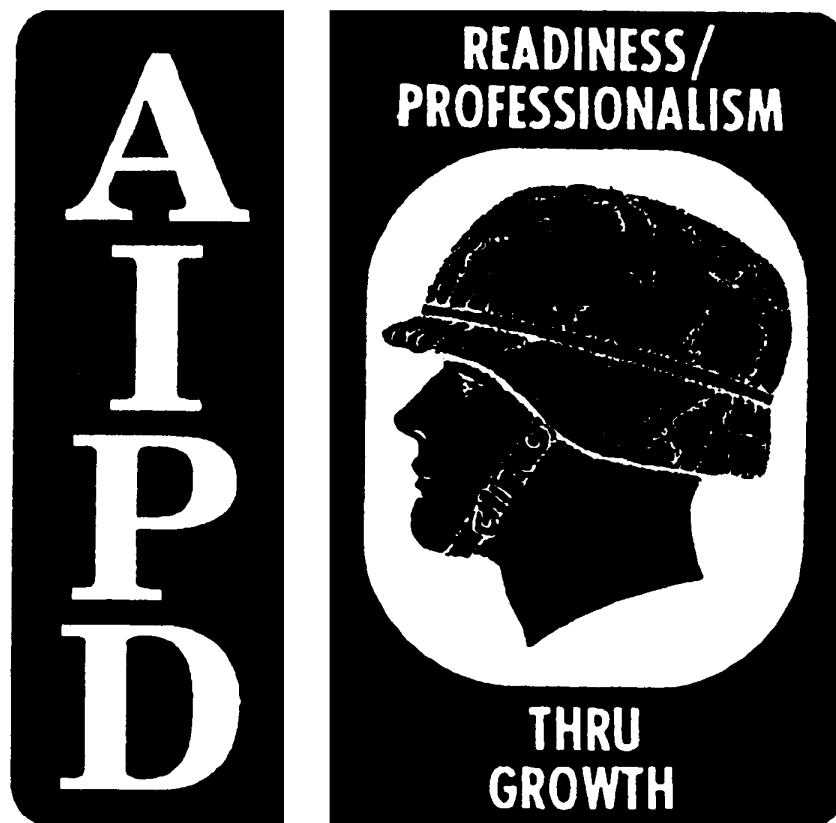
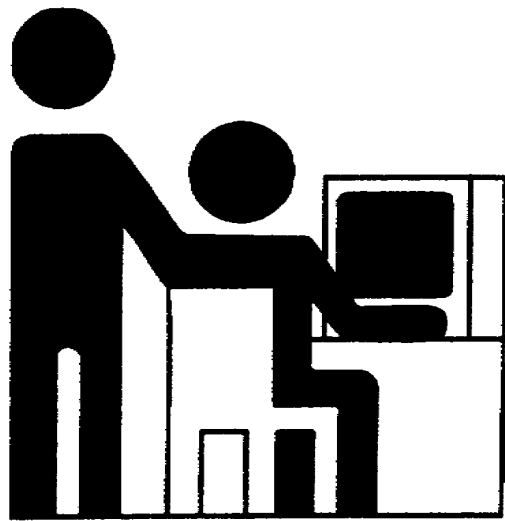


PRECISION MEASURING AND GAGING



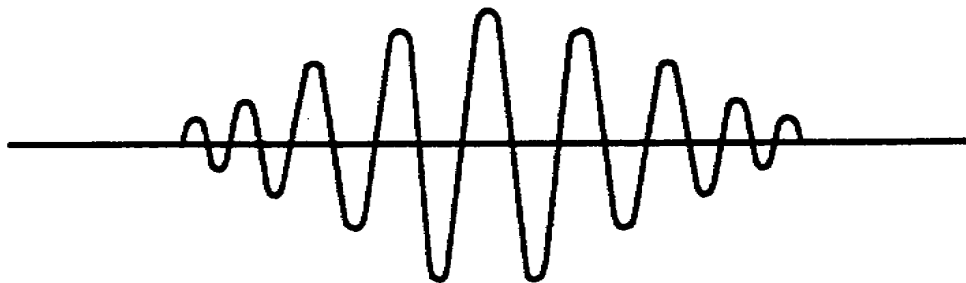
THE ARMY INSTITUTE FOR PROFESSIONAL DEVELOPMENT
ARMY CORRESPONDENCE COURSE PROGRAM



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US ARMY REPAIR SHOP TECHNICIAN
WARRANT OFFICER ADVANCE COURSE

MOS/SKILL LEVEL: 441A

PRECISION MEASURING AND GAGING

SUBCOURSE NO. OD1642
EDITION 8
US Army Correspondence
Course Program

6 Credit Hours

NEW: 1988

GENERAL

The purpose of this subcourse is to introduce the student to the different types of fits, tolerances, and allowances; and the proper use and care of precision measuring tools used in the machinist trade.

Six credit hours are awarded for successful completion of this subcourse. It consists of one lesson divided into two tasks.

Lesson 1: PRECISION GAGES AND MEASURING TOOLS, AND TYPES OF FITS,
 TOLERANCES, AND ALLOWANCES

TASK 1: Describe the different types of fits, tolerances, and allowances used in the machinist trades.

TASK 2: Describe the proper use and care of precision gages and measuring tools.

PRECISION MEASURING TOOLS - OD1642

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THE PASSING SCORE FOR ALL ACCP MATERIAL IS NOW 70%.
PLEASE DISREGARD ALL REFERENCES TO THE 75% REQUIREMENT.

STUDENT NOTES

PRECISION MEASURING AND GAGING - OD1642 - LESSON 1/TASK 1

LESSON 1

PRECISION GAGES AND MEASURING TOOLS, AND TYPES OF FITS, TOLERANCES, AND ALLOWANCES

TASK 1. Describe the different types of fits, tolerances, and allowances used in the machinist trades.

CONDITIONS

Within a self-study environment and given the subcourse text, without assistance.

STANDARDS

Within one hour

REFERENCES

No supplementary references are needed for this task.

1. Introduction

Some machinists are required to work to tolerances of ± 0.0002 inch, others to 0.002 inch. There is a vast difference between the two. Many components are manufactured to very close dimensions. Therefore, a machinist cannot afford to make a mistake while measuring or machining workpieces. Once the piece has been machined, there is no turning back or adding on. It is, therefore, important for him to become familiar with precision measuring tools, instruments, and with the types of fits, allowances and tolerances required for his job.

2. Type of Fits

a. *General.* Information concerning fits will be applied to plain cylindrical parts such as sleeves, bearings, pump wearing rings, and other non-threaded round parts that fit together. Fit is defined as the amount of tightness or looseness

PRECISION MEASURING AND GAGING - OD1642 - LESSON 1/TASK 1

between two mating parts when certain allowances are designed in them. An allowance is the total difference between the size of a shaft and the hole in the part that fits over it. This allowance and the resulting fit can be a clearance (loose) fit, an interference (tight) fit, or a transitional (somewhere between loose and tight) fit. These three general types of fits are further identified by classes of fits, with each class having a different allowance, based on the intended use or function of the parts involved. A brief description of each type of fit will be given in the following paragraphs. Any good handbook for machinists has complete charts with detailed information on each individual class of fit. Most major types of equipment repaired in machine shops will have the dimensional sizes and allowances noted, on blueprints, or in the appropriate manufacturer's technical manual.

