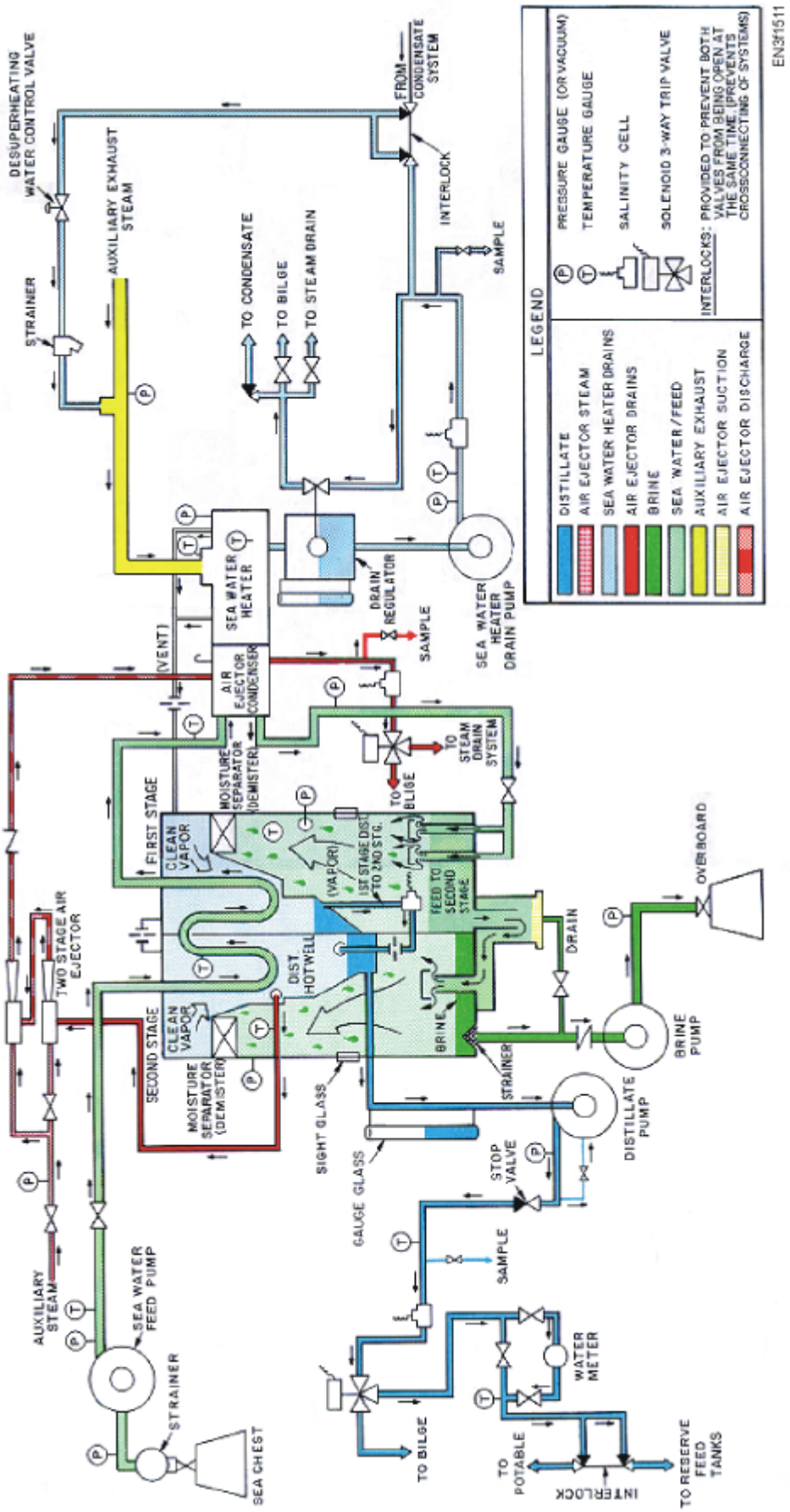


Figure 15-11.—Two-stage, flash-type distilling plant, 12,000 gpd capacity.

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the tubes of the heat exchanger in the first-stage condensing section. The condensing sections of the evaporator are tube bundles, one in each stage of the evaporator shell.

As it passes through the second-stage condenser section, the seawater feed carries heat away from the surrounding vapor and, as a result of the heat exchange process, the feedwater increases in temperature. When the incoming seawater feed has an injection temperature of 85°F (29°C), the feed leaving the first-stage condensing section of the evaporator should be approximately 138°F (59°C), an increase in sensible heat of 53°F (11°C).

Upon leaving the first-stage condensing section, the feed enters the air ejector condenser/seawater heater assembly. As it passes through this double-flow, shell and tube heat exchanger, the feed picks up more heat by condensing exhaust steam from the air ejectors and from steam admitted to the seawater heater from the auxiliary exhaust steam system.

The feedwater leaves the air ejector condenser/seawater heater assembly at a temperature of approximately 170°F (77°C) and is fed into the first stage of the evaporator shell. (A feedwater temperature of 170°F (77°C) is required to ensure that all harmful organic suspended matter is killed.) The feed enters the bottom of the shell through two spray pipes. In conjunction with the high vacuum in the first stage, these spray pipes atomize the water, an action that helps to flash the incoming feed water into vapor. Feed that does not flash to steam in the first stage is directed to the second stage through an internal loop seal located at the bottom of the shell. Flow control of the feedwater is accomplished by manual operation of the feed valve in the line just before the feedwater enters the first stage.

The feedwater enters the second stage in a manner similar to the way it entered the first-stage shell. The force that moves the feed from the first to the second stage is the difference in pressure between the two stages. The first-stage shell pressure is maintained at approximately 23 in.Hg, while the second-stage shell pressure is maintained at an even higher vacuum (lower pressure) of approximately 27 in.Hg. A loop seal arrangement at the bottom between the first and second stage prevents the pressure from equalizing between the stages. Feedwater that does not flash into vapor in the second stage becomes brine, which is pumped overboard.

VAPOR CIRCUIT.—Vapor (blue gray) is formed in the first-stage shell by the hot feedwater (170°F (77°C)) as it enters the shell which is "under" a vacuum (23 in.Hg). Saturation temperature for 23 in.Hg is approximately 148°F (64°C). The feed enters the first-stage shell through two spray pipes fitted with deflector plates, which cause the feed to spray downward and form a thin, circular curtain of water. This partially atomized curtain of spray results in more complete transformation of the water into steam vapor. The vapor then rises through mesh-type demisters (moisture separators), which removes moisture entrained in the vapor. (The moisture removed from the vapor drains back into the bottom (feed) section of the evaporator shell.) The vapor then passes through the condensing section of the first-stage evaporator shell, where it is condensed into distillate by the cooling action of the incoming feedwater. Vapor produced in the second stage goes through the same process. However, the shell pressure in the second stage is lower (27 in.Hg), with a corresponding lower saturation temperature of approximately 115°F (46°C), as shown in table 15-1.

DISTILLATE CIRCUIT.—Distillate (dark blue) is formed in the condensing section of both stages of the evaporator. The distillate from the first stage collects in the bottom of the first-stage condensing section in a hotwell-like area (trough) formed by the joint between the evaporator shell division plate and the first-stage collection tray. The distillate passes through a loop seal into a lower trough (or tray) in the second stage. The piping between the two stages contains an orifice plate that controls the liquid flow rate. Equalization of pressure between the stages is prevented by the two loop seals—one for the feedwater and one for the distillate—which connect the two troughs together. This arrangement also prevents premature flashing of the distillate as it enters the lower pressure area of the second stage.

The distillate is then pumped out of the second-stage distillate trough by the distillate pump. The distillate pump discharges the water through a three-way solenoid-operated trip valve which, when tripped, will automatically divert the flow of distillate to the bilge if the salinity content reaches a predetermined set point (usually 0.065 epm). When the valve is in the reset (normal) position, the distillate will be routed through a water meter and into an interlocked two-valve manifold. The two-valve manifold directs the distillate to either the potable water system or the reserve feed system. The manifold is interlocked to prevent opening of both valves at the same time. The potable water system can

be contaminated with chloride from a shore water source, which may be suitable for drinking but not for boiler feed. The potable water system and the reserve feed system, therefore, must NEVER be cross-connected in any way.

AIR EJECTOR CIRCUIT.—A two-stage air ejector unit (red and pink), using auxiliary steam, is located at the top of the distilling plant. It draws vacuum and maintains the vacuum in the evaporator shell. The air ejector second stage discharges into the air ejector condenser section of the air ejector condenser/seawater heater assembly. The air ejector condenser condenses the steam and vents air and noncondensables (such as CO_2) to the atmosphere. The condensate, which forms from the steam, drains to either the bilge or the steam drain collecting system through a three-way solenoid-operated trip valve. On some ships, however, the condensate is routed through a loop seal or trap to the seawater heater hotwell.

BRINE CIRCUIT.—Brine (dark green) is pumped out from the bottom of the second-stage shell. A centrifugal pump is used for this purpose.

HEATING STEAM CIRCUIT.—Auxiliary exhaust steam (yellow) is used in the seawater heater to provide the heat required to raise the temperature of the seawater feed to approximately 170°F (77°C). The auxiliary exhaust steam entering the seawater heater passes through an orifice that controls the quantity of the steam admitted to the heater. The steam pressure upstream of the orifice is approximately 3 psig.

The seawater heater is vented to the first-stage evaporator through a line with a 1/4-inch orifice to bring the seawater heater to a vacuum of approximately 9 in.Hg (10 psia). The pressure differential between the auxiliary exhaust steam pressure above the orifice and the seawater heater pressure is critical in providing proper steam flow through the heater. Improper steam flow will cause the distilling plant output to vary.

Before it enters the seawater heater, the auxiliary exhaust steam is desuperheated by water sprayed into the steam inlet piping. The amount of water for desuperheating is adjusted by a manual control valve to maintain the steam temperature 50 to 10°F higher than seawater heater shell temperature. In this manner the temperature of the seawater feed (light green) leaving the air ejector condenser/seawater heater assembly is maintained relatively constant.

The water supply for the desuperheating water is a portion of the discharge from the seawater heater drain pump. During plant startup, when water from the seawater heater drain pump may not be available, the ship's condensate system furnishes the water supply. A two-valve interlock between the supply from the seawater heater drain pump and the supply from the condensate system prevents cross-connecting of these two systems. The two-valve interlock is similar to that described for the distillate circuit.

SEAWATER HEATER DRAIN CIRCUIT.—Water condensed from auxiliary exhaust steam is pumped from the shell of the seawater heater by the seawater heater drain pump. A drain regulator serves as a hotwell and assures a constant suction head for the pump. The drain regulator is a ball float-operated valve attached below the condensate drain connection of the seawater heater. The ball float in the drain regulator operates the valve to maintain a relatively constant water level in the housing, which is indicated by a gauge glass. A decrease in water level will tend to close the valve in the drain regulator. Therefore, the amount of condensate discharged by the drain pump will be throttled until the water level in the float housing rises again. The water level in the regulator maintains a suction head for the seawater heater drain pump and prevents loss of vacuum in the seawater heater by maintaining a water seal between the heater and the pump.

The drain pump discharges condensate from the seawater heater to the condensate system (startup only), to the steam drain collecting system (normal lineup), or to the bilge.

SALINITY MONITORING AND INDICATING.—Four salinity cells in the plant provide continuous monitoring of water purity: (1) in the loop seal line between the first- and second-stage distillate; (2) in the distillate pump discharge; (3) in the air ejector drain line; and (4) in the seawater heater drain pump discharge. All of the salinity cells are read on a salinity indicating panel. Two of the cells, located at the distillate pump discharge and the air ejector drains, also control three-way solenoid-operated trip valves, which are automatically tripped by a salinity cell to divert the flow of water to the bilge to prevent contamination of the potable or reserve feedwater systems.

Other Applications of the Flash-Type Distilling Unit

Flash-type distilling plants may have any number of stages and output capacities. For example, the Navy uses one type of three-stage,

30,000 gpd plant as well as a five-stage, 50,000 gpd unit. All flash-type plants operate on the same basic principles as those described for the two-stage plant.

Operating Notes for Flash-Type Units

The water-making capacity of any distilling plant that uses heat to boil seawater is affected primarily by five factors: (1) the number of stages, (2) the temperature of the seawater through which the ship is passing, (3) the rate of flow of seawater feed through the plant (which is the only factor the operator can control), (4) the pressure (vacuum) in each stage, and (5) the temperature of the steam supplied to heat the feedwater. A change in any factor will upset the heat balance of the plant, and cause it to make water at less than rated capacity.

One factor which cannot be controlled is the injection temperature of seawater, which can change drastically as a ship travels from one part of an ocean to another. Therefore, when you are assigned as an operator of a distilling plant, you must be alert to such changes, which will be indicated by temperature and pressure gauges. To this end, you should have a good understanding of the meaning of saturation, which is simply a condition that can occur only for a given heat flow rate and value of temperature or pressure, as shown in table 15-1.

Saturation of water is a condition, which simply means that for any given operating pressure or temperature, the water has absorbed all of the Btus it can without changing state. In other words, the water is saturated with heat. Now, if the water absorbs any more Btus, the saturated water must change state by boiling into a vapor (steam). O-other hand, when steam vapor is at a saturation pressure or temperature, by losing the same number of Btus, the saturated steam must cool and change state back into saturated water. You must understand, however, that these changes cannot occur at any other value of pressure, or temperature, as indicated in table 15-1. To look at it another way, the seawater feed entering the first stage of a distilling plant has been heated to its saturation temperature, but the pressure is high enough to keep the water in its liquid state. Now, when this heated water enters the very low pressure area of the first stage, it flashes into saturated vapor and will continue to do this as long as the temperature of the incoming feedwater, the pressure in the first stage, and the flow rate of vapor being converted to condensate do not change. All that is required to change the vapor in the first stage back into water is to remove heat from the vapor at a fast enough rate, which is done by causing the vapor to flow continuously through a lower temperature area created by the heat exchanger in the upper part of the first stage. Because the seawater feed gives up some of its heat to the first stage, feedwater entering the second stage will have a slightly lower temperature. Therefore, the operating pressure in the second stage must be lower (higher vacuum), because the saturation point of the feedwater has been lowered. In any case, the saturated seawater feed entering the second stage will also flash into vapor (change state to steam). When the saturated vapor is directed to flow over the tubes carrying seawater feed passing through the upper part of the second stage, the vapor gives up its heat and changes state back into liquid water that we call distillate.

Flash-type plants are designed to operate with a feed temperature of 170°F (76°C) at a certain feed rate when the temperature of the seawater is 85°F (29°C). By using the feed control valve to regulate the rate of feed to the first-stage flash box, you can maintain the temperature of the feed entering the first stage at the required 170°F (± 5°F). When the seawater injection temperature is lower than 85°F, reduce the feed rate so that the 170°F feed temperature is maintained. The feed temperature should never be allowed to exceed 175°F (79°C). A higher operating temperature will greatly increase the amount of scale formation. All other valves in the feed line should be opened wide to prevent their interfering with the proper flow of feed through the plant.

Do not attempt to control the feedwater temperature after it leaves the feedwater heater and enters the first-stage flash box. Allow the temperature to adjust itself to the varying plant conditions. Full capacity will result from proper feed flow, proper vacuums throughout the plant, and proper steam pressure above the orifice for the seawater heater.

Remember, the capacity of the flash-type distilling plant depends on both the quantity of evaporator feedwater entering the first-stage feed box and the difference in temperature between the feedwater entering the first stage and the vapor in succeeding states; but you can change the capacity only by increasing or decreasing the amount of heat added to the seawater by controlling the flow of seawater through the feed-water heater.

DISTILLING PLANT CARRYOVER AND SALINITY

At this point, we need to mention the problem of distilling plant CARRYOVER. Practically all cases of high salinity (salt content) in the distillate (fresh water) output of a distilling unit will be caused by internal seawater leakage (from a tube) or by carryover. Carryover actually consists of molecules of seawater that have not been filtered out of the vapor before the vapor is condensed into distillate. All types of distilling plants have some type of device to prevent carryover. These devices may be called moisture separators, vapor separators, or demister pads. If the plant is operated improperly, these separators will not function properly. Some seawater will pass through them and show up as high salinity in the distillate. This may occur when you attempt to increase the output of the plant beyond its rated capacity. (NOTE: A common cause of carryover in distilling plants that use demister pads is leakage around the pads due to improper sealing of the edges of the pads. Therefore, when the pads are removed for any reason, extreme care must be taken for prevention of damage to the sealing surfaces.)

Salinity, which is caused by chemical salts in seawater, is undesirable. Chemical salts in boiler feedwater will cause corrosion of the tubes. In addition, the normal operating temperature of a naval distilling plant may not be high enough to completely sterilize the distillate. Therefore, any carryover (or leakage) of seawater is a potential health hazard. Many types of microorganisms (primarily coliform bacteria) may be present. For these reasons, restrictions are placed on the operation of distilling plants while operating in either contaminated seawater or fresh water. Freshwater carryover may not have enough salinity to be detected by either the operator or the salinity indicating system. Restrictions for operation under these conditions are found in chapter 531 (9580) of the *Naval Ships' Technical Manual.*

You have read that the distillate must meet specific standards of chloride content. For those standards to be met, the distillate must be monitored continuously by the salinity indicator and periodically tested for concentration levels of chemical impurities. The results of distillate tests for chloride are expressed in terms of either parts per million (ppm) or equivalents per million (epm).

Parts per million is a weight-per-weight unit denoting the number of parts of a specified substance in a million parts of water. For example, 58.5 pounds of salt in 1,000,000 pounds of water represents a concentration of 58.5 ppm. Note also that 58.5 ounces of salt dissolved in 1,000,000 ounces of water or 58.5 tons of salt dissolved in 1,000,000 tons of water represents the same concentration—58.5 ppm.

Equivalents per million can be defined as the number of equivalent parts of a substance per million parts of water. (The word equivalent refers to the chemical equivalent weight of a substance.) The chemical equivalent weight is different for each element or compound. The chemical equivalent weight of sodium chloride (common table salt) is 58.5. A solution containing 58.5 ppm of this salt is said to contain 1 epm. Chloride has an equivalent weight of 35.5. Therefore, a solution containing 35.5 ppm of chloride has a concentration of 1 epm of chloride.

SALINITY MONITORING

The salinity of distillate is monitored continuously by an electrical salinity monitoring system. A salinity cell (fig. 15-12) is placed in the

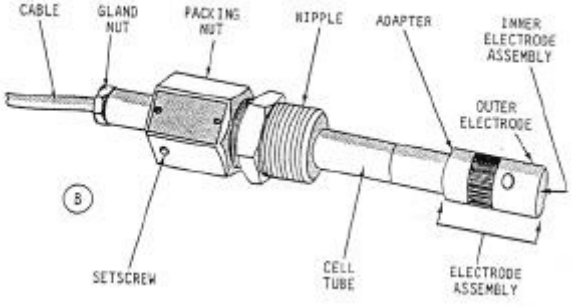


Figure 15-12.—Salinity indicator cell.

distillate line in constant contact with the distillate flowing out of the evaporator.

A salinity cell actually measures the ability of water to conduct electrical current (conductivity). The higher the concentration of chemical impurities in the water, the higher the conductivity of the water. This measurement is indicated on a salinity monitoring panel that may be of the type shown in figure 15-13. The electrical reading from the cell is converted to either epm or ppm chloride on the meter face. The chloride reading is based on the assumption that all of the impurities in the distillate are from seawater; however, a salinity cell cannot differentiate between seawater or any other impurity. For this reason, the salinity cell readings are checked frequently by a chemical test for chloride. You must always believe a high salinity cell reading (such as an alarm or tripped valve situation) until it is proven absolutely false.

In practically all cases, the measurement made by the distillate salinity cell will also activate the trip function of a three-way, solenoid-operated trip valve. If the salinity of the distillate reaches a preset value (2.3 ppm for some ships, 0.065 epm for others), the solenoid in the valve will be de-energized. This will allow spring pressure to disengage the latching linkage from the engaging lever, and the valve stem assembly will drop due to main spring pressure. When the stem assembly drops, the valve seat shuts off the water path of the distillate to the freshwater tanks or reserve feed system and opens a path to the bilge or waste drain system. This type of three-way valve is also used on the air ejector condenser drains and seawater heater drains of many distilling plants. These valves have locking pins that can be used to lock the main valve engaging lever in the reset position. The locking pins should NEVER be used without the specific permission of the engineer officer. Contaminated water can be put into clean tanks and systems at an excessive rate if these pins are used to prevent the trip valves from tripping.

Salinity cells are normally installed in other places in the evaporator system to monitor the salinity levels. Two examples are (1) the seawater heater drain pump discharge and (2) the loop seal between the first and second stages of the two-stage, flash-type distilling plant described earlier in this chapter. Cells installed in these places have a meter readout and an alarm, but do not actuate trip valves.

The temperature of the water affects the reading of the salinity cell. The higher the temperature of the water, the higher its conductivity. Salinity cells are designed to automatically compensate for changes in water temperature.

CHEMICAL TEST FOR CHLORIDE

The importance of keeping chloride contamination out of the reserve feed tanks cannot be overemphasized. As mentioned earlier in this chapter, serious damage can occur to boilers and steam generators if chlorides are not kept to an absolute minimum in the feed and condensate systems. High chloride concentration in boiler feedwater or condensate indicates that seawater has gotten into the system some place, which means other impurities are present as well. The process of boiling in boilers and steam generators results in the gradual buildup of chloride as well as other impurities. The gradual increase in concentrations of chemical impurities takes place even with very slight contamination in the boiler feedwater system.

One source of chloride contamination in the flash-type distillate may be seawater leaks in the main and auxiliary condensers. Seawater leaks in the submerged-tube type may be from the cooler or the condenser. Another major source is a faulty or improperly operated distilling plant.

In our discussion of salinity and the salinity monitoring system, we described one method of preventing contamination by the evaporators. In that situation, salinity cells serve continuously to monitor the salinity content of water in piping systems connected to the evaporator, to activate alarms, and to trip valves when the salinity concentration rises above the set point. Another method is to test the water chemically for chloride concentration. The chemical tests may be performed at some interval dictated by specific operating procedures. One chemical analysis is used to determine the actual chloride concentration in a sample of water by titration. Titration is a method of analyzing the composition of a solution by adding known amounts of a standardized solution until a given reaction (color change) is produced. When performed properly, the titration method is extremely accurate. This test for chloride can be used on distillate, air ejector drains, main condensate, or any other water that is not greatly discolored. (Even discolored water can be used if it is filtered.)

Additional specific information on water and water testing can be found in chapter 220, volume 2, of the *Naval Ships' Technical Manual.*

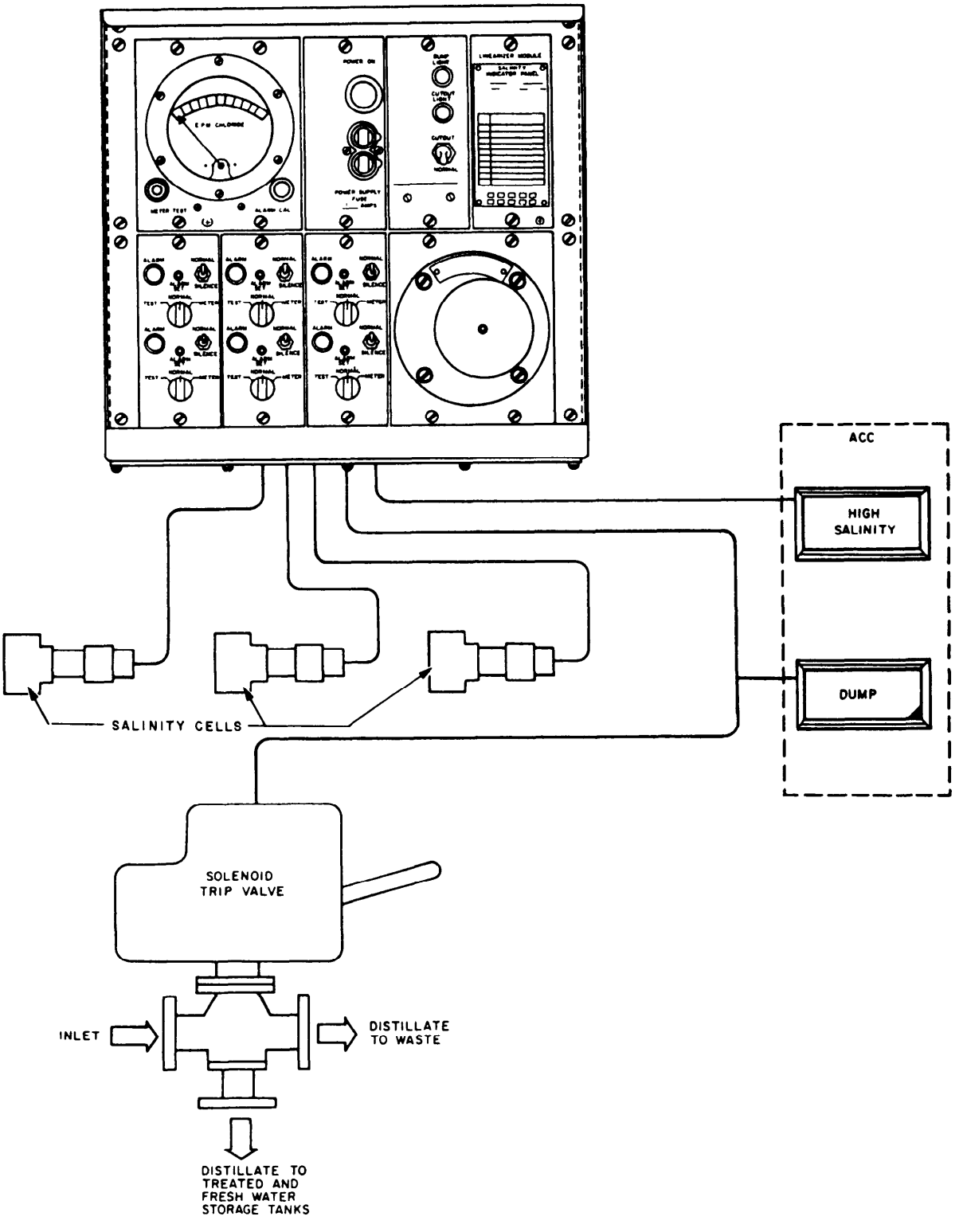


Figure 15-13.—Salinity monitoring system.

BRINE DENSITY OF SUBMERGED TUBE DISTILLING UNITS

Not all of the seawater feed that is fed into an evaporator is changed into distillate. That portion of the feed that does not become distillate is called brine. The concentration of sea salts in this water is called brine density, which has a direct bearing on the quantity and quality of the distillate produced by the evaporator. A low brine density indicates that not enough of the feedwater is being converted to distillate. A low brine density means poor efficiency in the plant, a condition that results in a reduced output capacity.

A high brine density indicates that too much of the feedwater is being converted into distillate. Operation with a high brine density causes excessive scale on heat transfer surfaces. This causes poor quality distillate due to excessive vapor formation. There is possible carryover and reduced efficiency due to the loss of heat energy carried over with the brine.

The ideal value of brine density is slightly less than 1.5/32. The density should never exceed this level. Since the average seawater contains approximately 1 part of dissolved sea salt to 32 parts of water (1/32 by weight), the brine density should be just under 1 1/2 times the density of average seawater, or 1.5/32.

Brine density is measured with a salinometer, which works on the same principle as a hydrometer. The float, or hydrometer, is a hollow metal shell attached to a square stem, weighted with shot at one end. Each side of the stem is graduated in thirty-seconds, from 0/32 to 5/32, and calibrated for four different temperatures: 110°, 115°, 120°, and 125°F.

Figure 15-14 shows a salinometer and a brine sampling pot. A brine sample is drained into the pot from a test valve and the temperature is measured. The temperature must be adjusted to correspond with one of the temperature scales on the salinometer to accurately measure the density. The salinometer is then placed in the pot, weighted end down, and allowed to float in the brine. The brine density is read where the brine water level crosses the scale on the side of the graduated stem that corresponds to the brine temperature.

You should check salinometers each month by measuring the density of distilled water. You can obtain a sample at the proper temperature by bypassing the distillate cooler, or you can heat a sample of the distillate. The reading of the pure water should always be zero (0/32 at a specified temperature). Follow the instructions and procedures in the EOSS for your plant and ship for adjusting the brine density. A properly operated and maintained distilling plant will give many years of satisfactory service.

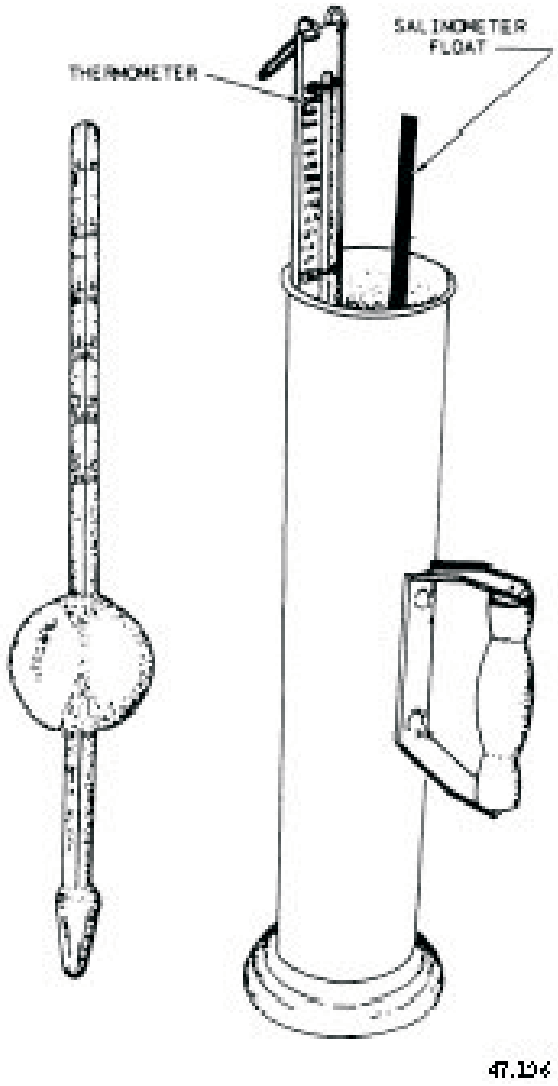


Figure 15-14.—Salinometer and sampling pot.

REVERSE OSMOSIS DESALINATION UNIT (RODU)

The purpose of the RODU is to produce pure water for drinking, cooking, and other freshwater uses. The process the RODU uses to remove salt is to force high-pressure saltwater through a membrane that has holes small enough that salt will not pass through but water will pass through.

GENERAL DESCRIPTION OF THE RODU

The RODU consists of the following major components:

1. Filter skid: Consists of an electric heater, centrifugal separator, 20-micron filter, 3 micron filter, and activated carbon filter
2. High pressure pump skid: Consists of a high pressure pump, high pressure pump motor, V-belt drive, and accumulator
3. Reverse osmosis module skid: Consists of a pressure vessel, dump valve, flow meters, flow totalizer, and relief valve
4. Control panel: Consists of a main control panel, power panel, salinity monitor panel, and gauge panel.

REVERSE OSMOSIS MODULE

The eight spiral–wound membranes are the core of the RODU. The unit has two parallel circuits of four membranes in series. The membranes permit permeate to pass through but prevents most of the solids from passing through. The water that does not pass through the first membrane becomes more concentrated as it flows from one membrane to the next membrane in line. What does not go through the fourth membrane gets discharged as waste (brine) over the side.

The membranes are arranged so that two membranes are in one titanium vessel (pressure vessel). The permeate from each membrane does flow together. The four pressure vessels are piped into two parallel circuits, with two in series per circuit, for the saltwater path.

The brine leaves the vessel and goes through a pressure reduction coil and brine restrictor valve. The coil dissipates most of the pressure to reduce the amount of noise that would be generated. The brine restrictor valve in used to adjust the backpressure.

Each permeate discharge tube is connected at a common header. Each tube has a cutout valve and sample valve on them. This allows you to isolate a failed membrane from the permeate header and leaves the unit online. There is a permeate temperature switch on the header to prevent the pressure vessel from freezing up and rupturing the membrane. The switch will shut down the system if proper temperature is not maintained.

The flow totalizer registers cumulative gallons of water produced by the RODU.

Dump Valve

The dump valve is a three-way solenoid valve that diverts permeate water from the RODU to either the wastewater drain system or to the fresh water storage tanks. The conductivity of the water decides where the water is going.

Flow Meter

There are two flow meters in the system. One is on the brine line and the other is on the permeate line. Both flow meters tell GPM (gallons per minute). By adding the two flow meters together you can tell whether the HP pump is performing properly.

FILTER SKID

The seawater is supplied to the RODU from the firemain system. Prior to the filter skid is a duplex strainer (which is not part of the filter skid) to remove sea growth and solid particles. The filter skid is used to remove large particles out of the seawater before it goes to the high-pressure pump.

The first component is the immersion heater to ensure that the temperature of the feed water is maintained to prevent the permeate from freezing in the RO pressure vessel. The heater is energized at 35ºF and de-energized at 38ºF to prevent the permeate from freezing in the RO pressure vessel.

The next component is the centrifugal separator, which uses centrifugal action to separate large suspended solids from the water.

After the centrifugal separator is the 20-micron filter assembly. The filter assembly consist of filter elements that will not allow any particles 20 microns or bigger to pass through. The next is a 3-micron filter assembly. This filter assembly also has eight filter elements, that will not allow any particles 3 microns or bigger to pass through.

Maintaining the filter elements and monitoring the differential pressure gauges are vital to the performance of the RODU. A large number of solid particles and/or sea growth entering the RO pressure vessel will shorten the life of the RO membrane or reduce the production of permeate water.

There is an active carbon filter assembly that has eight filter elements. This assembly is used to remove

any chlorine or bromine from fresh water. The fresh water is used for freshwater flush and cleaning modes. Chlorine and/or bromine will damage the RO membrane.

HIGH PRESSURE PUMP SKID

The pump skid consists of a high-pressure pump, high-pressure pump motor, V-belt drive, and accumulator. The purpose of the high-pressure skid is to increase the pressure above osmotic pressure to allow efficient reverse osmosis to take place across the RO membranes.

The HP pump is a three-plunger, reciprocating positive displacement type pump. Low- and high-pressure switches protect the pump. Both switches will shut the pump down to prevent damage to the pump and/or system.

The HP pump drive motor is equipped with thermistors embedded in the motor windings to protect the motor. In the event of the motor overheats they will shut the motor down.

The V-belt drive decreases the motor rpm down to the rpm used by the pump. The pump and the motor both have sheave pulleys. The reciprocating motion of the HP pump creates surges in both upstream and downstream piping. An accumulator is installed in the discharge piping to absorb the variation in fluctuation in cyclical flow and reduce the fluctuation in pressure. Without the accumulator these unhampered stressed or fluctuations in pressure would eventually cause failures in the pump and surrounding auxiliary components and membranes. The accumulator consists of nitrogen-charge rubber bladder inside a vessel.

CONTROL PANEL

The control panel is broken down into the main control panel, power panel, salinity monitor panel, and the gauge panel.

The main control panel houses the control switches, indicating lights, alarms, power supplies, controllers and protective devices. It is the central control system for the RODU. The indicating lights, push-buttons switches audible alarm and elapsed time meter are mounted on the outside cover.

SUMMARY

In this chapter, we have discussed two types of low-pressure distilling plants (submerged-tube unit and flash-type unit) and the reverse osmosis desalination unit. You should be able to identify the individual components of these distilling plants and how they contribute to the overall process of distillation. As an Engineman, you should be able to identify the ways in which these plants differ. You should also be able to identify the requirements that the distillate must meet for it to be usable. If you are unclear in any of these areas, go back and review this chapter before continuing to chapter 16.

CHAPTER 16

REFRIGERATION

As an Engineman, you must have a knowledge of refrigeration and air-conditioning systems. Much of the information pertaining to refrigeration will also apply to various air-conditioning systems that will be discussed in chapter 17. When you are assigned to a ship, you will learn how to start, operate, stand watch on, and secure these systems. You may also be assigned to assist with the maintenance of refrigeration plants. Before you can do these things, however, you must have a thorough understanding of the operating principles of these systems. You can learn these principles if you study this chapter thoroughly and carefully.

Most refrigeration systems used by the Navy use R-12 as a refrigerant. Chemically, R-12 is dichlorodifluoromethane ($CC1_2F_2$) one of a family of halocarbons. At atmospheric pressure, the boiling point of R-12 is – 21.6°F, which is more than 50° lower than the freezing point of water. The boiling point of R-12 may be lowered even more by operating the low pressure side of a refrigeration system at less than atmospheric pressure (partial vacuum). You should realize, however, that the cycle of operation and the main components of R-12 systems are basically the same as those in reciprocating refrigeration and air-conditioning plants that use other kinds of refrigerant.

After studying the information in this chapter, you should be able to understand the fundamental concepts of refrigeration. You should also be able to identify the major components of a refrigeration system in terms of their functions, relative locations, associated components, and purposes within the system.

FUNDAMENTALS OF REFRIGERATION

Refrigeration is a general term. It describes the process of removing heat from spaces, objects, or materials and maintaining them at a temperature below that of the surrounding atmosphere. To produce a refrigeration effect, the material to be cooled needs only to be exposed to a colder object or environment. The heat will flow in its NATURAL direction—that is, from the warmer material to the colder material. Refrigeration, then, generally means an artificial way of lowering the temperature. Mechanical refrigeration is a mechanical system or apparatus that transfers heat from one substance to another.

You will find the concept of refrigeration easier to understand if you know the relationships among temperature, pressure, and volume, and how pressure affects liquids and gases.

HEAT

The purpose of refrigeration is to maintain spaces at low temperatures. Remember, you cannot cool anything by adding coolness to it; you have to REMOVE HEAT from it. Therefore, refrigeration cools by removing heat.

Heat and Temperature

It is important to know the difference between heat and temperature. HEAT is a form of energy. TEMPERATURE is a measure of the intensity of heat. The quantity or amount of heat energy in a substance is measured in BRITISH THERMAL UNITS (Btus). At atmospheric pressure, 1 Btu is the amount of heat required to raise the temperature of 1 pound of pure water 1°F. In the opposite case, when 1 Btu is removed from 1 pound of water, the temperature of the water will drop 1°F. Temperature, as you know, is measured in degrees. The degrees indicate the intensity of the heat in a given substance. Temperature does not indicate the number of Btus in the substance. For example, let's consider a spoonful of very hot water and a bucketful of warm water. Which has the higher temperature? Which has more heat? The heat in the spoonful of hot water is more intense; therefore, its

temperature is higher. The bucketful of warm water has more Btus (more heat energy), but its heat is less intense.

Sensible Heat and Latent Heat

In the study of refrigeration, you must be able to distinguish between sensible heat and latent heat. SENSIBLE HEAT is the heat absorbed or given off by a substance that is NOT in the process of changing its physical state. Sensible heat can be sensed, or measured, with a thermometer, and the addition or removal of sensible heat will always cause a change in the temperature of the substance.

LATENT HEAT is the heat absorbed or given off by a substance while it is changing its physical state. The heat absorbed or given off does NOT cause a temperature change in the substance—the heat is latent or hidden. In other words, sensible heat is the heat that affects the temperature of things; latent heat is the heat that affects the physical state of things. You will find more information on sensible heat and latent heat in chapter 3 of *Fireman,* NAVEDTRA 10520-H.

Specific Heat

Substances vary with respect to their ability to absorb or lose heat. The ability of a substance to absorb (or lose) heat is known as the SPECIFIC HEAT of the substance. The specific heat of water is 1.0 (1 Btu/lb/°F), and the specific heat of every other substance is measured in relation to this standard. Thus, if it takes only 0.5 Btu to raise the temperature of 1 pound of a substance 1°F, the specific heat of that substance is 0.5 or one-half the specific heat of water. If you look up the specific heat of ice in a table, you will find it to be approximately 0.5.

Heat Flow

Heat flows only from objects of higher temperature to objects of lower temperature. This was described earlier as the natural flow of heat. When two objects at different temperatures are placed near each other, heat will flow from the warmer object to the cooler one until both objects are at the same temperature. Heat flows at a greater rate when there is a large temperature difference. As the temperature difference approaches zero, the rate of heat flow also approaches zero. Heat transfer will occur between two materials of different temperature. Heat will flow from the high-temperature body to the low-temperature body. However, all materials do not conduct heat at the same rate. Some materials, such as metals, conduct heat readily. Other materials, such as wood and cork, offer considerable resistance to the conduction of heat. The relative capacity of a material to conduct heat is known as its THERMAL CONDUCTIVITY. Heat flow may take place by radiation, conduction, convection, or some combination of these met hods.