b. *Clearance Fits.* Clearance fits or running and sliding fits provide a varying degree of clearance (looseness) depending on which one of the nine classes is selected for use. The classes of fit range from class 1 (close sliding fit) to class 9 (loose running fit). A class 1 fit permits a clearance allowance of from +0.0004 to +0.0012 inch on the mating parts with a 2.500 inch basic diameter. A class 9 fit permits a clearance allowance of from +0.009 to +0.0205 inch on the same parts. Even for a small basic diameter (2.500 inch) clearance allowance from a class 1 minimum to a class 9 maximum differs by +0.0201 inch. As the basic diameter increases, the allowance increases. Although the class of fit may not be referenced on a blueprint, the dimensions given for the mating parts are based on the service performed by the parts and the specific conditions under which they operate, as described in each of the class of fits. Some parts that fall within these classes of fits are a shaper ram (close sliding), a babbitt-lined bearing, and pump wearing rings (loose removal).

c. *Transitional Fits.* Transitional fits are subdivided into three types known as locational clearance, locational transitional, and locational interference fits. Each of these three subdivisions contain different classes of fits. These classes provide either a clearance or an interference allowance, depending on the intended use and class selected. All of the classes of fits in the transitional category are primarily intended

PRECISION MEASURING AND GAGING - OD1642 - LESSON 1/TASK 1

for the assembly and disassembly of stationary parts. Stationary means that the part will not rotate against another, although they may rotate together as part of a larger assembly. The allowances used as examples in the following descriptions of the various fits represent the sum of the tolerances of the external and internal parts. To achieve maximum standardization and to permit common size reamers and other fixed sized boring tools to be used as much as possible, use unilateral tolerance method.

(1) *Locational Clearance Fits.* These are broken down into 11 classes of fits. The same basic diameter with a class 1 fit ranges from a zero allowance to a clearance allowance of 0.0012 inch. A class 11 fit ranges from a clearance allowance of +0.014 to +0.050 inch. The nearer a part is to a class 1 fit, the more accurately it can be located without the use of force.

(2) *Locational Transitional Fits.* These type of fits have six different classes which provide either a small amount of clearance or an interference allowance, depending on the class of fit selected. The 2.500 inch basic diameter in a class 1 fit ranges from an interference allowance of -0.0003 inch to a clearance allowance of +0.0015 inch. A class 6 fit ranges from an interference allowance of -0.002 inch to a clearance allowance of +0.0004 inch. The interference allowance fits may require a very light pressure to assemble or disassemble the parts.

(3) *Locational Interference Fits.* These fits are divided into five different classes, providing an interference allowance of varying amounts. A class 1 fit for a 2.500 inch basic diameter ranges from an interference allowance of -0.0001 to -0.0013 inch. In comparison, a class 5 fit ranges from an interference allowance of from -0.0004 to -0.0023 inch. These classes of fits are used when parts must be located very accurately while maintaining alignment and rigidity. They are not suitable for applications where one part is subjected to a force that causes it to turn on the other part.

d. *Interference Fits.* There are five classes of fits within the interference type. They are all fits that require force to assemble or disassemble parts. These fits are often called force fits. In

PRECISION MEASURING AND GAGING - OD1642 - LESSON 1/TASK 1

certain classes of fits, they are referred to as shrink fits. Using the same basic diameter as an example, the class 1 fit ranges from an interference allowance of -0.0006 to -0.0018 inch. In comparison, a class 5 fit ranges from an interference allowance of -0.0032 to -0.0062 inch. The class 5 fit is normally considered to be a shrink fit class because of the large interference allowance required.

(1) A shrink fit requires that the part with the external diameter be chilled; or that the part with the internal diameter be heated. One can chill a part by placing it in a freezer, packing it in dry ice, spraying it with CO₂ (do not use a CO₂ bottle from a fire station) or by submerging it in liquid nitrogen. All of these methods except the freezer are potentially dangerous, especially the liquid nitrogen. They should not be used until all applicable safety precautions have been reviewed and implemented. When a part is chilled, it actually shrinks in size a certain amount depending on the type of material, design, chilling medium, and length of time of exposure to the chilling medium. A part can be heated by using an oxyacetylene torch, a heat-treating oven, electrical strip heaters, or by submerging it in a heated liquid. As with chilling, all applicable safety precautions must be observed. When a part is heated, it expands in size, allowing, easier assembly. All materials expand a different amount per degree of temperature increased. This is called the coefficient of expansion of a metal. It is important to determine the maximum temperature increase required to expand the part for the amount of shrinkage allowance, plus enough clearance to allow assembly. Overheating a part can cause permanent damage and produce so much expansion that assembly becomes difficult.

(2) A general rule of thumb for determining the amount of interference allowance on parts requiring a force or shrink fit is to allow approximately 0.0015 inch per inch of diameter of the internally bored part. There are, however, many variables that will prohibit the use of this general rule.

(a) The amount of interference allowance recommended decreases as the diameter of the part increases.

PRECISION MEASURING AND GAGING - OD1642 - LESSON 1/TASK 1

(b) The dimensional difference between the inside and the outside diameter (wall thickness) also has an effect on the interference allowance.

(c) A part that has large inside and outside diameters and a relatively thin wall thickness will split if installed with an excessive interference allowance.

When there are no blueprints or other dimensional references available, all of these variables must be considered before a fit is selected.

3. Tolerances

a. *General.* A clear understanding of *tolerance and allowance* will help to avoid making small, but potentially dangerous errors. These terms may seem closely related but each has a very precise meaning and application. Tolerance, for example, is defined as the allowable deviation from a standard size.

b. Working to the absolute or exact basic dimension is impractical and unnecessary in most instances; therefore, the designer calculates, in addition to the basic dimensions, an allowable variation. The amount of variation, or limit of error permissible, is indicated on the drawing as plus or minus ($\pm$) a given amount, such as $+0.005$ or $\pm 1/64$. The difference between the allowable minimum and the allowable maximum dimension is tolerance (figure 1 on the following page). For example,

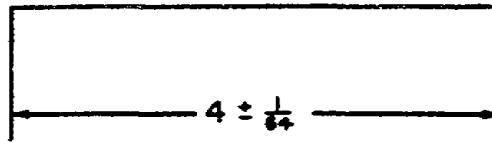
Basic dimension	=	4
Long limit	=	$4 \frac{1}{64}$
Short limit	=	$3 \frac{63}{64}$
Tolerance	=	$\frac{1}{32}$

c. When tolerances are not actually specified on a drawing, fairly concrete assumptions can be made concerning the accuracy expected, using the following principles. For dimensions that end in a fraction of an inch, such as $1/8$, $1/16$, $1/32$, or $1/64$, consider the expected accuracy to be to the nearest $1/64$ of an inch. When the dimension is given in decimal form, the following applies:

PRECISION MEASURING AND GAGING - OD1642 - LESSON 1/TASK 1

d. If a dimension is given as 3.000 inches, the accuracy expected is ± 0.0005 of an inch; or if the dimension given is 3.00 inches, the accuracy expected is ± 0.005 of an inch. The ± 0.0005 is called in shop terms, "plus or minus five ten-thousandths of an inch." The ± 0.005 is called "plus or minus five thousandths of an inch."

FIGURE 1. BASIC DIMENSION AND TOLERANCE.



4. Allowance

a. Allowance is an intentional or prescribed difference in dimensions of mating parts to provide a certain class of fits or a desired fit.

(1) *Clearance Allowance.* This allowance permits movement between mating parts when assembled. For example, when a hole with a 0.250 inch diameter is fitted with a shaft that has a 0.245 inch diameter, the clearance allowance is 0.005 of an inch.