RADIATION.—Heat transfer by radiation from one body to another occurs in the form of a wave motion similar to that of a light wave or radio wave. No intervening matter is required for heat transfer to take place by radiation. For example, the sun transmits great amounts of heat energy to the earth by radiation across the vacuum of space. By standing close to a fire, you can readily feel the heat radiated by the fire. Heat transfer by radiation will occur between any two bodies that are visible to one another and that exist at differing temperatures.

CONDUCTION.—Heat transfer by conduction occurs when energy is transferred by direct contact between molecules of a single body or among molecules of two or more bodies in physical contact with each other. Conduction takes place from the area of the higher temperature to that of the lower temperature. For example, if you hold an iron bar in one hand and place the other end of the bar in a bed of hot coals, the heat will pass from the coals to the bar, and then along the bar to your hand. Physical contact is made in each instance; the coals to the bar, and the bar to your hand.

CONVECTION.—Convection is the transfer of heat by the movement of a substance (gas or liquid) through a space. Examples of heat transfer by convection include a current of warm air in a room and warm air rising from hot water.

Refrigeration Ton

The unit of measure for the amount of heat removed is known as the REFRIGERATION TON. The capacity of a refrigeration unit is usually stated in refrigeration tons. The refrigeration ton is based on the cooling effect of 1 ton (2,000 pounds) of ice at 32°F melting in 24 hours. The latent heat of fusion of 1 pound of ice (or water) is

144 Btus. Therefore, the number of Btus required to melt 1 ton of ice is 144 x 2,000 = 288,000. The standard refrigeration ton is defined as the transfer of 288,000 Btus in 24 hours. On an hourly basis, a refrigeration ton is equivalent to 12,000 Btus per hour (288,000 is divided by 24).

The refrigeration ton is the standard unit of measure that designates the heat flow capacity of a refrigeration unit. It is NOT a measure of the ice-making capacity of a machine, since the amount of ice that can be made depends on the initial temperature of the water and other factors.

PRESSURE, TEMPERATURE, AND VOLUME

We said earlier that it is important that you understand some of the ways in which pressure affects liquids and gases and some of the relationships between pressure, temperature, and volume in gases.

The boiling point of any liquid varies according to the pressure on the liquid—the higher the pressure, the higher the boiling point. You should remember that condensing a gas to a liquid is just the reverse process of boiling a liquid until it vaporizes. The same pressure and temperature relationship is required to produce either change of state.

Water boils at 212°F at the atmospheric pressure of 14.7 psia, at 80°F under a vacuum of 29 inches of mercury, and at 489°F at a pressure of 600 psig. Refrigerants used in vapor compressor cycle equipment usually have much lower boiling points than water under any given pressure. However, these boiling points also vary according to pressure. At atmospheric pressure, for example, the refrigerant R-12 boils at – 21.6°F. At 30 psig, R-12 boils at 32°F, which is the freezing point of water. You should see that R-12 cannot exist as a liquid at ordinary temperatures. It must be confined within a container or closed space.

When the temperature of a liquid is raised to the boiling point corresponding to its pressure and if application of heat is continued, the liquid will begin to boil and vaporize. The vapor that is formed will remain at the same temperature as the boiling liquid as long as it is in contact with the liquid. A vapor CANNOT be superheated as long as it is in contact with the liquid from which it is being generated.

The pressure-temperature-volume relationships of gases are expressed by Boyle's law, Charles's law, and the general gas law or equation. We will briefly discuss each of these laws.

BOYLE'S LAW states that the volume of any dry gas varies inversely with its absolute pressure, provided the temperature remains constant. This law may also be expressed as the formula

$$V_1P_1 = V_2P_2$$

wherein V_1 is the original volume of the gas, P_1 is its original absolute pressure, V_2 is its new volume, and P_2 is its new absolute pressure.

CHARLES'S LAW states that the volume of a gas is directly proportional to its absolute temperature, provided the pressure is kept constant. The equation for Charles's law is

$$V_1T_2 = V_2T_1$$

The GENERAL GAS EQUATION combines Boyle's law and Charles's law. It expresses the interrelationship of the volume, the absolute pressure, and the absolute temperature of gases. The general gas law is expressed by the formula

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

In Boyle's law, Charles's law, and the general gas law, the equations indicate the nature of the interrelationship of the pressure, the volume, and the temperature of any gas. You probably will not find it necessary to use the equations themselves, but you should have a thorough understanding of the principles they express. Let's summarize them:

1. When TEMPERATURE is held constant, increasing the pressure on a gas causes a proportional decrease in volume. Decreasing the pressure causes a proportional increase in volume.

2. When PRESSURE is held constant, increasing the temperature of a gas causes a proportional increase in volume. Decreasing the temperature causes a proportional decrease in volume.

3. When the VOLUME is held constant, increasing the temperature of a gas causes a proportional increase in pressure. Decreasing the temperature causes a proportional decrease in pressure.

In discussing the effects of pressure on a gas, we have pointed out that the volume and the temperature of gas are different AFTER the pressure has been changed. It is important to note, however, that a temperature change normally occurs in a gas WHILE the pressure is being changed. Compressing a gas raises its temperature; allowing a gas to expand lowers its temperature. As you will see, these two facts are important to your understanding of the operating principles of the refrigeration cycle.

MECHANICAL REFRIGERATION SYSTEMS

Various types of refrigerating systems are used for naval shipboard refrigeration and air conditioning. The system that is used most often for refrigeration purposes is the vapor compression cycle with reciprocating compressors.

Figure 16-1 is a simple drawing of the vapor compression refrigeration cycle. As you study this system, try to understand what happens to the refrigerant as it passes through each part of the cycle. In particular, be sure you understand why the refrigerant changes from liquid to vapor and from vapor to liquid and what happens in terms of heat because of these changes of state. We will trace the refrigerant through its entire cycle, beginning with the thermostatic expansion valve (TXV).

Liquid refrigerant enters the expansion valve, which separates the high-pressure side of the system and the low-pressure side of the system. This valve regulates the amount of refrigerant that enters the cooling coil. Because of the pressure differential, as the refrigerant passes through the TXV, some of the refrigerant "flashes" to a vapor (changes state from a liquid to a gas).

From the TXV, the refrigerant passes into the cooling coils or evaporator. The boiling point of the refrigerant under the low pressure in the evaporator is usually maintained at about 20°F lower than the temperature of the space in which the cooling coil is installed. As the liquid boils and vaporizes, it absorbs latent heat of vaporization from the space being cooled. The refrigerant continues to absorb latent heat of vaporization until all the liquid has been vaporized. By the time the refrigerant leaves the cooling coils, it has not only absorbed its latent heat of vaporization but has also picked up some additional (sensible) heat. In other words, the vapor has become SUPERHEATED. As a rule, the amount of superheat is 8° to 12°F.

The refrigerant leaves the evaporator as low-pressure superheated vapor. The remainder of the vapor compression cycle serves to carry this heat away and convert the refrigerant back into a liquid state. In this way, the refrigerant can again vaporize in the evaporator and absorb the heat.

The low-pressure superheated vapor flows out of the evaporator to the compressor, which provides the mechanical force to keep the refrigerant circulating through the system. In the compressor cylinders, the refrigerant is compressed from a low-pressure, low-temperature vapor to a high-pressure vapor, and its temperature rises accordingly.

The heated high-pressure R-12 vapor is discharged from the compressor into the condenser, which is simply a heat exchanger that uses water or air as a coolant. Here the refrigerant condenses, giving up its superheat (sensible heat) and latent heat of condensation. The cooled refrigerant, still at high pressure, is now a liquid again.

From the condenser, the refrigerant flows into a receiver, which serves as a storage place for the liquid refrigerant in the system. From the receiver, the refrigerant goes to the TXV and the cycle begins again.

This type of refrigeration system has two pressure sides. The LOW-PRESSURE SIDE extends from the TXV up to and including the intake side of the compressor cylinders. The HIGH-PRESSURE SIDE extends from the discharge valve of the compressor to the TXV.

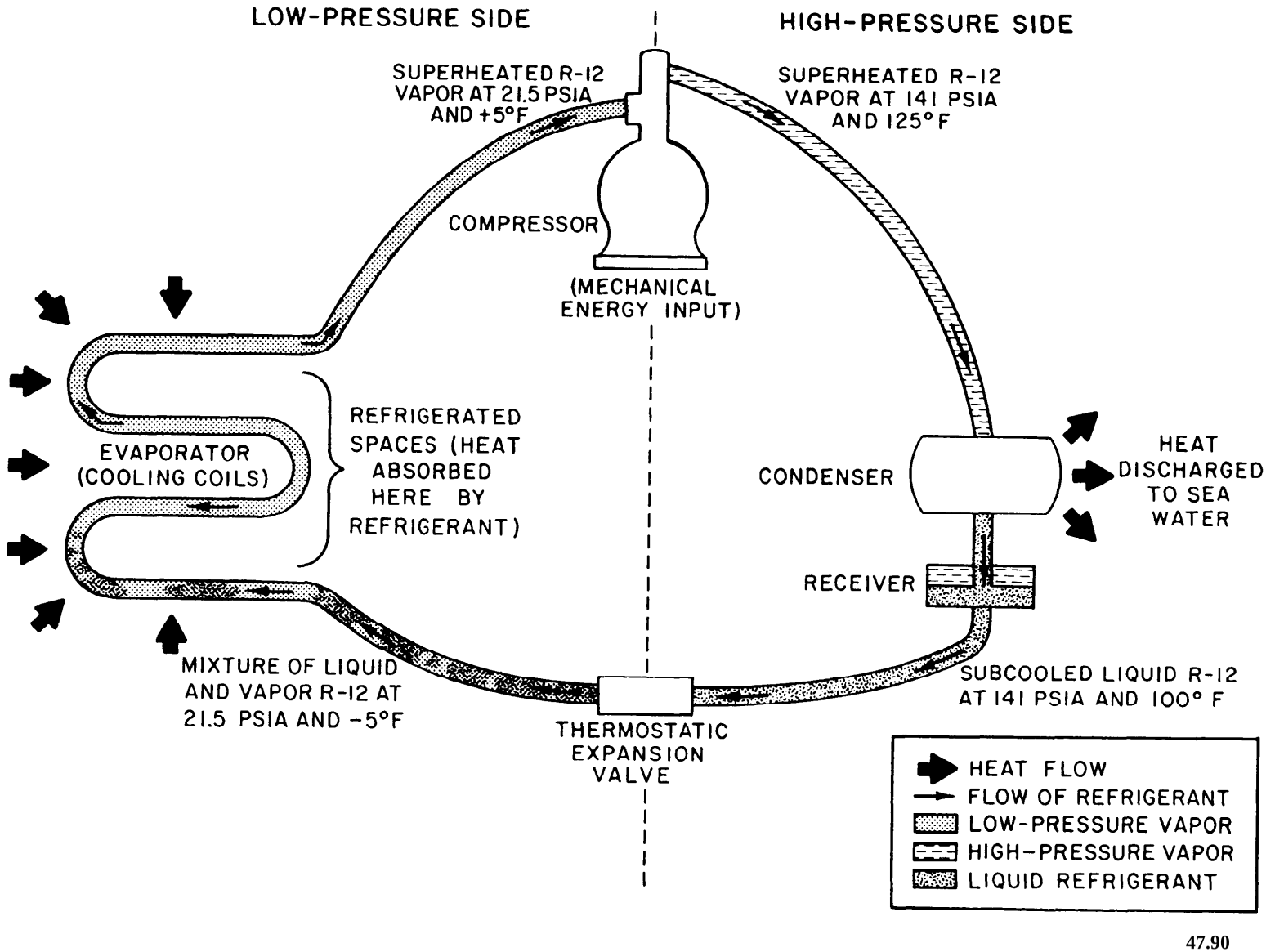
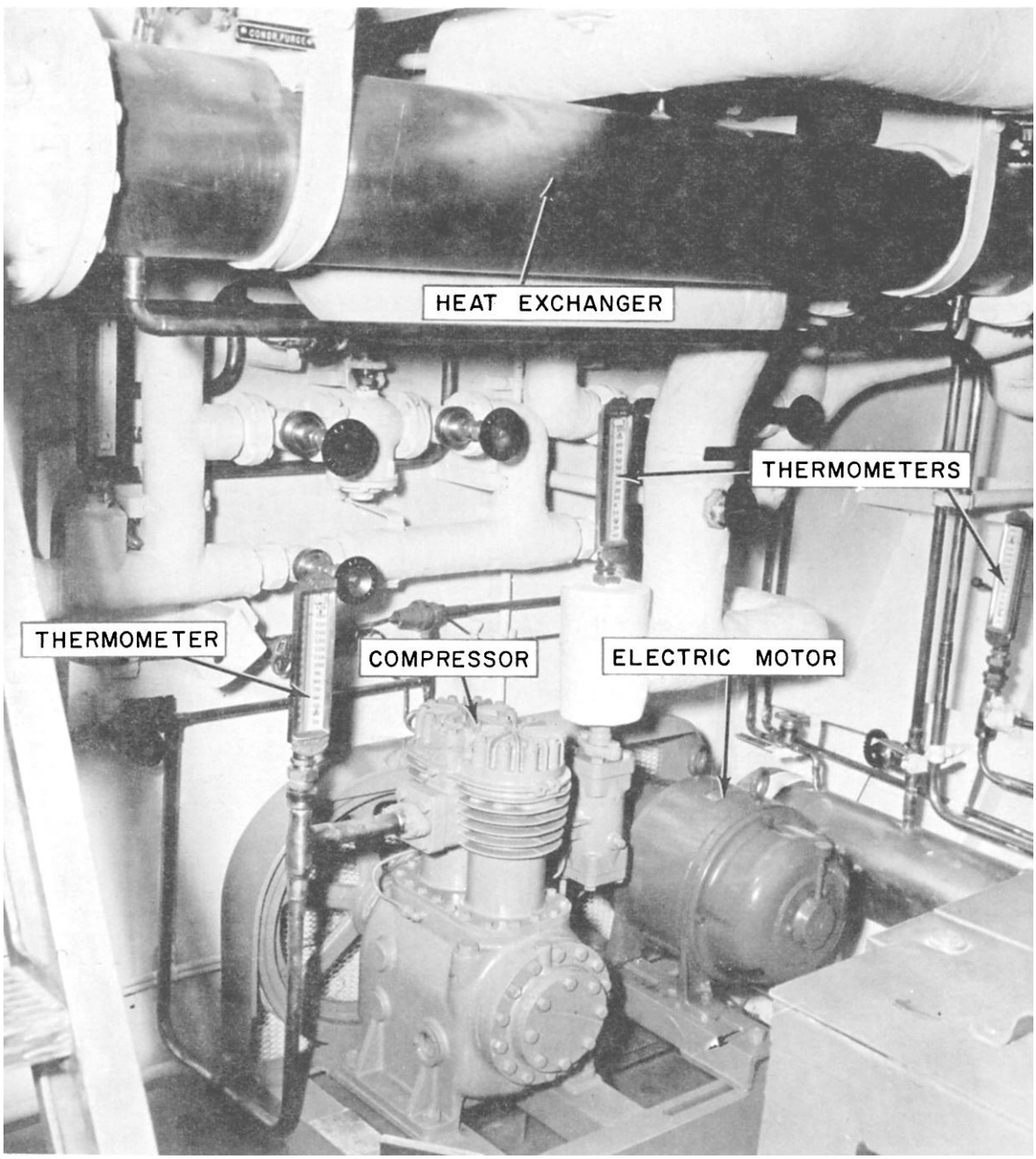


Figure 16-1.—A refrigeration cycle.

Figure 16-2 shows most of the components on the high-pressure side of an R-12 system as it is installed aboard ship.

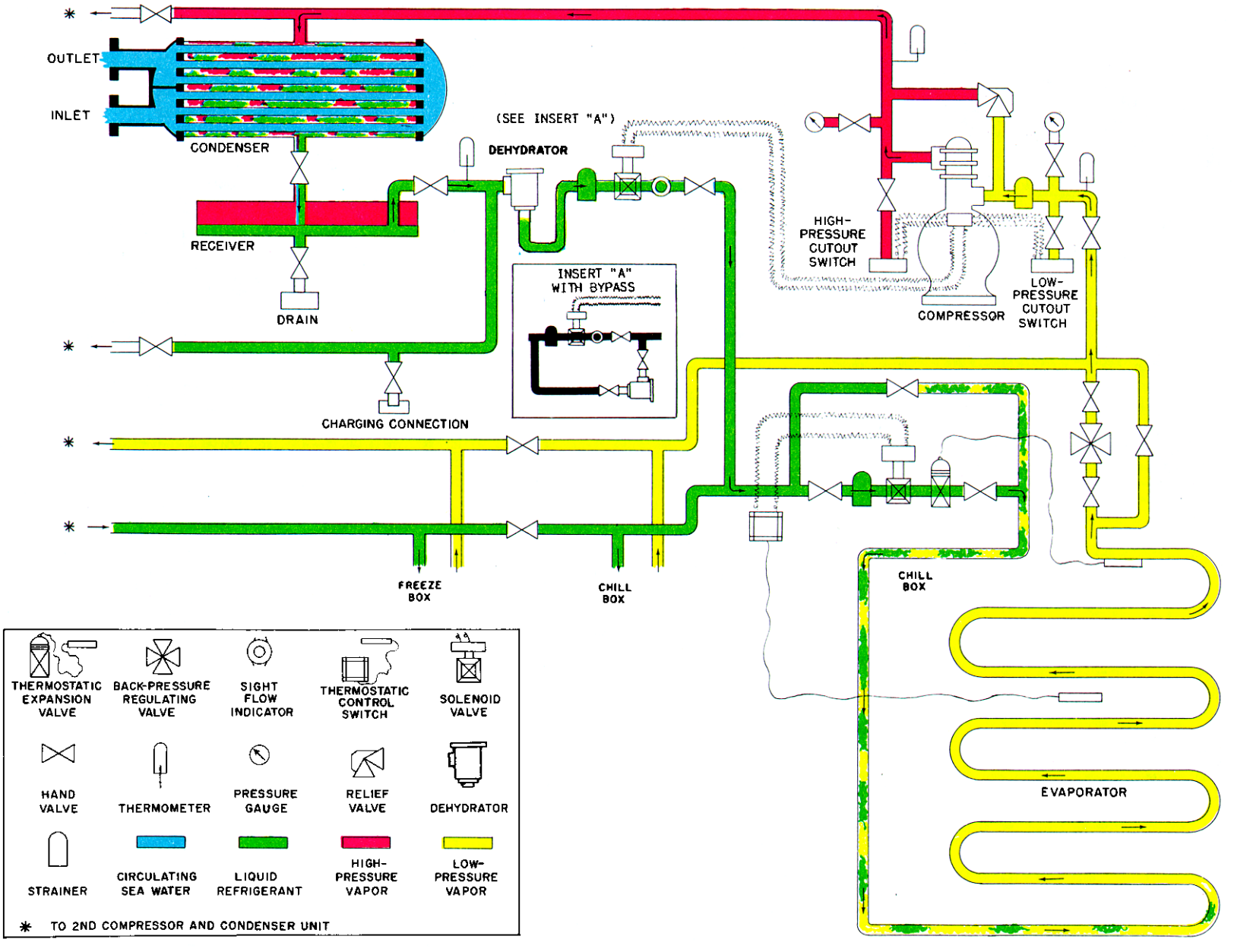
MAIN COMPONENTS OF AN R-12 REFRIGERATION SYSTEM

Figure 16-3 is a general diagram of the main parts of an R-12 refrigeration system. The primary components of the system are the TXV, the evaporator, the compressor, the condenser, and the receiver. Additional equipment required to complete the plant includes piping, pressure gauges, thermometers, various types of control switches and control valves, strainers, relief valves, sight-flow indicators, dehydrators, and refrigerant charging connections.



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Figure 16-2.—The high-pressure side of an R-12 refrigeration installation aboard ship.



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Figure 16-3.—Diagram of an R-12 refrigeration system.

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In this chapter, we will discuss the R-12 system as though it had only one evaporator, one compressor, and one condenser. You should realize, however, that a refrigeration system may (and usually will) include more than one evaporator. It may also include an additional compressor and other condenser units. We will discuss the main components and their functions.

THERMOSTATIC EXPANSION VALVE (TXV)

We mentioned earlier that the TXV regulates the amount of refrigerant to the cooling coils. The amount of refrigerant needed in the coils depends, of course, on the temperature of the space being cooled.

The thermal control bulb, which controls the opening and closing of the TXV, is clamped to the evaporator coil near the outlet. The substance in the thermal bulb will vary depending on the refrigerant used. The expansion and contraction (because of temperature change) transmit a pressure to the diaphragm. This causes the diaphragm to be moved downward, opening the valve and allowing more refrigerant to enter the cooling coil. When the temperature at the control bulb falls, the pressure above the diaphragm decreases and the valve tends to close. Thus, the temperature near the evaporator outlet controls the operation of the TXV.

EVAPORATOR

The evaporator consists of coils of copper, aluminum, or aluminum alloy tubing installed in the space to be refrigerated. Figure 16-4 shows some of this tubing. As mentioned before, liquid R-12 enters the tubing at a reduced pressure and, therefore, with a lower boiling point. As the refrigerant passes through the evaporator, the heat flowing to the coils from the surrounding air causes the rest of the liquid refrigerant to boil and vaporize. After the refrigerant has absorbed its latent heat of vaporization (that is, after it is entirely vaporized), the refrigerant continues to absorb heat until it becomes superheated. The amount of superheat is determined by the amount of liquid refrigerant admitted to the evaporator. The amount of liquid refrigerant, in turn, is controlled by the spring adjustment of the TXV.



47.93

Figure 16-4.—Evaporator tubing.

A range of 8° to 12°F of superheat is considered desirable because it increases the efficiency of the plant by ensuring that all of the liquid entering has changed state to a vapor before it leaves the evaporator. Evaporation of all the liquid prevents any liquid carry-over into the compressor. Remember, the compressor is designed to pump a gas—not a liquid.

COMPRESSOR

The compressor in a refrigeration system is essentially a pump. The compressor pumps heat "uphill" from the cold side to the hot side of the system.

The compressor also keeps the refrigerant circulating and maintains the required pressure difference between the high-pressure and low-pressure sides of the system.

The heat absorbed by the refrigerant in the evaporator must be removed before the refrigerant can again absorb latent heat. The only way the vaporized refrigerant can be made to give up the latent heat of vaporization it absorbed in the evaporator is by cooling it and causing it to condense. Because of the relatively high temperature of the available cooling medium, the only way to make the vapor condense is by first compressing it.

When we raise the pressure, we also raise the temperature. By doing so, we have raised its

condensing temperature, which allows us to use readily available seawater as a cooling medium in the condenser.

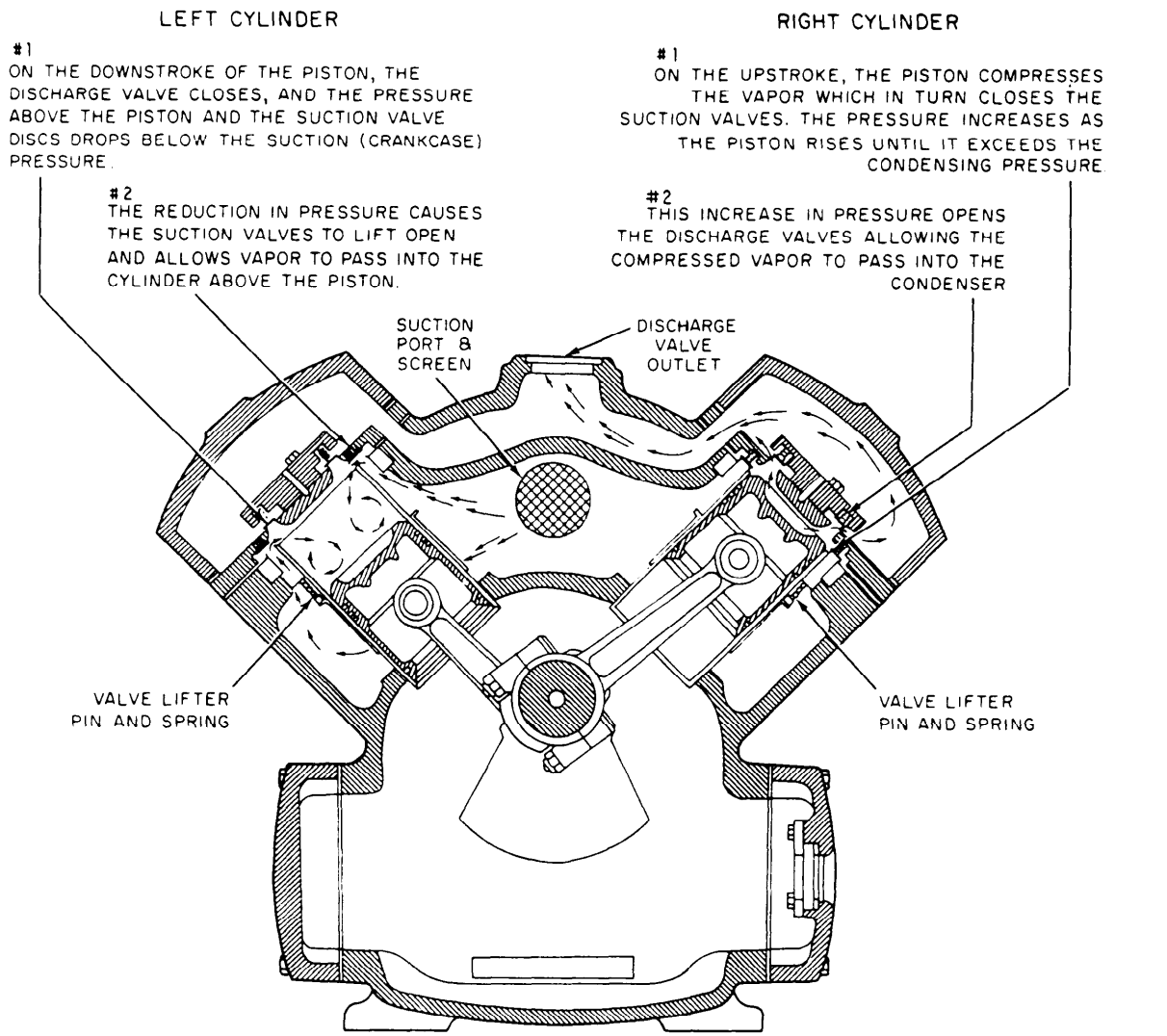
Many different types of compressors are used in refrigeration systems. The designs of compressors vary depending on the application of the refrigerants used in the system. Figure 16-5 shows a motor-driven, single-acting, two-cylinder, reciprocating compressor, such as those commonly used in naval refrigeration plants.

Lubrication

Compressors used in R-12 systems may be lubricated either by splash lubrication or by pressure lubrication. Splash lubrication, which depends on maintaining a fairly high oil level in the compressor crankcase, is usually satisfactory for smaller compressors. High-speed or large-capacity compressors use pressure lubrication systems.

Shaft Seals

Where the crankshaft extends through the crankcase, a crankshaft seal assembly prevents the refrigerant from escaping and air from entering the crankcase when the pressure in the crankcase is lower than the surrounding atmospheric pressure. There are several designs of seals used, such as the rotary seal, the stationary bellows, the rotating bellows, and the diaphragm.

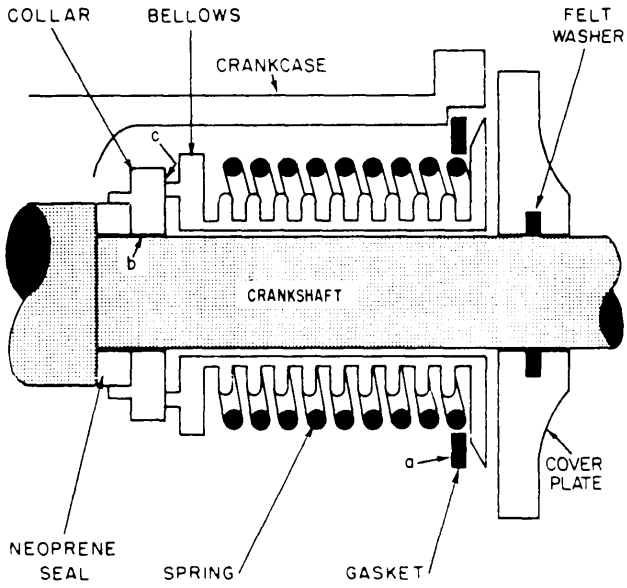


47.215

Figure 16-5.—Reciprocating compressor.

The rotary seal, shown in figure 16-6, consists of a stationary cover plate and gasket and a rotating assembly, which includes a carbon ring, a neoprene seal, a compression spring, and compression washers. The sealing points are (a) between the crankshaft and the rotating carbon rings and sealed by a neoprene ring, (b) between the rotating carbon ring and the cover plate and sealed by lapped surfaces, and (c) between the cover plate and the crankcase and sealed by a metallic gasket. The seal is adjusted by adding or removing metal washers between the crankshaft shoulder and the shaft seal compression spring.

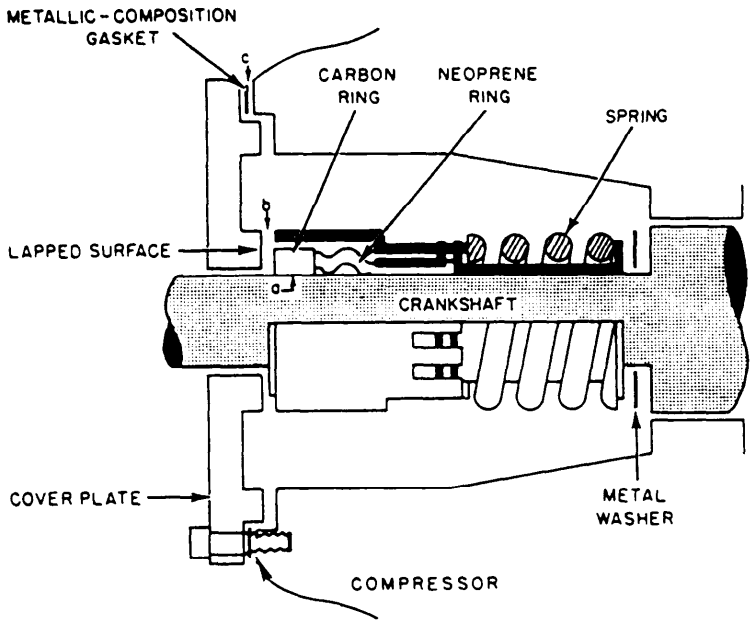
A stationary bellows seal is illustrated in figure 16-7. It consists of a bellows clamped to the compressor housing at one end to form a seal against a rotating shaft seal collar on the other end. The sealing points are (a) between the crankcase and the bellows and sealed by the cover plate gasket, (b) between the crankshaft and the shaft seal collar and sealed by a neoprene gasket, and (c) between the surface of the bellows nose and the surface of the seal collar and sealed by lapped surfaces. The stationary bellows seal is factory set for proper tension. You should not alter this seal.



168.8

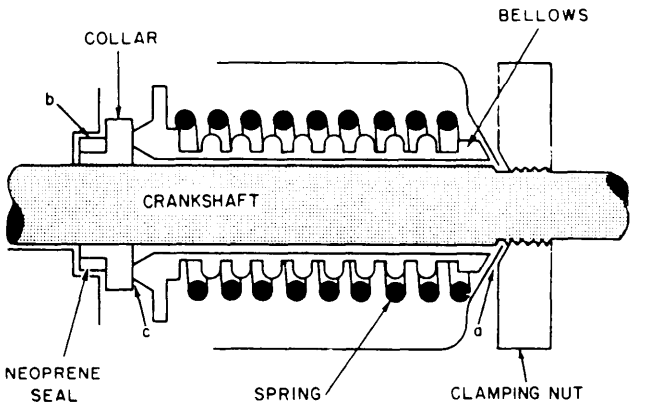
Figure 16-7.—Stationary bellows seal.

The rotating bellows seal in figure 16-8 consists of a bellows clamped to the crankshaft at one end to form a seal against a stationary, removable shaft seal shoulder on the other end. The sealing points are located (a) between the



168.7

Figure 16-6.—Rotary seal.



168.9

Figure 16-8.—Rotating bellows seal.

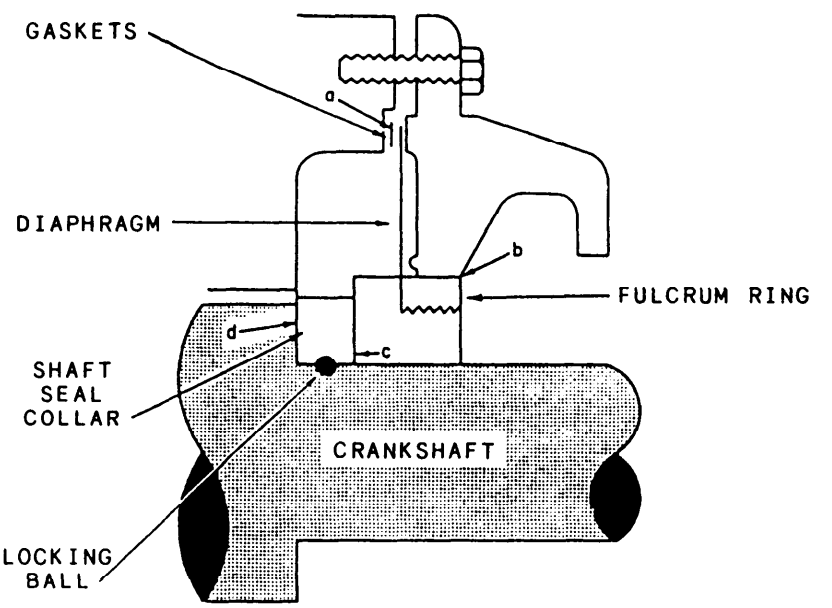
crankshaft and bellows and sealed by a shaft seal clamping nut, (b) between the removable shaft seal shoulder and the crankcase and sealed by a neoprene gasket, and (c) between the bellows nosepiece and the shaft seal collar and sealed by lapped surfaces. This seal is also factory set.

The diaphragm seal in figure 16-9 consists of a diaphragm clamped to the crankcase at its outer circumference and to a fulcrum ring at its center. The shaft seal collar is locked to the shaft with the steel ball and, therefore, rotates with the shaft. All other parts in the seal assembly are stationary. The fulcrum ring forms a seal collar which is locked to the diaphragm. The sealing points are located (a) between the outer circumference of the diaphragm and the crankcase and sealed by a copper ring gasket, (b) between the fulcrum ring and the diaphragm—sealed at the factory and not to be broken, (c) between the fulcrum ring and the rotating shaft seal collar and sealed by lapped surfaces, and (d) between the shaft seal collar and the crankshaft shoulder and also sealed by lapped surfaces.

You can adjust the tension in a diaphragm seal to obtain the specified deflection by adding or removing diaphragm-to-crankcase gaskets. For information on handling, cleaning, and replacing shaft seal assemblies, consult the NAVSEA technical manual or the directions enclosed with the new seal.

Capacity Control System

Most compressors are equipped with an oil pressure operated automatic capacity control system. The capacity control system unloads or cuts cylinders out of operation following any decrease in the refrigeration "load" requirements of the plant. A cylinder may be unloaded by a mechanism that holds the suction valve open so that no gas can be compressed.



168.10

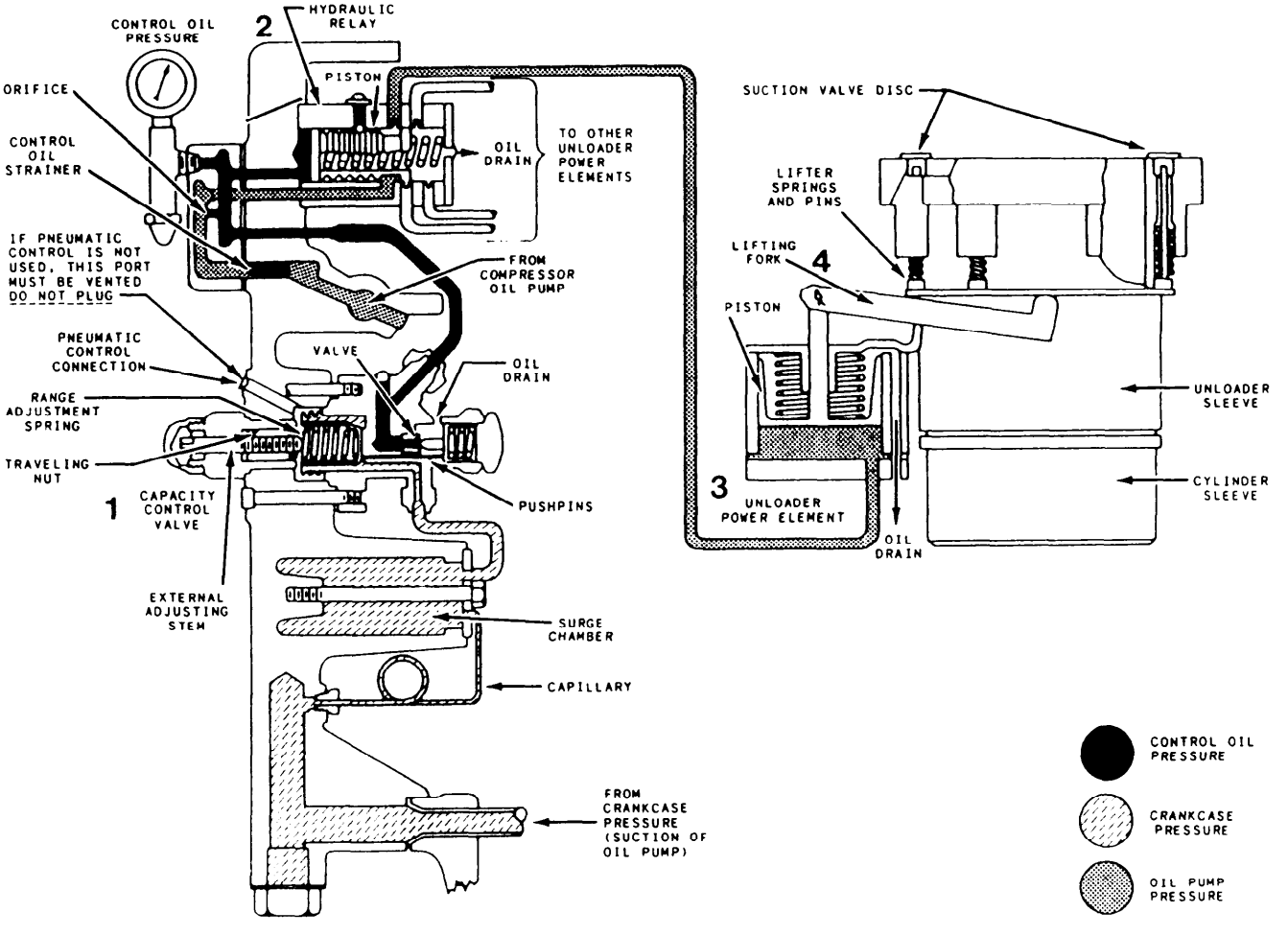
Figure 16-9.—Diaphragm-type seal.

Since oil pressure is required to load or put cylinders into operation, the compressor will start with all controlled cylinders unloaded. But as soon as the compressor is brought up to speed and full oil pressure is developed, all cylinders will become operative. After the temperature pulldown period, the refrigeration load imposed on the compressor should decrease, and the capacity control system will unload the cylinders accordingly. Unloading of the cylinders results in reduced power consumption. In designs where numerous cooling coils are supplied by one compressor, the capacity control system will prevent the suction pressure from dropping to the low-pressure cutout setting. This action will prevent the compressor from stopping before all solenoid valves are closed.

Several designs of capacity control systems are in use. One of the most common is shown in figure 16-10. The capacity control system consists of four major elements: (1) a capacity control valve, (2) a step control hydraulic relay, (3) a power element,. and (4) a valve lifting mechanism. We will briefly discuss each of these components.

CAPACITY CONTROL VALVE.—The function of the capacity control valve is to raise or lower control oil pressure to the hydraulic relay piston in response to changes in refrigerant suction pressure. An increase in suction pressure increases the control oil pressure in the hydraulic relay.

HYDRAULIC RELAY.—The function of the hydraulic relay is to feed the lubrication oil from the oil pump at full pressure in sequence to one



75.404

Figure 16-10.—Capacity control system.

or more power elements. The hydraulic relay is activated by the control oil pressure from the capacity control valve.

POWER ELEMENT.—In brief, the power element supplies the force required to operate the valve lifting mechanism.

VALVE LIFTING MECHANISM.—The valve lifting mechanism consists of a sleeve and pushpin assembly mounted around each controlled cylinder. The valve lifting mechanism either holds the suction valve open or allows it to remain in a normal operating position. The position of the valve depends on the action of the valve lifting mechanism which, in turn, depends on actuation by the power element.

We will now explain the operation of the capacity control system and how the four major components work together to provide for changes in refrigerant load requirements of the plant. Follow along as we discuss how the system operates under both a loaded condition and an unloading condition.