(2) *Interference Allowance.* This allowance is just the opposite of a clearance allowance. The difference in dimensions in this case provides a tight fit. Force is required when assembling parts that have an interference allowance. If a shaft with a 0.251 inch diameter is fitted into the hole identified in the preceding example, the difference between the dimensions will give an interference allowance of 0.001 inch. As the shaft is larger than the hole, force is necessary to assemble the parts.

b. What is the relationship between tolerance and allowance? In the manufacture of mating parts, the tolerance of each part must be controlled so that the parts will have the proper allowance when

PRECISION MEASURING AND GAGING - OD1642 - LESSON 1/TASK 1

assembled. For example, if a hole with a 0.250 inch diameter with a tolerance of 0.005 of an inch (± 0.0025) is prescribed for a job, and the shaft that is to be fitted into that hole is to have a clearance allowance of 0.001 of an inch, the hole must first be finished within the limits and the required size of the shaft determined exactly, before the shaft can be made. The hole is then termed the basic hole. If the hole is finished to the upper limit of the basic dimension (0.2525 of an inch), the shaft would be machined to 0.2515 of an inch or 0.001 of an inch smaller than the hole. If the dimension of the shaft was given with the same tolerance as the hole, there would be no control over the allowance between the parts. As much as 0.005 of an inch allowance (either clearance or interference) could result.

c. To provide a method of retaining the required allowance while permitting some tolerance in the dimensions of the mating parts, the tolerance is limited to one direction on each part. This single direction (unilateral) tolerance stems from the basic hole system. If a clearance allowance is required between the mating parts, the hole may be larger but not smaller than the basic dimension. The part that fits into the opening may be smaller, but not larger than the basic dimension. Thus, shafts and other parts that fit into a mating opening have a minus tolerance only, while the openings have a plus tolerance only.

d. If an interference allowance between the mating parts is required, the situation is reversed. The opening can be smaller but not larger than the basic dimension, while the shaft can be larger but not smaller than the basic dimension. Therefore, one can expect to see a tolerance such as $+0.005$, -0 , or $+0$, -0.005 inch, but with the required value not necessarily 0.005 of an inch. One way to get a better understanding of a clearance allowance, or an interference allowance, is to make a rough sketch of the piece and add dimensions to the sketch where they apply.

5. Conclusion

There are various workpieces made by the machinist that require certain types of fits. These fits can be extremely close or they can be a loose or sliding fit. Whatever type of fit, the engineer notes tolerances and allowances on the blueprint.

PRECISION MEASURING AND GAGING - OD1642 - LESSON 1/TASK 1

The more familiar the machinist becomes with these terms, the easier his job will be. This task described the types of fits, tolerances, and allowances. Task 2 will describe the proper use and care of precision gages and measuring tools used in the machinist trades.

PRECISION MEASURING AND GAGING - OD1642 - LESSON 1/TASK 2

LESSON 1

PRECISION GAGES AND MEASURING TOOLS, AND TYPES OF FITS, TOLERANCES, AND ALLOWANCES.

TASK 2. Describe the proper use and care of precision gages and measuring tools.

CONDITIONS

Within a self-study environment and given the subcourse text, without assistance.

STANDARDS

Within four hours

REFERENCES

No supplementary references are needed for this task.

1. Introduction

To become effective in any job, one should become proficient with the use and care of the tools of the trade. As the carpenter could not effectively perform his job without the proper tools, so it is with the machinist. There are various types of tools used by the machinists. They are classified as precision and non-precision gages. However, during this task, we will describe the proper use and care of precision gages and precision measuring tools.

2. Precision Gages

a. *General.*

(1) Practically all shops require measuring or gaging. A machinists will most likely measure or gage flat or round stock; the outside diameters of rods, shafts, or bolts; slots, grooves, and other openings; thread pitch and angles; spaces between surfaces or angles and circles.

PRECISION MEASURING AND GAGING - OD1642 - LESSON 1/TASK 2

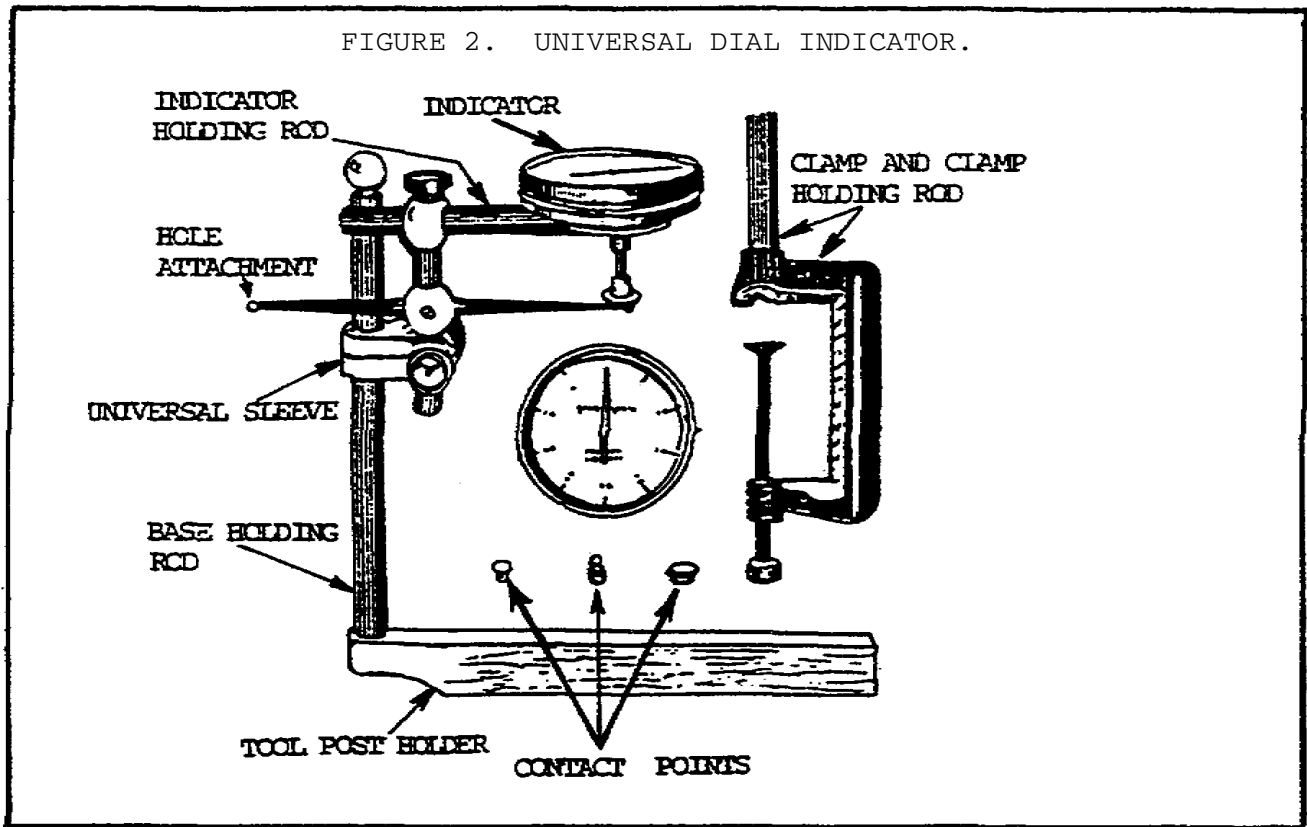
(2) The term "gage", as used in this lesson, identifies any device which can be used to determine the size or shape of an object. There is no significant difference between gages and measuring instruments. They are both used to compare the size and shape of an object against a scale or fixed dimension. However, there is a distinction between measuring and gaging which is easily explained by an example. Suppose that the machinist is turning a workpiece in the lathe and wants to know the diameter of the workpiece. He would take a micrometer, or perhaps an outside caliper, adjust its opening to the exact diameter of the workpiece, and determine that dimension numerically. On the other hand, if he wants to turn a piece of work down to a certain size without frequently taking time to measure it, he could set the caliper at a reading slightly greater than the final dimension desired; then, at intervals during the turning operations, measure, gage, or "size" the workpiece with the locked instrument. After the workpiece dimension has been reduced to the dimension set on the instrument, he would measure the workpiece to the exact dimension desired.

b. *Adjustable Gages.* Adjustable gages can be adjusted by moving the scale or by moving the gaging surface to the dimensions of the object being measured or gaged. For example, on the dial indicator, the face is adjusted to align the indicating hand with the zero point on the dial. On verniers, the measuring surface would be moved to the dimensions of the object being measured.