LOADED OPERATION.—When a compressor is started with a warm load on the refrigeration system, the following events occur. A rise in the suction pressure increases the pressure against the capacity control valve bellows, compressing the range adjustment spring. The compression of the range adjustment spring allows the valve spring to move the pushpins and needle point of the valve toward the valve seat.

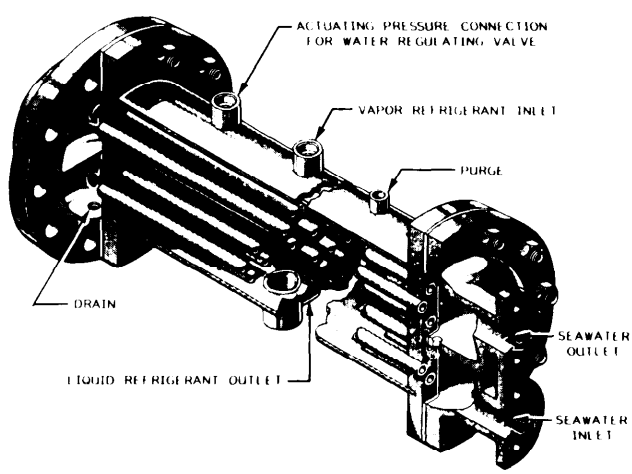
The flow of control oil to the crankcase through the oil drain is throttled. Control oil pressure rises as oil enters the capacity control circuit through the orifice from the compressor oil pump circuit. Then increased control oil pressure advances the hydraulic relay piston (against the spring), which feeds oil at full pressure to one or more controlled cylinder power elements, depending upon the position of the control valve. The pump oil pressure in the unloader power elements forces the piston upward, pivoting the lifting fork(s) downward. The lifter pins then drop, allowing the suction valve(s) to seat and load the cylinder(s).

UNLOADING OPERATION.—A drop in suction pressure decreases the pressure against the control valve bellows. The range adjustment spring presses against the pushpins, compressing the valve spring. This moves the needle valve off the seat. Control oil bleeds from the hydraulic relay and control valve to the crankcase, relieving oil pressure on the hydraulic piston. The piston retracts, preventing transmission of pressurized oil to the controlled cylinder power element(s) and to the oil drains to the crankcase. As oil pump pressure to the power element drops, the piston moves downward. The lifting fork(s) is(are) pivoted upward, moving the lifting pins upward; the suction valves are raised from their seats; and the controlled cylinders are then unloaded.

CONDENSER

The condenser receives the high-pressure, high-temperature refrigerant vapor from the compressor. In the condenser, the refrigerant vapor flows around tubes through which seawater is flowing. As the vapor gives up its superheat (sensible heat) to the seawater, the temperature of the vapor drops to the condensing point. The refrigerant then changes to a liquid and is subcooled slightly below its condensing point. This is done at the existing pressure to ensure that the liquid refrigerant will not flash into vapor.

A water-cooled condenser for an R-12 refrigeration system is shown in figure 16-11. Circulating water is obtained through a branch connection from the fire main or by an individual pump taking suction from the sea. The purge connection, shown in figure 16-11, is on the refrigerant side. It removes air and other noncondensable gases that are lighter than the R-12 vapor.



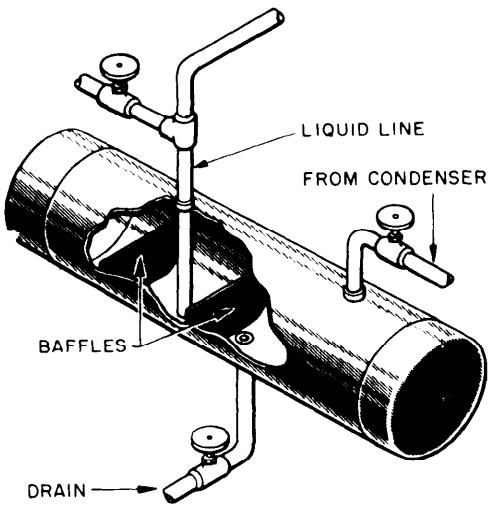
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Figure 16-11.—Cutaway view of a water-cooled condenser for an R-12 refrigeration system.

Most condensers used for shipboard refrigeration plants are of the water-cooled type. However, some small units have air-cooled condensers. Air-cooled condensers consist of tubing with external fins to increase the heat transfer surface. Most air-cooled condensers have fans to ensure positive circulation of air around the condenser tubes.

RECEIVER

The receiver, shown in figure 16-12, acts as a temporary storage space and surge tank for the liquid refrigerant. The receiver also serves as a vapor seal to keep vapor out of the liquid line to the expansion valve. Receivers may be constructed for either horizontal or vertical installation.



47.96

Figure 16-12.—Receiver.

ACCESSORIES OF AN R-12 REFRIGERATION SYSTEM

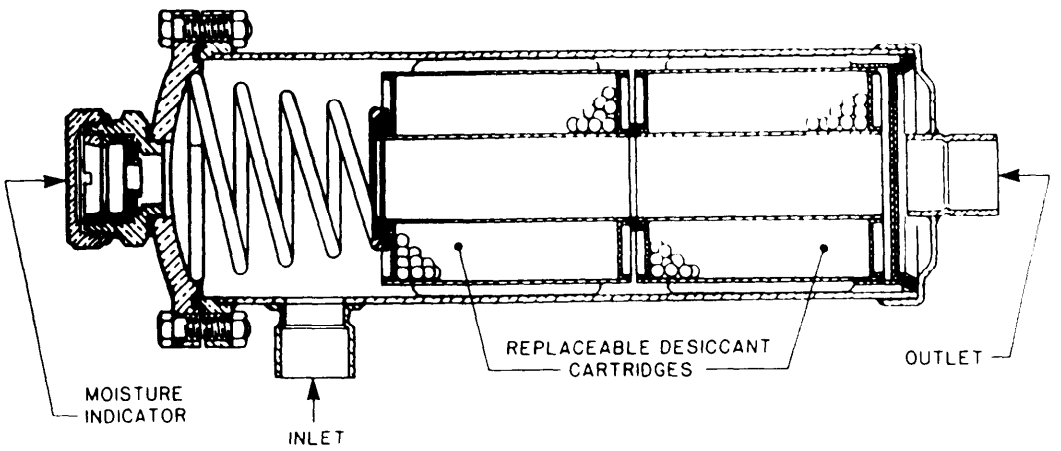
In addition to the five main components we have just described, a refrigeration system requires several controls and accessories. We will briefly describe the most important ones.

DEHYDRATOR

A dehydrator, or dryer, containing silica-gel or activated alumina, is placed in the liquid refrigerant line between the receiver and the TXV. In older installations, bypass valves allow the dehydrator to be cut in or out of the system. (See fig. 16-3, insert A.) In newer installations, the dehydrator is installed in the liquid refrigerant line without any bypass arrangement. (See fig. 16-3.)

MOISTURE INDICATOR

A moisture indicator is located either in the liquid refrigerant line or is built into the dehydrator as shown in figure 16-13. The moisture indicator contains a chemically treated element that changes color when there is an increase of moisture in the refrigerant. In an R-12 system, the indicator shows pink when the moisture level is too high; it shows blue when the moisture level is satisfactory. The color change is reversible and should change back to a DRY (blue) indication after the moisture has been removed from the



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Figure 16-13.—Refrigeration dehydrator with moisture indicator.

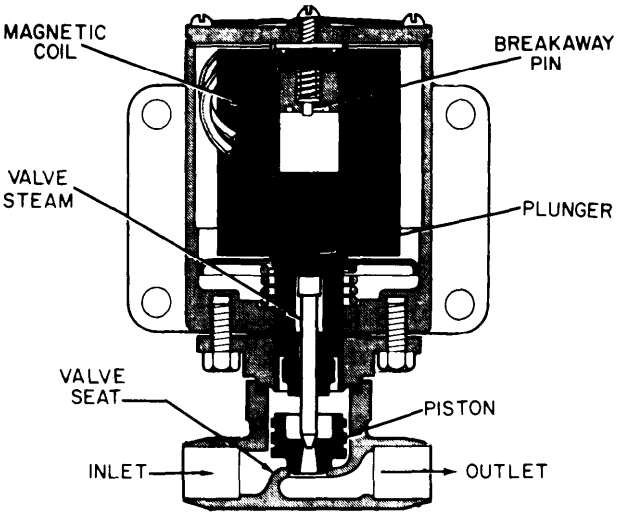
refrigerant. If excessive moisture or free water comes into contact with the moisture indicator element, the indicator will no longer register pink for wet, but will be light gray in color. It will no longer change color and must be replaced.

SOLENOID VALVE AND THERMOSTATIC CONTROL SWITCH

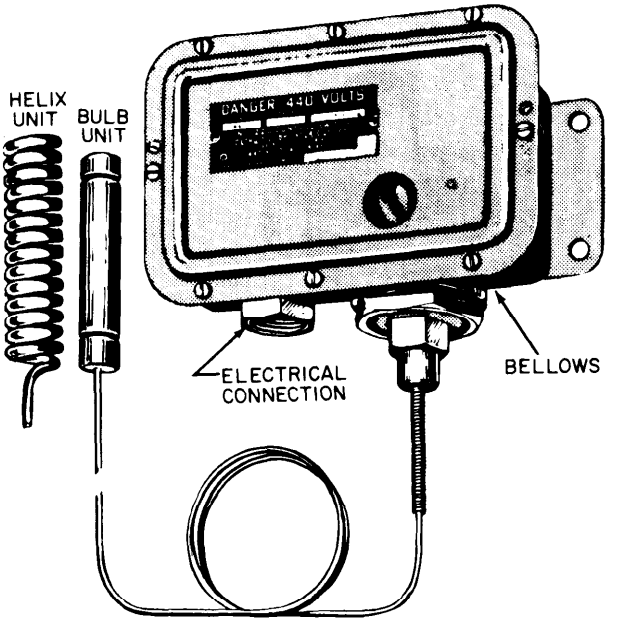
A solenoid valve is installed in the liquid line leading to each evaporator. Figure 16-14 shows a solenoid valve (view A) and the thermostatic control switch (view B) that operates it. The thermostatic control switch is connected by long flexible tubing to a thermal control bulb that is located in the refrigerated space. When the temperature in the refrigerated space drops to the desired point, the thermal control bulb causes the thermostatic control switch to open. This action closes the solenoid valve and shuts off all flow of liquid refrigerant to the TXV. When the temperature in the refrigerated space rises above the desired point, the thermostatic control switch closes, the solenoid valve opens, and liquid refrigerant once again flows to the TXV.

The solenoid valve and its related thermostatic control switch maintain the proper temperature in the refrigerated space. You may wonder why the solenoid valve is necessary if the TXV controls the amount of refrigerant admitted to the evaporator. Actually, the solenoid valve is not necessary on units that have only one evaporator. In systems that have more than one evaporator, where there is wide variation in load, the solenoid valve provides additional control to prevent the spaces from becoming too cold at light loads.

In addition to the solenoid valve installed in the line to each evaporator, a large refrigeration plant usually has a main liquid line solenoid valve installed just after the receiver. If the compressor stops for any reason except normal suction pressure control, the main liquid solenoid valve closes. This action prevents liquid refrigerant from flooding the evaporator and from flowing to the compressor suction. Extensive damage to the compressor can result if liquid is allowed to enter the compressor suction.



A. SOLENOID VALVE



B. THERMOSTATIC CONTROL SWITCH

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Figure 16-14.—Solenoid valve and thermostatic control switch.

EVAPORATOR PRESSURE REGULATING VALVE

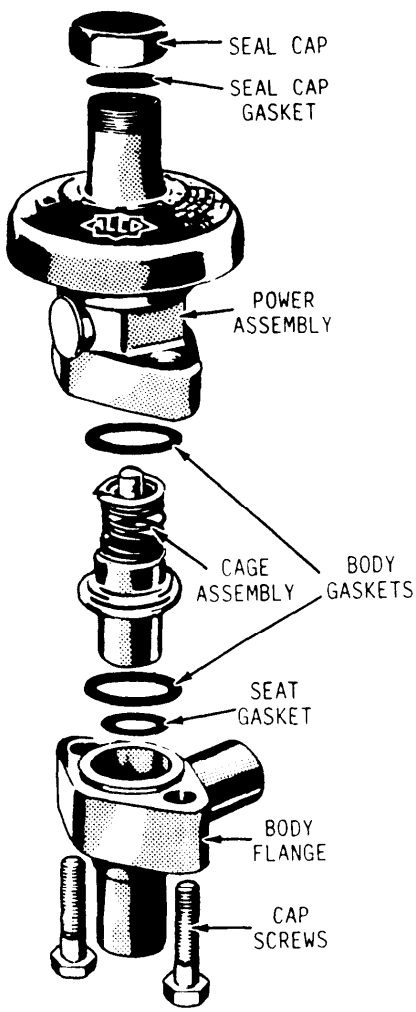
In some ships, several refrigerated spaces of varying temperatures are maintained by one compressor. In these cases, an evaporator pressure regulating (EPR) valve is installed at the outlet of each evaporator EXCEPT the evaporator in the space in which the lowest temperature is to be maintained. The EPR valve is set to keep the pressure in the coil from falling below the pressure corresponding to the lowest evaporator temperature desired in that space.

The EPR valve is used mostly on water coolers, on units where high humidity is required

(such as fruit and vegetable stowage spaces), and in installations where two or more rooms are maintained at different temperatures by the use of the same refrigeration unit.

A cross section of a common EPR valve is shown in figure 16-15. The tension of the spring above the diaphragm is adjusted so that when the evaporator coil pressure drops below the desired minimum, the spring will shut the valve.

The EPR valve is not really a temperature control—that is, it does not regulate the temperature in the space. It is only a device that prevents the temperature from becoming too low.



87.70

Figure 16-15.—Exploded view of a typical evaporator pressure regulating (EPR) valve.

LOW-PRESSURE CUTOUT SWITCH

The low-pressure cutout switch is also known as a suction pressure control switch. It is the control that causes the compressor to go on or off as required for normal operation of the refrigeration plant. This switch is connected to the suction side of the compressor and is actuated by pressure changes in the suction line. When the solenoid valves in the lines to the various evaporators are closed so that the flow of refrigerant to the evaporators is stopped, the pressure of the vapor in the compressor suction line drops quickly. When the suction pressure has dropped to the set pressure, the low-pressure cutout switch causes the compressor motor to stop. When the temperature in the refrigerated spaces has risen enough to operate one or more of the solenoid valves, refrigerant is again admitted to the cooling coils, and the compressor suction pressure builds up again. At the desired pressure, the low-pressure cutout switch closes, starting the compressor again and repeating the cycle.

HIGH-PRESSURE CUTOUT SWITCH

A high-pressure cutout switch is connected to the compressor discharge line to protect the high-pressure side of the system against excessive pressure. The design of this switch is essentially the same as that of the low-pressure cutout switch. However, the low-pressure cutout switch is made to CLOSE when the suction pressure reaches its upper normal limit. The high-pressure cutout switch is made to OPEN when the discharge pressure is too high. As mentioned before, the low-pressure cutout switch is the compressor control for normal operation of the plant. The high-pressure cutout switch, on the other hand, is a safety device only and does not have control of compressor operation under normal conditions.

OIL FAILURE SWITCH

An oil failure switch is provided with high-speed compressors. This differential pressure switch is designed to prevent operation of the compressor in the event of low oil pressure. The switch has one bellows connected to the discharge oil line of the compressor oil pump and the other connected to the compressor crankcase suction refrigeration pressure. The switch is set to open the electrical circuit and to stop the compressor when the oil pressure drops to a low-pressure set point. The switch closes the electrical circuit and

starts the compressor when the oil pressure reaches the reset set point.

To start the compressor after it has been stopped and the contacts of the oil failure switch have opened, a time delay mechanism works in conjunction with the compressor motor controller. The time delay switch should open 10 to 30 seconds after the compressor motor has started. The oil pressure will normally build up within this time interval. The oil pressure switch will have made contact to keep the compressor motor electrical circuit energized after the time delay switch opens. If the oil pressure has not built up within about 30 seconds after the compressor is started, the contacts of the oil pressure differential switch will not have closed. The compressor will stop because the time delay relay switch is open.

WATER FAILURE SWITCH

A water failure switch stops the compressor in the event of failure of the cooling water supply for the condenser. This is a pressure-actuated switch. It is generally similar to the low-pressure cutout switch and the high-pressure cutout switch previously described. If the water failure cutout switch fails to function, the refrigerant pressure in the condenser will quickly build up to the point that the high-pressure switch stops the compressor.

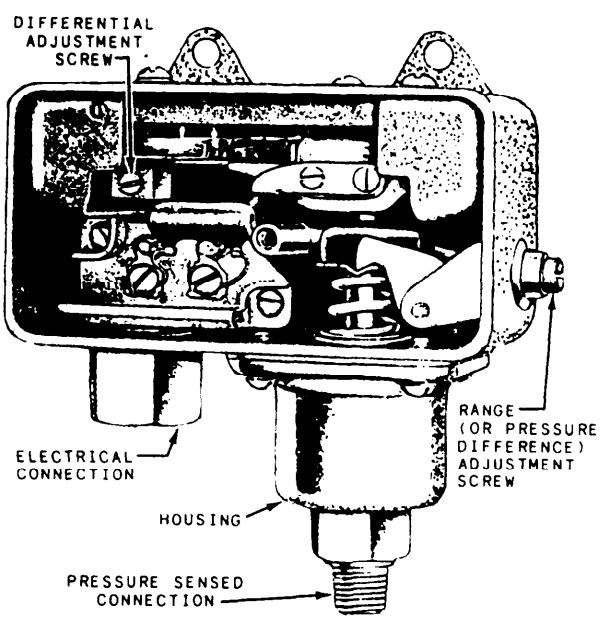
Figure 16-16 illustrates the general type of pressure-actuated control switch that is used in most installations. (In the illustration, the cover to the switch has been removed.) These switches are designed to operate at various pressure ranges. Some switches have manual reset buttons to prevent automatic restoration of power after the event of a high-pressure shutdown, such as high compressor discharge pressure. The oil pressure failure switch we discussed earlier has two bellows instead of one as shown in figure 16-16.

SUCTION STRAINER

Because of the solvent action of R-12, any particles of grit, scale, dirt, or metal that the system may contain are readily circulated through the refrigerant lines. As a precaution against damage to the compressor from foreign matter, a strainer is installed in the compressor suction connection.

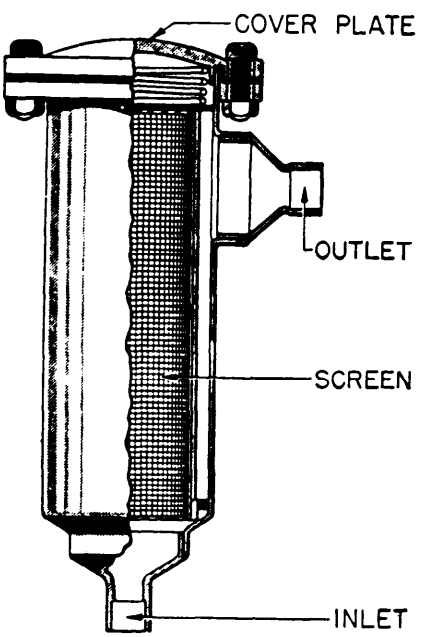
LIQUID STRAINER

A liquid strainer of the type shown in figure 16-17 is installed in the liquid line leading



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Figure 16-16.—Pressure-actuated control switch.



47.101

Figure 16-17.—Liquid refrigerant strainer.

to each evaporator. These strainers protect the solenoid valves and the TXV.

SPRING-LOADED RELIEF VALVE

A spring-loaded relief valve is installed in the compressor discharge line as an additional precaution against excessive pressures. The relief valve is set to open at approximately 225 psig. Therefore, it functions only in case of failure or improper setting of the high-pressure cutout switch. If the relief valve opens, it discharges high-pressure vapor to the suction side of the compressor.

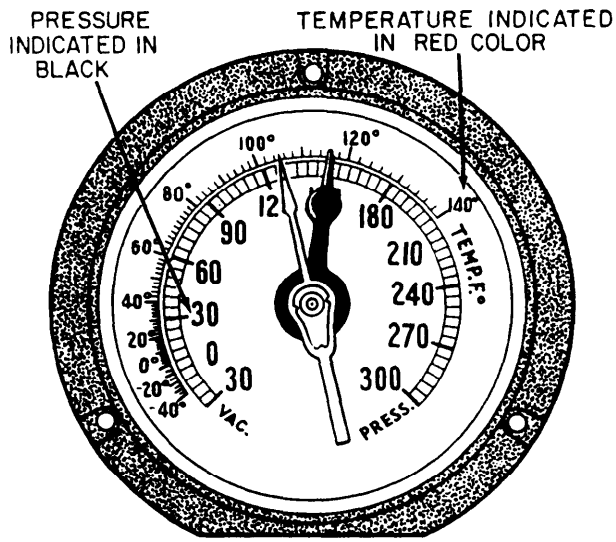
WATER REGULATING VALVE

A water regulating valve controls the quantity of cooling water flowing through the refrigerant condenser. The water regulating valve is actuated by the refrigerant pressure in the top of the condenser. This pressure acts upon a diaphragm (or, in some valves, a bellows arrangement), which transmits motion to the valve stem.

The primary function of the water regulating valve is to maintain a constant refrigerant condensing pressure. Basically, two variable conditions exist: (1) the amount of refrigerant to be condensed and (2) changing water temperatures. The valve maintains a constant refrigerant condensing pressure by controlling the water flow through the condenser. By sensing the refrigerant pressure, the valve permits only enough water through the condenser to condense the amount of refrigerant vapor coming from the compressor. The quantity of water required to condense a given amount of refrigerant varies with the water temperature. Thus, the flow of cooling water through the condenser is automatically maintained at the rate actually required to condense the refrigerant under varying conditions of load and temperature.

PRESSURE GAUGES AND THERMOMETERS

A number of pressure gauges and thermometers are used in refrigeration systems. Figure 16-18 shows a compound R-12 gauge. The temperature markings on this gauge show the boiling point (or condensing point) of the refrigerant at each pressure; the gauge cannot measure temperature directly. The fixed pointer (usually red) can be set manually to indicate the minimum or maximum allowable working pressure.



47.102

Figure 16-18.—Compound R-12 pressure gauge.

A water pressure gauge is installed in the circulating water line to the condenser to indicate the circulating water supply pressure.

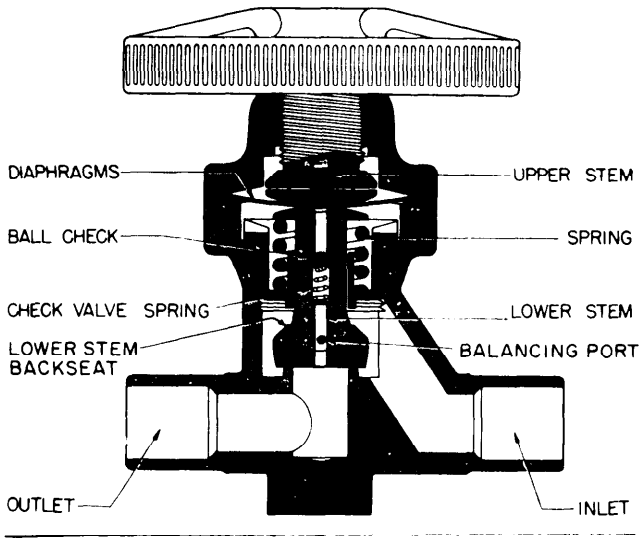
Standard liquid-in-glass or bimetallic thermometers of appropriate range are installed at strategic points within the refrigerant system.

REFRIGERANT PIPING

Refrigerant piping in modern naval installations is made of seamless copper tubing, which is good for this purpose because (1) it does not become corroded by refrigerants, (2) the internal surface of the tubing is smooth enough to minimize friction, and (3) copper tubing is easily shaped to meet installation requirements. The piping of refrigeration systems is covered with insulation after all joints have been checked for leaks. The insulation prevents condensation from forming on and dripping off the cold piping on the low-pressure side of the system. On the high-pressure side, insulation reduces heat stress conditions and protects personnel from being burned by hot piping.

PACKLESS VALVES

Nearly all hand-operated valves in large refrigeration systems are packless valves of the type shown in figure 16-19. In this type of valve, the upper part is sealed off from the lower part by a diaphragm. An upward-seating ball check



47.103

Figure 16-19.—Packless valve for a refrigeration system.

in the lower valve stem makes it possible for the spring to lift the lower stem regardless of pressure differences developed while the valve was closed. Thus, the valve will operate properly regardless of direction of flow. By backseating the valve, you can change the diaphragm without placing the system or unit out of operation.

OPERATING PROCEDURES FOR AN R-12 SYSTEM

You will need some very specific training before you become a good refrigeration system operator. First, you need a lot of practical experience on the systems. Second, you need to pay close attention to the procedures followed by qualified personnel.

Your first responsibility with an R-12 system will probably require you to check temperatures and pressures, maintain the plant operating log, detect symptoms of faulty operation, and check conditions in the spaces or units being cooled.

The intervals of time between plant inspections will vary depending on the purpose of the plant. The temperatures and pressures throughout the system and the oil level in the compressor crankcase must be checked every hour. The results should be recorded unless watch-standing instructions specify otherwise. These checks allow operating personnel to determine whether the plant is operating properly. One of the best methods for checking is to compare the existing temperatures and pressures with those recorded when the plant was known to be operating properly, under conditions similar to the present conditions.

AUTOMATIC OPERATION OF AN R-12 REFRIGERATION PLANT

After you have obtained the prescribed operating pressures and temperatures with the compressor running in MANUAL, place the selector switch in the AUTOMATIC position. A refrigeration compressor should NEVER be left unattended when in the MANUAL mode of operation.

You should remember from our discussion that the suction-pressure control (low-pressure cutout switch) is connected electrically to start and stop the compressor automatically on the basis of load conditions. If the automatic control valves and switches are in proper adjustment, the operation of the plant, after proper starting, should be entirely automatic.

When you set the selector switch for automatic operation, the water failure switch, the high-pressure cutout switch, or the low-pressure cutout switch will close and energize their respective control circuits. In some installations, the supply of condenser cooling water comes directly from a centrifugal pump or from the fire and flushing main. If cooling water in your system comes from the fire and flushing main, you must open the pump controller switch manually. The water failure switch must remain closed regardless of the source of condenser cooling water.

In systems that are not equipped with water regulating valves, normal operating conditions will generally produce condensing pressures of less than 125 psi. This happens because the condensing water temperature is usually less than 85°F. If your system does have these valves, you should adjust them to maintain the condensing pressure at 125 psi. With the valves adjusted properly, the quantity of cooling water will decrease rapidly with decreasing circulating water temperatures. In systems equipped with air-cooled condensers, condensing pressures may exceed 125 psi when the temperature of the surrounding air is higher than normal.

Only one compressor should serve a cooling coil circuit. When compressors are operated in parallel on a common cooling circuit, lubricating oil may be transferred from one compressor to

another. This may cause serious damage to all compressors on the circuit.

An R-12 compressor should not remain idle for an extended period of time. When a plant has two or more compressors, you should operate them alternately. You should make certain that the total operating time on each of the compressors is approximately the same. (An idle compressor should be operated at least once a week.)

CHARACTERISTICS OF REFRIGERANTS

Pure R-12 ($CC1_2F_2$) is colorless. It is odorless in concentrations of less than 20 percent by volume in air. In higher concentrations, its odor resembles that of carbon tetrachloroethylene (dry-cleaning fluid). It has a boiling point of – 21.6°F at atmospheric pressure. At a room temperature of 70°, R-12 is a liquid, provided it is kept at a pressure of at least 90 psig.

In either the liquid or vapor state, R-12 is nonflammable and nonexplosive. It will not corrode the metals commonly used in refrigerating systems.

Because it does not decompose, R-12 is a stable compound capable of undergoing the physical changes required of it in refrigeration service. It is an excellent solvent and has the ability to loosen and remove particles of dirt, scale, and oil with which it comes in contact within a refrigerating system.

Other refrigerants, such as R-22 ($CHC1F_2$) and R-11 ($CC1_3F$), are colorless, nonexplosive, and nonpoisonous. These refrigerants have many properties in common with R- 12; however, their operating characteristics are different.

SAFETY PRECAUTIONS

Personnel working with refrigerants may be injured or killed if proper precautions are not taken.

HALOCARBONS

Refrigerants are halocarbons, which are organic chemical compounds containing hydrogen and one or more atoms of carbon, fluorine, bromine, chlorine, or iodine. These substances may be present in various combinations in the compound.

Familiar brand names of refrigerants include Freon, Gentron, Gension D., or Frigen. Working with these compounds regularly aboard ship will make it easy for you to gain a false sense of security. This may tempt you to forget about the potential hazards of halocarbon refrigerants. Remember: Halocarbon refrigerants are especially dangerous when used in high concentrations in confined or poorly ventilated spaces.

HANDLING OF REFRIGERANT CYLINDERS (BOTTLES)

Before handling refrigerant bottles, review the safety precautions listed in *Naval Ships' Technical Manual*, chapter 516, "Refrigeration Systems."

Refrigerants are furnished in cylinders for use in shipboard refrigeration systems. The following precautions must be observed in the handling, use, and storage of these cylinders:

1. NEVER drop cylinders or permit them to strike each other violently.
2. NEVER use a lifting magnet or a sling (rope or chain) to handle cylinders. (A crane may be used if a safe cradle or platform is provided to hold the cylinders.)
3. Caps on refrigerant cylinders are provided for valve protection. Always keep the caps on the cylinders except when the cylinders are being used.
4. Whenever refrigerant is discharged from a cylinder, always weigh the cylinder immediately and record the weight of the refrigerant remaining in the cylinder.
5. NEVER attempt to mix gases in a cylinder.
6. NEVER put the wrong refrigerant into a refrigeration system! No refrigerant except the one for which a system was designed should ever be introduced into the system. Check the equipment nameplate or the NAVSEA technical manual to determine the proper refrigerant type and charge. Putting the wrong refrigerant into a system can cause a violent explosion.
7. When a cylinder has been emptied, close the cylinder valve immediately to prevent the entrance of air, moisture, or dirt. Also, be sure to replace the valve protection cap.
8. NEVER use cylinders for any purpose other than their intended purpose. Do NOT use cylinders as rollers and supports.
9. Do NOT tamper with the safety devices in the valves or cylinders.
10. Open cylinder valves slowly. NEVER use wrenches or other tools except those provided by the manufacturer.

11. Be sure the threads on regulators or other connections are the same as those on the cylinder valve outlets. NEVER force connections that do not fit.

12. ALWAYS use the correct pressure gauges and regulator with the gas cylinders for which they were intended.

13. NEVER attempt to repair or alter cylinders or valves.

14. NEVER fill R-12 cylinders beyond 85 percent capacity.

15. Store cylinders in a cool, dry place, in an UPRIGHT position. If the cylinders are exposed to excessive heat, a dangerous increase in pressure will occur. If cylinders must be stored in the open, make sure they are protected against extremes of weather. NEVER allow a cylinder to be subjected to temperatures above 130°F.

16. NEVER allow R-12 to come in contact with a flame or red-hot metal! When exposed to excessively high temperatures, (approximately 1,000°F or above) R-12 breaks down into phosgene gas, an extremely poisonous substance.

As a freezing agent, R-12 is so powerful that even a very small amount can freeze the delicate tissues of the eye, causing permanent damage. It is essential that goggles be worn by all personnel who may be exposed to a refrigerant, particularly in its liquid form. If refrigerant does get into the eyes, the person suffering the injury should receive immediate medical treatment to avoid permanent damage. In the meantime, immediately start irrigating and washing the victim's eyes gently with water at room temperature for 15 minutes. Make sure the person does not rub the eyes.

If R-12 comes in contact with the skin, it may cause frostbite. This injury should be treated as any other cause of frostbite. Immerse the affected part in a warm bath for about 10 minutes, then dry carefully. Do not rub or massage the affected area.

Generally, mixtures of R-12 vapor and air, in all proportions, are not irritating to the eyes, nose, throat, and lungs. The refrigerant will not contaminate or poison foods or other supplies with which it may come in contact. The vapor, too, is nonpoisonous. However, if R-12 concentrations become excessive, unconsciousness or even death may result from lack of oxygen to the brain.

SUMMARY

An EN3 should be familiar with the refrigeration plants that are most commonly used aboard naval vessels. You should recognize the major components and know the locations and functions of those parts as well as other supporting equipment in the system. Our discussion of refrigeration plants would be incomplete if you are not made aware of the safety precautions and dangers involved in working with refrigerants. For additional information, you should refer to the *Naval Ships' Technical Manual*, chapter 516.

If you are uncertain as to the major components of a refrigeration system and their functions within the system, you should reread this chapter before continuing to chapter 17.

CHAPTER 17

AIR CONDITIONING

Air conditioning is a field of engineering that deals with the design, construction, operation, and maintenance of equipment used to establish and maintain desirable indoor air conditions. It is used to maintain the environment of an enclosure at any required temperature, humidity, and air quality. Simply stated, air conditioning involves the cooling, heating, dehumidifying, ventilating, and cleaning of air. This chapter deals with that process.

THE PURPOSES OF AIR CONDITIONING AND RELATED FACTORS

One of the chief purposes of air conditioning aboard ship is to keep the crew comfortable, alert, and physically fit. None of us can long maintain a high level of efficiency under adverse environmental conditions. We have to maintain a variety of compartments at a prescribed temperature with proper circulation. They must have proper moisture content, the correct proportion of oxygen, and an acceptable level of air contamination (dust, airborne dirt, and so forth). The comfort and fitness of the crew is only one purpose of air conditioning. Mechanical cooling or ventilation must also be provided in ammunition spaces to prevent deterioration of ammunition components and in gas storage spaces to prevent excessive pressure buildup in the metal bottles and contamination of the space by gas leakage. Finally, we must provide cooling and ventilation in electrical/electronic equipment spaces. This is done to maintain the ambient temperature and humidity as specified for the equipment.

Proper air conditioning must consider the humidity, total heat of the air, temperature, body heat balance, effect of airflow, and physical sensation of comfort.

HUMIDITY

Humidity is the vapor content of the atmosphere; it has a great influence on human comfort. The common expression “It isn’t the heat, it’s the humidity,” indicates discomfort produced by moisture-laden air in hot weather. Extremely low moisture content also has undesirable effects on the human body. The measurement and control of moisture in the air is an important phase of air conditioning. To understand this phase, you should become familiar with the meaning of saturated air, absolute and specific humidity, and relative humidity.

Saturated Air

Air can hold varying amounts of water vapor. It depends on the temperature of the air at a given atmospheric pressure. As the temperature rises, the amount of moisture the air can hold increases (assuming no change in atmospheric pressure). But for every temperature there is a definite limit to the amount of moisture the air can hold. When air contains the maximum amount of moisture it can hold at a specific temperature and pressure, it is said to be saturated.

The temperature at which air becomes saturated with water vapor is called the DEW POINT. If the temperature of air falls below its dew point, some of the vapor in the air must condense to water. An example is the dew that appears on decks and bulkheads in the early morning. This normally happens when there is a drop in temperature. Another is the “sweating” of cold water pipes as water vapor from the relatively warm air condenses on the cold surface of the pipes.

Absolute and Specific Humidity

The amount of water vapor in the air is expressed in terms of the weight of the moisture.

The weight is usually given in grains (7,000 grains = 1 pound). ABSOLUTE HUMIDITY is the weight in grains of water vapor per cubic foot of air. SPECIFIC HUMIDITY is the weight in grains of water vapor per pound of air. (The weight of water vapor refers only to moisture that may be present in the liquid state, such as rain or dew.)

Relative Humidity

RELATIVE HUMIDITY is the ratio of the weight of water vapor in a sample of air to the weight of water vapor the same sample of air would contain if saturated at the existing temperature. This ratio is usually stated as a percentage. For example, when air is fully saturated, the relative humidity is 100 percent. When air contains no moisture at all, its relative humidity is 0 percent. If air is half-saturated, the relative humidity is 50 percent. The normal comfort range of relative humidity for humans is between 30 percent and 70 percent. The deciding factor in human comfort is the relative humidity—not the absolute or specific humidity.

Just as heat flows from a higher temperature to a lower temperature, moisture always travels from areas of greater wetness to areas of lesser wetness. If the air above a liquid is saturated, the two are in balance and no moisture can travel from the liquid to the air; that is, the liquid cannot evaporate. If the air is only partially saturated, some moisture can travel to the air; that is, some evaporation can take place.

When the temperature of the air is 76°F and the relative humidity is nearly 90 percent, the air is nearly saturated. At such a relative humidity, the body may perspire freely but the perspiration does not evaporate rapidly; thus a general feeling of discomfort results.

However, when the temperature of the same air is 86°F, the relative humidity would then be only 64 percent. Although the absolute amount of moisture in the air is the same, the relative humidity is lower, because at 86°F the air is capable of holding more water vapor than it can hold at 76°F. The body is now able to evaporate its excess moisture and the general feeling is much more agreeable, even though the temperature of the air is 10° higher. (The cooling effect on the body is brought about by the absorption of latent heat during the evaporating process.)

In both examples, the specific humidity is the same, but the ability of the air to evaporate liquid is quite different at the two temperatures. The ability to evaporate moisture is directly indicated by the relative humidity. This is the reason the control of relative humidity is of extreme importance in air conditioning.

HEAT OF AIR

The total heat content of air is the sum of two parts: (1) sensible heat and (2) latent heat.

SENSIBLE HEAT is the amount of heat which, when added to or removed from air, changes the temperature of the air. Temperature changes caused by sensible heat can be measured by the common (dry-bulb) thermometer.

Air always contains some water vapor. Any water vapor in the air contains LATENT HEAT OF VAPORIZATION, which means the heat necessary to cause the water to change state from a liquid to a gas (heat added). The opposite case is called LATENT HEAT OF CONDENSATION, which refers to the heat that must be removed to cause the water vapor to change state from a gas back into a liquid. (The amount of latent heat present has no effect on temperature, and it cannot be measured with a dry-bulb thermometer.)

Any mixture of air and water vapor contains both sensible heat and latent heat. The sum of the sensible heat and the latent heat in any sample of air is called the TOTAL HEAT of the air.

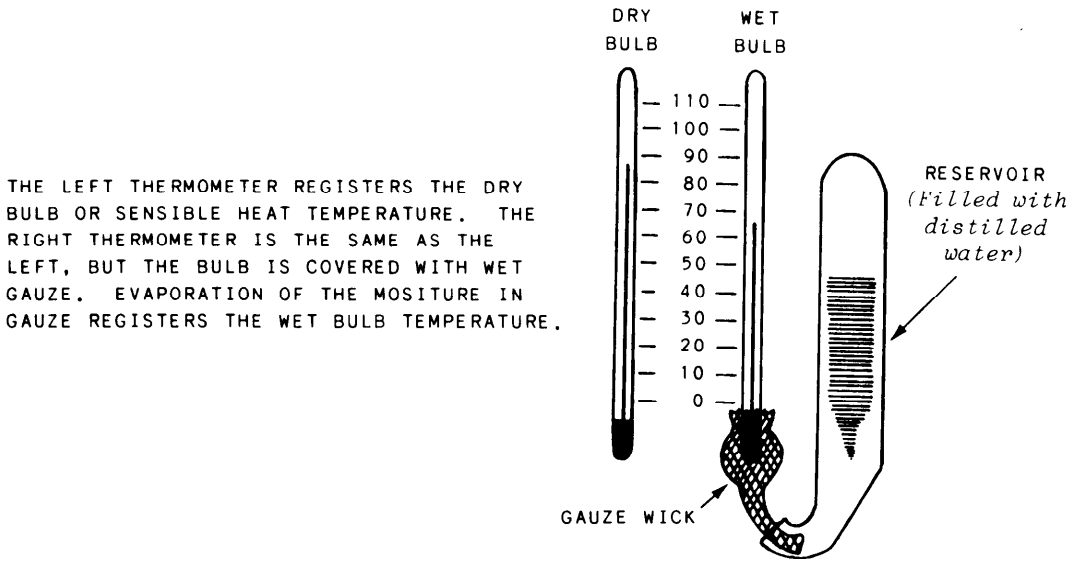
TEMPERATURES

To test the effectiveness of air-conditioning equipment and to check the humidity of a space, we must consider two different temperatures. These are the dry-bulb and wet-bulb temperatures.