(1) *Dial Indicators.*

(a) Dial indicators are used by the machinist in setting up workpieces in machines and in checking the alignment of machinery. Proficiency in the use of the dial indicator requires a lot of practice; the more one uses it, the more it will aid in doing more accurate work.

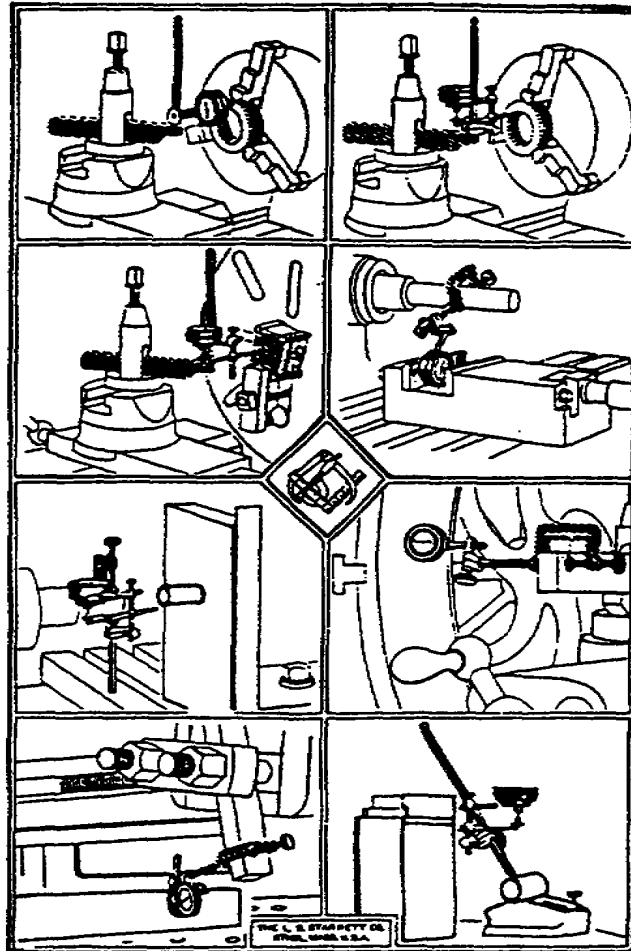
(b) Dial indicator sets (figure 2 on the following page) usually have several components that permit a wide variation of uses. The contact points allow the indicator to be used on different types of surfaces. The universal sleeve permits flexibility of setup. The clamp and the holding rods permit setting the indicator to the work. The hole attachment is used to indicate the variation, or run out, of the inside surfaces of holes and the



tool post holder can be used to clamp the indicator in various lathe setups. Figure 3 on the following page shows some of the practical applications of the dial indicator.

(c) When preparing to use the dial indicator, there are several things that should be checked. Dial indicators come in different degrees of accuracy. Some will give readings to one ten thousandths (0.0001) of an inch, while others will indicate to only five thousandths (0.005) of an inch. Dial indicators also differ in the total range or amount that they will indicate. If a dial indicator has a total of one hundred thousandths (0.100) of an inch in graduations on its face, and has a total range of two hundred thousandths (0.200) of an inch, the needle will only make two revolutions before it begins to exceed its limit and jams up. The degree of accuracy and the range of a dial indicator is usually shown on its face. Before using a dial indicator, carefully depress the contact point and release it slowly; rotate the movable dial face so that the dial needle is on zero. Depress and release the contact point again and check to ensure that the dial pointer returns to zero; if it does not, have the dial indicator checked for accuracy.

FIGURE 3. APPLICATIONS OF A DIAL INDICATOR.



(d) *Care.* Dial indicators and other instruments that have a mechanically-operated dial as part of their design are easily damaged by misuse and lack of proper maintenance. The following instructions apply to dial indicators in general:

1 Make sure the dial indicator that has been selected for use has the range capability required. When a dial indicator is extended beyond its design limit, some lever, small gear, or rack in the housing must give way to the exerted pressure applied on it. The dial indicator will be rendered useless if this happens.

PRECISION MEASURING AND GAGING - OD1642 - LESSON 1/TASK 2

2 Never leave a dial indicator on any surface that will be subjected to a shock (such as hammering on a part when dialing in on the workpiece); an erratic and uncontrolled movement of a surface could cause the dial to be over traveled.

3 Protect the dial when it is not being used. Provide a storage area where the dial will not receive accidental blows, and where dust, oil, and chips will not come in contact with it.

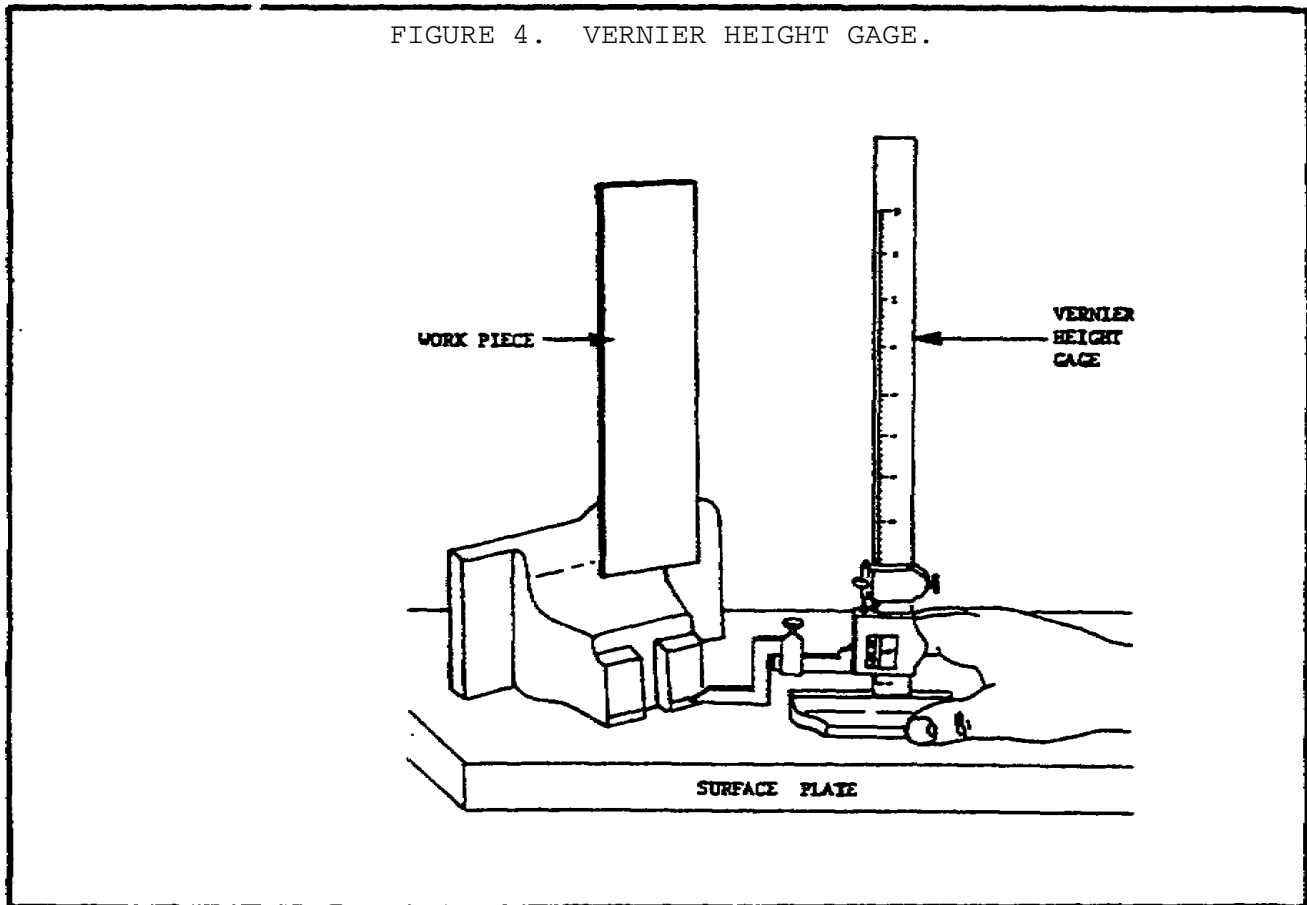
4 When a dial indicator becomes sluggish or sticky in operating, it may be either damaged or dirty. Also, one may find that the pointer is rubbing the dial crystal or that the pointer is bent or rubbing the dial face. A sluggish dial should never be oiled. Oil will compound the problem. A suitable cleaning solvent should be used to remove all dirt and residue.