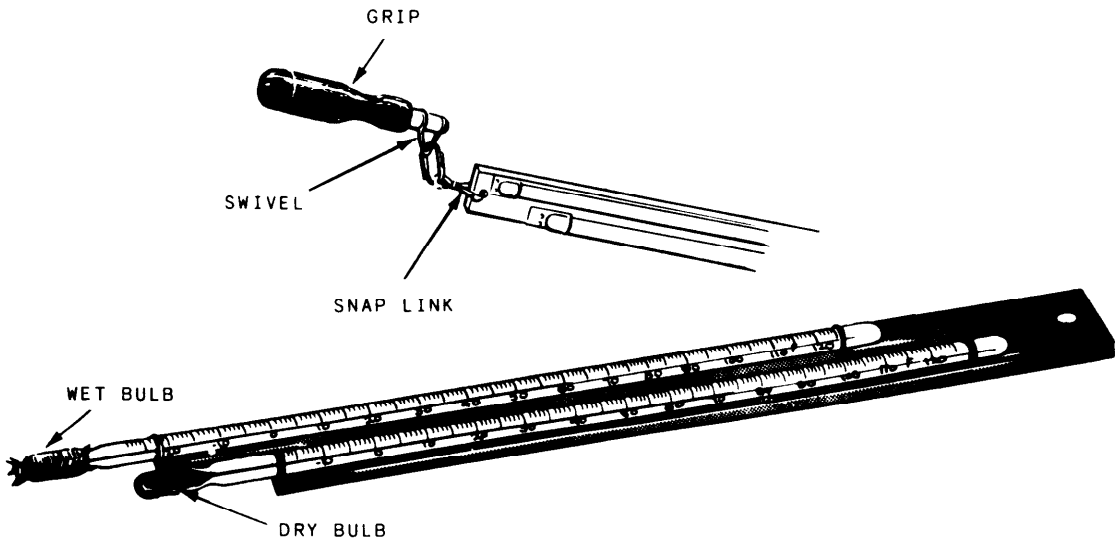
Measurement of Temperatures

The DRY-BULB TEMPERATURE is the temperature of the sensible heat of the air, as measured by an ordinary liquid-in-glass thermometer. Such a thermometer in air conditioning is referred to as a dry-bulb thermometer because its sensing bulb is dry, in contrast with the wet-bulb type described next.

The WET-BULB TEMPERATURE is best explained by a description of a wet-bulb thermometer. (Refer to fig. 17-1, view A.) It is also a liquid-in-glass thermometer with a loosely woven cloth sleeve or wick placed around its bulb, which is then wet with distilled water. The water in the sleeve or wick is forced to evaporate by a



A. DRY-BULB AND WET-BULB THERMOMETERS



B. STANDARD SLING PSYCHROMETER

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Figure 17-1.—Temperature monitoring devices.

current of air (see next paragraph) at high velocity. This evaporation withdraws heat from the thermometer bulb, lowering the temperature by several degrees. The difference between the dry-bulb and the wet-bulb temperatures is called the WET-BULB DEPRESSION. When the wet-bulb temperature is the same as the dry-bulb temperature, the air is saturated (that is, evaporation cannot take place). This condition of saturation is unusual, however, and some value of wet-bulb depression is normally expected.

The wet-bulb and dry-bulb thermometers are usually mounted side by side on a frame that has a handle and a short chain attached. This allows the thermometers to be whirled in the air, thus providing a high-velocity air current to promote

evaporation. This device, known as a SLING PSYCHROMETER, is shown in figure 17-1, view B. When using the sling psychrometer, whirl it rapidly—at least four times per second. Observe the wet-bulb temperature at intervals. The point at which there is no further drop in temperature is the wet-bulb temperature for that space.

Another variation of this device, known as a MOTORIZED PSYCHROMETER, is shown in figure 17-2. Motorized psychrometers are provided with a small motor-driven fan and dry-cell batteries. Motorized psychrometers are generally preferred and are gradually replacing sling psychrometers.

Relationships Between Temperatures

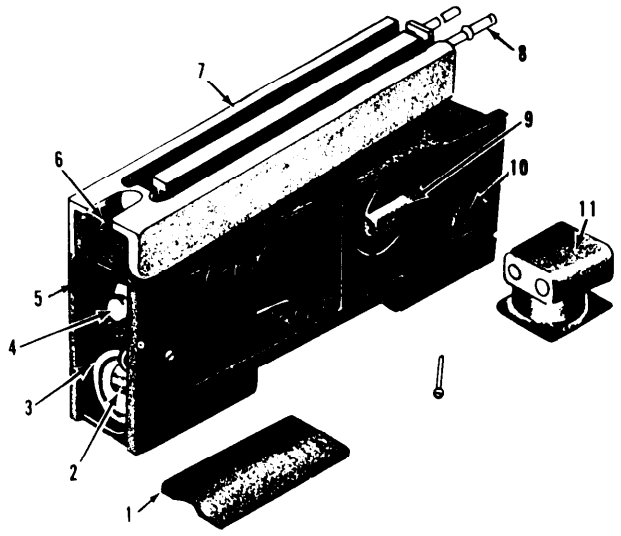
You should clearly understand the definite relationships of the three temperatures—dry-bulb, wet-bulb, and dew point.

1. When air contains some moisture but is not saturated, the dew-point temperature is lower than the dry-bulb temperature; the wet-bulb temperature lies between them.

2. As the amount of moisture in the air increases, the difference between the dry-bulb temperature and the wet-bulb temperature becomes less.

3. When the air is saturated, all three temperatures are the same.

4. By using both the wet-bulb and the dry-bulb temperature readings, you can determine the percent of relative humidity and the dew-point temperature by using a psychrometric chart. (See fig. 17-3.) The dry-bulb temperatures are equally spaced vertical lines. The wet-bulb temperature lines are angled across the chart. The dew-point temperature lines are horizontal straight lines across the chart, as are the lines labeled GRAINS OF MOISTURE PER POUND OF DRY AIR. Find where the wet-bulb and dry-bulb lines cross and interpolate the relative humidity from the nearest curved relative humidity lines to the temperature-line crossing point. Then find the dew point by following the straight dew-point line closest to the intersection across to the left of the chart. Now read the dew-point temperature.

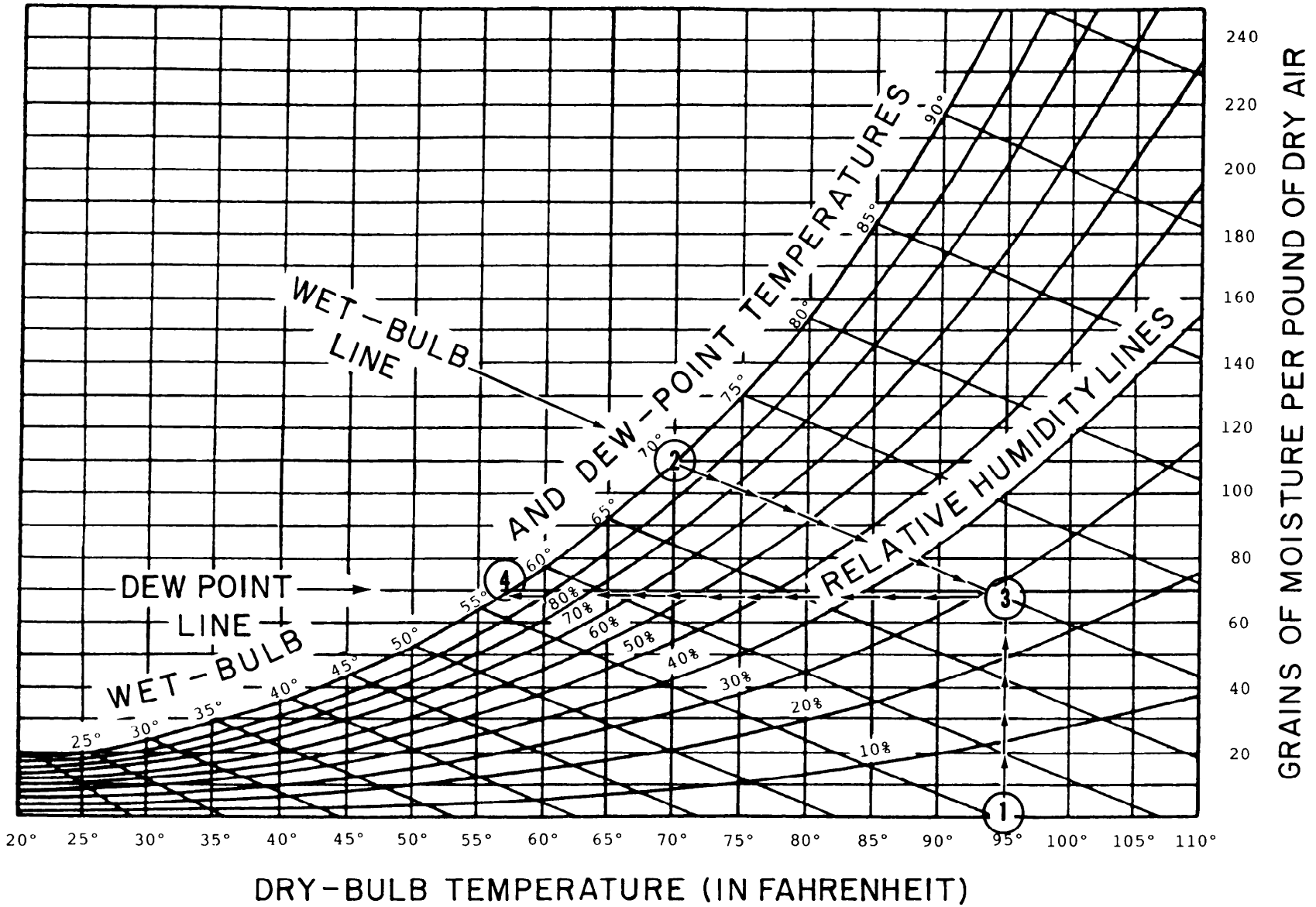


1. Sliding door.
2. Spring contact.
3. Battery compartment.
4. Water bottle.
5. Bottle compartment.
6. Hinge pin.
7. Thermometer holder.
8. Wet-bulb wick.
9. Knob.
10. Exhaust ports.
11. Sliding air intake.

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Figure 17-2.—Exposed view of a motorized psychrometer.

We will use the following example to help you learn how to use a psychrometric chart to determine the percent of relative humidity and the dew-point temperature. Use the following conditions: the dry-bulb temperature is 95°F and the wet-bulb temperature is 70°F. Locate the line for 95°F along the bottom of the chart (1). Next, locate the wet-bulb temperature of 70°F on the curved line marked with values of temperature (2). Use the intersection of these two lines (3) to determine the percent of relative humidity. As shown in the figure, the point of intersection occurs between two curved lines labeled 20% and 30%. Since the point is closer to the 30% line, we can interpolate and estimate a value of about 28% relative humidity. To determine the dew-point temperature, follow over to the left in a straight line from the point of intersection. This line intersects the curved line labeled WET-BULB AND DEW-POINT TEMPERATURES at a point between 55°F and 60°F (4). Since the intersection is closer to 55°F, we can interpolate again and estimate that the air must be cooled to a temperature of about 57°F to cause the water vapor in the air to condense into a liquid (which will cause the air to dry out).



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Figure 17-3.—Simplified psychrometric chart.

BODY HEAT BALANCE

Ordinarily the body remains at a fairly constant temperature of 98.6°F. It is very important that this body temperature be maintained and, since there is a continuous heat gain from internal body processes, there must also be a continuous loss to maintain body heat in balance. Excess heat must be absorbed by the surrounding air or lost by radiation. As the temperature and humidity of the environment vary, the human body automatically regulates the amount of heat it gives off. However, the body's ability to adjust to varying environmental conditions is limited. Furthermore, although the body may adjust to a certain (limited) range of atmospheric conditions, it does so with a distinct feeling of discomfort. The following discussion will help you understand how atmospheric conditions affect the body's ability to maintain a heat balance.

Body Heat Gains

The human body gains heat (1) by radiation, (2) by convection, (3) by conduction, and (4) as a by-product of the physiological processes that take place within the body (for example, the conversion of food into energy).

Heat gain from radiation comes from our surroundings. However, heat always travels from areas of higher temperature to areas of lower temperature. Therefore, the human body receives heat from those surroundings that have a temperature higher than body surface temperature. The greatest source of heat radiation is the sun. Some sources of indoor heat radiation are heating devices, operating machinery, and hot steam piping.

Heat gain from convection comes only from currents of heated air. Such currents of air may come from a galley stove or an operating diesel engine.

Heat gain from conduction comes from objects with which the body comes in contact.

Most body heat comes from within the body itself. Heat is produced continuously inside the body by the oxidation of food, by other chemical processes, and by friction and tension within muscle tissues.

Body Heat Losses

There are two types of body heat losses: loss of sensible heat and loss of latent heat. Sensible heat is given off by (1) radiation, (2) convection, and (3) conduction. Latent heat is given off in the breath and by evaporation of perspiration.

EFFECTS OF AIR MOTION

In perfectly still air, the layer of air around a body absorbs the sensible heat given off by the body and increases in temperature. The layer of air also absorbs some of the water vapor given off by the body, thus increasing in relative humidity. This means the body is surrounded by an envelope of moist air that is at a higher temperature and relative humidity than the ambient air. Therefore, the amount of heat the body can lose to this envelope is less than the amount it can lose to the ambient air. When the air is set in motion past the body, the envelope is continually being removed and replaced by the ambient air, thereby increasing the rate of heat loss from the body. When the increased heat loss improves the heat balance, the sensation of a breeze is felt; when the increase is excessive, the rate of heat loss makes the body feel cool and the sensation of a draft is felt.

SENSATION OF COMFORT

From the foregoing discussion, it is evident that the three factors—temperature, humidity, and air motion—are closely interrelated in their effects upon the comfort and health of personnel aboard ship. In fact, a given combination of temperature, humidity, and air motion will produce the same feeling of warmth or coolness as a higher or lower temperature in conjunction with a compensating humidity and air motion. The term given to the net effect of these three factors is known as the EFFECTIVE TEMPERATURE. Effective temperature cannot be measured by an instrument, but can be found on a special psychrometric chart when the dry-bulb temperatures and air velocity are known.

The combinations of temperature, relative humidity, and air motion of a particularly effective temperature may produce the same feeling of warmth or coolness. However, they are NOT all equally comfortable. Relative humidity below 15 percent produces a parched condition of the mucous membranes of the mouth, nose, and lungs, and increases susceptibility to disease germs. Relative humidity above 70 percent causes an accumulation of moisture in clothing. For the best health conditions, you need a relative humidity ranging from 40 percent to 50 percent for cold weather and from 50 percent to 60 percent for warm weather. An overall range from 30 percent to 70 percent is acceptable.

EFFECTS OF HEAT STRESS

Navy personnel who are required to work in hot, humid spaces must be aware of heat stress. To ensure this awareness, the Navy has established a strict program to prevent incidents of heat stress. This program requires that any circumstances that result in a case of heat exhaustion or heatstroke be reported to higher authority.

When personnel are required to work in hot spaces with stagnant, moisture-laden air, the environmental conditions (temperature, humidity, and airflow) are such that the heat load in the human body builds up. As the body's internal temperature rises and the rate of heat buildup cannot be balanced by the evaporation of perspiration, the human body becomes stressed. A person who continues to work in this environment may experience heat cramps (painful muscle spasms). Heat cramps are an early symptom of a more serious problem called HEAT EXHAUSTION. Similar to the symptoms of physical shock to the body, the signs and symptoms of a person suffering from heat exhaustion are dizziness, headache, and nausea. The skin will appear gray in color and will feel cold and clammy. Correct treatment for this condition is the IMMEDIATE removal of the person to a cooler environment. Loosen the clothing and apply cool wet cloths to the head, groin, and ankles. Lightly fan the victim. If the person is conscious, you should make him or her drink cool water. (Do NOT administer more liquid if the victim begins to vomit.) The victim should be transported to a medical facility as soon as possible.

A less common, but far more serious, condition of heat stress is known as HEATSTROKE. Heatstroke is fatal in about 20 percent of all cases. With heatstroke, the body's temperature control system completely malfunctions and is unable to rid itself of excess heat. Bodily temperatures may rise as high as 105°F (a high fever), and prolonged high body temperatures can result in failure of vital organs such as the kidneys, liver, and brain. Although the early symptoms of heatstroke appear to be similar to those of heat exhaustion, the symptoms of heatstroke are distinct. In a victim of heatstroke, breathing becomes shallow, almost absent, as the heat builds up within the body. The skin will appear flushed or reddened and will feel dry and hot. The pupils of the eyes will be constricted to pinpoints, and the pulse will be fast and very strong. Navy personnel must understand that HEATSTROKE IS A TRUE LIFE-AND-DEATH EMERGENCY.

Proper treatment of heatstroke requires immediate action to cool the victim's body by moving it to a cooler place and dousing the body with cool water. Remove as much clothing as possible. A conscious victim should be made to drink cool water. Every case of heatstroke must be transported to a medical facility as soon as possible.

An important part of the Navy's heat stress awareness and prevention program is the constant monitoring of environmental conditions in work spaces, where liquid-in-glass (dry-bulb) thermometers are located at key watch and work stations. The temperature at each work site must be read and recorded at least once per watch. When the temperature in any work space rises to the point where work must be slowed down or curtailed for personnel to avoid heat stress (usually 100^{o}F), a heat survey must be taken. Safe stay time limits must then be determined and imposed for people who must continue to work in the space. More information about heat stress awareness and prevention may be found in OPNAV Instruction 5100.20 (latest edition).

VENTILATION EQUIPMENT

Proper circulation of air is necessary for all ventilating and air-conditioning systems and

related processes. Therefore, we will first consider methods used aboard ship to circulate air. In the following sections, you will find general information on shipboard equipment used to supply, circulate, and distribute fresh air, and to exhaust used, contaminated, and overheated air from shipboard working and living spaces.

Shipboard ventilation systems normally use two-speed electric motors to drive intake fans and exhaust fans. For proper operation, the speed settings must be the same. This is because the exhaust fans have a higher air-handling capacity in cubic feet per minute (cfm) than the intake fans. When the fans are operated at different speeds, problems occur. For example, when the exhaust is on high and the intake is on low, a partial vacuum is caused and it will be difficult to open watertight doors to gain entry to the space. When the opposite condition occurs (high intake, low exhaust), the watertight doors will be difficult to close.

Fans used in Navy ships in conjunction with supply and exhaust systems are divided into two general classes—axial flow and centrifugal.

Most fans in duct systems are of the axial-flow type because they generally require less space for installation.

Centrifugal fans are generally preferred for exhaust systems that handle explosive or hot gases. The motors of these fans, being outside the air stream, cannot ignite the explosive gases. The drive motors for centrifugal fans are subject to overheating to a lesser degree than are motors of vane-axial fans.

VANE-AXIAL FANS

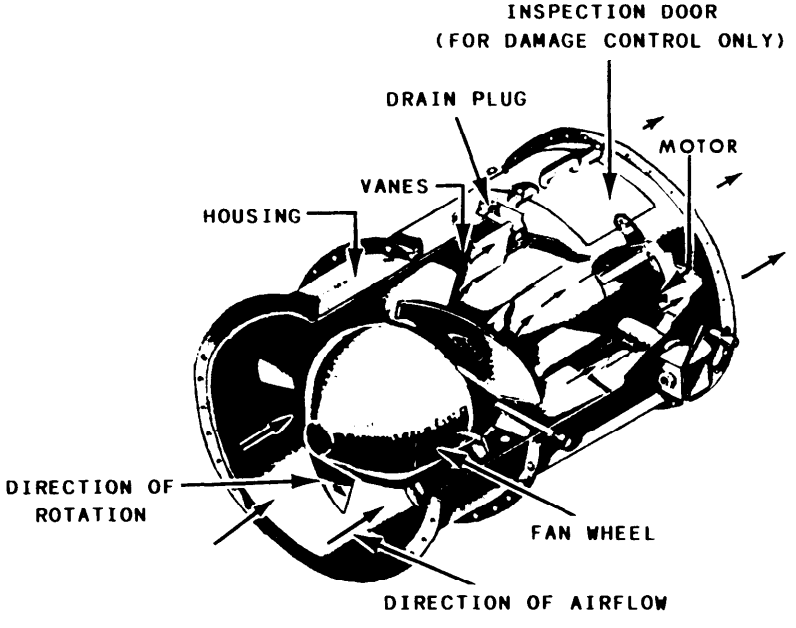
Vane-axial fans, such as the one shown in figure 17-4, are generally installed in duct systems. They have vanes at the discharge end to straighten out rotational air motion caused by the impeller. The motors for these fans are cooled by the air in the duct and will overheat if they are operated with the air supply to the fan shut off.

TUBE-AXIAL FANS

Tube-axial fans are low-pressure fans, usually installed without duct work. However, they do have sufficient pressure for a short length of duct.

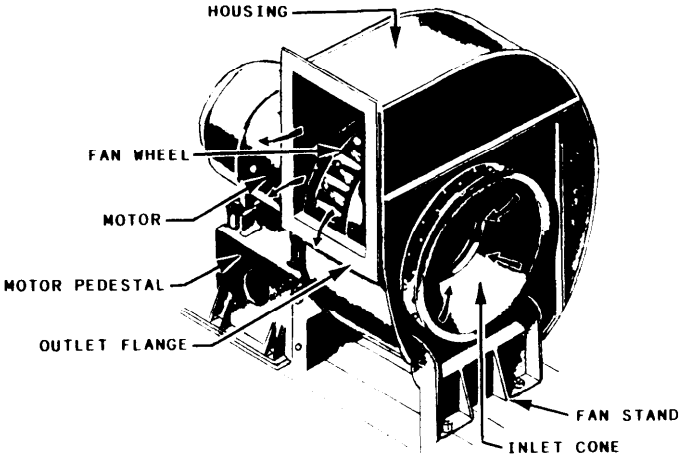
CENTRIFUGAL FANS

Centrifugal fans, such as the one shown in view A of figure 17-5, are used primarily

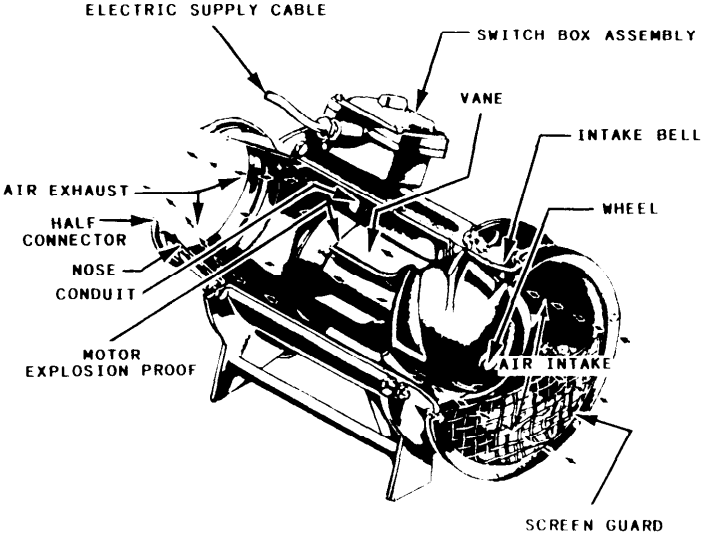


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Figure 17-4.—Vane-axial ventilating fan (cutaway view).



A. CENTRIFUGAL FAN, CUTAWAY VIEW.



B. PORTABLE AXIAL FAN, CUTAWAY VIEW.

47.107.1

Figure 17-5.—Ventilating fans.

to exhaust explosive or hot gases. However, they may be used in place of axial-flow fans if they work better with the arrangement or if their pressure-volume characteristics suit the installation better than an axial-flow fan. Centrifugal fans are also used in some fan-coil assemblies, which are discussed later in this chapter.

PORTABLE FANS

Portable axial fans, such as the example in view B of figure 17-5, are used with flexible air hoses aboard ship for ventilating holds and cofferdams. ‘They are also used in unventilated spaces (voids) to clear out stale air or gases before personnel enter and for emergency cooling of machinery.

Most portable fans are the axial-flow type, driven by electric, explosion-proof motors. On ships carrying gasoline, a few air turbine-driven centrifugal fans are normally provided. You can place greater confidence in the explosion-proof characteristics of these fans.

WATERPROOF VENTILATOR

The waterproof ventilator, shown in figure 17-6, consists of an outer housing, an inner ventilator shaft extending up to the other housing, and a bucket-type closure supported over the ventilator shaft by a compression spring. The bucket has drain tubes that extend into a sump between the ventilator shaft and the outer housing. The sump has scupper valves that drain onto the weather deck.

The ventilator operates automatically and is normally open. Small amounts of water, which enter the ventilator, fall into the bucket and drain out through the drain tubes and scuppers. In heavy seas, when water enters the bucket faster than it drains out, the weight of the water forces the bucket down against the top of the ventilator shaft. Thus, a watertight seal is formed and maintained until sufficient water drains out to permit the force of the spring to raise the bucket to the open position. Normally, some provision is made so that the ventilator can also be closed manually. With slight variations in construction, ventilation of this type may be used for both the supply and exhaust of air.

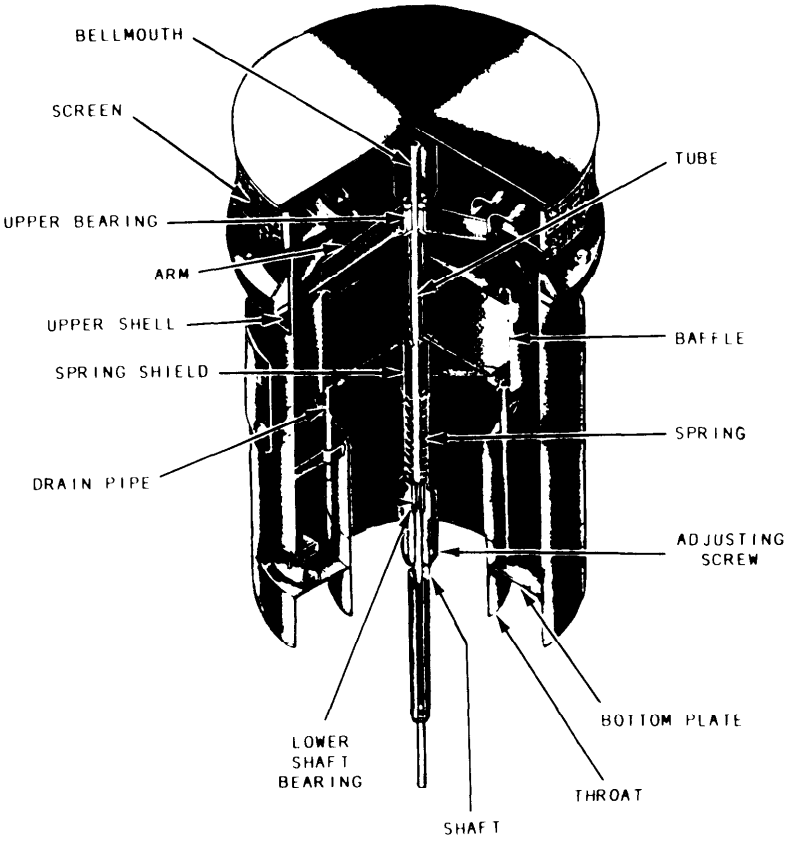
BRACKET FANS

Bracket fans are used in hot weather to provide local circulation. These fans are normally installed in living, hospital, office, commissary, supply, and berthing spaces. Where air-conditioning systems are used, bracket fans are sometimes used to facilitate proper circulation and direction of cold air.

EXHAUSTS

Local exhausts are used to remove heat and odors. Machinery spaces, laundries, and galleys are but a few of the spaces aboard ship where local exhausts are used.

Most exhausts used on Navy ships are mechanical (contain an exhaust fan), although natural exhausts are sometimes used in ships' structures and on small craft.



47.108.1

Figure 17-6.—Waterproof ventilator (cutaway view).

MECHANICAL COOLING EQUIPMENT

Almost all working and living spaces on newer ships are air conditioned. The cooling equipment used on these ships was carefully tested to see which types would best dehumidify and cool ship compartments. Two basic types of equipment have been found most effective and are now in general use. They are chilled water circulating systems and self-contained air conditioners.

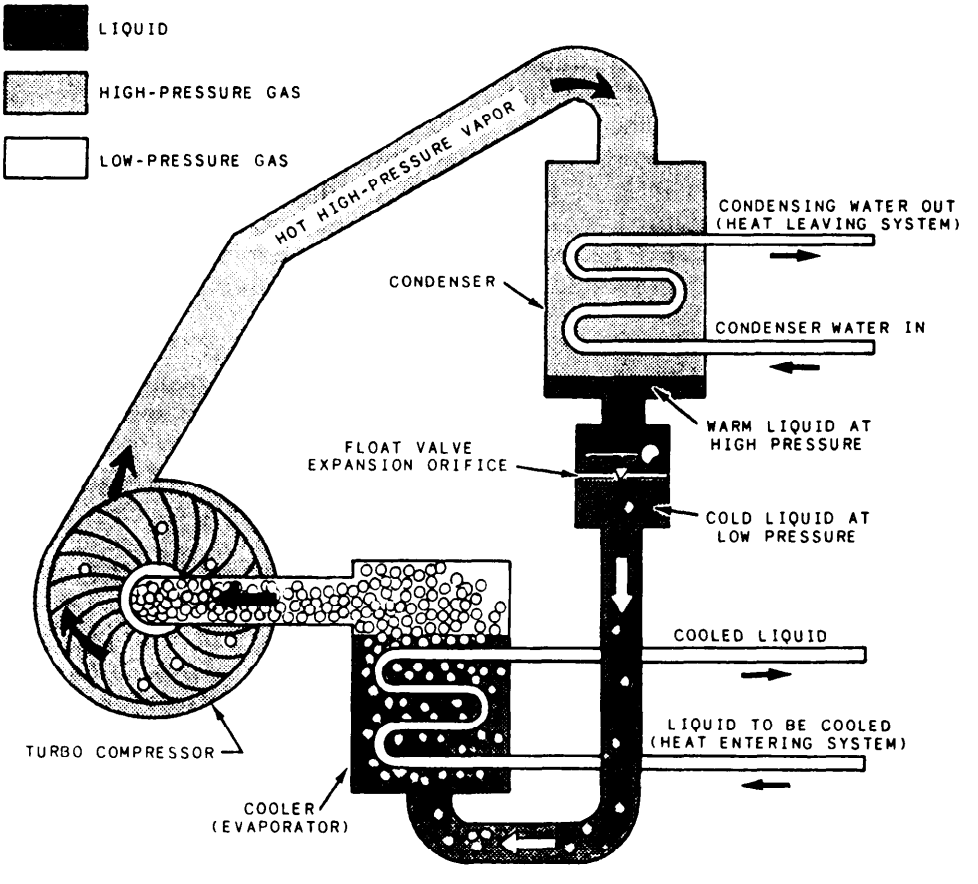
CHILLED WATER CIRCULATING SYSTEMS

Two basic types of chilled water air-conditioning systems are now in use. They are a vapor compression unit and a lithium bromide absorption unit. In the vapor compression unit, the primary refrigerant cools the secondary refrigerant (chilled water) that is used to cool the spaces. This type uses the vapor compression cycle and R-11, R-12, R-22, or R-114 as the primary refrigerant. The type of primary refrigerant depends on the size and type of compressor. The lithium bromide unit operates on the absorption cycle and uses water as the primary refrigerant. Lithium bromide is used as an absorbent. Lithium bromide plants are primarily used on submarines. Vapor compression plants are primarily used on surface ships. We will discuss only the vapor compression cycle in this chapter.

Vapor Compression Units

The vapor compression chilled water circulating system differs from a refrigerant circulating (direct expansion) air-conditioning system in this way: The air is conditioned by use of a secondary refrigerant (chilled water) which is circulated to the various cooling coils. Heat from the air-conditioned space is absorbed by the circulating chilled water. Heat is then removed from the water by the primary refrigerant system in the water chiller. In large tonnage vapor compression systems, the compressor is a centrifugal type that uses R-11 or R-114 as the primary refrigerant.

The operating cycle of the centrifugal refrigeration plant shown in figure 17-7 is basically



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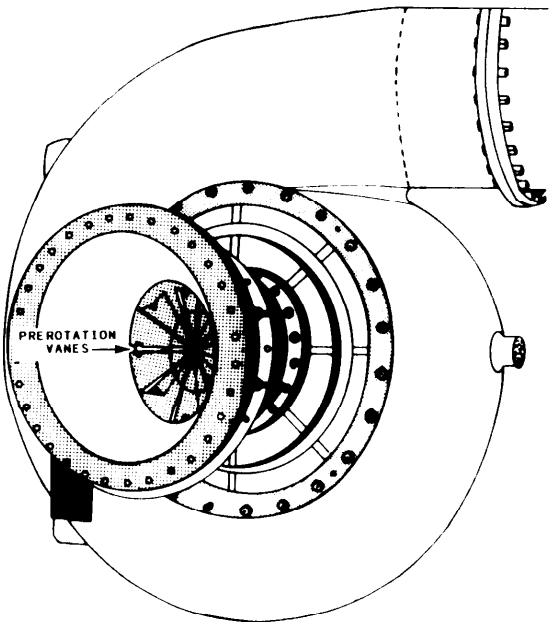
Figure 17-7.—Vapor compressor (centrifugal) unit.

the same as other refrigeration plants except for the method of compression. In this type of plant, the refrigerant gas is pressurized by a centrifugal turbocompressor. Then, the gas is discharged into the condenser where it changes state from a gas to a liquid by means of cool seawater circulating through the condenser tubes. The condensed liquid refrigerant drains to the bottom of the condenser into high-pressure liquid orifice chambers. When the refrigerant level is high enough, a float-operated valve opens. (NOTE: In some R-11 units, which originally used a float valve, an orifice has been installed.) The action of these orifices allows the liquid high-pressure refrigerant to flow to the bottom of the water chiller (evaporator) at a controlled rate. Water to be chilled flows through the tubes of the water chiller. As the refrigerant from the condenser boils around and over the tubes, the water within the tubes is chilled or cooled by the vaporization (boiling) of the liquid refrigerant. The vaporized refrigerant then reenters the suction side of the compressor to start the cycle again.

The load on the air-conditioning plant is determined by the temperature and flow of the returning chilled water. The compressor load is changed by either an increased or decreased demand of the chilled water. Upon demand, the load is changed by the use of adjustable prerotation vanes, which are located on the suction side of the compressor. The vanes act as dampers to increase or decrease the flow of refrigerant vapor through the inlet of the compressor. This throttling action at the compressor suction allows an increase or decrease of the capacity of the compressor without a change in the compressor speed.

Figure 17-8 shows a centrifugal compressor with the inlet piping removed. Note that the prerotation vanes are in the fully open position. The vane position is normally controlled automatically through an electropneumatic control system. The control system senses and maintains the chilled water outlet temperature of the chiller at a preset value by varying the position of the vanes.

In some plants, the electric motor that drives the compressor is hermetically sealed and is cooled by a flow of refrigerant through it. The compressor is lubricated by a forced feed lubrication system. This system normally consists of an auxiliary oil pump, an attached oil pump (integral with compressor), an oil cooler, and a set of oil filters. The auxiliary oil pump is used when starting and securing the plant.



168.14

Figure 17-8.—Suction end of a centrifugal compressor showing prerotation vanes.

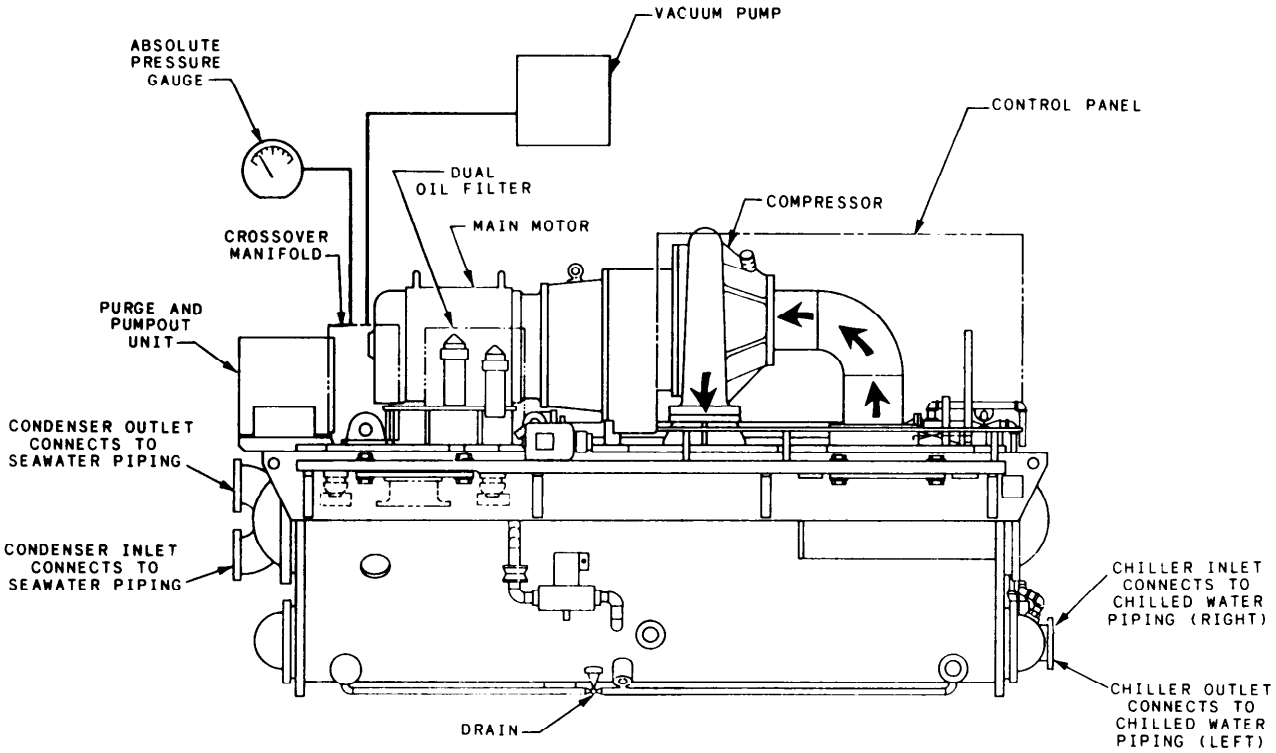
Several automatic controls are built into the centrifugal compressor control system. These devices increase the reliability of the plant by automatically shutting down the compressor if a hazardous situation develops. Some of these conditions are high condenser pressure, low compressor lube oil pressure, loss of seawater to the condenser, loss of chilled water, low refrigerant temperature, low chilled water temperature, and high compressor discharge temperature.

A heater warms the oil in the sump of the compressor during plant shutdown. If the oil is not kept heated, it absorbs large amounts of refrigerant. This results in excessive oil foaming when the unit is started. The heaters in most plants are connected so that they are automatically turned on when the compressor is off and automatically turned off when the compressor is on.

Figure 17-9 shows a centrifugal compressor air-conditioning unit. This particular plant has a 150-ton capacity and uses R-114 as the refrigerant. The gauges and controls for the plant are on the control panel.

Fan-Coil Unit Coolers

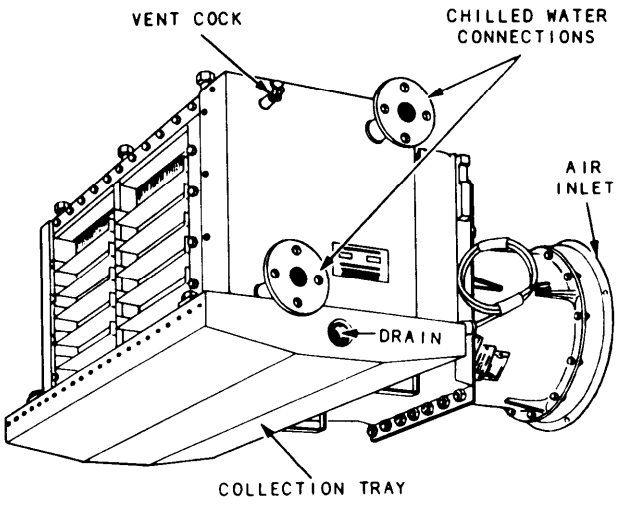
Fan-coil unit coolers use chilled water for the air conditioning of spaces. These assemblies are



47.217

Figure 17-9.—Centrifugal chilled water air-conditioning plant.

known as spot coolers. Chilled water is piped through the cooling coils of the units, and a fan forces air over the coils. One type of fan-coil assembly is shown in figure 17-10. Note the chilled water connections, the vent cock at the top, and the condensate collection tray at the bottom of the unit.



168.18

Figure 17-10.—Fan-coil unit cooler.

The condensate collection tray collects the moisture condensed out of the air. The condensate is generally piped to the bilge or a waste water drain system. It is important that the drain for the collection tray be kept clear. If the condensate cannot drain out of the tray, it collects and may promote the growth of harmful bacteria. When the condensate evaporates, it leaves impurities which rapidly lead to corrosion of the tray.

SELF-CONTAINED AIR CONDITIONERS

Ships without central air conditioning may use self-contained air-conditioning units. NAVSEA approval is required.

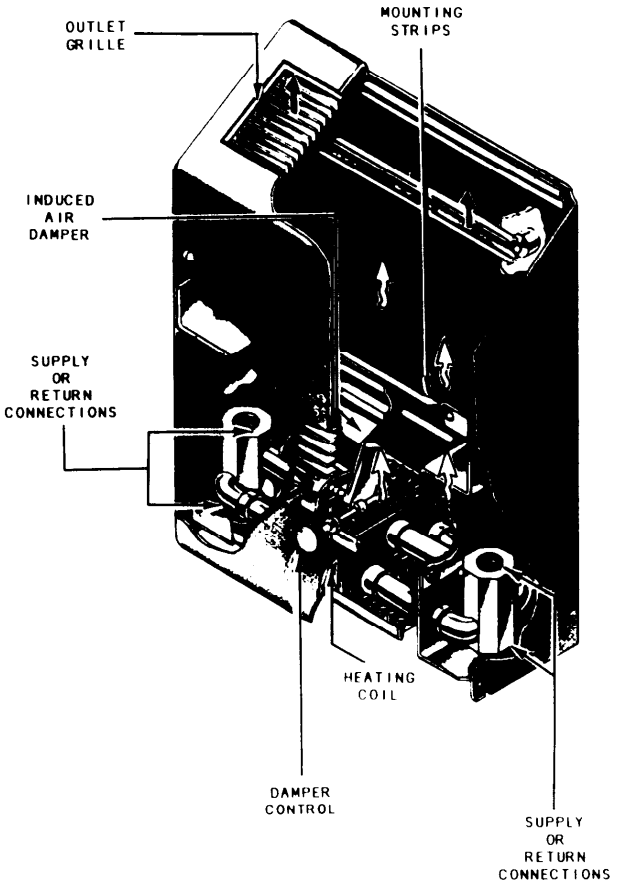
A self-contained air-conditioning unit is simply the type of air conditioner you see installed in the windows of many homes. All that is required for installation is to mount the proper brackets for the unit case and provide electrical power.

These units use nonaccessible hermetically sealed compressors (motor and compressor are contained in a welded steel shell). For this reason, shipboard maintenance of the motor-compressor unit is impractical. The type of thermal expansion valve used in these units is preset and nonadjustable. However, a thermostat and fan speed control are normally provided for comfort adjustment.

HEATING EQUIPMENT

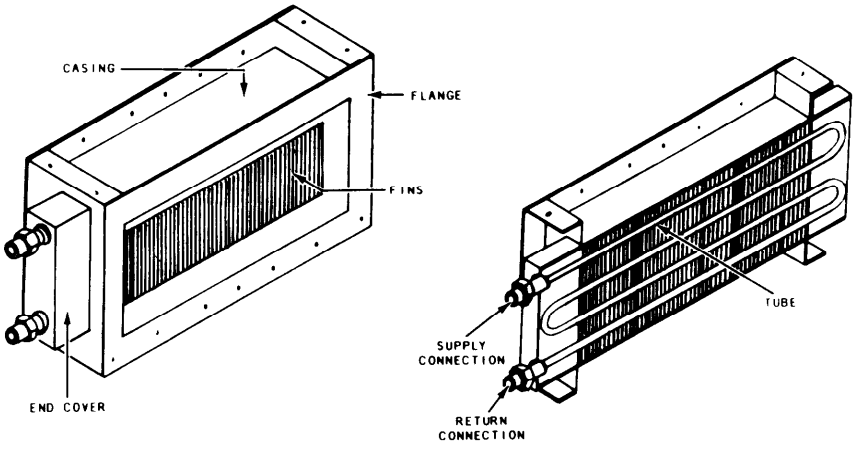
Ventilation heaters are installed in ventilation ducting to heat spaces in cold weather and to control humidity. Aboard Navy surface ships, heating a space is accomplished either by steam or by electric duct heaters, convection heaters, or unit heaters. Duct heaters are installed in mechanical supply ducts as preheaters or reheaters, and in recirculation ducts as reheaters. (Fig. 17-11 illustrates a steam duct heater.) Convection heaters (fig. 17-12) are generally used in spaces that are not served by mechanical supply systems or recirculation systems. Unit heaters (heating coils with their own fan) are used where the heat load is larger than can be adequately handled by convection heaters. All of these heaters can be used with steam pressures up to 150 psi.

Electric heaters are simply banks of heating elements installed in the airflow of a ventilation system.



47.112

Figure 17-12.—Convection heater (cutaway view).



47.111.1

Figure 17-11.—Steam ventilation heater.

MAINTENANCE OF VENTILATION EQUIPMENT

Ventilation equipment that fails to perform properly may jeopardize the health or life of crew members. Therefore, the individuals responsible for inspection and maintenance must be thoroughly familiar with the common hazards that can prevent normal operation of ventilation equipment.

GUARDING AGAINST OBSTRUCTIONS TO VENTILATION

Items such as swabs, deck cleaning gear, and trash stowed in fan rooms or ventilation trunks restrict airflow and increase dirt and odors taken inboard. Ventilation terminals must NEVER be used for stowage. Wet clothing secured to ventilation terminals increases the moisture content of the compartment air and restricts airflow. Stowage arrangements should be such that weather openings for a ventilation system are NEVER restricted.

KEEPING THE SYSTEM CLEAN

Dirt accumulation in a ventilation system restricts airflow and creates a serious fire hazard. In a clean duct, the cooling effect of the metal tends to act as a flame arrester, but an accumulation of foreign matter within a duct is a potential source of combustion. One method of reducing the amount of dirt and combustible matter which may be carried into a ventilation system is to wet down the deck areas near the air intakes before sweeping.

Since a large volume of air passes through or over the elements of a ventilation system, dirt collects in various units in spite of all precautionary measures. Therefore, periodic inspections and consistent regular service procedures are necessary to keep the system clean.

Filters help keep ventilation systems free of dust and dirt. Navy standard air filters have pressure taps on each side of the filter bank. By using a portable differential pressure gauge, you can quickly read the pressure drop across the filter. When the pressure drop increases to three times that of a clean filter, replace the filter. Ships carry spare filters so that a clean one may be substituted for the dirty one.

Special cleaning sinks are installed in ships with enough filters to justify the space, expense, and weight. These sinks are either of two types—steam or ultrasonic. In the steam type, steam is used to heat and agitate the water. In the ultrasonic type, cleaning is done by vibration caused by sound waves passing through the cleaning fluid.

Navy standard air filters have a thin film of oil applied to the wires. The oil film retains fine particles of dust and lint. After they are washed, the filters should be reoiled by spraying with filter oil. Sprayers furnished for oiling air filters must NOT be used for any other purpose. This precaution is to prevent contamination of the filters with toxic, flammable, or smelly materials. Flame arresters and grease filters should never be oiled.

SUMMARY

In this chapter, we have presented general information on the principles, equipment, and processes of air conditioning as these factors pertain to the ventilating, cooling, and heating of a ship's living and working spaces. Detailed information concerning the operation and maintenance of air-conditioning equipment may be found in the *Naval Ships' Technical Manual*, chapters 510 and 516.

You should have a basic understanding of the use of a psychrometric chart, which shows the relationship between the dry-bulb temperature, the wet-bulb temperature, and the dew point. These concepts are important in the operation and maintenance of air-conditioning equipment. In addition, you should recognize the general arrangement of air duct systems; how ventilation systems are adapted to various compartments of your ship; and how the various types of cooling and heating systems are used.

For efficient operation of air-conditioning and ventilation systems, you should strictly follow PMS requirements of the 3-M Systems and the specified technical manuals for your equipment.

If you have any questions concerning the material in this chapter, we recommend you reread the sections with which you are having difficulties before continuing to chapter 18.

CHAPTER 18

ADDITIONAL AUXILIARY EQUIPMENT

As an Engineman, you will work with a variety of equipment that is not directly related to the propulsion plant. Some examples are electro-hydraulic steering engines, cargo or weight-handling equipment, hydraulic systems, and laundry and galley equipment. Some equipment such as that in the laundry and galley will be operated by personnel assigned to the supply department. However, you will be expected to handle preventive maintenance and repairs.

In general, the operator will clean the equipment and make minor adjustments. In some cases, the operator will perform routine maintenance. You, the Engineman, will handle repairs, replacements, or adjustments. An Electrician's Mate will handle electrical work on all machinery and may be responsible for the entire machine if its operation is primarily electrical.

After studying the information in this chapter, you should have a good understanding of the functions and basic operating principles of various kinds of electrohydraulic drive machinery and weight-handling equipment. You should be able to identify the major components associated with shipboard galley and laundry equipment and the major components of auxiliary boilers, and their functions, and their basic operating principles. You should also be able to recognize the requirements for boiler water testing and to identify the firemain components and isolation procedures.

ELECTROHYDRAULIC DRIVE MACHINERY

Hydraulic units drive or control steering engines, windlasses, winches, capstans, cranes, ammunition hoists, and distant control valves. This chapter contains information on some hydraulic units that will concern you.

The electrohydraulic type of drive operates several different kinds of machinery. The following are some of the advantages of electrohydraulic machinery:

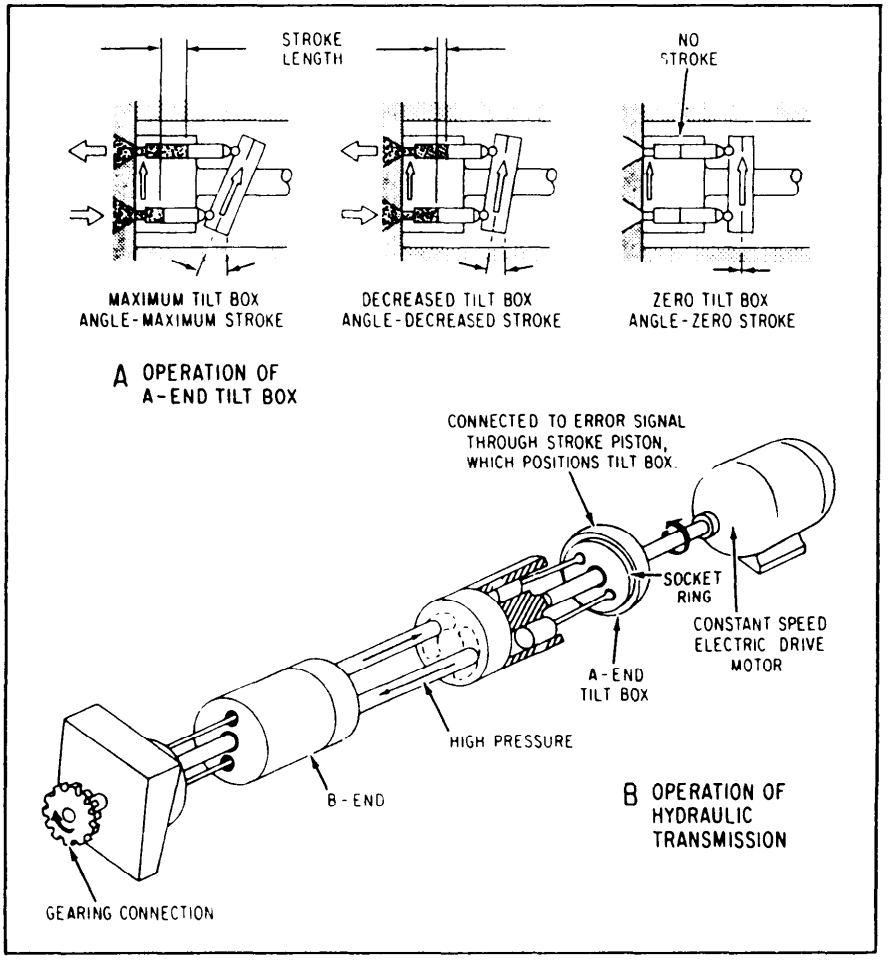
1. Tubing, which can readily transmit fluids around corners, conducts the liquid which transmits the force. Tubing requires very little space.
2. The machinery operates at variable speeds.
3. Operating speed can be closely controlled between minimum and maximum design limits.
4. The controls can be shifted from no load to full load rapidly without damage to machinery.
5. The machinery accelerates quickly.

ELECTROHYDRAULIC SPEED GEAR

An electrohydraulic speed gear is frequently used for hydraulic power applications. Different variations of the basic design are used for specific applications, but the principles remain the same. Basically, the unit consists of an electric motor-driven hydraulic pump (A-end) and a hydraulic motor (B-end). (See chapter 13 of this manual for a discussion on axial-piston, variable-stroke pumps.)

The B-end (fig. 18-1) is already on stroke and will be made to rotate by the hydraulic force of the oil acting on the pistons. Movement of the pumping pistons at the A-end is controlled by a tilt box (also called a swash plate) in which the socket ring is mounted, as shown in part A of figure 18-1.

The length of piston movement, one way or the other, is controlled by the movement of the tilt box and by the amount of angle at which the tilt box is placed. The length of the piston movement controls the amount of fluid flow. When the drive motor is energized, the tilt box and pistons at the A-end rotate. However, when the tilt box is in the neutral or vertical position, there can be no reciprocating motion of the pistons. Therefore, no oil is pumped to the B-end. Any angular movement of the tilt box, no matter how



83.81(83B)

Figure 18-1.—Electrohydraulic speed gear.

slight, causes pumping action to start. This causes immediate rotation of the B-end because of the transmission of force by the hydraulic fluid. To cause reverse rotation of the motor at the B-end, the tilt box at the A-end must be moved to shorten the stroke of the piston at the top and to lengthen the stroke of the piston at the bottom.

When reciprocating motion is required, such as for a steering engine, the B-end is replaced by two cylinders and a piston, or a ram. The force of the hydraulic fluid causes the ram (piston) to move inside the cylinders. The angle of the tilt box in the A-end may be set locally (as on the anchor windlass) or by remote control (as on the steering gear).

ELECTROHYDRAULIC STEERING GEAR

The direction of a ship moving through the water is controlled by changing the angle of its rudder(s), located in the stern of the ship. As the gross tonnage of ship increases, more and more force is required to move the rudder(s) through the required angle. On a large ship, the power required to position the rudder is provided by one or more electrohydraulic steering engines which respond to rudder orders transmitted electrically from the helm (steering wheel) in the pilot house to the steering gear, located directly above the rudder(s) in the stern.

The steering engine or gear transmits power from the steering engine to the rudder stock. The term *steering gear* normally includes the driving engine and the transmitting mechanism.

Although several different designs of steering engines are in common use, their operating principles are similar. One example of an electrohydraulic steering engine for a ship with two rudders is shown in figure 18-2. It

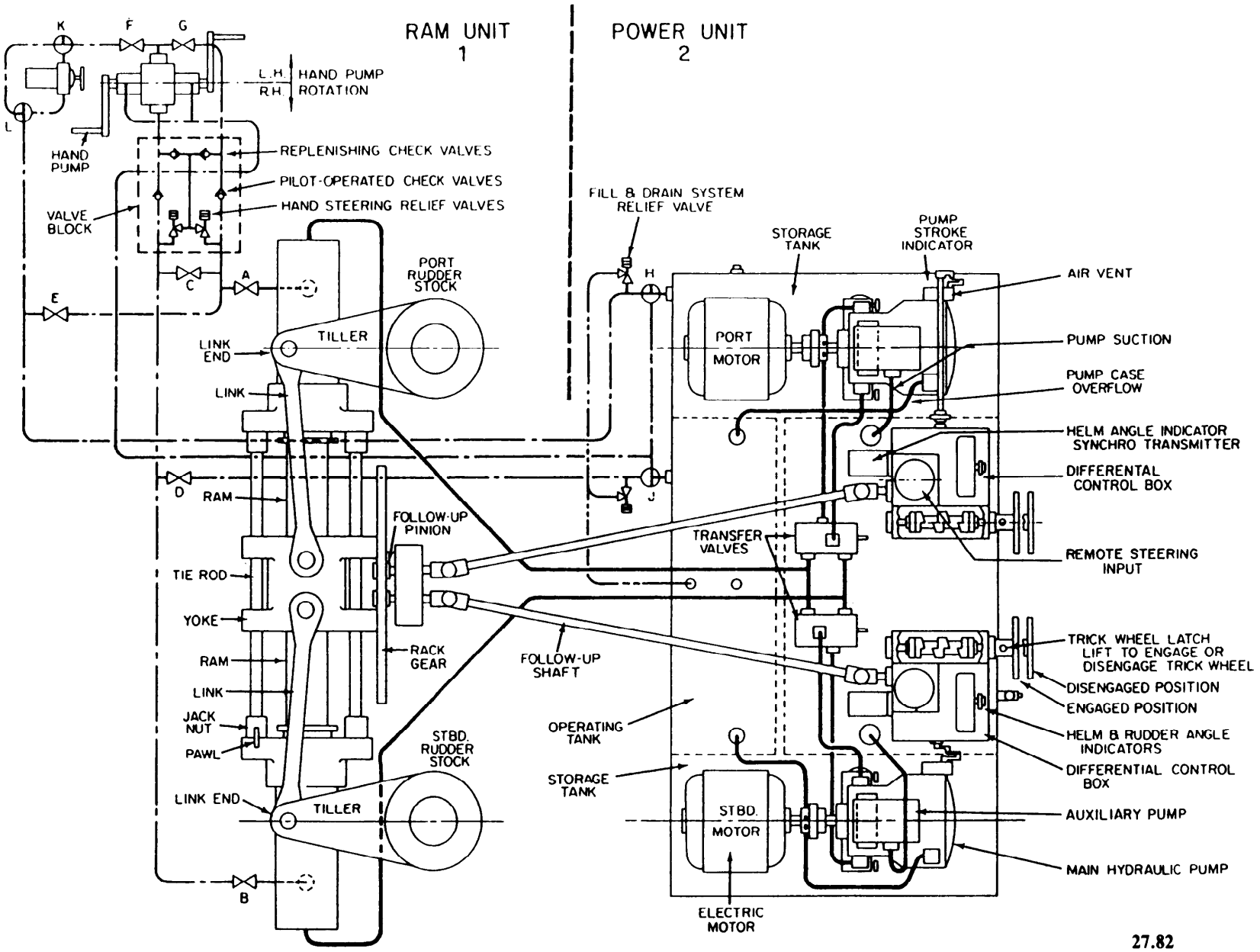


Figure 18-2.—Electrohydraulic steering engine.

consists essentially of (1) a ram unit and (2) a power unit.

Ram Unit

Refer to section 1 in figure 18-2. The ram unit is mounted athwartship (from side to side) and consists of a single ram (piston) between opposed cylinders. The ram is connected by links to the tillers of the twin rudders. When oil pressure is applied to one end of the operating cylinder, the ram will move, causing each rudder to move along with it. Oil forced out of the cylinder at the other end of the ram returns through ports in the transfer valve to the suction side of the main hydraulic pump of the power unit that is on line. (Oil supply and return piping is shown by wider black lines in fig. 18-2.)

Power Unit

Refer to section 2 of figure 18-2. The power unit consists of two independent pumping systems. Two systems are used for reliability. One pump can be operated while the other is on standby.

Each pumping unit consists of a variable-delivery, axial-piston main pump and a vane-type auxiliary pump. Both are driven by a single electric motor through a flexible coupling. Each system also includes a transfer valve with operating gear, relief valves, a differential control box, and trick wheels. The whole unit is mounted on a bedplate, which serves as the top of an oil reservoir. Steering power is taken from either of the two independent pumping units.

The pumps of the power unit are connected to the ram cylinders by high-pressure piping. The two transfer valves are placed in the piping system to allow for the lineup of one pump to the ram cylinders with the other pump isolated. A hand lever and mechanical linkage (not shown) are connected to the two transfer valves in such a way that both valves are operated together. This allows for rapid shifting from the on-service pumping unit to the standby unit; it also prevents both pumps from being lined up to the ram at the same time. The hand lever is usually located between the trick wheels. It has three positions marked P, N, and S. P denotes the port pump connected to the ram; N denotes neutral (neither pump connected to the ram); and S denotes the starboard pump connected to the ram. Also, the hand lever is usually connected to motor switches. This permits the operator to connect the selected pump to the ram and start the pump drive motor in one quick operation. In most modern ships this valve is electrically controlled by the motor controller and by pressure switches.

Principles of Operation

The on-service hydraulic pump is running at all times and is a constant-speed pump. Unless steering is actually taking place, the tilt box of the main hydraulic pump is at zero stroke, and no oil is being moved within the main system. The auxiliary pump provides control oil and super-charge flows for the system. Assume that a steering order signal comes into the differential control box. It may come from either the remote steering system in the ship's wheelhouse or the trick wheel. The control box mechanically positions the tilt box of the main hydraulic pump to the required angle and position. Remember that direction of fluid and flow may be in either direction in a hydraulic speed gear. It depends on which way the tilt box is angled. For this reason, a constant speed, unidirectional motor can be used to drive the main hydraulic pump. The pump will still have the capability to drive the ram in either direction.

With the main hydraulic pump now pumping fluid into one of the cylinders, the ram will move, moving the rudders. A rack and pinion gear assembly is attached to the rudder yoke between the rudder links. As the ram and the rudder move, the rack gear moves, driving the follow-up pinion gear. Each pinion drives a follow-up shaft which is mechanically coupled to the differential control box. This feedback (servo) system tells the directional control box when the steering operation has been completed and that the rudder angle is at the position ordered by the helm. As the ordered rudder angle is approached, the differential control box will begin to reduce the angle of the tilt box of the main hydraulic pump. By the time the desired rudder angle is reached, the tilt box should be at zero stroke. When this happens, the ordered signal (from the pilot house or trick wheel) and the actual signal (from the follow-up shafts) are the same. (NOTE: The ram is held in positon between the two cylinders by "hydraulic lock" due to the incompressible oil, which is prevented by the transfer valve from flowing into or out of the supply and return piping.) If either of these changes, the differential control box will react accordingly to cause the main hydraulic unit to pump oil to one end or the other of the ram.

The trick wheels provide local-hydraulic control of the steering system in case of failure of the remote steering system. A hand pump and associated service lines are also provided for local-manual operation of the ram in case of failure of both hydraulic pump units.

Steering Engine Room Watch

As an Engineman, you may be required to stand watch in the steering engine room. The duties of the steering engine room watch include operation and emergency repair of the machinery in your charge. Operating instructions and system diagrams are posted in the steering engine room. The diagrams describe the various methods of operating the steering gear under normal and emergency conditions and show the relative positions of the valves concerned for each method of operation.

During your watch in the steering engine room, you should take the following actions:

1. Make sure the standby equipment is ready for instant use in an emergency.
2. Inspect the steering gear thoroughly. Check the unit by feeling the various parts. Report any part that feels HOT to the bare hand to the officer of the deck on the bridge and to the engineering officer of the watch (EOOW) in the main engine room.
3. Investigate for binding, overloading, and lack of lubrication.
4. Listen for new or unusual noises, which may indicate loose parts or wear.
5. Bleed all air out of the system.
6. Check for leaks in the line and fittings. Piping leaks usually occur following unusual strain (as from rough seas). Most leaks can be corrected by tightening the flange bolts. Small leaks at ram packing glands are not objectionable since the small flow of hydraulic fluid provides lubrication. Always maintain sufficient liquid level in the storage, operating, and replenishing tanks.
7. Check and ensure all grease fittings and surfaces requiring lubrication are lubricated according to the instructions on the lubrication chart.
8. Observe all applicable safety precautions. Keep oil off the deck. Exercise extreme caution when working in confined spaces around the ram and actuating gear. All clothing should be free of loose ends that might catch in the machinery.

The Planned Maintenance System (PMS) lists the individual requirements for the equipment. The electricians maintain the electrical portion of the steering system, including the control system.

WEIGHT-HANDLING EQUIPMENT

To qualify for advancement in rating, you must be familiar with the construction, operation, and maintenance of anchor windlasses, winches, capstans, and cranes. The following discussion of such machinery and other weight-handling equipment is supplementary to that given in *Fireman,* NAVEDTRA 10520.

Anchor Windlasses

In an electrohydraulic mechanism, one constant-speed electric motor drives two variable-stroke pumps through a coupling and reduction gear. Other installations include two motors, one for driving each pump. Each pump normally drives one wildcat. However, when a cross-connect valve is used, either pump may drive either of the two wildcats. The hydraulic motors drive the wildcat shafts with a multiple-spur gearing and a locking head. The locking head allows the operator to disconnect the wildcat shaft and permit free-wheeling operation of the wildcat when dropping anchor.

Each windlass pump is controlled either from the weather deck or windlass room. The controls are handwheels on shafting leading to the pump control. The hydraulic system will require your attention. Be certain the hydraulic system is always serviced with the specified type of clean oil.

You may have to maintain two types of anchor windlasses—electric and electrohydraulic. In an electrohydraulic windlass, your principal concern is the hydraulic system.

A windlass is used intermittently and for relatively short periods of time. However, it must handle the required load under severe conditions. This means you must maintain and adjust the machinery when it is not in use. This practice will prevent deterioration and ensure windlass reliability.

Windlass brakes must be kept in satisfactory condition if they are to function properly. Wear and compression of brake linings will increase the clearance between the brake drum and band after a windlass has been in operation. Brake linings and clearances should be inspected frequently. Adjustments should be made according to the technical manual for the equipment.

Follow the lubrication instructions listed on applicable maintenance requirement cards (MRCs). If a windlass has been idle for some time, it should be lubricated. Lubrication protects the finished surfaces from corrosion and prevents seizure of moving parts.

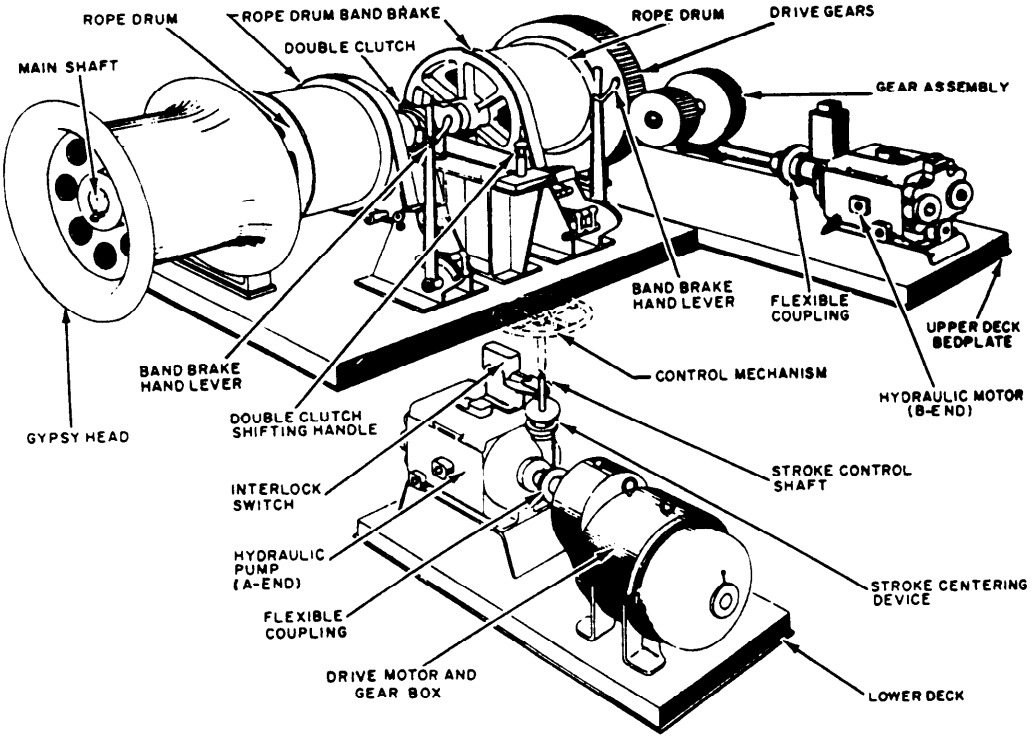
The hydraulic transmission of electrohydraulic windlasses and other auxiliaries are manufactured with close tolerances between moving and stationary parts. Use every precaution to keep dirt and other abrasive material out of the system. When the system is replenished or refilled, use only clean oil. Filter the oil as you pour it into the tank. If a hydraulic transmission has been disassembled, clean it thoroughly before reassembly. Before installing piping or valves, clean their interiors to remove any scale, dirt, preservatives, or other foreign matter.

Winches

Winches are used to heave in on mooring lines, to hoist boats, as top lifts on jumbo booms of large auxiliary ships, and to handle cargo. Power for operating shipboard winches is usually furnished by electric motors. Sometimes delicate control and high acceleration without jerking are required, such as for the handling of aircraft. Electrohydraulic winches are usually installed for this purpose. Most auxiliary ships are equipped with either electrohydraulic or electric winches.

CARGO WINCHES.—Some of the more common winches used for general cargo handling are the double-drum, double-gypsy and the single-drum, single-gypsy units. Four-drum, two-gypsy machines are generally used for minesweeping.

ELECTROHYDRAULIC WINCHES.—Electrohydraulic winches (fig. 18-3) are always the drum type. The drive equipment is like most hydraulic systems. A constant-speed electric motor drives the A-end (variable-speed hydraulic pump), which is connected to the B-end (hydraulic motor) by suitable piping. The drum shaft is driven by the hydraulic motor through a set of speed reduction gears.



47.145

Figure 18-3.—Electrohydraulic winch units.

Winches normally have one horizontally mounted drum and one or two gypsy heads. If only one gypsy is required, it may be easily removed from or assembled on either end of the drum shaft. When a drum is to be used, it is connected to the shaft by a clutch. (NOTE: Another word for gypsy is wanderer. The head is called a gypsy because one or two turns of ship-handling line wrapped around it will wander over the surface between the raised ends of the drum-shaped gypsy when it is rotating. A gypsy head is NOT used to take up wire rope as is done with a rope drum, which resembles a reel used for fishing.)

ELECTRIC WINCHES.—An electrically driven winch is shown in figure 18-4. This winch is a single-drum, single-gypsy type. The electric motor drives the unit through a set of reduction gears. A clutch engages or disengages the drum from the drum shaft. Additional features include an electric brake and a speed control switch.

Capstans

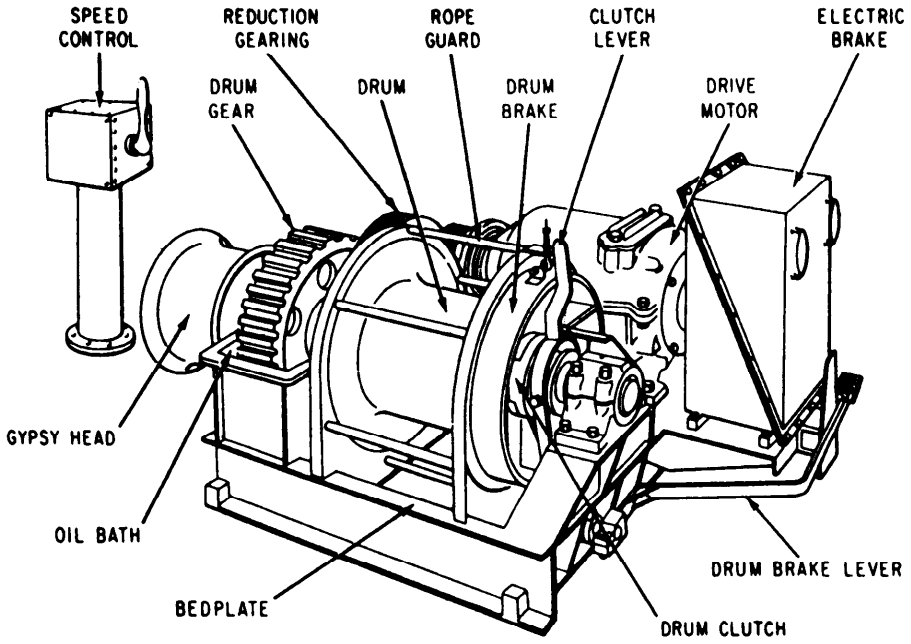
The terms *capstan* and *winch* should not be confused. A winch has a horizontal shaft, and a capstan has a vertical shaft. The type of capstan installed aboard ship depends on the load requirements and the type of power available. In general, a capstan consists of a single head mounted on a vertical shaft, reduction gearing, and a power source.

Electric capstans are usually of the reversible type. They develop the same speed and power in either direction. Capstans driven by alternating current motors run at either full, one-half, or one-third speed. Capstans driven by direct current motors usually have from three to five speeds in either direction of rotation.

Maintenance of Winches and Capstans

In several respects, you will maintain a winch or a capstan in the same way you maintain a windlass. Inspect the friction brake linings regularly and replace them when necessary. Take steps to prevent oil or grease from accumulating on the brake surfaces. Periodically check the operation of brake-actuating mechanisms, latches, and pawls.

Frequently inspect winch drums driven by friction clutches for deterioration of the friction



47.227

Figure 18-4.—Electric winch.

material. Check also to see if oil and grease on the surface is causing improper operation. Lubricate the sliding parts of positive clutches properly. Check the locking device on the shifting gear to see if it will hold under the rated load.

Shipboard Cranes

Cranes used on board United States Navy ships are classified by the functional use of the crane. The following crane designations are in common use:

1. Boat and aircraft (B&A)
2. Boat and repair (B&R)
3. Boat and missile (B&M)
4. Boat and helicopter (B&H)
5. Cargo stores

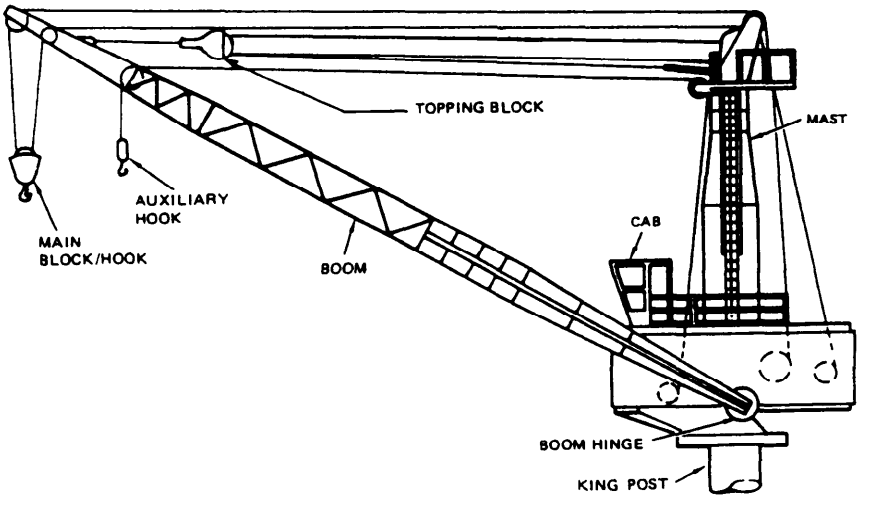


Figure 18-5.—Topping (king post) crane.

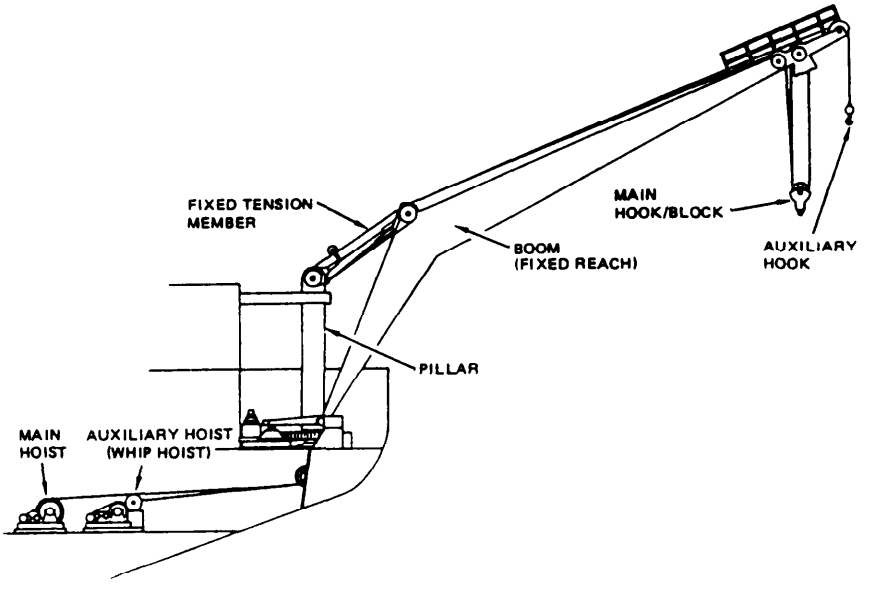


Figure 18-6.—Nontopping (pillar) crane.

6. Sail-service
7. Minesweeping
8. Salvage
9. Torpedo

CLASSIFICATION AND DESIGN.—The classification of the cranes we will discuss in this chapter is based on crane design and operational features rather than shipboard use or location. Operating features include the following categories:

1. Rotating cranes
2. Topping cranes
3. Nonrotating cranes
4. Nontopping cranes

Rotating Cranes.—In general, rotating cranes may be topping or nontopping. Topping, rotating cranes are characterized by a topping boom attached to a king post or pedestal that resists the overturning forces created by the boom and attached load (fig. 18-5). Nontopping, rotating cranes have a boom rigidly attached to a rotating column or base (fig. 18-6).

The topping, rotating crane (fig. 18-5) is the most common type of hull-mounted crane used by the Navy. This type of crane has a boom attached to a rotating structure by a boom hinge, which allows for raising and lowering (resulting in inward and outward movement of the load). The rotating structure, which supports the boom and contains the machinery and hoisting systems, is attached to a base structure (king post or pedestal) about which the structure rotates. The base structure may be fixed or may travel on wheels mounted on rails. When the base structure is elevated to a height above the deck to permit passage of objects or personnel on the deck under the crane, the crane is also a portal type.

Nonrotating Cranes.—Nonrotating cranes are characterized by a bridge and trolley arrangement. Hoisting equipment is located on the trolley that, in turn, is transported on movable bridge girders and wheel trucks. Figure 18-7 illustrates a nonrotating, raised runway, overhead traveling crane. The crane is mounted on a pair of elevated parallel rails, adapted to raise or lower a load and to carry it horizontally, parallel, or at right angles to the rails. This crane consists of one or more trolleys operating on the top or bottom of a bridge. The bridge consists of one or more girders or trusses mounted on trucks operating on elevated rails. The operational area is limited to the space between the bridge rails.

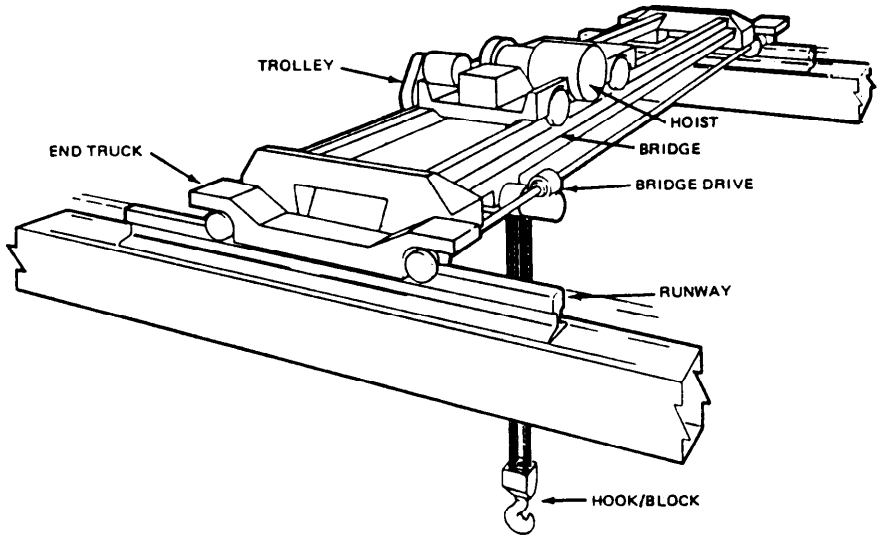


Figure 18-7.—Overhead traveling crane.

Another version of a nonrotating crane is the traveling support gantry crane (fig. 18-8). This crane is similar to an overhead traveling crane, except that the bridge for carrying the trolley(s) is rigidly supported on two or more gantry legs. This assembly moves on fixed rails. You can find additional detailed information concerning the major types of Navy cranes in *Naval Ships' Technical Manual,* Chapter 589, "Cranes."

OPERATION AND MAINTENANCE.—Your ship should have qualified personnel assigned to supervise and carry out required maintenance of specific cranes. Qualified personnel must complete formal training in regard to the safety devices and the load-bearing and load-controlling components of the cranes used on your ship. Some maintenance situations may require the use of personnel who are not formally qualified as maintenance technicians. The personnel who are routinely involved in crane maintenance, however, must be qualified technicians.

Before beginning any adjustments, repairs, or inspections on a crane, maintenance personnel must take the following precautions:

1. Stow the crane to be repaired where it will cause the least interference with other cranes and operations.
2. Place the boom in the stowed position for work on the topping.
3. Place all controls in the OFF position.,
4. De-energize the power supplies; place the power supply breaker in the OFF position and tag out.
5. Perform maintenance on energized electrical equipment only when specifically authorized to do so by the commanding officer.
6. After completing adjustments and or repairs, do not restore the crane to service until all guards have been reinstalled, systems untagged, safety devices reactivated, maintenance equipment removed, and required testing completed.
7. Unless otherwise authorized by the crane officer on a case basis for unusual repairs, only qualified personnel should perform maintenance on cranes.