(2) *Vernier Caliper.* A vernier caliper can be used to measure both inside and outside dimensions. To take a measurement, position the appropriate sides of the jaws to the surface to be measured and read the side marked inside or outside as required. There is a difference in the zero marks on the two sides that is equal to the thickness of the tips of the two jaws, so be sure to read the correct side. Vernier calipers are available in sizes ranging from 6 inches to 6 feet and are graduated in increments of thousandths (0.001) of an inch. The scales on the vernier calipers made by different manufacturers may vary slightly in length or number of divisions; however, they are all read basically the same way. Detailed instructions for reading and using the vernier calipers are covered in paragraph k(2) beginning on page 71 of this subcourse.

(3) *Vernier Height Gage.* A vernier height gage (figure 4 on the following page) is used to lay out work for machining operations or to check the dimensions on the surfaces of work which has been machined. The offset scriber allows one to measure from the surface plate with readings taken directly from the scale without having to make any calculations. If a straight scriber were used, the actual height would have to be calculated by taking into account the distance between the surface plate and the zero mark. Some models have a slot in the base for the scriber to move down to the surface and a scale that permits direct

PRECISION MEASURING AND GAGING - OD1642 - LESSON 1/TASK 2

reading. Another attachment is a rod that permits depth readings. Small dial indicators can be connected to the scriber to permit extremely close work in checking or laying out work. A vernier height gage is read the same way as the vernier caliper.



(a) *Care.* Vernier gages also require careful handling and proper maintenance if they are to remain accurate. The following instructions apply to the vernier gages in general:

1 Always loosen the binding screws before attempting to move the sliding arms.

2 Never force a gage into position. Forcing, besides causing an inaccurate reading, is likely to force the arms out of alignment.

3 When taking a measurement, use only gentle pressure on the fine adjustment screw. Heavy pressure will force the two scales out of parallel.

PRECISION MEASURING AND GAGING - OD1642 - LESSON 1/TASK 2

4 Prior to putting a vernier gage away, wipe it clean and give it a light coat of oil. (Perspiration from the hands will cause the instrument to corrode rapidly.)

(b) *Use.* The most accurate means of using the height gage is to place the workpiece on the top of the surface plate. After the correct setting has been made, place the base of the vernier height gage on the surface plate and scribe the desired height onto the workpiece.

(4) *Depth Gages.* A depth gage is an instrument for measuring the depth of holes, slots, counter bores, recesses, and the distance from the surface to some recessed part. The most commonly used depth gages are the vernier depth gage, the rule depth gage, and the micrometer depth gage.

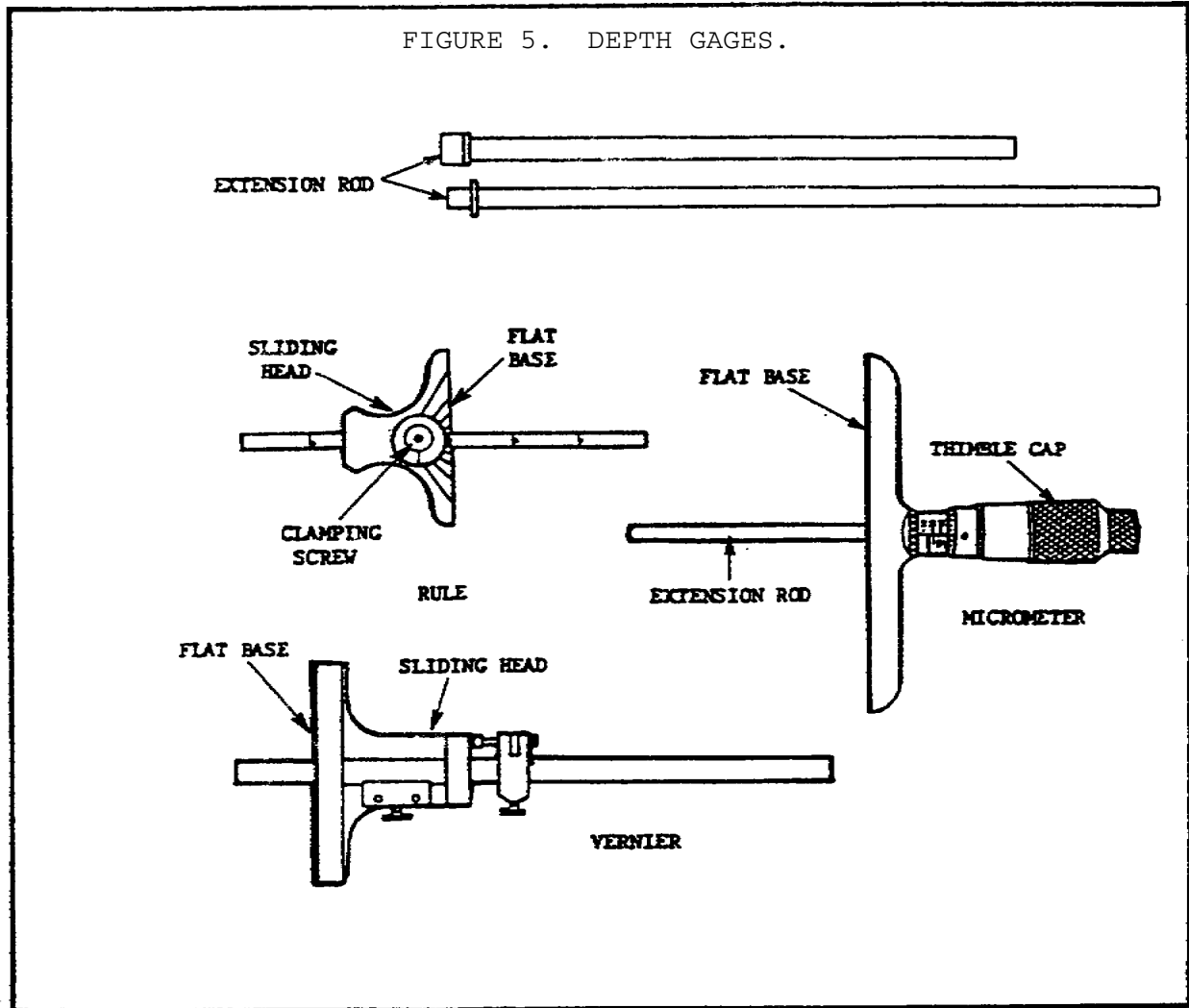
(a) *Vernier Depth Gage.* The vernier depth gage (figure 5 on the following page) consists of a graduated scale (1) either 6 or 12 inches long. It also has a sliding head (2) similar to the one on the vernier caliper. The sliding head is designed to bridge holes and slots. The vernier depth gage has the range of the rule depth gage. It does not have quite the accuracy of a micrometer depth gage. It cannot enter holes less than 1/4 inch in diameter. However, it will enter a 1/32 inch slot. The vernier scale is adjustable and may be adjusted to compensate for wear.