All qualified personnel must accomplish PMS requirements according to the instructions listed on applicable MRCs. For additional information on the operation and maintenance of cranes, consult *Naval Ships' Technical Manual,* Chapter 589, "Cranes."

GALLEY AND LAUNDRY EQUIPMENT

The Navy uses a variety of equipment to perform galley and laundry functions. The type of equipment installed will depend on the size of the ship, the availability of steam, and other factors. Operating and maintenance procedures and information about repair parts can be found in the technical manual for each item of equipment. Preventive maintenance should be scheduled and performed according to the requirements of the 3-M system.

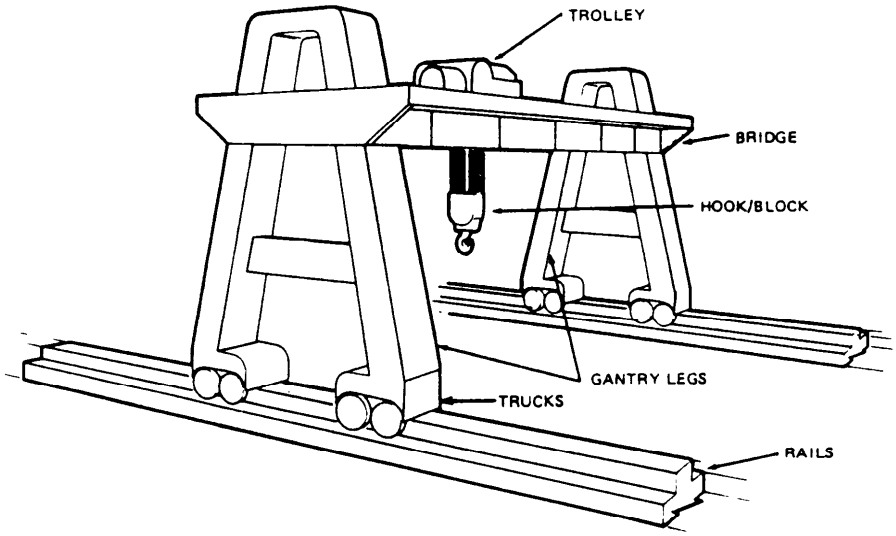


Figure 18-8.—Gantry crane.

GALLEY AND SCULLERY EQUIPMENT

As an Engineman, you may be required to work with galley or scullery equipment. This equipment includes such items as vegetable peeling machines, garbage grinders, steam-jacketed kettles, and dishwashers. In the following sections, we will discuss some characteristics of steam kettles and dishwashing machines.

Steam-Jacketed Kettles

Steam-jacketed kettles come in various sizes from 5 gallons to 80 gallons. The kettles are made of corrosion-resisting steel. They are constructed to operate at a maximum steam pressure of 45 psi. A relief valve, installed in the steam line leading to the kettles, is set to lift at 45 psi.

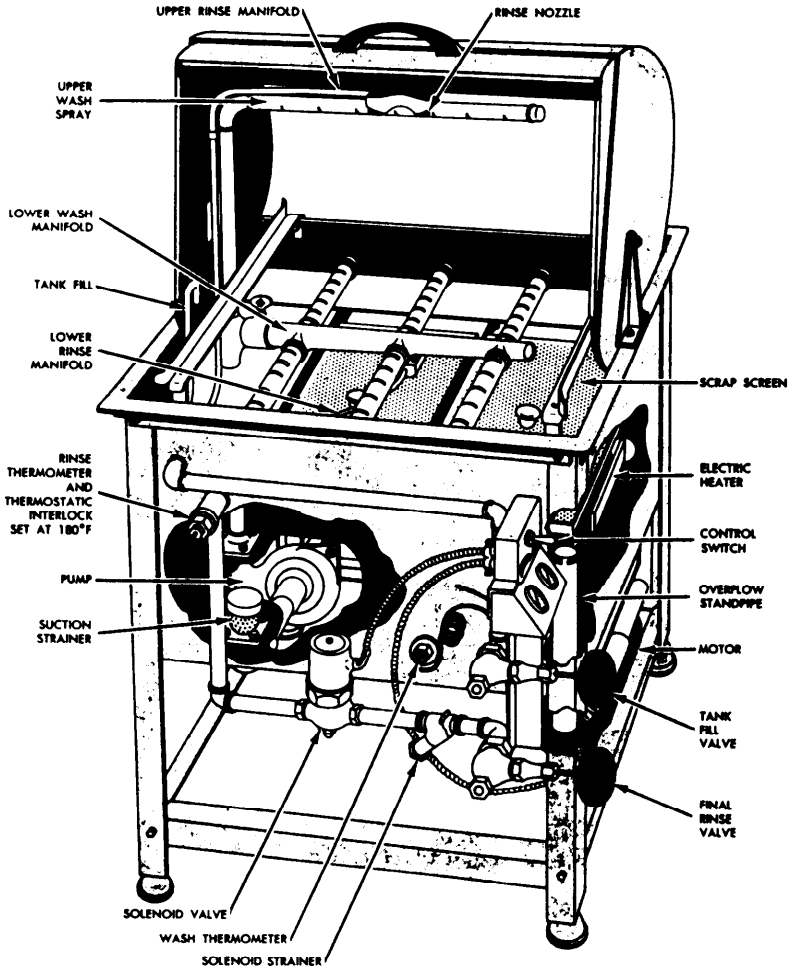
Other steam-operated cooking equipment items include steamers and steam tables. Steamers use steam at a pressure of 5 to 7 psi; steam tables use steam at a pressure of 40 psi or less. Any maintenance you may perform on these units will normally be limited to the associated steam supply and drain lines and valves.

Dishwashing Machines

Dishwashing machines used in the Navy are classified as one-tank, two-tank, or three-tank machines. The three-tank machine is a fully automatic, continuous-racking machine which scrapes, brushes, and provides two rinses. It is used at large activities.

SINGLE TANK.—Single-tank machines (fig. 18-9) are used in small ships where larger models are not feasible.

To control the bacteria to a satisfactory minimum in single-tank machines, the temperature of the washwater in the tank must



48.34

Figure 18-9.—Typical semiautomatic single-tank dishwashing machine.

be between 140° and 160°F. Consequently, a thermostat in the machine prevents operation when the temperature of the water falls below 140°F. Water temperatures higher than 160°F result in less efficient removal of certain foods. The washing time in the automatic machines is 40 seconds.

For rinsing, hot water is sprayed on the dishes at a temperature between 180° and 195°F.

To conserve fresh water, the rinse time interval is usually limited to 10 seconds. When water supply is not a problem, a rinse of 20 seconds is recommended.

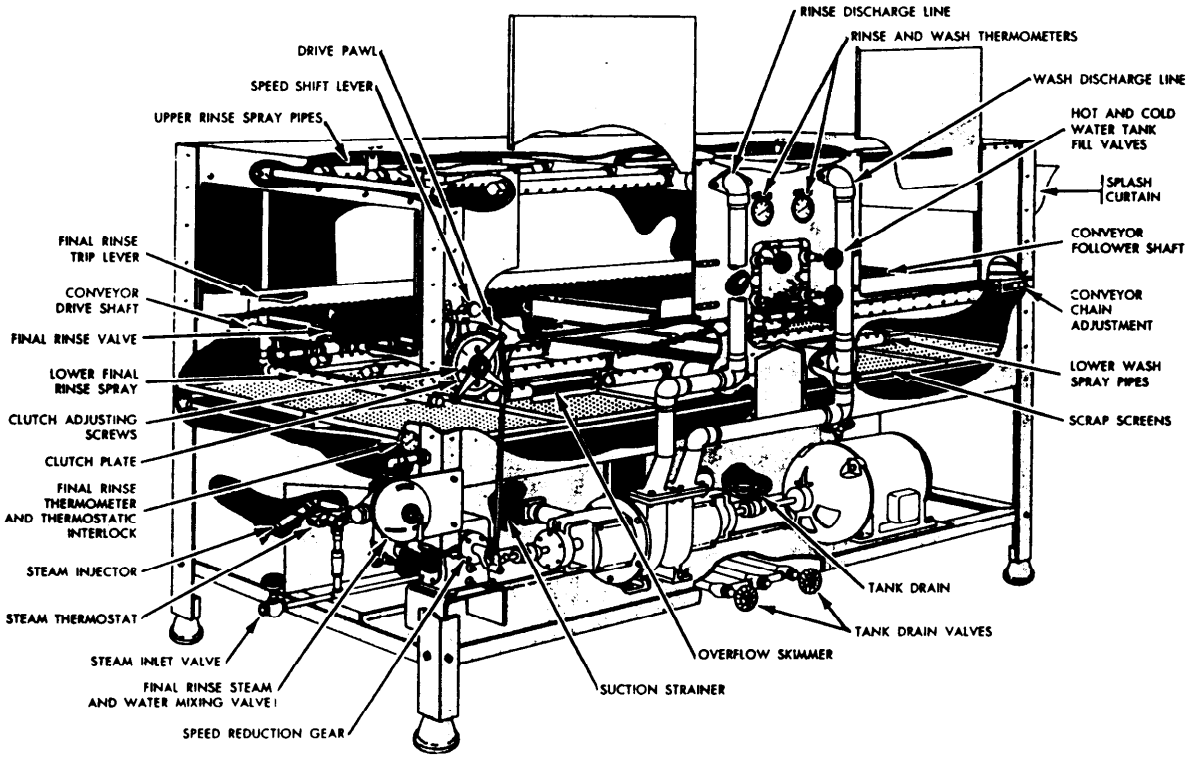
Wash and rinse sprays are controlled separately by automatic, self-opening and closing valves in the automatic machine. The automatic machines provide a 40-second wash and a 10-second rinse.

DOUBLE TANK.—Double-tank machines (fig. 18-10) are available in several capacities and are used when more than 150 persons are to be served at one meal. These machines have separate wash and rinse tanks. They also have a final rinse of hot water which is sprayed on the dishes from an external source. This spray is actuated by the racks as they pass through the machines. The spray automatically stops when the rinse cycle is completed. The final rinse is controlled by an adjustable automatic steam mixing valve which maintains the temperature between 180° and 195°F. Double-tank machines are also equipped with a thermostatically operated switch in the rinse tank which prevents operation of the machine if the temperature of the rinse water falls below 180°F. The racks pass through the machine automatically on conveyor chains. The double-tank dishwashing machine should be timed so that the utensils are exposed to the machine sprays for not less than 40 seconds (20-second wash, 20-second rinse).

Descaling Dishwashers

The accumulation of scale deposits in dishwashing machines should be prevented for at least two reasons. First, excessive scale deposits on the inside of pipes and pumps will clog them and interfere with the efficient performance of the machine by reducing the volume of water that comes in contact with the utensils during the washing and sanitizing process. Second, scale deposits provide a haven for harmful bacteria.

Chemicals used to descale dishwashing machines are available through Navy supply channels.



48.35

Figure 18-10.—Typical automatic double-tank dishwashing machine.

LAUNDRY EQUIPMENT

Equipment used in the cleaning, drying, and pressing of clothing includes washers, extractors, dryers, dry-cleaning machines, and various types of presses.

Most of the maintenance associated with this equipment is concerned with inspecting and lubricating the various parts.

Most laundry equipment is equipped with a number of safety devices. For example, air-operated presses are equipped with two operating valves for the safety of personnel. The arrangement is such that the operator must use both hands to close the press. In this way, the hands of the operator cannot be caught in the press. In no case shall either of these valves be bypassed or permanently left open. Disabled safety devices can result in shipboard fires, damage to equipment, damage to clothing and, in many cases, personnel injuries. Special attention must be given to these safety devices during preventive and corrective maintenance with extra special attention given to those devices designed to protect equipment operators.

AUXILIARY BOILERS

On diesel-driven ships, auxiliary boilers are used to supply steam for distilling plants and space heating and to heat water, for use in the galley and laundry. These boilers are equipped with all auxiliaries, accessories, and controls to operate as complete, self-contained steam-generating plants. (See fig. 18-11.)

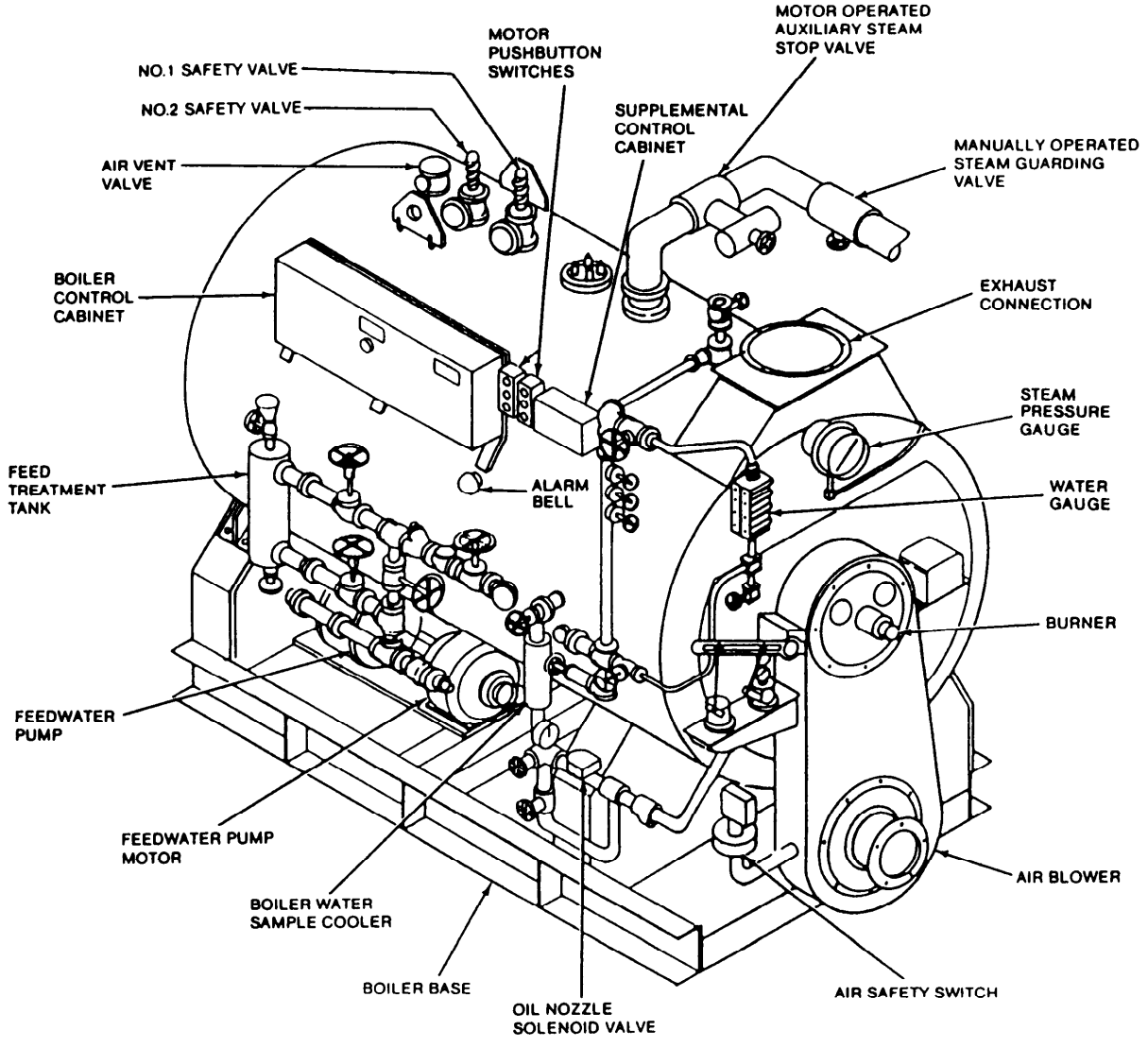
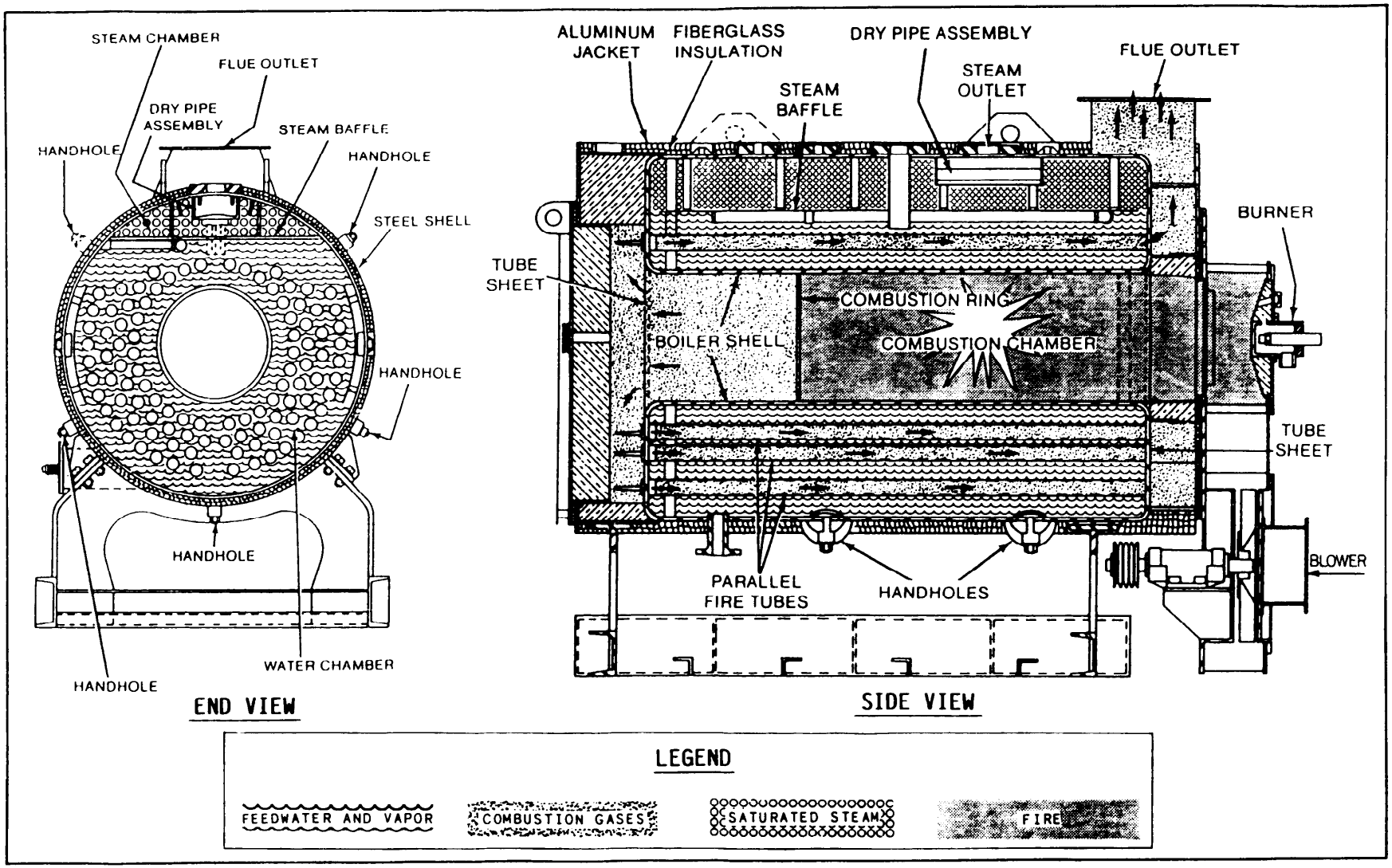


Figure 18-11.—Left front view of auxiliary boiler.



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Figure 18-12.—Fire-tube auxiliary boiler (cutaway view).

TYPES OF BOILERS

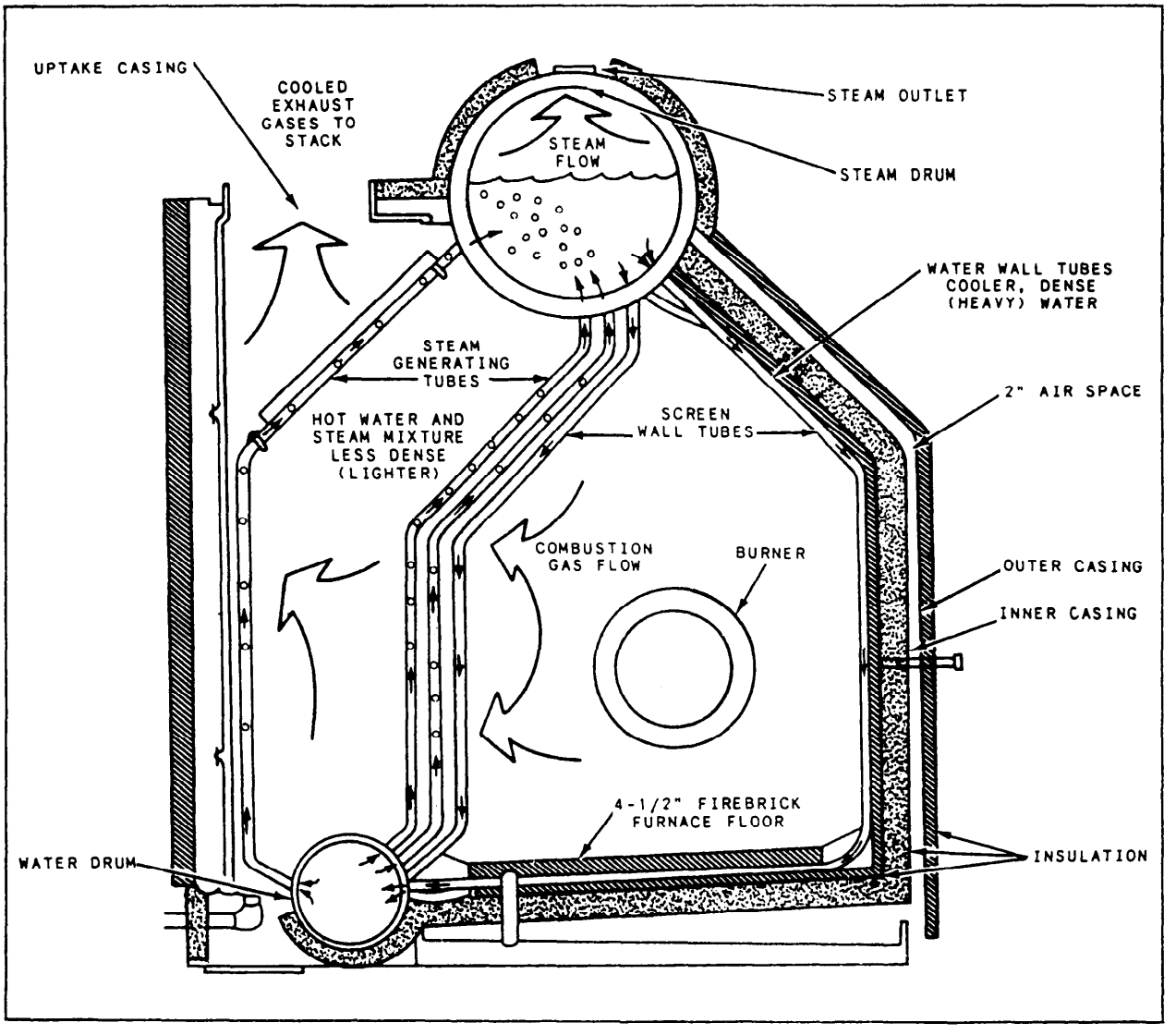
Auxiliary boilers on Navy ships may be divided into two groups: FIRE-TUBE BOILERS and WATER-TUBE BOILERS.

Fire-Tube Boilers

Fire-tube boilers are generally similar to Scotch marine or locomotive boilers. In this type of boiler, the gases of combustion pass through tubes that are surrounded by water. There are a number of auxiliary boilers of the fire-tube type in use in diesel-driven ships. Figure 18-12 illustrates a cutaway view of the fire-tube boiler shown in figure 18-11.

Water-Tube, Natural-Circulation Boilers

Water-tube, natural-circulation boilers consist basically of a steam drum and a water drum connected by a bank of generating tubes. (See fig. 18-13.) The two drums are also connected by a row of water tubes, which forms a water-cooled sidewall opposite the tube bank. The water-wall tubes pass beneath the refractory furnace floor before they enter the water drum. In natural-circulation boilers, the steam and water



75.406

Figure 18-13.—Natural-circulation, water-tube boiler.

drums are connected by several tubes of larger diameter, called DOWNCOMERS or WATER TUBES (not shown). These tubes are positioned away from the flow of hot gases of combustion. Refractory is also used to protect these downcomers from contact with the combustion gases.

The operating principle of a natural-circulation boiler is quite simple. It relies on the difference in density (weight) between the cooler (heavier) water in the water tubes (or downcomers) and the hot, less dense (lighter) water in the steam-generating tubes. This is the force that causes the hot water and steam mixture to rise in the tubes in the generating bank, from the water drum to the steam drum, where the steam is separated from the water and rises to the top of the steam drum. The flow of water up the tubes of the steam-generating bank must be maintained; otherwise, the tubes would quickly melt. A constant flow of water and steam up the tubes is required to carry away heat at the proper rate. If the flow from natural circulation is allowed to stop, such as when the water level in the steam drum falls below the openings of the bank of tubes for the water wall, the tubes of the generating bank will be severely damaged and the boiler will need major repairs. (Replacing boiler tubes is an expensive operation.)

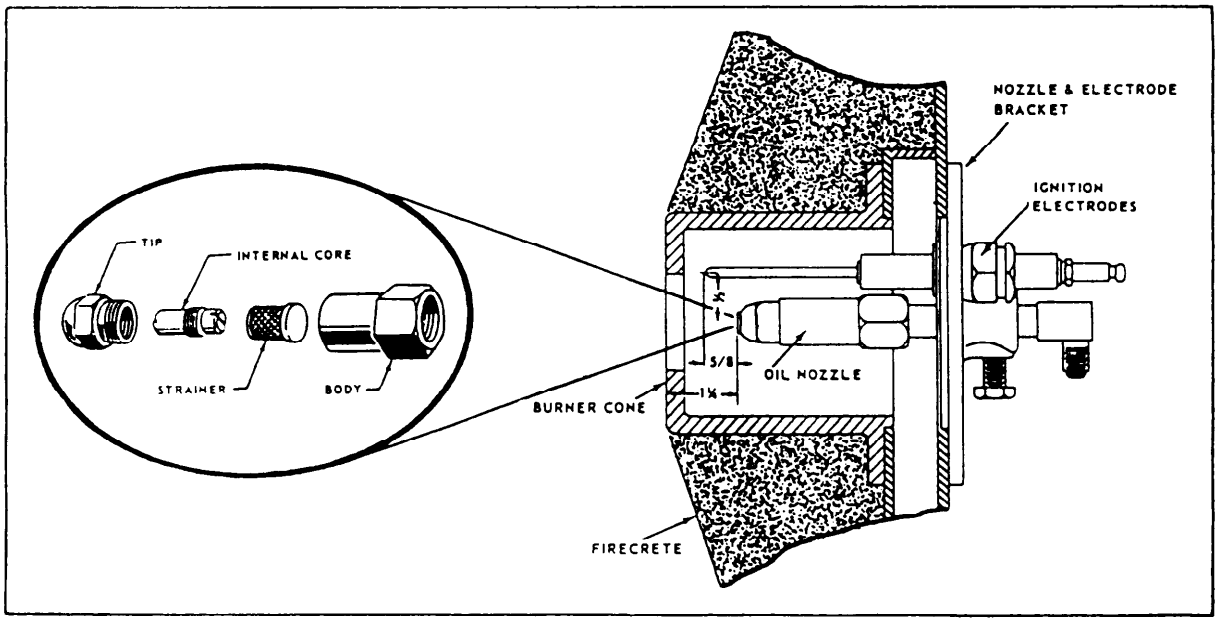
OIL BURNERS

Oil burners used on auxiliary boilers are the mechanical atomizing type. Two types commonly used are the constant-capacity, pressure-atomizing burner and the variable-capacity, pressure-atomizing burner.

Constant-Capacity, Pressure-Atomizing Burners

Constant-capacity, pressure-atomizing burners are designed for electric ignition and automatic control. Basically, these burners consist of a burner cone or plenum chamber connected to the combustion air fan casing, brackets for nozzle and electrodes, and an oil-atomizing nozzle. Variations of boiler load with this type of burner is accomplished by the automatic "off and on" cycling of the burner. Burners intended for wide variations of boiler steaming loads are designed with dual or triple nozzle arrangements to eliminate excessive cycling. In such burners, one nozzle is used as a pilot, and additional nozzles are manually cut in as required. Standard commercial nozzles are used with burners of this type.

A typical arrangement of a burner and construction of the oil-atomizing nozzle are shown in figure 18-14.



75.297:298

Figure 18-14.—Constant-capacity, pressure-atomizing burner as installed in the boiler front.

Variable-Capacity, Pressure-Atomizing Burners

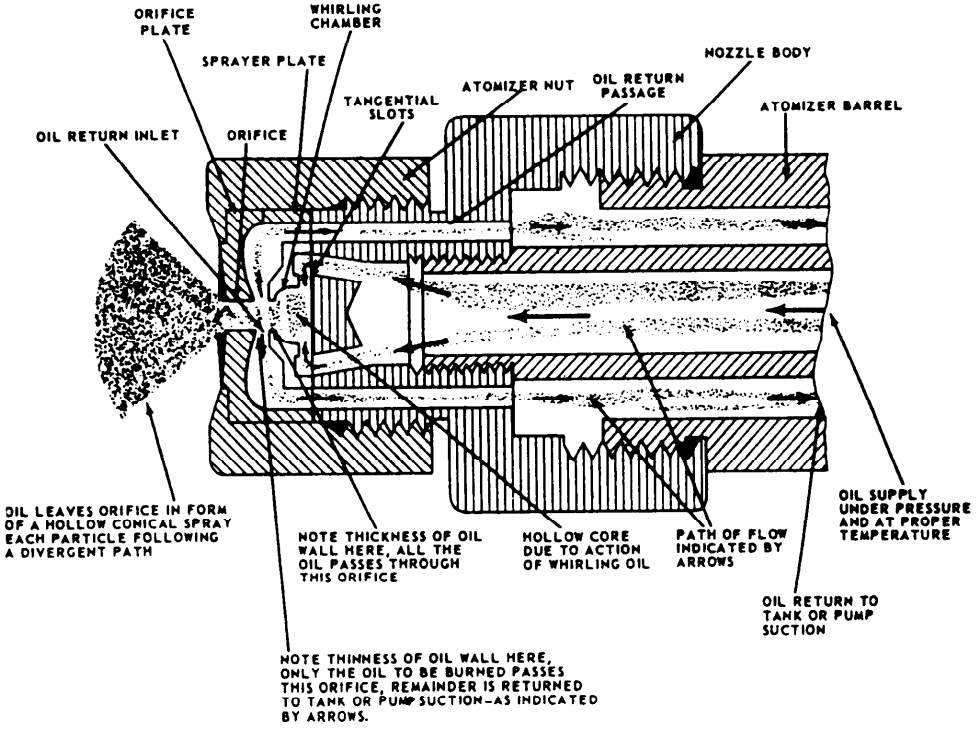
The atomizing unit of a variable-capacity, pressure-atomizing burner consists of a burner barrel, a nozzle body or distributor sprayer plate, an orifice plate, and an atomizer nut. The capacity of these atomizers is regulated by an oil control valve placed in the oil return line. While the supply of oil to the atomizer is kept at a constant pressure necessary for proper atomization, amounts of oil returned from the atomizer may be varied by increasing or decreasing pressure at the oil control valve. The amount of oil atomized is always the difference between the oil supplied to and the oil returned from the atomizer. An oil metering valve is linked with a mechanism regulating air admission to the burner so that air and oil may be properly proportioned over the entire range of burner operation. The operating principle of this type of atomizer is illustrated in figure 18-15.

BOILER CONTROLS

Methods of operating auxiliary boilers may be manual, semiautomatic, or automatic. Any controls installed on auxiliary boilers will depend on the method of operation. The feedwater controls that are used may be classified as the (1) thermomechanical, (2) float, or (3) electrode type. We will briefly explain each type.

Thermomechanical feedwater regulators are used on water-tube, natural-circulation boilers. The control element depends on the water level in the boiler steam drum. Thus, a certain water level in the drum corresponds to a certain opening of the feedwater control valve.

The float type of feedwater regulating and low-water cutoff controls are used on water-tube and fire-tube boilers designed for semiautomatic or automatic operation. These controls consist of a float chamber, a float, and a switch. The float chamber is connected to the boiler drum so that the water level in the chamber is always the same as the water level in the drum. The float is interlinked with a switch which is wired into the feed pump control circuit. The switch contacts are open when the water level in the drum and float chamber is normal. A drop in the water level closes the switch contacts. This reaction starts the feed pump. When the water level is restored to a predetermined high position, the switch breaks



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Figure 18-15.—Variable-capacity, pressure-atomizing burner, showing oil flow.

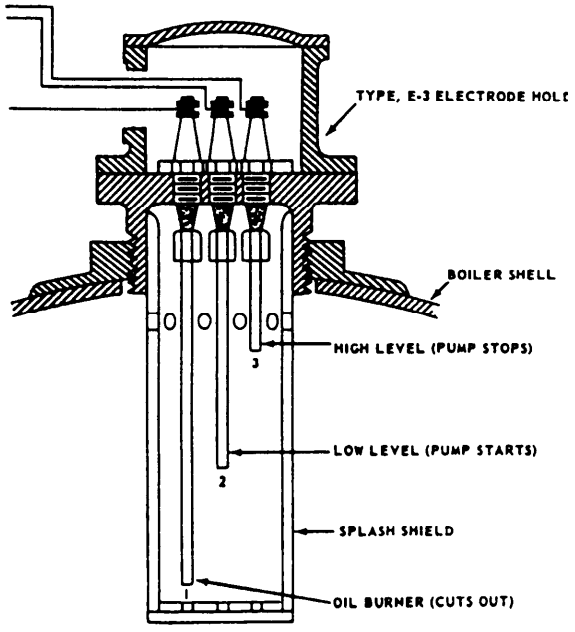
the contact and stops the feed pump. The low-water cutoff feature consists of an additional switch. This switch is mounted in the same case as the pump switch but is wired into the burner circuit. If the water level drops below a permissible minimum, the low-water cutoff switch breaks the burner circuit and stops the burner.

Electrode-type feedwater regulating and low-water cutoff controls are used on water-tube and fire-tube boilers designed for semiautomatic or automatic operation. These controls consist of an electrode assembly and a water level relay. The electrode assembly contains three electrodes of different lengths, corresponding to the high, low, and cutoff water levels in the boiler drum. A typical water level electrode assembly is illustrated in figure 18-16.

The electrode assembly is installed on the top of the boiler drum so that the normal water level is at approximately the midpoint between the high-level and the low-level electrodes. The electrodes are electrically wired to the water level relay assembly. The relay contains the feedwater pump START and STOP contacts, which are wired to the feedwater pump controller, and the low-water cutoff, which is wired into the burner circuit. The feed pump is started when the water level in the boiler drops below the middle electrode. After the water level is restored and reaches the high-level electrode, the feed pump is stopped. In the event the water level is not restored and drops below the longest electrode, the cutoff contacts of the water level relay stop the burner by breaking the burner circuit.

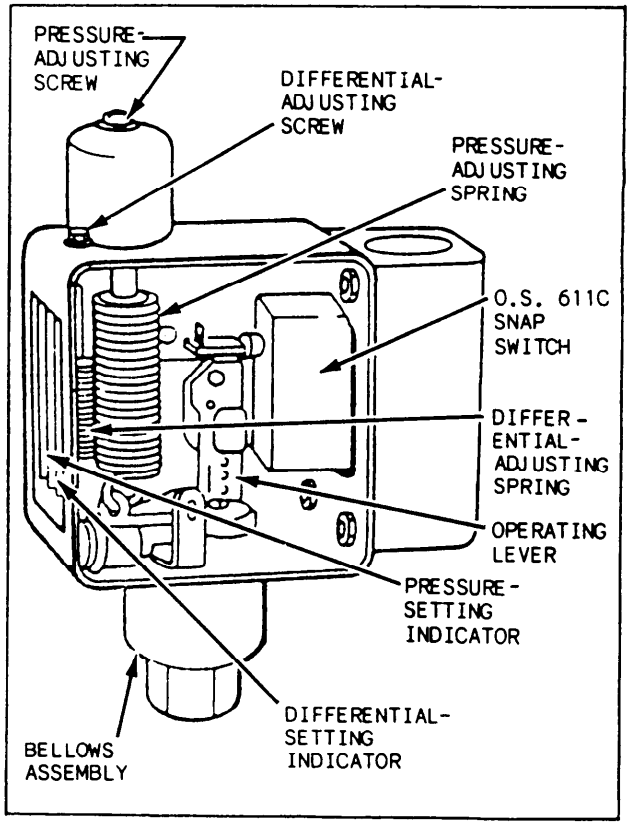
Pressure-limit switches and pressuretrols are operated by steam pressure. A typical pressure switch is shown in figure 18-17. They control burner operation within a fixed range of boiler pressures. Basically, they consist of a bellows assembly linked with a snap switch through a pressure-adjusting mechanism. The bellows assembly expands or contracts with any increase or decrease in boiler pressure and causes the snap switch to open or close its contacts. The pressure-adjusting mechanism is set so that the contacts open and close at specified values of cutout and cut-in boiler pressures. The differential between the cutout and cut-in pressures may be either adjustable or fixed.

On boilers set up for automatic operation, the snap switch is wired into the burner electric circuit so that it will break the circuit and stop the burner when the cutoff pressure is reached and will make the circuit and restart



75.299

Figure 18-16.—Water level electrode assembly.



75.300

Figure 18-17.—Pressure switch for an auxiliary boiler.

the burner when the boiler pressure falls below the cut-in pressure.

On boilers set up for semiautomatic operation (manual ignition), the snap switch is wired into the burner circuit in such a way that it will break the circuit at the cutoff pressure and will hold it open, preventing manual restart of the burner, until pressure falls below the cut-in setting.

Modulating pressuretrols are steam-operated rheostat switches used for automatic regulation of oil and air admission to the burners. These switches are similar in design to limit pressuretrols, except they are equipped with a potentiometer coil (a variable electrical resistance element). The switch is wired into the circuit of a reversing type of motor which operates the linkage of the air-oil ratio adjusting mechanism. When boiler pressure increases or decreases with variation of the boiler load, the bellows assembly of the switch expands or contracts, causing a sliding contact to move across the resistance element (potentiometer coil). The change in electrical balance of the motor circuit causes the motor to rotate. The movement of the motor, transmitted by a crank arm to the linkage between the fuel metering valve and the damper air vanes, resets the oil metering valve and the damper to positions corresponding to the firing rate required by the boiler load.

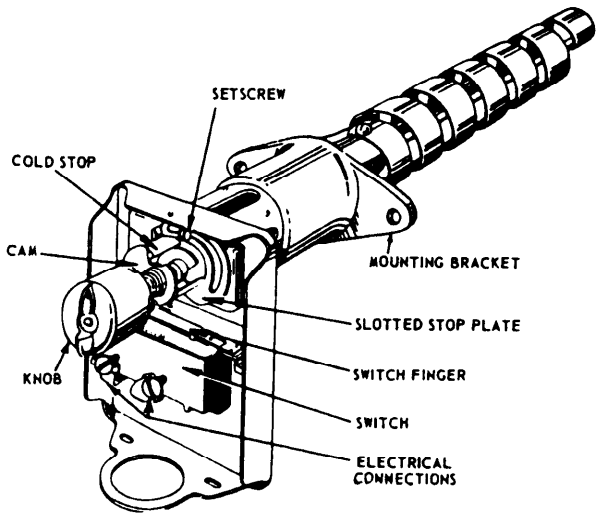
SAFETY COMBUSTION CONTROLS

Safety combustion controls are designed to shut down the burner to prevent flooding the furnace with oil after initial ignition or in the event of ignition failure or flame failure. These controls are either thermostatic (stack switches and pyrostats) or photoelectric.

Stack Switches and Pyrostats

Stack switches and pyrostats consist basically of a bimetallic helix, a mounting frame, a shaft carrying a contact mechanism, and an electric switch. The helix is connected to the mounting frame at one end and to the shaft at the other. Typical construction of a pyrostat is shown in figure 18-18.

Stack switches and pyrostats are mounted on the boiler smoke pipe or hood, with the helix protruding into the path of the combustion gases. The switch is wired into the burner electric circuit so that when the contacts are open, no current is supplied to the burner except through the Protectorelay (to permit initial ignition). When there is no heat in the boiler, the switch contacts



75.301

Figure 18-18.—Construction details of a pyrostat.

are open. When the burner is ignited, the increase in the stack temperature causes the helix to expand, and this expansion in turn causes the shaft to rotate and close the contacts. Unless the stack temperature decreases, the contacts will remain closed, permitting the operation of the burner. In the event of flame failure, the helix contracts as the stack temperature falls and causes the shaft to rotate in the reverse direction. This opens the contacts and shuts down the burner.

Photoelectric Safety Combustion Controls

Photoelectric safety combustion controls consist basically of a photoelectric cell, an amplifying unit, and a relay. These controls operate by the luminosity (light) of the flame acting upon the photoelectric cell. The photoelectric cell makes a contact within itself when light rays impinge upon it. The amplified current of the photoelectric cell operates the relay, which is wired into the burner control circuit, causing the relay to close the burner circuit when the flame is established and to break the burner circuit in the event of flame failure.

OPERATION AND MAINTENANCE OF AUXILIARY BOILERS

The wide variation in design of auxiliary boilers and their auxiliaries, accessories, and controls makes it impractical for this chapter to

include specific operating and maintenance instructions for all types of boilers.

All personnel charged with the operation of an auxiliary boiler should be thoroughly familiar with the boiler, its controls, and all safety precautions. Operating instructions can be found in the appropriate manufacturer's technical manual. All boiler operators must be concerned with two hazardous conditions that could occur in a boiler when the automatic control system malfunctions: (1) low water level or (2) excess fuel in the combustion space (which tends to turn the boiler into a bomb). Operator and maintenance personnel must NEVER bypass or defeat any of the safety controls and devices used on auxiliary boilers. Maintenance requirements for auxiliary boilers are contained in your ship's PMS Manual.

Testing the Boiler Water

You must be able to determine the actual condition of the water used in auxiliary boilers. You can make this determination by chemically testing the water. The tests you may be required to perform are for alkalinity, phosphate, chloride content, and conductivity. We will briefly discuss each of these tests.

TESTING FOR ALKALINITY.—Alkalinity is a property that water acquires from certain chemical impurities. The allowable limits for alkalinity authorized by NAVSEA are 0.10 to 0.50 epm.

There are two methods of testing for alkalinity. The phenolphthalein test is used to test water samples from steaming boilers and to test water samples from idle boilers which have been steamed. The methyl-purple test is used to test water from freshly filled boilers which have NOT been steamed. If a boiler has been idle for a long time, it is best to use both tests.

TESTING FOR PHOSPHATE.—Phosphate is a chemical that is added to boiler water to aid in making suspended solids of the scale-forming impurities in the boiler water. The chemical action of suspending impurities helps to prevent boiler waterside scale formations that may interfere with the circulation of the boiler water and the effectiveness of the heat transfer surfaces. The phosphate test will indicate the amount of phosphate dissolved in the boiler water. The allowable limits for phosphate treatment of water in auxiliary boilers, as authorized by NAVSEA, are between 50 and 100 ppm.

TESTING FOR CHLORIDE CONTENT.—The term *chloride content* really refers to the concentration of the chloride ion, rather than the concentration of any one sea salt. Because the concentration of chloride ions is relatively constant in seawater, the chloride content may be used as a measure of the amount of solid matter in boiler water that is caused by contamination, either from poor quality output from distilling plants or from leakage into feedwater storage tanks located below the ship's waterline. The result of the chloride test is used as one indication of the need for blowdown of the boiler to prevent excessive contamination of the water. The allowable limit for chloride content authorized by NAVSEA is 1.0 epm.

TESTING FOR CONDUCTIVITY.—Conductivity, a measure of how well a substance can pass an electric current, is measured in micromhos per centimeter (µmho/cm). The reason you should be concerned about conductivity is that conductivity is directly related to corrosion. An increase in boiler water conductivity is an indication that boiler metal may be corroding.

Pure water is the ideal boiler water, because pure water has a high resistance and low conductivity. The rate of metal corrosion is low in pure water. As suspended and dissolved solids (impurities), such as the chlorides and sulphates of sodium, calcium, and magnesium, form in the water, they add ions to the water. IONS are charged particles that provide a path for current to travel. As the level of impurities rises, the level of ions also rises and the conductivity of the boiler water increases. This condition will accelerate corrosion. Therefore, by measuring for conductivity of the boiler water, you can determine the purity of the water and whether or not corrosion is taking place. The allowable limit for conductivity, as authorized by NAVSEA, is 600 µmhos/cm.

Making boiler water tests is a rather complicated job which requires a great deal of care and attention on your part. A water test result that is based on careless or inaccurate test procedures is not only useless but also may be dangerously misleading. You will not be able to obtain any useful information about the condition of the boiler water unless you perform each test with accuracy.

Since you must complete the prescribed certification course to conduct boiler water/feedwater tests, we will not cover the test procedures in this chapter. You can find the testing

procedures in the *Naval Ships' Technical Manual,* Chapter 220, Volume 2, "Boiler Water/Feedwater Test and Treatment."

FIREMAIN SYSTEM AND ISOLATION VALVES

As a Fireman, you were introduced to the firemain systems used in Navy ships. As an Engineman, you will be required to know the location of the principal isolation valves of the firemain system in the engineering spaces and adjacent spaces on your ship. The location of the valves used to isolate sections of the firemain varies from one ship to another. In general, isolation valves are located in the mainstream, in the fire main, in the risers, and in horizontal leads. In learning the location of isolation valves in your ship, study the piping diagram of the firemain system. Make a sketch of the system, noting particularly the location of each valve.

So that confusion and the possibility of error can be eliminated when sections of the firemain are being isolated, all important valves in the firemain system are marked with identification numbers. All engineering personnel should know both the location and the identification number of each valve.

SUMMARY

In this chapter, we have discussed the design and function of various electrohydraulic drive machinery and weight-handling equipment. We have also provided a brief discussion of the galley, scullery, and laundry equipment you may be required to maintain. In our discussion of auxiliary boilers, we have explained the basic design and components of water-tube and fire-tube boilers and the importance of boiler water testing, and the types of chemical tests for water used in auxiliary boilers. We have stressed the importance of safety components and procedures and your responsibility for learning about the location and function of the firemain and isolation valves. If you are uncertain concerning any of these sections, we recommend you review the information in this chapter before you begin to answer the questions in the correspondence course.

APPENDIX I

GLOSSARY

ABDC: Abbreviation for after bottom dead center.

ABSOLUTE PRESSURE: Gauge pressure plus atmospheric pressure.

ABSOLUTE TEMPERATURE: The temperature measured when absolute zero is used as a reference. Absolute zero is – 273.16°C or .469.69°F, and is the lowest measured temperature known.

ABT: Abbreviation for automatic bus transfer; an automatic electric device that supplies power to vital equipment. This device will shift from the normal power supply to an alternate power supply any time the normal supply is interrupted.

ACCELERATION: The rate of increase of velocity per time unit (for example, seconds, minutes, or hours).

ACCESSORY DRIVE: A drive consisting of gears, chains, or belts of secondary importance, not essential in itself but essential for the operation of engine accessories (fuel pump, water pump, and so forth).

ACCUMULATOR: A device used for storing liquid under pressure; sometimes used to smooth out pressure surges in a hydraulic system.

ACTUATOR: A device that uses fluid power to produce mechanical force and motion.

ADDITIVE: A material that is added to improve fuel or oil.

ADVANCE: To set the timing of the injection pump or injectors for an earlier injection.

AFTERCOOLER: A device used on turbocharged engines to cool air that has undergone compression.

AIR BIND: The presence of air in a pump or pipes, which prevents the delivery of liquid.

AIR BLEEDER: A device that removes air from a hydraulic system. Types include a needle valve, capillary tubing to the reservoir, and a bleed plug l

AIR CLEANER: A device (filter) for removing unwanted solid impurities from the air before the air enters the intake manifold.

AIR COMPRESSOR: A device used to increase air pressure.

AIR EJECTOR: A jet pump that removes air and noncondensable gases.

AIR-FUEL RATIO: The ratio (by weight or by volume) between air and fuel.

AIR GAP: The distance between two components.

AIR-STARTING VALVE: A valve that admits compressed air to the air starter for starting purposes.

ALIGN: To bring two or more components of a unit into the correct positions with respect to one another.

ALLOY: A mixture of two or more different metals, usually to produce improved characteristics.

ALLOWANCE: The difference between the minimum and the maximum dimensions of proper functioning.

ALTERNATING CURRENT (a.c.): Current that is constantly changing in value and direction at regularly recurring intervals.

AMBIENT TEMPERATURE: The temperature of the surrounding environment.

AMMETER: An instrument for measuring the rate of flow of electrical current in amperes.

AMPERE: The basic unit of electrical current.

ANNEAL: To heat a metal and to cool it in such a manner as to toughen and soften it. Brass or copper is annealed by heating it to a cherry red color and dipping it suddenly into water while hot. Iron or steel is slowly cooled from the heated condition to anneal.

ANNUNCIATOR: A device, usually electro-mechanical, used to indicate or transmit information. See ENGINE ORDER TELEGRAPH.

ANTIFRICTION BEARING: A bearing containing rollers or balls plus an inner and outer race. The bearing is designed to roll, thus minimizing friction.

API: Abbreviation for American Petroleum Institute.

API GRAVITY: Gravity expressed in units of standard API (hydrometer).

ARC: Portion of a curved line or of the circumference of a circle.

ARCING: Electrons leaping the gap between the negative and the positive poles.

ARMATURE: The movable part of a relay, regulator, or horn, or the rotating part of a generator or starter.

ATDC: Abbreviation for after top dead center.

ATMOSPHERE: The mass or blanket of gases surrounding the earth.

ATMOSPHERIC PRESSURE (BAROMETRIC PRESSURE): The pressure exerted by the atmosphere, averaging 14.7 psi at sea level with a decrease of approximately 1/2 pound per 1000 feet of altitude gained.

ATOMIZATION: The spraying of a liquid through a nozzle so the liquid is broken into tiny droplets or particles.

AUTOMATIC CONTROLLER: An instrument or device that operates automatically to regulate a controlled variable in response to a set point and/or input signal.

AUTOMATIC CONTROL SYSTEM: A system of instruments or devices arranged systematically to control a process or operation at a set point without assistance from operating personnel.

AUTOMATIC OPERATION: Operation of a control system and the process under control without assistance from the operator.

AUXILIARY MACHINERY: Any system or unit of machinery that supports the main propulsion units or helps support the ship and the crew. Examples of auxiliary machinery are pumps, evaporators, steering engines, air-conditioning and refrigeration equipment, laundry and galley equipment, deck winches, and so forth.

AXIAL: In a direction parallel to the axis. Axial movement is movement parallel to the axis.

AXIS: The centerline running lengthwise.

BABBIT: An antifriction metal lining for bearings that reduces the friction between moving components.

BACKLASH: The distance (play) between two movable components.

BACK PRESSURE: A pressure exerted contrary to the pressure producing the main flow.

BAFFLE: A device which slows down or diverts the flow of gases, liquids, sound, and so forth.

BALANCED VALVE: A valve in which the fluid pressure is equal on both sides (the opening and closing directions).

BALL BEARING: A bearing that uses steel balls as its rolling element between the inner and outer ring (race).

BALL CHECK VALVE: A valve consisting of a ball held against a ground seat by a spring. It serves to check the flow or to limit the pressure of a liquid or substance.

BAROMETER: An instrument which measures atmospheric pressure.

BBDC: Abbreviation for before bottom dead center.

BDC: Abbreviation for bottom dead center. The position of a reciprocating piston at its lowest point of travel.

BEARING: A mechanical component which supports and guides the location of another rotating or sliding member.

BEARING CLEARANCE: The distance between the shaft and the bearing surface.

BELL BOOK: An official record of engine orders received and answered.

BIMETALLIC: Composed of two metals with different rates of expansion, which curve to a greater, or lesser, extent when subjected to temperature changes.

BLEEDER: A small cock, valve, or plug that drains off small quantities of air or fluids from a container or system.

BLOCK DIAGRAM: A diagram in which the major components of a piece of equipment or a system are represented by squares, rectangles, or other geometric figures, and the normal order of progression of a signal or current flow is represented by lines.

BLOWBY: Exhaust gases that escape past the piston rings.

BLOWER: A low-pressure air pump, usually a rotary or centrifugal type of pump, that supplies air above atmospheric pressure to the combustion chambers of an internal-combustion engine.

BLUEPRINTS: Copies of mechanical or other types of technical drawings.

BOILER: Any vessel, container, or receptacle that is capable of generating steam by the internal or external application of heat. The two general classes are fire tube and water tube.

BOILER BLOW PIPING: Piping from the individual boiler blow valves to the overboard connection at the skin of the ship.

BOILER DESIGN PRESSURE: Pressure specified by the manufacturer, usually about 103% of normal steam drum operating pressure.

BOILER FEEDWATER: Deaerated water in the piping system between the deaerating feed tank and the boiler.

BOILER LOAD: The steam output demanded from a boiler, generally expressed in pounds per hour (lb/hr).

BOILER REFRACTORIES: Materials used in the boiler furnace to protect the boiler from the heat of combustion.

BOILER WATER: The water actually contained in the boiler.

BONNET: A cover used to guide and enclose the tail end of a valve spindle.

BORE: A cylinder hole or the inside diameter of a cylinder or hole.

BOSCH METERING SYSTEM: A metering system with a helical groove in the plunger which covers or uncovers ports in the pump barrel.

BOTTOM BLOW: A procedure that removes suspended solids and sludge from a boiler.

BOTTOM DEAD CENTER: See BDC.

BOURDON TUBE: A C-shaped hollow metal tube that is used in a gauge for measuring pressures of 15 psi and above. One end of the C is welded or silver-brazed to a stationary base. Pressure on the hollow section forces the tube to try to straighten. The free end moves a needle on the gauge face.

BOYLE'S LAW: The volume of any dry gas varies inversely with the applied pressure, provided the temperature remains constant.

BRAKE HORSEPOWER (bhp): The usable power delivered by an engine.

BRAKE MEAN EFFECTIVE PRESSURE (bmep): Mean effective pressure acting on the piston, which would result in a given brake horsepower output if there were no losses from friction, cooling, or exhaust. Bmep is equal to mean indicated pressure times mechanical efficiency.

BRAKE THERMAL EFFICIENCY: Ratio of power output (in the form of brake horsepower) to equivalent power input (in the form of heat from fuel.

BRAZING: A method of joining two metals at high temperature with a molten alloy.

BREAKER POINTS: Metal contacts that open and close a circuit at timed intervals.

BRINE: (1) A highly concentrated solution of salt in water, normally associated with the overboard discharge of distilling plants. (2) Any water in which the concentration of chemical salts is higher than seawater.

BRITISH THERMAL UNIT (Btu): A unit of heat used to measure the efficiency of combustion. It is equal to the quantity of heat required to raise 1 pound of water 1°F.

BRUSH: The conducting material, usually a block of carbon, bearing against the commutator or sliprings through which the current flows in or out.

BTDC: Abbreviation for before top dead center.

BULL GEAR: The largest gear in a reduction gear train-the main gear, as in a geared turbine drive.

BUS BAR: A primary power distribution point connected to the main power source.

BUSHING: A renewable lining for a hole in which a shaft, rod, or similar part moves.

BUS TRANSFER: A device for selecting either of two available sources of electrical power. It may be accomplished either manually or automatically.

BUTTERFLY VALVE: A lightweight, relatively quick acting, positive shutoff valve.

BYPASS: To divert the flow of gas or liquid. Also, the line that diverts the flow.

CALIBRATE: To make adjustments to a meter or other instrument so that it will indicate correctly with respect to its inputs.

CAM: A rotating component of irregular shape. It is used to change direction of the motion of another part moving against it. (For example, rotary motion is changed into reciprocating or variable motion.)

CAM FOLLOWER (VALVE LIFTER): A part that is held in contact with the cam and to which the cam motion is imparted and transmitted to the push rod.

CAM NOSE: That portion of the cam that holds the valve wide open. It is the high point of the cam.

CAMSHAFT: A shaft with cam lobes.

CAMSHAFT GEAR: The gear that is fastened to the camshaft.

CAPACITOR: An arrangement of insulated conductors and dielectrics for the accumulation of an electric charge with small voltage output.

CARBURETOR: An apparatus for supplying atomized and vaporized fuel mixed with air to an internal-combustion engine.

CARRYOVER: (1) Boiler water entrained with the steam (by foaming or priming). (2) Particles of seawater trapped in vapor in a distilling plant and carried into the condensate.

CASING: A housing that encloses the rotating element (rotor) of a pump or turbine.

CASING THROAT: An opening in a turbine or pump casing through which the shaft protrudes.

CASUALTY: An event or series of events in progress during which equipment damage and/or personnel injury has already occurred. The nature and speed of these events are such that proper and correct procedural steps are taken to limit damage and/or personnel injury only.

CASUALTY POWER SYSTEM: Portable cables that are rigged to transmit power to vital equipment in an emergency.

CATALYST: A substance used to speed up or slow down a chemical reaction, but is itself unchanged at the end of the reaction.

CELSIUS: The temperature scale with a freezing point of 0° and a boiling point of 100°, with 100 equal divisions (degrees) between. This scale was formerly known as the centigrade scale.

CENTRIFUGAL FORCE: A force exerted on a rotating object in a direction outward from the center of rotation.

CETANE VALUE: A measure of the ease with which diesel fuel will ignite.

CHECK VALVE: A valve which permits fluid flow in one direction, but prevents flow in the reverse direction.

CHEMICAL ENERGY: Energy stored in chemicals (fuel) and released during combustion of the chemicals.

CHLORIDE: A compound of the chemical element chlorine with another element or radical.

CIRCUIT: An arrangement of interconnected electrical components that offers a route for current between the two points of the power source.

CIRCUIT BREAKER: An electromagnetic or thermal device that opens a circuit when the current in the circuit exceeds a predetermined amount. Circuit breakers can be reset.

CIRCULATING WATER: Water circulating through a heat exchanger (condenser or cooler) to transfer heat away from an operating component.

CLARIFIER: A water tank containing baffles that slow the rate of water flow sufficiently to allow heavy particles to settle to the bottom and light particles to rise to the surface. This separation permits easy removal, thus leaving the "clarified" water. The clarifier is sometimes referred to as a settling tank or sedimentation basin.

CLOSED COOLING SYSTEM: Consisting of two entirely separate circuits-a freshwater circuit and a seawater circuit.

CLUTCH: A form of coupling that connects or disconnects a driving or driven member.

COCK: A valve that is opened or closed by a quarter turn of a disk or a tapered plug. When a plug is used, it is slotted to correspond with the ports in the valve.

COLD IRON CONDITION: An idle plant, when all services are received from an external source such as shore or tender.

COMBUSTION: The burning of fuel in a chemical process accompanied by the evolution of light and heat.

COMBUSTION AIR: The air delivered to a boiler furnace, engine, or gas turbine combustor to support burning of atomized fuel.

COMBUSTION CHAMBER: The chamber in which combustion mainly occurs.

COMBUSTION-CHAMBER VOLUME: The volume of the combustion chamber (when the piston is at TDC) measured in cubic centimeters.

COMBUSTION CYCLE: A series of thermodynamic processes through which the working gas passes to produce one power stroke. The full cycle is-intake, compression, power, and exhaust.

COMMUTATOR: The copper segments on the armature of a motor or generator. It is cylindrical in shape and is used to pass power into or from the brushes.

COMPENSATING DEVICE: Mechanical or hydraulic action which prevents overcorrection of change.

COMPONENT: Individual unit, or part, of a system; also, the major units which, when suitably connected, comprise a system.

COMPRESSION RING: The piston rings used to reduce combustion leakage to a minimum.

COMPRESSION STROKE: That stroke of the operating cycle during which air is compressed into a smaller space creating heat by molecular action.

CONDENSATE: In a distilling plant, the product resulting from the condensation of steam (vapor) produced by the evaporation of seawater. Condensate may also be referred to by different names such as freshwater, freshwater distillate, or distillate.

CONDENSATE DEPRESSION: The difference between the temperature of condensate in the condenser hotwell and the saturation temperature corresponding to the vacuum maintained in the condenser.

CONDENSATION: The change from a gaseous (or vapor) state to a liquid state.

CONDENSER: A heat transfer device in which vapor is condensed to liquid.

CONDUCTANCE: The ability of a material to conduct or carry electrical or thermal energy. Electrical conductance is the reciprocal of the resistance of the material and is expressed in mhos.

CONDUCTION: Heat transfer by actual contact between substances or from molecule to molecule within a substance.

CONDUCTIVITY: The ease with which a substance transmits electricity.

CONDUCTOR: Any material suitable for carrying electric current.

CONSOLE: A panel equipped with remote manual controls and visual indicators of system performance.

CONTROL AIR SUPPLY: Clean, dry air at proper pressure for operation of pneumatic control equipment.

CONTROLLER (electrical): A device used to stop, start, and protect motors from overloads while they are running.

COOLER: Any device that removes heat. Some devices, such as oil coolers, remove heat to waste in overboard seawater discharge; other devices, such as ejector coolers, conserve heat by heating condensate for boiler feedwater.

COOLING SYSTEM: Heat removal process that uses mechanical means to remove heat to maintain the desired air temperature. The process may also result in dehumidification.

CORROSION: A gradual wearing away or alteration of metal by a chemical or electrochemical process. Essentially, it is an oxidizing process, such as the rusting of iron by the atmosphere.

COTTER, PIN, SPRING: A round split pin used to position and secure a nut on a bolt. The pin is passed through a hole in the nut and bolt. The ends of the pin opposite its head are forced apart by a screwdriver, pliers, or similar tool, thus preventing the cotter from slipping out.

COUNTERBALANCE: A weight, usually attached to a moving component, that balances another weight.

COUNTERBORE: (1) The enlargement of the end of a hole for receiving and recessing the head of a screw or bolt below or flush with the surface. (2) A tapered enlargement at the end of an engine cylinder to reduce ridging by the piston's top compression ring.

COUNTERSUNK HOLE: A hole tapered or beveled around its edge to allow a rivet or bolt head or a rivet point to seat flush with or below the surface of the riveted or bolted object.

COUNTERWEIGHT: Weights that are mounted on the crankshaft opposite each crank throw. These weights reduce the vibration caused by putting the crank in practical balance and also reduce bearing loads due to inertia of moving parts.

COUPLING: A device for securing together adjoining ends of piping, shafting, and so forth, in such a manner to permit disassembly whenever necessary.

CRANE: A machine used for hoisting and moving pieces of material or portions of structures or machines that are either too heavy to be handled by hand or cannot be handled economically by hand.

CRANKCASE: The part of an engine frame which serves as a housing for the crankshaft.

CRANKCASE SCAVENGING: Scavenging method that uses the pumping action of the power piston in the crankcase to pump scavenging air.

CRANKPIN: The portion of the crank throw attached to the connecting rod.

CRANKSHAFT: A rotating shaft for converting rotary motion into reciprocating motion.

CRANKSHAFT GEAR: The gear that is mounted to the crankshaft.

CRANK THROW: One crankpin with its two webs (the amount of offset of the rod journal).

CRANK WEB: The portion of the crank throw between the crankpin and main journal. This makes up the offset.

CREEP-RESISTANT ALLOY: A metal which resists the slow plastic deformation that occurs at high temperatures when the material is under constant stress.

CREST: The surface of the thread corresponding to the major diameter of an external thread and the minor diameter of an internal thread.

CRITICAL SPEED: The speed at which natural torsional vibrations of a crankshaft tend to reinforce themselves, causing vibration and potentially destructive stresses.

CROSS-CONNECT: To align systems to provide flow or to exchange energy between machinery groups.

CROSS-CONNECTED PLANT: A method of operating two or more plants as one unit from a common supply.

CYCLE: An interval of time during which a sequence of a recurring succession of events is completed.

CYLINDER: A solid figure with two circular bases. A hollow tube which contains the actions of combustion gases and the piston in an internal-combustion reciprocating engine.

CYLINDER BLOCK: A rigid unit of the engine frame which supports the engine's cylinder liners and heads. A cylinder block may contain passages to allow circulation of cooling water and drilled lube oil passages.

CYLINDER LINER: A sleeve which is inserted in the bores of the engine block which make up the cylinder wall.

DAMPER: A device for reducing the motion or oscillations of moving parts.

DAMPING: (1) A characteristic of a system that results in dissipation of energy and causes decay in oscillations. (2) The negative feedback of an output rate of change.

DAY TANK: A fuel tank with the capacity to operate an engine for 24 hours. Also called SERVICE TANK.

DEAD CENTER: Either of the two positions when the crank and connecting rod are in a straight line at the end of the stroke.

DEAERATE: Process of removing dissolved oxygen.

DEAERATING FEED TANK (DFT): A unit in the steam-water cycle used to (1) free the condensate of dissolved oxygen, (2) heat the feedwater, and (3) act as a reservoir for feedwater.

DEGREE OF SUPERHEAT: The amount by which the temperature exceeds the saturation temperature.

DEHUMIDIFICATION: The mechanical process of removing water vapor from the air.

DENSITY: The weight per unit volume of a substance.

DENTAL COUPLING: A flexible coupling assembly, consisting of a set of external/internal gear teeth, that compensates for shaft misalignment between a driver and a driven machinery component.

DEPTH: The distance from the root of a thread to the crest, measured perpendicularly to the axis.

DESIGN PRESSURE (BOILER): The pressure specified by a manufacturer as a criterion in design. (In a boiler, it is approximately 103% of operating pressure.)

DESIGN TEMPERATURE: The intended operating temperature of the fresh water and lube oil at the engine outlet, at some specified rate of operation. The specified rate of operation is normal load.

DESUPERHEATED STEAM: Steam from which some of the superheat has been removed.

DETONATION: Burning of a portion of the fuel in the combustion chamber at a rate faster than desired (knocking).

DIAL GAUGE OR INDICATOR: A precision micrometer-type instrument that indicates the reading by a needle moving across a dial face.

DIAPHRAGM: A dividing membrane or thin partition.

DIESEL CYCLE (ACTUAL): Combustion induced by compression ignition, begins on a constant-volume basis and ends on a constant-pressure basis.

DIESEL CYCLE (TRUE): Combustion induced by compression ignition, theoretically occurs at a constant pressure.

DIESEL ENGINE: An engine using the diesel or semidiesel cycle of operation; air alone is compressed and diesel fuel is injected before the end of the compression stroke. Heat of compression produces ignition.

DIFFUSER: (1) A duct of varying cross sections designed to convert a high-speed gas flow into low-speed flow at an increased pressure. (2) A device that spreads a fluid out in all directions and increases fluid pressure while decreasing fluid velocity.

DIRECT CURRENT (d.c.): An electric current that flows in one direction only.

DIRECT DRIVE: One in which the drive mechanism is coupled directly to the driven member.

DIRECTIONAL CONTROL VALVE: A valve which selectively directs or prevents flow to or from desired channels. Also referred to as selector valve, control valve, or transfer valve.

DISPLACEMENT: The volume of air or fluid which can pass through a pump, motor, or cylinder in a single revolution or stroke.

DISTILLATE: The product (fresh water) resulting from the condensation of vapors produced by the evaporation of seawater.

DISTILLATION: The process of evaporating seawater, then cooling and condensing the resulting vapors. Produces fresh water from seawater by separating the salt from the water.

DISTILLING PLANTS: Units commonly called evaporators used to convert seawater into fresh water.

DOUBLE REDUCTION: A reduction gear assembly that reduces the high input rpm to a lower output rpm in two stages.

DOUBLE SUCTION IMPELLER: An impeller with suction inlet on each side.

DRAWING: (1) Illustrated plans that show fabrication and assembly details. (2) The original graphic design from which a blueprint may be made. Also called plans.

DRAWING NUMBER: An identifying number assigned to a drawing, or a series of drawings.

DRUM, WATER: A tank at the bottom of a boiler. Also called mud drum.

DUPLEX STRAINER: A strainer containing two separate elements independent of each other.

DYNAMIC PRESSURE: (1) The pressure of a fluid resulting from its motion, equal to one-half the fluid density times the fluid velocity squared. (2) In incompressible flow, dynamic pressure is the difference between total pressure and static pressure.

ECONOMIZER: (1) A device provided in a carburetor to give the fuel-air mixture the richness required for high power. (2) A heat transfer device that uses the gases of combustion to preheat the feedwater in the boiler before it enters the steam drum. See FEED HEATER.

EDUCTOR: A jet-type pump (no moving parts) which uses a flow of water to entrain and thereby pump water.

EFFICIENCY: The ratio of output power to input power, generally expressed as a percentage.

ELASTICITY: The ability of a material to return to its original size and shape.

ELBOW-ELL: A pipe fitting that makes an angle between adjacent pipes, always 90° unless another angle is stated.

ELECTRICAL ENERGY: Energy derived from the forced induction of electrons from one atom to another.

ELECTRODE: A metallic rod (welding rod), used in electric welding, that melts when current is passed through it.

ELECTROHYDRAULIC STEERING: A system having a motor-driven hydraulic pump that creates the force needed to actuate the rams to position the ship's rudder.

ELECTROLYSIS: A chemical action that takes place between unlike metals in systems using seawater.

ELECTROLYTE: A solution of a substance which is capable of conducting electricity. An electrolyte may be in the form of either a liquid or a paste.

ELECTROMECHANICAL DRAWING: A special type of drawing combining electrical symbols and mechanical drawing to show the composition of equipment that combines electrical and mechanical features.

ELEMENT: (1) A substance which consists of chemically united atoms of one kind. (2) An indivisible part of a logic function or circuit. Fluidic elements are interconnected to form working circuits. (3) Parts of systems; for example, filter element, valving element, and so forth.

EMERGENCY: An event or series of events in progress which will cause damage to equipment unless immediate, timely, and correct procedural steps are taken.

EMULSIFIED OIL: A chemical condition of oil in which the molecules of the oil have been broken up and suspended in a foreign substance (usually water).

ENERGY: The capacity for doing work.

ENGINE: A machine which converts heat energy into mechanical energy.

ENGINEERING LOG: A legal record of important events and data concerning the machinery of a ship.

ENGINEER'S BELL BOOK: A legal record, maintained by the throttle watch, of all ordered main engine speed changes.

ENGINE ORDER TELEGRAPH: Electromechanical device which transmits orders concerning desired direction and general speed of the engines to the engine room. See ANNUNCIATOR.

ENGINE ORDER INDICATOR: A device on the ship's bridge which transmits orders to the engine room for specific shaft speeds in revolutions per minute.

ENGINEERING OFFICER OF THE WATCH (EOOW): Officer on duty in the engineering spaces.

EPM (equivalent per million): A term used to describe the chemical concentration of dissolved material; used in reporting sample test results. It expresses the chemical equivalent unit weight of material dissolved in a million unit weights of solution. (The chemical equivalent weight of chloride is 35.5. If 35.5 pounds of chloride were dissolved in 1,000,000 pounds of water, the water would contain 1.00 epm chloride).

EQUILIBRIUM: The state of balance between opposing forces or actions.

EVAPORATION: The action that takes place when a liquid changes to a vapor or gas.

EVAPORATOR: A distilling device to produce fresh water from seawater.

EXPANSION JOINT: (1) A junction in a piping system which allows for expansion and contraction. (2) A term applied to a joint which permits linear movement to take up the expansion and contraction due to changing temperature of ship movement.

EXPANSION TANK: Provides for expansion, overflow, and replenishment of cooling water in an engine.

EXPLODED VIEW: A pictorial view of a device in a state of disassembly, showing the appearance and interrelationship of parts.

EXTERNAL THREAD: A thread on the outside of a member (for example, a thread of a bolt).

FAHRENHEIT: The temperature scale using the freezing point as 32 and the boiling point as 212, with 180 equal divisions (degrees) between.

FAIL: (1) The loss of control signal or power to a component. (2) The breakage or breakdown of a component or component part.

FATIGUE: The tendency of a material to break under repeated strain.

FEEDBACK: (1) A transfer of energy from the output circuit of a device back to its input. (2) Information about a process output which is communicated to the process input.

FEEDER: An electrical conductor or group of conductors between different generating or distributing units of a power system.

FEED HEATER: A heat transfer device that heats the feedwater before it goes to the boiler.

FEEDWATER: Water that meets the requirements of *Naval Ships' Technical Manual,* Chapter 220, for use in a boiler.

FERROUS METAL: Metal with a high iron content.

FIELD WINDING. The coil used to provide the magnetizing force in motors and generators.

FILTER: A device through which gas or liquid is passed; dirt, dust, and other impurities are removed by the separating action.

FIRELINE: Section of piping and hose on discharge side of a proportioner leading to a fire location.

FIRE MAIN: The seawater line that provides firefighting and flushing water throughout the ship.

FIRING ORDER: The order in which the cylinders deliver their power stroke.

FIRING PRESSURE: The highest pressure reached in the cylinder during combustion.

FIRE TUBE BOILER: Boilers in which the gases of combustion pass through the tubes and heat the water surrounding them.

FLASHPOINT: The temperature at which a substance, such as an oil, will give off a vapor that will flash or burn momentarily when ignited.

FLEXIBLE COUPLING. A coupling that transmits rotary motion from one shaft to another while compensating for minor misalignment between the two units.

FLOOR PLATES: The removable deck plating of a fireroom or engine room aboard ship. Also called deck plates.

FLOWMETER: An instrument used to measure quantity or the flow rate of a fluid motion.

FLUID: A substance capable of flowing or conforming to the shape of its container (a liquid or gas or mixture thereof).

FLYWHEEL: A heavy wheel attached to the crankshaft. It stores up energy during the power event and releases it during the remaining events of the operating cycle.

FLYWEIGHT: A governor; weights which move and assume positions in accordance with the speed of rotation.

FOAM NOZZLE: A nozzle designed to entrain air and mix it with water and foam liquid to produce a foam blanket.

FOOT-POUND: (1) The amount of work accomplished when a force of 1 pound produces a displacement of 1 foot. (2) The amount of torque produced by 1 pound of effort applied at a radius of 1 foot.

FORCE: The action of one body on another tending to change the state of motion of the body acted upon. Force is usually expressed in pounds.

FORCE-BALANCE: An arrangement of control system components using a mechanical force as the feedback signal. The feedback applied force must "null" the forces acting on a balanced mechanism.

FORCED FEED LUBRICATION: A lubrication system that uses a pump to maintain a constant pressure.

FREE FLOW: Flow which encounters negligible resistance.

FREQUENCY: The number of complete cycles per second (hertz) existing in any form of wave motion.

FRESH WATER: Water of relatively low dissolved solids content as compared to seawater. There are two types of shipboard fresh water: (1) feedwater (the low-pressure drains of the steam generator condensate system), and (2) potable water (supplied from either a shore water source or a shipboard distilling plant).

FRESHWATER SYSTEM: A piping system which supplies fresh water throughout the ship.

FRICTION: The action of one body or substance rubbing against another, such as fluid flowing against the walls of a pipe; the resistance to motion caused by this rubbing.

FRICTION PRESSURE DROP: The decrease in the pressure of a fluid flowing through a passage attributable to the friction between the fluid and the passage walls.

FUEL MIXTURE: A ratio of fuel and air.

FUEL OIL SERVICE TANKS: Tanks from which the fuel oil service pumps take suction for supplying diesel fuel oil to the engine. See DAY TANKS.

FUEL TRANSFER PUMP: A mechanical device used to transfer fuel from the tank to the injection pump.

FUEL VALVE: A valve admitting fuel to the combustion chamber. In a more general sense, this term may also apply to any manual or automatic valve controlling the flow or fuel.

FULCRUM: The pivot point of a lever.

FULL-FLOATING PISTON PIN: A piston pin free to turn in the piston boss of the connecting rod eye.

FULL-FLOW OIL FILTER: A type of oil filter through which all engine oil passes before entering the lubrication channels.

FUSE: A protective device inserted in series with a circuit. It contains a metal that will melt or break when current is increased beyond a specific value for a definite period of time.

GAUGE GLASS: A device for indicating the liquid level in a tank.

GAUGE PRESSURE: Pressure above atmospheric pressure.

GALVANIZING: The process of coating one metal with another, ordinarily applied to the coating of iron or steel with zinc. The chief purpose of galvanizing is to prevent corrosion.

GAS: The form of matter that has neither a definite shape nor a definite volume.

GAS FREE: A term used to describe a space that has been tested and its atmosphere found safe for human occupation and for hot work (welding and cutting).

GASKET(S): (1) A class of material that provides a seal between two stationary parts. (2) Packing materials by which air, water, oil, or steam tightness is secured in such places as on doors, hatches, cylinders, manhole covers, or in valves, between the flanges of pipes, and so forth. Such materials as rubber, canvas, asbestos, paper, sheet lead and copper, soft iron, and commercial products are extensively used.

GEARING: A term applied to wheels which have teeth that mesh, engage, or gear with similar teeth or other wheels in such manner that motion given one wheel will be imparted to the other.

GENERATOR: A machine that converts mechanical energy into electrical energy.

GLAND SEALING: Water piped to a pump casing stuffing box to maintain a seal against air entering the pump casing.

GOVERNOR: A speed-sensitive device designed to control or limit the speed of the engine.

GRAPHITE: A crystalline form of carbon having a slippery feel and black color with metallic luster. Used for a lubricant.

GRAVITY HEAD: A supply of fluid above the suction level of a pump; also called "static head."

GROUND PLUG: A three-pronged electrical plug used to ground portable tools to the ship's structure. It is a safety device which always must be checked prior to your using portable tools.

HALIDE LEAK DETECTOR: A device that is used to locate leaks in refrigeration systems.

HANDHOLE: An opening large enough for the hand and arm to enter areas, such as the engine, for making slight repairs and for inspection purposes.

HARDENING: The treatment or heating and cooling (quenching) of metal to harden the surface.

HARDNESS: A quality exhibited by water containing various dissolved salts, principally calcium and magnesium. Hard water can deposit a heat transfer resistant scale on the heat exchanger surface.

HEAD: (1) A separate unit from the engine cylinder block designed to seal the cylinder at the combustion end. (2) The pressure or energy content of a hydraulic system, expressed in the height of a column of water in feet.

HEAT: A thermal form of energy.

HEAT EXCHANGER: Any device that is designed to allow the transfer of heat from one fluid (liquid or gas) to another.

HEATING SURFACE: The exposed surface of a heating unit in a heat exchanger which is directly exposed to the heat of the flue gases.

HEATING SYSTEM: A system for adding heat to maintain the desired air temperature, as distinguished from heat added incidentally or unavoidably.

HELICAL: A spiraling shape such as that made by a coil spring.

HELIX: The curve formed on any cylinder by a straight line in a plane that is wrapped around the cylinder with a forward progression.

HELM: (1) The term applied to the tiller, wheel, or steering gear, and also the rudder. (2) A mechanical device used to turn the rudder; usually a wheel aboardship, or a lever ***(tiller)*** in boats.

HERTZ: The measurement of frequencies in cycles per second, 1 hertz being equal to 1 cycle per second.

HORSEPOWER (hp): A unit for measuring the power of motors or engines, equal to a rate of 33,000 foot-pounds per minute. The force required to raise 33,000 pounds at the rate of 1 foot per minute.

HOT WELL: A reservoir attached to the bottom of a condenser for collecting condensate.

HUMIDITY: The vapor content of the atmosphere. Humidity can vary depending on air temperature; the higher the temperature, the more vapor the air can hold.

HUNTING: A rhythmic variation of speed that can be eliminated by blocking the fuel supply manually or with load limit. The speed variation will reappear when the engine is returned to governor control.

HYDRAULICS: That branch of mechanics or engineering that deals with the action or use of liquids forced through tubes and orifices under pressure to operate various mechanisms.

HYDROCARBON: Chemical compound of hydrogen and carbon. All petroleum fuels are composed of hydrocarbons.

HYDROGEN: A highly explosive, light, invisible, nonpoisonous gas. It is produced in small quantities when batteries are charged.

HYDROMETER: An instrument used to determine the specific gravities of liquids.

HYDROSTATIC: Static (nonmoving) pressure generated by pressurizing liquid.

HYDROSTATIC TEST: A test using pressurized water to detect leaks in a closed system.

IGNITION, COMPRESSION: When the heat generated by compression in an internal-combustion engine ignites the fuel (as in a diesel engine).

IGNITION, SPARK: When the mixture of air and fuel in an internal-combustion engine is ignited by an electric spark (as in a gasoline engine).

IMPEDANCE: The total opposition offered to the flow of an alternating current. It may consist of any combination of resistance, inductive reactance, and capacitive reactance.

IMPELLER: An encased, rotating element provided with vanes, which draw in fluid at the center and expel it at a high velocity at the outer edge.

IMPINGEMENT: The striking or hitting against an object with a clash or sharp collision, as air impinging upon the rotor of a turbine or motor.

IMPULSE LINES: Piping that connects a sensing element to the point at which it is desired to sense pressure, flow, temperature, etc.

INDICATED HORSEPOWER (ihp): The power transmitted to the pistons by the gas in the cylinders.