(b) *The Rule Depth Gage.* The rule depth gage is a graduated rule with a sliding head designed to bridge a hole or slot, and to hold the rule perpendicular to the surface on which the measurement is taken. This gage has a measuring range of 0 to 5 inches. The sliding head has a clamping screw so that it may be clamped in any position. The sliding head has a flat base which is perpendicular to the axis of the rule and ranges in size from 2 to 2 5/8 inches in width and from 1/8 to 1/4 inch in thickness.

(c) *Micrometer Depth Gage.* The micrometer depth gage consists of a flat base attached to the barrel (sleeve) of a micrometer head. These gages have a range of 0 to 9 inches, depending on the length of the extension rod used. The hollow micrometer screw (the threads on which the thimble rotates) has a range of either 1/2 or 1 inch. Some

PRECISION MEASURING AND GAGING - OD1642 - LESSON 1/TASK 2

are provided with a ratchet stop. The flat base ranges in size from 2 to 6 inches. Several extension rods are normally supplied with this type of gage.



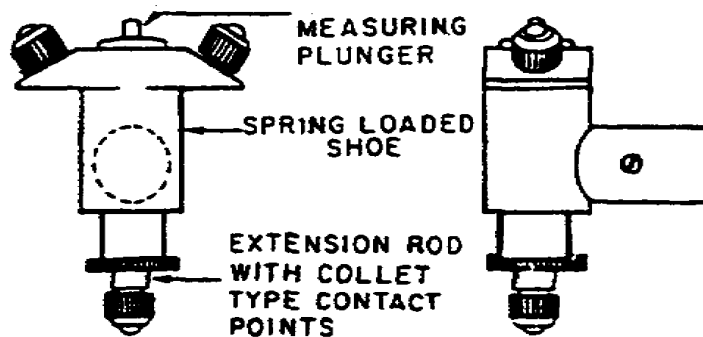
(5) *Dial Vernier Caliper.* A dial vernier caliper looks much like a standard vernier caliper and is also graduated in one thousandths (0.001) of an inch. The main difference is that instead of a double scale, as on the vernier caliper, the dial vernier caliper has the inches marked only along the main body of the caliper and a dial with two hands to indicate hundredths (0.010) and thousandths (0.001) of an inch. The range of the dial vernier caliper is usually 6 inches.

(6) *Dial Bore Gage.* One of the most accurate tools for measuring a cylindrical bore, or for

PRECISION MEASURING AND GAGING - OD1642 - LESSON 1/TASK 2

checking a bore for out-of-roundness or taper, is the dial bore gage. The dial bore gage (figure 6) does not give a direct measurement; it gives the amount of deviation from a preset size, or the amount of deviation from one part of the bore to another. A master ring gage, an outside micrometer, or a vernier caliper can be used to preset the gage. A dial bore gage has two stationary spring-loaded points and an adjustable point to permit a variation in range. These three points are evenly spaced to allow accurate centering of the tool in the bore. A fourth point, the tip of the dial indicator, is located between the two stationary points. By simply rocking the tool in the bore, the amount of variation on the dial can be observed. Accuracy to one ten thousandth (0.0001) of an inch is possible with some models of the dial bore gage.

FIGURE 6. DIAL BORE GAGE.

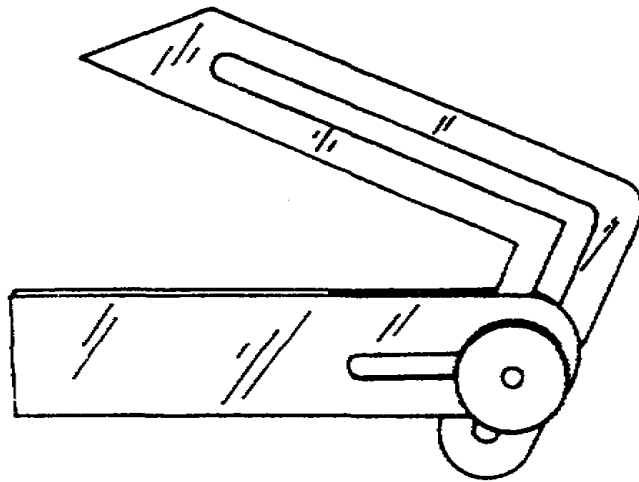


(7) *Internal Groove Gage.* The internal groove gage is very useful for measuring the depth of an O-ring groove or of other recesses inside a bore. This tool allows one to measure a deeper recess, or one that is located farther back into the bore, than would be possible with an inside caliper. As with the dial bore gage, this tool must be set with gage blocks, a vernier caliper, or an outside micrometer. The reading taken from the dial indicator on the groove gage represents the difference between the desired recess or the groove depth and the measured depth.

PRECISION MEASURING AND GAGING - OD1642 - LESSON 1/TASK 2

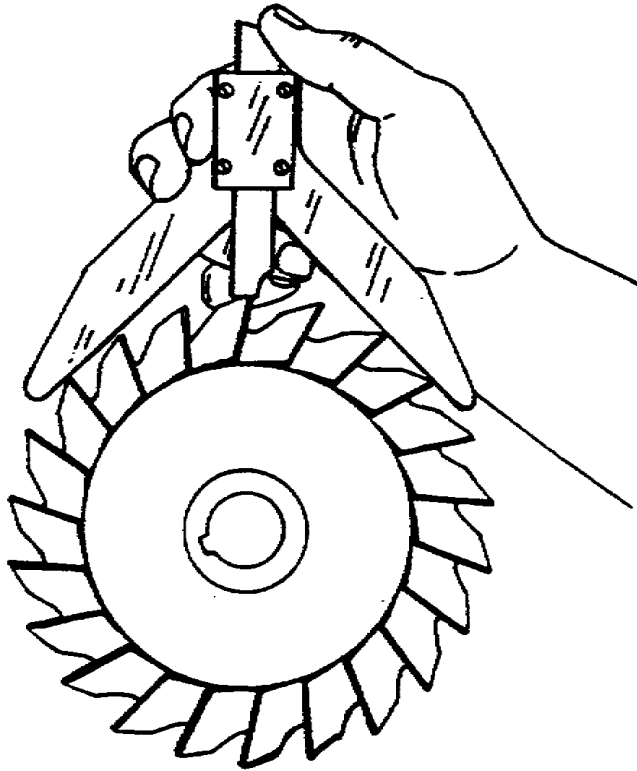
(8) *Universal Bevel.* The universal bevel (figure 7), because of the offset in the blade, is very useful for bevel gear work and for checking angles on lathe workpieces which cannot be reached with an ordinary bevel. The universal bevel must be set and checked with a protractor, or another suitable angle-measuring device, to obtain the desired angle.