INDICATED THERMAL EFFICIENCY: The ratio of indicated horsepower to equivalent power input in the form of heat from fuel.

INDICATOR: An instrument for recording the variation of cylinder pressure during the cycle.

INDICATOR CARD: A graphical record of the cylinder pressures made by an indicator.

INDIRECT DRIVE: A drive mechanism coupled to the driven member by gears or belts.

INDUCTION: The act or process of producing voltages by the relative motion of a magnetic field across a conductor.

INERT: Inactive, such as gases that will not burn or support combustion.

INERTIA: The tendency of a body at rest to remain at rest, and a body in motion to continue to move at a constant speed along a straight line, unless the body is acted upon in either case by an unbalanced force.

INHIBITOR: Any substance which retards or prevents such chemical reactions as corrosion or oxidation.

INJECTION NOZZLE: A device which protrudes into the combustion chamber and delivers fuel to the cylinder.

INJECTION SYSTEM: A system designed to deliver fuel to the cylinder at the proper time and in the proper quantity under various engine loads and speeds.

IN-LINE ENGINE: An engine in which the cylinders are arranged in one straight line.

IN PHASE: Applied to the condition that exists when two waves of the same frequency pass through their maximum and minimum values of like polarity at the same instant.

INPUT SIGNAL: A pressure or flow of fluid that is directed into an input port to control an element or logic function.

INSULATION: A material used to retard heat transfer. A dielectric material which prevents the flow of electricity from an electric component.

INTAKE SYSTEM: Combination of components designed to supply air required for combustion.

INTEGRAL: Essential to completeness, as an integral part. (The valve stem is an integral part of the valve.)

INTERCOOLER: A device which cools a gas between the compression stages of a multiple stage compressor.

INTERFACE: Surface or area between abutting parts usually of different materials.

INTERNAL THREAD: A thread on the inside of a member (for example, the thread inside a nut).

INVERSELY: Inverted or reversed in position or relationship.

INVERSE PROPORTION: The relation that exists between two quantities when an increase in one of them produces a corresponding decrease in the other.

ISOCHRONOUS GOVERNOR: A device that maintains the speed of the engine truly constant, regardless of the load.

ISOMETRIC DRAWING: A type of pictorial drawing. See ISOMETRIC PROJECTION.

ISOMETRIC PROJECTION: A set of three or more views of an object that appears rotated, giving the appearance of viewing the object from one corner. All lines are shown in their true length but angles are not accurately represented.

JACKBOX: A receptacle, usually secured to a bulkhead, in which telephone jacks are mounted.

JACKET: An outer case such as a water jacket or an insulative covering.

JACKET WATER: Water used as a coolant in the cooling system of an engine (usually chemically treated distilled water).

JACKING: Mechanically rotating an engine or reduction gear at very low speed.

JAM NUT: A second nut used on a bolt or stud to lock the holding nut. See LOCK NUT.

JOB ORDER: An order issued by a repair activity to its own subdivision to perform a repair job in response to a work request.

JOURNAL: Serves as the point of support and center of rotation for the shaft. That part of a shaft that is prepared to accept a bearing (connecting rod, main bearing).

JUMPER: Any connecting pipe, hose, or wire normally used in emergencies aboard ship to bypass damaged sections of a pipe, hose, or wire. See BYPASS.

KELVIN SCALE: The temperature scale using absolute zero as the zero point and divisions that are the same size as Celsius degrees.

KEY: A small wedge or rectangular piece of metal inserted in a slot or groove between a shaft and a hub to prevent slippage.

KEYWAY: A slot cut in a shaft, pulley hub, wheel hub, and so forth. A square key is placed in the slot and engages a similar keyway in the mating piece. The key prevents slippage between the two parts.

KILO: A prefix meaning 1,000.

KINETIC ENERGY: The energy which a substance has while it is in motion.

LABYRINTH PACKING: A soft metal ring or rings arranged inside a casing throat in such a manner that the inside diametrical edges will form a series of seals along the surface of the rotating shaft. The edges fit either close to the surface of the shaft or in grooves machined in the shaft.

LAGGING: (1) A protective and confining cover placed over insulating material. (2) A term applied to the insulating material that is fitted on the outside of engine exhaust, piping, and so forth.

LAMBERT SEAL: The hydraulic equivalent of labyrinth packing.

LAP: To work two surfaces together with abrasives until a very close fit is produced; to polish.

LASH: The clearance or play between adjacent movable mechanical parts. See VALVE LASH.

LATENT HEAT: Heat that is given off or absorbed by a substance while it is changing its state.

LATENT HEAT OF CONDENSATION: The amount of heat (energy) required to change the state of a substance from a vapor to a liquid without a change in temperature.

LATENT HEAT OF VAPORIZATION: The amount of heat (energy) required to change the state of a substance from a liquid to a vapor without a change in temperature.

LEAD: (1) The distance a screw thread advances in one turn, measured parallel to the axis. On a single-thread screw, the lead and the pitch are identical; on a double-thread screw, the lead is twice the pitch; on a triple-thread screw, the lead is three times the pitch. (2) A wire or connection.

LIFT CHECK VALVE: A valve having a guide-mounted, spring-loaded disk wherein liquid exerting pressure on the bottom of the disk will lift the disk and pass through. Pressure against the top of the disk shuts the disk and ensures only one direction of flow.

LIGHT OFF: To start; literally, to start a fire in, such as to light off a boiler.

LIMIT SWITCH: A switch that is actuated by the mechanical motion of an element.

LIQUID: A form of matter that has a definite volume but takes the shape of its container.

LOAD: (1) External resistance overcome by a prime mover. (2) The power that is being delivered by a generator.

LOADING: The act of transferring energy into or out of a system.

LOCAL MANUAL OPERATION: Direct manual positioning of a control valve or power operator by means of a handwheel or lever.

LOCKED TRAIN: A gear arrangement that has each high-speed (prime mover) pinion "locked" between two primary gears which cancel the tooth loading on the pinion bearings.

LOCK NUT: (1) A thin nut that is turned down over the regular nut on a bolt to lock the regular nut against turning off. (See JAM NUT.) (2) A thin nut placed on a pipe to hold packing at a joint or used on both sides of a bulkhead through which a pipe passes to secure tightness.

LOG: (1) A ship's speedometer. (2) The act of a ship in making a certain speed, as "The ship logged 20 knots." (3) A book or ledger in which the watch officer records data or events that occurred during the watch.

LOG BOOK: Any chronological record of events, such as the engineering watch log.

LOG ROOM: Engineer's office aboard ship.

LOOP SEAL: A vertical U-bend in drain piping in which a water level is maintained to create an airtight seal.

LUBE OIL PURIFIER: A unit that removes water and sediment from lubricating oil by centrifugal force.

LUBRICANT: Any material, usually of a petroleum nature, such as grease, oil, and so forth, that is placed between two moving parts in an effort to reduce friction.

LUG: An earlike projection that is frequently split, such as the clamping lug on the tailstock of a lathe.

MACHINABILITY: The ease with which a metal may be turned, planed, milled, or otherwise shaped.

MACHINE FINISH: Operation of turning or cutting an amount of stock from the surface of metal to produce a finished surface.

MAGNETIC FIELD: The space in which a magnetic force exists.

MAGNETO: A generator that produces alternating current and has a permanent magnet as its field.

MAIN CONDENSER: A heat exchanger that converts exhaust steam to feedwater.

MAIN DRAIN SYSTEM: System used for pumping bilges; consists of pumps and associated piping.

MAIN INJECTION (SCOOP INJECTION): An opening in the skin of a ship designed to deliver cooling water to the main condenser by the forward motion of the ship.

MAJOR DIAMETER: The largest diameter of an internal or external thread.

MALLEABILITY: That property of a material which enables it to be stamped, hammered, or rolled into thin sheets.

MANIFOLD: (1) A fitting or header that receives exhaust gases from several cylinders. (2) A fitting that has several inlets or outlets to carry liquids or gases.

MAXIMUM OPERATING PRESSURE: The highest pressure that can exist in a system or subsystem under normal operating conditions.

MAXIMUM SYSTEM PRESSURE: The highest pressure that can exist in a system or subsystem during any condition.

MEAN EFFECTIVE PRESSURE (MEP): The calculated combustion in pounds per square inch (average) during the power stroke, minus the pounds per square inch (average) of the remaining three strokes.

MEAN INDICATED PRESSURE (MIP): The net mean gas pressure acting on the piston to produce work.

MECHANICAL ADVANTAGE (MA): The advantage (leverage) gained by the use of devices, such as wheels, to open large valves and chain falls; blocks and tackles to lift heavy weights; and wrenches to tighten nuts on bolts.

MECHANICAL CLEANING: A method of cleaning the firesides of boilers by scraping and wirebrushing.

MECHANICAL CYCLE: The number of piston strokes occurring during any one series of events (for example, 2-stroke or 4-stroke cycle).

MECHANICAL DRAWING: Scale drawings of mechanical objects. (See DRAWING.)

MECHANICAL EFFICIENCY: (1) The ratio of brake horsepower to indicted horsepower, or ratio of brake mean effective pressure to mean indicated pressure. (2) An engine's rating, which indicates how much of the potential horsepower is wasted through friction within the moving parts of the engine.

METERING: Accurate measuring of the fuel for the same fuel setting where exactly the same quantity of fuel will be delivered to each cylinder for each power stroke of the engine.

MHO: The unit of conductance; the reciprocal of an ohm.

MICRO: A prefix meaning one millionth.

MICROMHO: Electrical unit used with salinity indicators for measuring the conductivity of water.

MILLI: A prefix meaning one-thousandth.

MONITORING POINT: The physical location at which any indicating device displays the value of a parameter at some control station. See PARAMETER.

MOTOR: (1) A rotating machine that transforms electrical energy into mechanical energy. (2) An actuator which converts fluid power to rotary mechanical force and motion.

MOTOR CONTROLLER: A device (or group of devices) that governs, in some predetermined manner, the operation of the motor to which it is connected.

MOTOR GENERATOR SET: A machine consisting of a motor mechanically coupled to a generator and usually mounted on the same base.

NAVAL DISTILLATE DIESEL FUEL: The fuel normally used in diesel engines. The most commonly used for boilers and diesel engines is naval distillate (NATO symbol F-76), but other fuels such as JP-5 (NATO symbol F-44) and naval distillate lower pour point (NATO symbol F-75) are also used.

NEEDLE VALVE: Type of valve with a rod-shaped, needle-pointed valve body which works into a valve seat so shaped that the needle point fits into it and closes the passage. Suitable for precise control of flow.

NEGATIVE CHARGE: The electrical charge carried by a body which has an excess of electrons.

NEOPRENE: A synthetic rubber highly resistant to oil, light, heat, and oxidation.

NIGHT ORDER BOOK: A notebook containing standing and special instructions from the engineering officer to the engineering officers of the night watches.

NIPPLE: A piece of pipe that has an outside thread at both ends for use in making pipe connections. Various names are applied to different lengths, such as close, short, long, and so forth.

NITROGEN: An inert gas which will not support life or combustion.

NOMINAL OPERATING PRESSURE: The approximate pressure at which an essentially constant-pressure system operates. This pressure is used for the system's basic pressure identification.

NONFERROUS METAL: Metal that is composed primarily of a metallic element, or elements other than iron.

NORMALIZE: To heat steel to a temperature slightly above its critical point and then allow it to cool slowly in air.

NOZZLE: A taper or constriction used to speed up or direct the flow of gas or liquid.

NOZZLE AREA: Smallest opening (area) of a nozzle that is at a right angle to the direction of flow.

OCCUPATIONAL STANDARDS: Requirements that describe the work of each Navy rating.

OFFSET SECTION: A section view of two or more planes in an object to show features that do not lie in the same plane.

OHM: The unit of electrical resistance.

OHMMETER: An instrument for directly measuring resistance in ohms.

OIL KING: A petty officer who receives, transfers, discharges, and tests fuel oil and maintains fuel oil records.

OIL STRAINER: A strainer placed at the inlet end of the oil pump to prevent dirt and other particles from getting into moving parts.

OILTIGHT: Having the property of resisting the passage of oil.

ONBOARD PLANS: See SHIP'S PLANS.

OPERATING CHARACTERISTICS: The combination of a parameter and its set points. See PARAMETER.

OPERATING PRESSURE: The constant pressure at which a component is designed to operate in service.

OPERATING TEMPERATURE: The actual temperature of a component during operation.

OPERATION (AUTOMATIC): The regulation of a process by a controlling system without manual intervention.

OPERATION (LOCAL-MANUAL): Positioning of a final control element by attending personnel from the element's manual control station.

ORIFICE: A circular opening in a flow passage which acts as a flow restriction.

OSCILLATION: A backward and forward motion; a vibration.

OTTO COMBUSTION CYCLE: Combustion induced by spark ignition occurring at constant volume. The basic combustion cycle of a gasoline engine.

OUTPUT SIGNAL: The pressure or flow of fluid leaving the output port of a fluidic device.

OVERHAUL: To inspect, repair, and put in proper condition for operation.

OVERLOAD: A load greater than the rated load of an engine or electrical device.

OXIDATION: The process of various elements and compounds combining with oxygen. The corrosion of metal is generally a form of oxidation; rust on iron, for example, is iron oxide or oxidation.

OXYGEN-FREE FEEDWATER: Water from which dissolved oxygen has been removed.

PACKING: A class of seal that provides a seal between two parts of a unit, which move in relation to each other.

PANT, PANTING: A series of pulsations caused by minor, recurrent explosions in the firebox of a ship's boiler. Usually caused by a shortage of air.

PARALLEL CIRCUIT: An electrical circuit with two or more resistance or impedance units connected to split the current flow through both units at the same time.

PARALLEL OPERATION: Two or more units operating simultaneously and connected so their output forms a common supply, as opposed to series or independent operation.

PARAMETER: A variable such as temperature, pressure, flow rate, voltage, current, frequency, etc., which may be indicated, monitored, checked or sensed in any way during operation or testing.

PARTIAL SECTION: A sectional view consisting of less than a half-section. Used to show the internal structure of a small portion of an object. Also known as broken section.

PARTICULATE: Minute particles or quantities of solid matter resulting from incomplete combustion. Carbon, sulphur, ash, and various other compounds are all referred to as particulate, either collectively or individually, when discharged into a flue or into the atmosphere.

PERIPHERY: (1) The curved line which forms the boundary of a circle (circumference), elipse, or similar figure. (2) The outside surface, especially that of a rounded object or body.

pH: A chemistry term that denotes the degree of acidity or alkalinity of a solution. The pH of water solution may have any value between 0 and 14. A solution with a pH of 7 is neutral. Above 7, it is alkaline; below 7, it is acidic.

PHANTOM VIEW: A view showing the alternate position of a movable object, using a broken line convention.

PHASE: An impulse of alternating current. The number of phases depends on the generator windings. Most large generators produce a 3-phase current that must be carried on at least three wires.

PHYSICAL CHANGE: A change that does not alter the composition of the molecules of a substance, such as from gas to liquid.

PICTORIAL DRAWING: A drawing which gives the real appearance of an object showing general location, function, and appearance of parts and assemblies.

PILOT VALVE: A small valve disk and seat, usually located within a larger disk, which controls the operation of another valve or system.

PILOT VALVE (GOVERNOR): A hydraulic control valve that regulates hydraulic pressure to a piston and cylinder.

PINION: A gear that meshes with a larger gear.

PINTLE-TYPE NOZZLE: A closed-type nozzle having a projection on the end of the fuel valve which extends into the orifice when the valve is closed.

PIPE: A tube or hollow body for conducting a liquid or gas. Dimensions of a pipe are designated by nominal (approximate) outside diameter (OD) and wall thickness.

PIPING: An assembly of pipe or tubing, valves, and fittings that forms the transferring part of a system.

PISTON: A cylindrical plug which slides up and down in the cylinder and which is connected to the connecting rod.

PISTON BOSS: The reinforced area around the piston-pin bore.

PISTON DISPLACEMENT: The volume of air moved or displaced by a piston as the piston moves from BDC to TDC.

PISTON HEAD: The portion of the piston above the top ring.

PISTON LANDS: The spaces in pistons between the ring grooves.

PISTON PIN (WRIST PIN): A cylindrical alloy pin that passes through the piston bore and connects the connecting rod to the piston.

PISTON RING: A split ring of the expansion type placed in a groove of the piston to seal the space between the piston and the wall.

PISTON-RING END GAP: The clearance between the ends of a piston ring.

PISTON-RING GROOVE: The grooves cut in the piston into which the piston rings are fitted.

PISTON-RING SIDE CLEARANCE: The clearance between the sides of the ring and the ring lands.

PISTON SKIRT: The portion of the piston that is below the piston bore.

PISTON SPEED: The total distance traveled by each piston in one minute.

PITCH: A term applied to (1) the distance a propeller will advance during one revolution; (2) the distance between the centers of the teeth of a gear wheel; (3) the axial advance of one convolution of the thread on a screw; and (4) the spacing of rivets, and so forth.

PITTING: The localized corrosion of iron and steel in spots, usually caused by irregularities in surface finish and resulting in small indentations or pits.

PLAN VIEW: A view of an object or area as it would appear from directly above.

PLUG COCK: A valve that has a rotating plug, which is drilled for the passage of fluid.

PLUNGER: See RAM-TYPE CYLINDER.

PNEUMATIC: Driven, or operated, by air pressure.

PNEUMATICS: That branch of physics pertaining to the pressure and flow of gases.

POLAR TIMING DIAGRAM: A graphic method of illustrating the events of an engine cycle with respect to crankshaft rotation. (See figures 2-1 and 2-2.)

PORT SCAVENGING: Introducing scavenging air through ports in the cylinder wall when they are uncovered by the piston near the end of the power stroke.

POTABLE WATER: Water that is suitable for drinking. The potable water system supplies scuttlebutts, sinks, showers, sculleries, and galleys, as well as provides makeup water for various freshwater cooling systems.

POTENTIAL: The amount of charge held by a body as compared to another point or body. Usually measured in volts.

POTENTIAL ENERGY: (1) Energy at rest; stored energy. (2) The energy a substance has because of its position, its condition, or its chemical composition.

POWER: The rate of doing work or the rate of expending energy. The unit of electrical power is the watt; the unit of mechanical power is horsepower.

PPM (PARTS PER MILLION): Concentration of the number of parts of a substance dissolved in a million parts of another substance. Used to measure the salt content of water. If 1 pound of sea salt were dissolved in l,000,000 pounds of water, the sea salt concentration would be 1.00 ppm.

PRECISION INSERT BEARING: A precision type of bearing consisting of an upper and lower shell.

PRECOMBUSTION CHAMBER: A portion of the combustion chamber connected to the cylinder through a narrow throat. Fuel is injected into and is partly burned in the precombustion chamber. Heat released by this partial burning causes the contents of the precombustion chamber to be ejected into the cylinder with considerable turbulence.

PRESSURE: The amount of force distributed over each unit of area. Pressure is expressed in pounds per square inch (psi), atmospheric units, or kilograms per square centimeter, inches of mercury, and other ways.

PRESSURE DIFFERENTIAL: The difference in pressure between any two points of a system or a component.

PRESSURE RELIEF VALVE: A valve designed to open when pressure in the system exceeds a certain limit.

PRESSURE SWITCH: An electrical switch operated by the increase and decrease of pressure.

PRESSURE-TIME FUEL SYSTEM: A system in which fuel is injected into the cylinders at a specific pressure in separately timed events.

PRIMARY SENSING ELEMENT: The control component that transforms energy from the controlled medium to produce a signal which is a function of the value of the controlled variable.

PRIME MOVER: (1) the source of motion—as a diesel engine. (2) The source of mechanical power used to drive a pump or compressor. (3) The source of mechanical power used to drive the rotor of a generator.

PRIMING: To fill, load, or put in working order (to fill a fuel system with fuel or a pump with water).

PROMPTNESS: The time it takes a governor to move the fuel control from a no load position to a full load position.

PROPELLER: A propulsive device consisting of a boss or hub carrying two or more radial blades. Also called a SCREW.

PROPELLER ARCH: The arched section of the stern frame above the propeller.

PROPELLER GUARD: A framework fitted somewhat below the deck line on narrow, high-speed vessels with large screws, designed to overhang and thus protect the tips of the propeller blades.

PROPELLER THRUST: The effort delivered by a propeller in pushing a vessel ahead.

PROPULSION PLANT: The entire propulsion plant or system, including prime movers and those auxiliaries essential to their operation.

PSYCHROMETER: A form of hygrometer consisting of a wet and a dry bulb thermometer.

PULSATION: A rhythmical throbbing or vibrating.

PUMP: (1) A device which converts mechanical energy into fluid energy. (2) A device that raises, transfers, or compresses fluids or gases.

PUMP CAPACITY: The amount of fluid a pump can move in a given period of time, usually stated in gallons per minute (gpm).

PUMP RISER: The section of piping from the pump discharge valve to the piping main.

PURGE: To make free of an unwanted substance (as to bleed air out of a fuel system).

PURPLE-K-POWDER (PKP): A purple powder composed of potassium bicarbonate that is used on class B fires. Can be used on class C fires; however, CO_2 is a better agent for such electrical fires because it leaves no residue.

PYROMETER: A device for measuring high temperatures such as the exhaust temperature of an internal-combustion engine.

RACE (bearing): The inner or outer ring that provides a contact surface for the balls or rollers in a bearing.

RADIAL BEARINGS: Bearings designed to carry loads applied in a plant perpendicular to the axis of the shaft and used to prevent movement in a radial direction.

RADIAL THRUST BEARINGS: Bearings designed to carry a combination of radial and thrust loads. The loads are applied both radially and axially with a resultant angular component.

RADIANT HEAT: Heat transferred without physical contact between the emitting region and the receiving region.

RADIUS: A straight line from the center of a circle or sphere to its circumference or surface.

RAM TYPE CYLINDER: A fluidic actuating cylinder in which the cross-sectional area of the piston rod is more than one-half the cross-sectional area of the movable piston-like element. The piston used is also referred to as a PLUNGER.

RATE ACTION: That action of a control system component whose output is proportional to the rate of change in its input for slowly changing signals and proportional to the input for rapidly changing signals.

RATIO: The value obtained by dividing one number by another, indicating their relative proportions.

RAW WATER: Untreated water used for cooling.

REACH ROD: A length of pipe or bar stock used as extension on valve stems.

RECEIVER: (1) A container in which compressed gas is stored to supply pneumatic power. (2) A reservoir for pressure refrigerant.

RECEIVER INDICATOR: Pressure-sensitive instrument indicating the loading pressure signals in percentage.

RECIPROCATING: Moving back and forth, as a piston reciprocating in a cylinder.

REDUCER: (1) Any coupling or fitting that connects a large opening to a smaller pipe or hose. (2) A device that reduces pressure in a fluid (gas or liquid) system.

REDUCING STATION: An assembly consisting of a reducing valve, isolation valves, and bypass valves for the reducer.

REDUCING VALVES: Automatic valves that provide a steady pressure lower than the supply pressure.

REDUCTION GEAR: An arrangement of shafts and gears such that the number of revolutions of the output shaft is less than that of the input shaft-generally used between a prime mover and the propeller shaft.

REEFER: (1) A provision cargo ship or a refrigerated compartment. (2) An authorized abbreviation for refrigerator.

REFRIGERANT 12 (R-12): A gas used in air conditioning and refrigeration systems. One of a series of fluorocarbon refrigerants.

REFRIGERATION TON: Unit of measure for the amount of heat removed, equal to 12,000 Btu per hour.

REGULATOR (gas): An instrument that controls the flow of gases from compressed gas cylinders.

RELATIVE HUMIDITY: The ratio of the weight of water vapor in a quantity of air to the weight of water vapor which that quantity of air would hold if saturated at the existing temperature. Usually expressed as a percentage; for example, if air is holding half the moisture it is capable of holding at the existing temperature, the relative humidity is 50%.

RELAY: A magnetically operated switch that makes and breaks the flow of current in a circuit.

RELIEF VALVE: A pressure control valve used to limit system pressure.

REMOTE OPERATING GEAR: Flexible cables or shafts attached to valve wheels so the valves can be operated from another compartment.

RESERVOIR: A container which serves primarily as a supply source of the liquid for a hydraulic system.

RESISTANCE: The oppositon to the flow of current caused by the nature and physical dimensions of a conductor.

RESPONSE TIME: The time lag between a signal input and the resulting change of output.

RESTRICTION: A reduced cross-sectional area in a line or passage which reduces the rate of flow.

RETURN LINE: A line used for returning fluid to the reservoir or atmosphere.

RHEOSTAT: A variable resistor. Similar in function and construction to a potentiometer.

RISER: A vertical pipe leading off a large one; for example, a firemain line.

ROCKER ARM: Part of the valve actuating mechanism of a reciprocating engine.

ROOT: The surface of the thread corresponding to the minor diameter of an external thread and the major diameter of an internal thread.

ROOT VALVE: A valve located where a branch line comes off the main line.

ROTOR: The rotating element of a motor, pump, or turbine.

RUDDER STOCK: A vertical shaft that has a rudder attached to its lower end and a yoke, quadrant, or tiller fitted to its upper portion by which it may be turned.

RUDDER STOPS: Fittings attached to the ship structure or to shoulders on the rudder post to limit the swing of the rudder.

SAFETY VALVE: An automatic, quick opening and closing valve that has a reset pressure lower than the lift pressure.

SALINE/SALINITY: (1) Constituting, or characteristic of, salt. (2) Relative salt content of water.

SALINOMETER: A hydrometer that measures the concentration of salt in a solution.

SATURATED AIR: Air that attains the maximum amount of moisture it can hold at a specified temperature.

SATURATED STEAM: Steam at the saturation temperature.

SATURATION PRESSURE: The pressure corresponding to the saturation temperature.

SATURATION TEMPERATURE: The temperature at which a liquid boils under a given pressure. For a given pressure there is a corresponding saturation temperature.

SAY BOLT VISCOSIMETER: An instrument that determines the fluidity or viscosity (resistance to flow) of an oil.

SCALE: Undesirable deposit, mostly calcium sulfate, which forms in the tubes of boilers.

SCAVENGING AIR: Increased amount of air available as a result of blower action used to fill an engine cylinder with a fresh charge of air and, during the process, to aid in clearing the cylinder of the gases of combustion.

SCHEMATIC DIAGRAM: A diagram using graphic symbols to show how a circuit functions electrically.

SCREW: See PROPELLER.

SEA CHEST: An arrangement for supplying seawater to engines, condensers, and pumps and for discharging waste water from the ship to the sea. It is a cast fitting or a built-up structure located below the waterline of the vessel and having means for attachment of the piping. Suction sea chests are fitted with strainers or gratings.

SEA COCK, SEA CONNECTION: A sea valve secured to the plating of the vessel below the waterline for use in flooding tanks, magazines, and so forth, to supply water to pumps and for similar purposes.

SEAWATER: The water in the sea. Seawater is an aqueous solution of various minerals and salts (chlorides). In suspension also, but not dissolved in the water, may be various types of vegetable and animal growths, including, in many cases, bacteria and organisms harmful or actually dangerous to health.

SECTION: A view showing internal features as if the viewed object had been cut or sectioned.

SEDIMENT: An accumulation of matter that settles to the bottom of a liquid.

SENSIBLE HEAT: Heat that is given off or absorbed by a substance without changing its state.

SENSING POINT: (1) The physical and/or functional point in a system at which a signal may be detected and monitored or may cause some automatic operation to result. (2) Where parameters are determined.

SENSITIVITY: The change in speed required before the governor will make a corrective movement.

SENSOR: A component that senses physical variables and produces a signal to be observed or to actuate other elements in a control system. Temperature, sound, pressure and position sensors are examples.

SENTINEL VALVE: A relief valve designed to emit an audible sound; does not have substantial pressure-relieving capacity.

SEPARATOR: A trap for removing oil and water from compressed gas before it can collect in the lines or interfere with the efficient operation of pneumatic systems.

SERVICE TANKS: Tanks in which fluids for use in the service systems are stored. Also DAY TANK.

SERVO: A device used to convert a small movement into a greater movement or force.

SET POINT: The level or value at which a controlled variable is to be maintained.

SETSCREW: A machine screw with a slotted, allen, or square head used to hold a part in place.

SHAFT ALLEY: A watertight passage, housing the propeller shafting from the engine room to the bulkhead at which the stern tube commences.

SHAFT/SHAFTING: The cylindrical forging, solid or tubular, used for transmission of rotary motion from the source of power, the engine, to the propellers.

SHIM: A thin layer of metal or other material used to true up a machine or inserted in bearings to permit adjustment after wear of the bearing.

SHIP'S PLANS: A set of drawings of all significant construction features and equipment of a ship, as needed to operate and maintain the ship. Also called ONBOARD PLANS.

SHORE WATER: A broad term for classifying water originating from a source ashore.

SHUTOFF VALVE: A valve which operates fully open or fully closed.

SIMPLEX PUMP: A pump that has only one liquid cylinder.

SLEEVE: A casing fitted over a line or shaft for protection against wear or corrosion.

SOLENOID: An electromagnetic coil that contains a movable plunger.

SOLID COUPLING: A device that joins two shafts rigidly.

SOUNDING PIPE OR SOUNDING TUBE: A vertical pipe in an oil or water tank, used to guide a sounding device during measurement of the depth of liquid in the tank.

SPECIFIC GRAVITY: The ratio of the weight of a given volume of any substance to the weight of an equal volume of distilled water. Since the distilled water weighs approximately 62.4 pounds per cubic foot, any substance which weighs less than this has a specific gravity of less than one and will float on water. Any substance of greater weight per cubic foot has a specific gravity of more than one and will sink. Specific gravity of gases is based in a like manner on the weight of air.

SPECIFIC HEAT: The amount of heat required to raise the temperature of 1 pound of a substance 1°F. All substances are compared to water, which has a specific heat of 1 Btu/lb/°F.

SPEED DROOP: A progressive drop in speed as load is picked up by the prime mover from no load to full load without manually changing the speed setting.

SPEED-LIMITING GOVERNOR: A device for limiting the speed of a prime mover.

SPEED-REGULATING GOVERNOR: A device that maintains a constant speed on an engine that is operating under varying load conditions.

SPLIT PLANT: A method of operating propulsion plants so that they are divided into two or more separate and complete units.

SPRING BEARINGS: Bearings positioned at varying intervals along a propulsion shaft to help keep it in alignment and to support its weight.

STABILITY: The ability of a governor to correct a speed disturbance with a minimum of corrective motions.

STANDBY EQUIPMENT: Two auxiliaries that perform one function. When one auxiliary is running, the standby is so connected that it may be started if the first fails.

STATOR: The stationary element of a motor or generator.

STEAM: Vapor of water; invisible, odorless, tasteless, and usually under greater than atmospheric pressure.

STEERING ENGINE: The machinery that turns the rudder.

STEERING GEAR: A term applied to the steering wheels, leads, steering engine, and fittings by which the rudder is turned.

STEP-TOOTHED LABYRINTH: Labyrinth type packing having each alternate tooth ring installed on the shaft and running in close proximity to the fixed packing ring.

STERN TUBE: (1) The bearing supporting the propeller shaft where it emerges from the ship. (2) A watertight enclosure for the propeller shaft.

STERN TUBE FLUSHING WATER: Water circulated through the stern tube from inboard to prevent accumulation of debris in the stern tube while the ship is at rest or backing down.

STUFFING BOX: A device to prevent leakage between a moving and a fixed part.

SUMP: A container, compartment, or reservoir used as a drain or receptacle for engine oil.

SUPERCHARGE: To supply a charge of air at a pressure higher than that of the surrounding atmosphere.

SUPERCHARGER: A device for increasing the volume of the air charge of an internal-combustion engine.

SUPERHEAT: Amount of heat applied to vapor to raise its temperature above the saturation temperature, while maintaining constant pressure.

SUPPLY AIR: Compressed air required for the proper operation of pneumatic control components.

SURGING: A rhythmic variation of speed of an engine, which can be eliminated by blocking the fuel supply manually or with load limit, and which will not reappear when returned to governor control unless the speed adjustment is changed or the load changes.

SWING CHECK VALVE: A valve that has a guide-mounted disk swung from the top by a horizontal pin. A liquid exerting pressure against the disk will cause it to open, allowing a flow. Pressure exerted in the opposite direction will close the valve, ensuring only one direction of flow.

SWITCHBOARD: A panel or group of panels with automatic protective devices, used to distribute the electrical power throughout the ship.

SYNCHRONIZE: (1) To make two or more events or operations occur at the proper time with respect to each other. (2) To adjust two engines to run at the same speed.

SYNTHRON SEAL: A rubber strip seal installed on the shaft to prevent seawater from leaking into the ship along the shaft.

TACHOMETER: An instrument for indicating revolutions per minute.

TAIL SHAFT: The aft section of the shaft that receives the propeller.

TAKE LEADS: A method of determining bearing and other clearances. Mostly replaced by other methods such as plastigage and bearing shell thickness measurements.

TDC (TOP DEAD CENTER): The position of a reciprocating piston at its uppermost point of travel.

TEFLON: A plastic with excellent self-lubricating bearing properties.

TELEGRAPH: An apparatus, either electrical or mechanical, for transmitting orders, as from a ship's bridge to the engine room, steering gear room, or elsewhere about the ship.

TELEMOTOR: A device for operating the steering engine from the pilothouse by means of either fluid pressure or electricity.

TEMPER: To harden steel by heating and sudden cooling by immersion in oil, water, or other coolant.

TENSILE STRENGTH: The measure of a material's ability to withstand a tensile, or pulling, stress without rupture, usually measured in pounds or tons per square inch of cross section.

THERMAL ENERGY: Energy contained in or derived from, heat.

THERMAL EXPANSION: The increase in volume of a substance due to temperature change.

THERMOCOUPLE: (1) A bimetallic device capable of producing an electromotive force roughly proportional to temperature differences on its hot and cold junction ends and used in the measurement of elevated temperatures. (2) A junction of two dissimilar metals that produces a voltage when heated.

THREAD: The spiral part of a screw.

THROAT: Opening in the cylinder block through which the crankshaft end is extended.

THROTTLEMAN: Person in the engine room who operates the throttles to control the main engines.

THROTTLE VALVE: A type of valve especially designed to control rate of flow.

THROTTLING: Operating a valve partially open to produce a pressure drop with flow.

THRUST BEARINGS: Bearings that limit the axial (longitudinal) movement of the shaft.

TILLER: An arm attached to the rudder head for operating the rudder.

TIMING GEARS: Gears attached to the crankshaft, camshaft, idler shaft, or injection pump to provide a means to drive the camshaft and injection pump and to regulate the speed and performance.

TOLERANCE: The amount that a manufactured part may vary from its specified size.

TORQUE: A force or combination of forces that produces or tends to produce a twisting or rotary motion.

TOUGHNESS: The property of a material that enables it to withstand shock as well as to be deformed without breaking.

TRANSDUCER: A device that converts signals received in one medium into outputs in some other medium; for example, electrical inputs to fluidic outputs.

TRANSFER VALVE: A manually operated direction valve used to switch automatic control systems from automatic to manual operation and vice versa.

TRANSFORMER: A device composed of two or more coils, linked by magnetic lines of force, used to transfer energy from one circuit to another. Also, an electrical device used to step up or step down an a.c. voltage.

TRANSMISSION: A device that transmits power from the engine (driving unit) to the load (driven unit).

TRICK WHEEL. A steering wheel in the steering engine room or emergency steering station of a ship, used in case of emergency.

TUBING: That type of fluid line the dimensions of which are designated by actual measured outside diameter (OD) and by actual measured wall thickness.

TURBINE: (1) A rotary motor actuated by the reaction, impulse, or both, of a flow of pressurized fluid. A turbine usually consists of a series of curved vanes on a centrally rotating shaft. (2) A multibladed rotor, driven by steam, hot gas, or water.

TURBULENCE: Air in the combustion space in motion.

UNBURNABLE OIL: That quantity of oil below the stripping suction in storage tanks and below the service suction in service tanks.

UNIT INJECTOR: A diesel engine injector that combines a pump and a fuel-spray nozzle in a single unit.

UNSTABLE: That action of an automatic control system and controller process that is characterized by a continuous cycling of one or more system variables for a degree greater than a specified maximum.

VACUUM: Pressure less than atmospheric pressure.

VALVE: A mechanism that can be opened or closed to control or stop the flow of a liquid, gas, or vapor from one place to another place.

VALVE GUIDE: A hollow-sized shaft pressed into the cylinder head to keep the valve in proper alignment.

VALVE KEEPER (VALVE RETAINER): A device designed to lock the valve-spring retainer to the valve stem.

VALVE LASH: Clearance between the top of the valve stem and the valve-lifting mechanism.

VALVE LIFT: The distance a valve moves from the fully closed to the fully open position.

VALVE OVERLAP: The period of crankshaft rotation during which both the intake and exhaust valves are open. It is measured in degrees.

VALVE ROTATOR: A mechanical device locked to the end of the valve stem that forces the valve to rotate about 5° with each rocker-arm action.

VALVE SEAT: The surface, normally curved, against which the valve disk's operating face comes to rest to provide a seal against leakage of liquid, gas, or vapor.

VALVE SEAT INSERT: Metal ring inserted into a valve seat, made of a special metal that can withstand operating temperature satisfactorily.

VALVE SPRING: The compression-type spring that closes the valve when the valve-operating cam assumes a closed-valve position.

VAPOR: The gaseous state of a substance that is usually a liquid or solid at atmospheric temperature and pressure.

VARIABLE DISPLACEMENT: The type of pump or motor in which the volume of fluid delivered per cycle can be varied.

VELOCITY: The rate of motion in a particular direction. The velocity of fluid flow is usually measured in feet per second.

VENT: A valve in a system used primarily to permit air to escape.

VENTILATION SYSTEM: A system that removes heat and stale air and provides fresh air by means of mechanical or natural distribution ductwork. The system may also include filters and heaters.

VENTURI: A tube that has a narrowing throat or constriction to increase the velocity of fluid flowing through it. The flow through the venturi causes a pressure drop in the smallest section.

VIEW: A drawing of a side or plane of an object as seen from one point.

VISCOSITY: The internal resistance of a fluid that tends to prevent it from flowing.

VITAL CIRCUITS: Electrical circuits that provide power or lighting to equipment and spaces necessary for propulsion, ship control, and communications.

VOID: An empty tank.

VOLATILE: The term that describes a liquid that vaporizes quickly.

VOLT: The unit of electrical potential.

VOLTAGE TESTER. A portable instrument that detects electricity.

VOLTMETER: An instrument designed to measure a difference in electrical potential in volts.

VOLUME OF FLOW: The quantity of fluid that passes a certain point in a unit of time. The volume of flow is usually expressed in gallons per minute for liquids and in cubic feet per minute for gases.

VOLUTE: A gradually widening spiral. A section or component of a centrifugal pump where velocity head becomes pressure head.

WATER DRUM: A tank at the bottom of a boiler, sometimes called MUD DRUM, that equalizes distribution of water to the generating tubes and collects loose scale and other solids in boiler water.

WATER JACKET: Internal passages and cavities cast into the cylinder block of engines and air compressors through which water is circulated around and adjacent to friction (heat) areas.

WATER TUBE BOILER: Boiler in which the water flows through the tubes where it is heated by the gases of combustion.

WATT: The unit of electrical power.

WATTMETER: An instrument for measuring electrical power in watts.

WINCH: A hoisting or pulling machine fitted with a horizontal single or double drum. A small drum is generally fitted on one or both ends of the shaft supporting the hoisting drum. These small drums are called gypsies, or winch heads. The hoisting drums either are fitted with a friction brake or are directly keyed to the shaft. They are in the form of a spool and carry the working wire rope. The driving power is usually electricity, but hand power is also used. A winch is used principally for handling, hoisting, and lowering cargo from a dock or lighter to the hold of a ship and vice versa.

WINDLASS: An apparatus in which horizontal or vertical drums or gypsies and wildcats are operated by means of a steam engine or motor for the purpose of handling heavy anchor chains, hawsers, and so forth.

WIPED BEARINGS: A bearing in which the babbit has melted because of excess heat.

WORK: The transference of energy from one body or system to another.

WORK REQUEST: Request issued to naval shipyard, tender, or repair ship for repairs.

WORM, WORM SHAFT: A threaded shaft designed to engage the teeth of a wheel lying in the plane of the shaft axis. This type of gear is used for the transmission of heavy loads at low speeds.

WYE GATE: A fitting with two separately controlled hose fittings, designed to connect to an outlet.

YOKE: A frame or bar having its center portion bored and keyed or otherwise constructed for attachment to the rudder stock. Steering effort from the steering gear is applied to each end of the yoke for the purpose of turning the rudder.

ZERK FITTING: A small fitting to which a grease gun can be applied to force lubricating grease into bearings or moving parts of machinery.

ZERO SETTING: The output of a device when its input is minimum.

ZINC: (1) A primary metal useful in a number of anticorrosion applications. (2) A metal block or form placed in seawater systems to counteract the effects of electrolysis.