FIGURE 7. UNIVERSAL BEVEL.



(9) *Cutter Clearance Gage.* The cutter clearance gage (figure 8 on the following page) is one of the simplest gages to use, yet it is suitable for gaging clearance on all styles of plain milling cutters which have more than 8 teeth and a diameter range from 1/2 inch to 8 inches. To gage a tooth with the instrument, bring the surfaces of the "V" into contact with the cutter and lower the gage blade upon the tooth to be gaged. Rotate the cutter sufficiently to bring the tooth face into contact with the gage blade. If the angle of clearance on the tooth is correct, it will correspond with the angle of the gage blade. Cutter clearance gages that have an adjustable gage blade for checking clearance angles of 0°-30° on most common cutter styles are also available.

FIGURE 8. CUTTER CLEARANCE GAGE.



(10) *Adjustable Parallel.* The adjustable parallel (figure 9 on the following page) consists of two wedges connected on their inclined surfaces by a sliding dovetail. The distance between the two outside parallel surfaces is varied by moving the mating parts together or apart. The distance is then measured with a micrometer. An adjustable parallel can be locked at any height between the maximum and the minimum limits. This instrument, constructed to about the same accuracy of dimensions as parallel blocks, is very useful in leveling and positioning setups in a milling machine or in a shaper vise. Adjustable parallels are available in various sizes depending on the nature of the work.

(11) *Surface Gage.* A surface gage (figure 10 on page 21) is used to measure or gage an object and to indicate the parallelism of surfaces. It is used primarily in layout and alignment of the work. The surface gage is commonly used with a surface plate and a scriber to transfer dimensions and layout lines to the work. In some cases, a dial

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indicator is used with the surface gage to check the trueness or alignment of an object or workpiece. The surface gage consists of a base with an adjustable spindle (1) to which may be clamped a scriber or an indicator (2). Surface gages are made in several sizes and are classified by the length of the spindle. The smallest spindle is 4 inches long, the average 9 to 12 inches, and the largest 18 inches. The scriber is fastened to the spindle with a clamp. The bottom and the front end of the base of the surface gage have deep V-grooves. The grooves allow the gage to measure from a cylindrical surface. The base has two gage pins (3). They are used against the edge of a surface plate or a slot to prevent movement or slippage.

FIGURE 9. ADJUSTABLE PARALLELS.

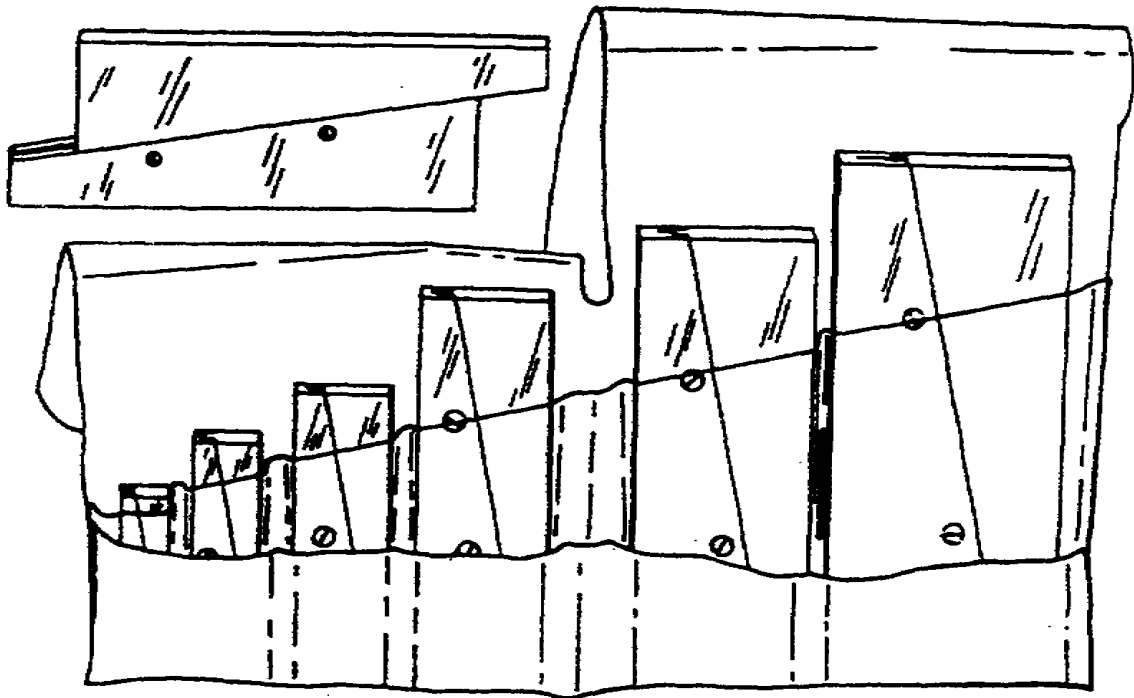
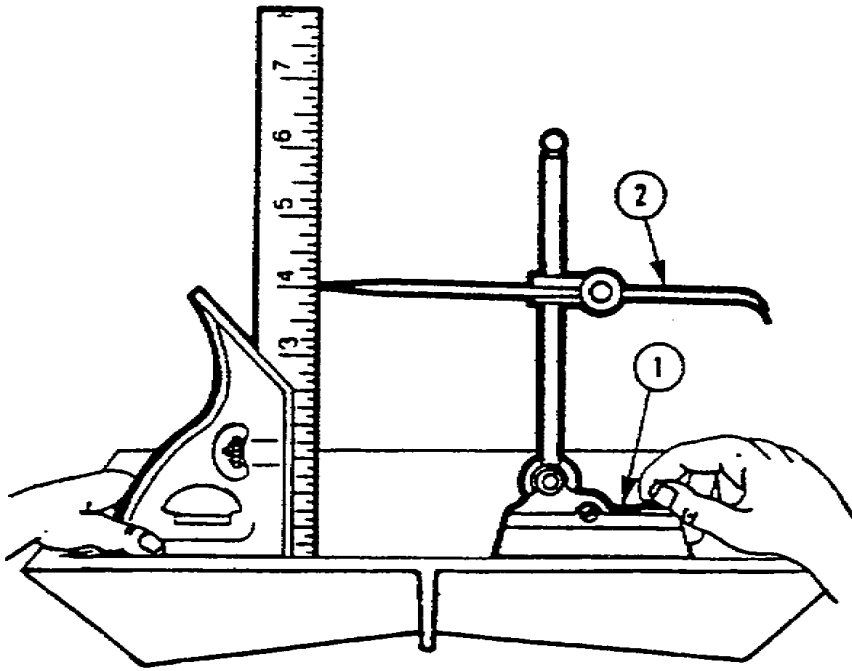


FIGURE 10. SURFACE GAGE/SURFACE PLATE.



(12) *Toolmaker's Buttons.* Toolmaker's buttons (figure 11 on the following page) are hardened and ground cylindrical pieces of steel, used to locate the centers of holes with extreme accuracy. As many buttons may be used as necessary on the same layout by spacing them the proper distance from each other with gage blocks.

(13) *Telescoping Gages.*

(a) *General.* Telescoping gages (figure 12 on the following page) are used to gage large holes and to measure inside distances. These gages are equipped with a plunger (1) that can be locked in the measuring position by a knurled screw or locking nut (2) in the end of the handle (3). Maximum measuring capacity is 6 inches. Measurements must be calipered on the gage by a micrometer, as in the case of the small hole gages. They are also used when measurements cannot be taken with a standard micrometer. Telescoping gages are particularly adaptable for roughly bored work and odd sizes and shapes of holes.

FIGURE 11. TOOLMAKER'S BUTTON AND ITS APPLICATION.

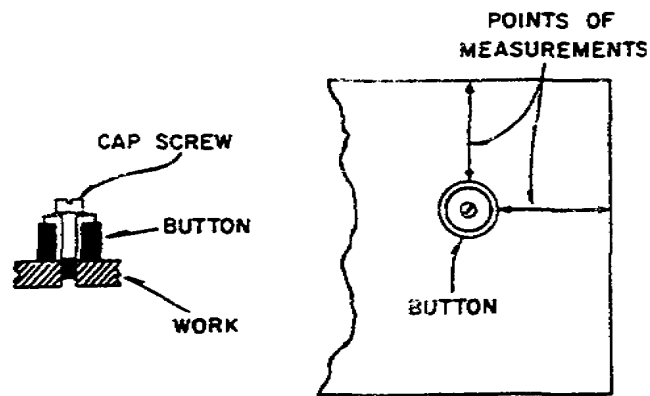
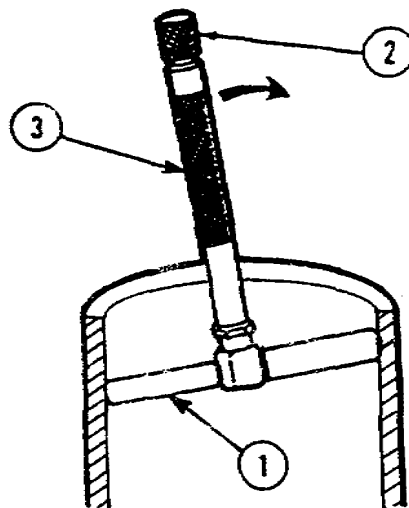


FIGURE 12. TELESCOPING GAGES.



(b) *Uses.* To use the telescoping gage loosen the knurled locking nut (2) at the end of the handle (3). Compress the plungers, place them into the hole to be measured, release the turning handle screw (2), slightly tilt the telescoping gage, and rock it back and forth slightly, while at the same

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time gradually tightening the turning handle screw (2). Remove the gage from the hole. Take measurements only once. Repeated attempts will produce an inaccurate reading. Measure the gage setting with an outside micrometer.

(14) *Small Hole Gages.*

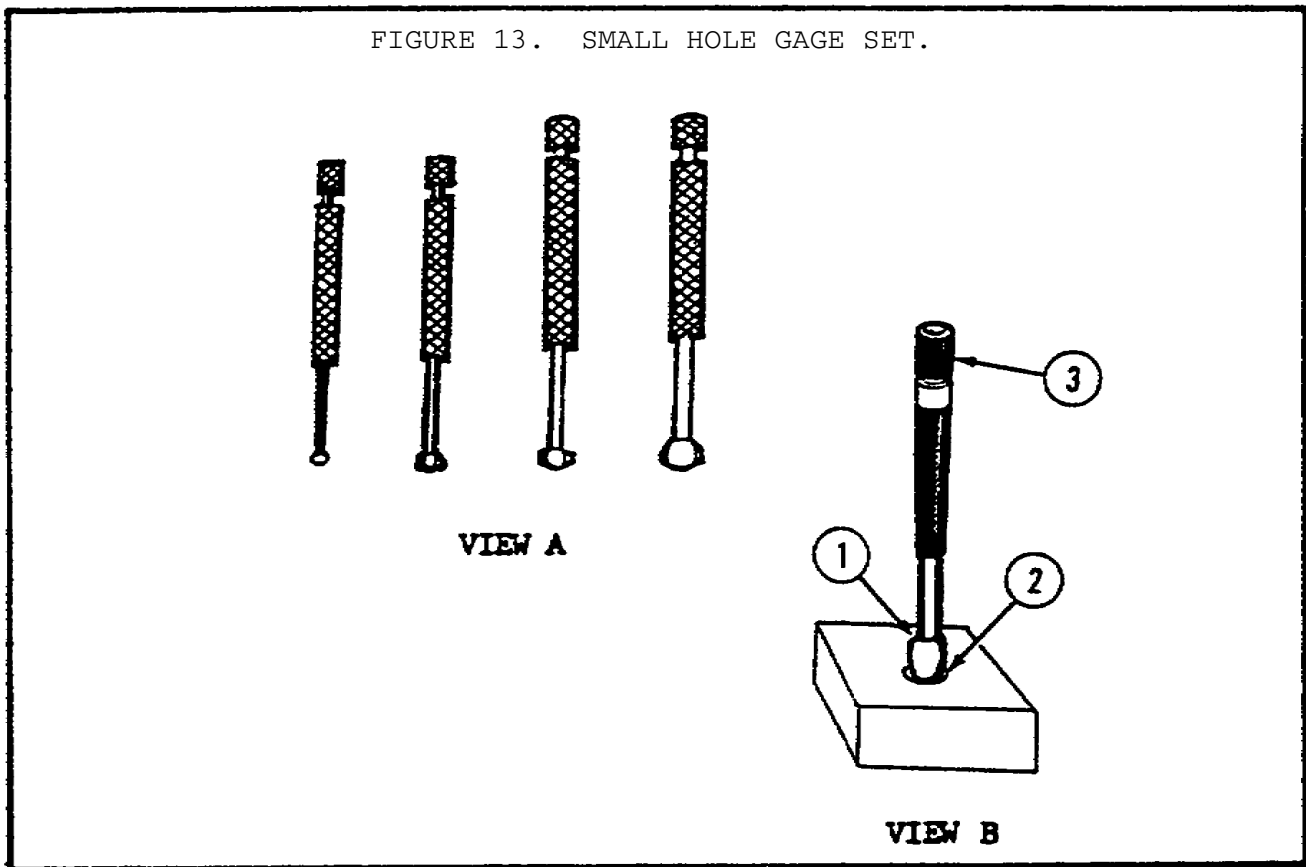
(a) *General.* Small hole gages (figure 13 on the following page) are similar to telescoping gages. They are smaller in size, adjustable, having a rounded measuring member. A knurled screw in the end of the handle is turned to expand the ball-shaped end in small holes and recesses. A micrometer is used to measure the ball end. Maximum measuring capacity is 1/2 inch. The set of four or more gages is used to check the dimensions of small holes, slots, grooves and so forth from approximately 1/8 to 1/2 inch in diameter.

(b) *Uses.* The small hole gages perform the same function as the telescoping gages, except that they are used to transfer measurements in smaller work. To use the small hole gages (figure 13, view B) fit the ball-shaped point (1) into the hole or slot (2). Expand the ball-shaped end by turning the screw (3) at the end of the handle. Use the same procedures in taking measurements of the hole as explained in (13)(b) above for the telescoping gages. After the measurements have been made, use an outside micrometer to gage the measurement.

(15) *Snap Gages.*

(a) *General.* The plain snap gage is made in two general types, the nonadjustable and the adjustable.

(b) *Nonadjustable Snap Gage.* The nonadjustable type (figure 14 on page 25) is of a solid construction, having two gaging members, GO (1) and NO GO (2) as shown in figure 14. The part to be inspected is first tried on the GO side and then the gage is reversed and the part is tried on the NO GO side. Some solid snap gages (3) have combined gaging members in the same set of jaws, known as a progressive snap gage. The outer member (4) gages the GO dimension and the inner member (5) the NO GO dimension.



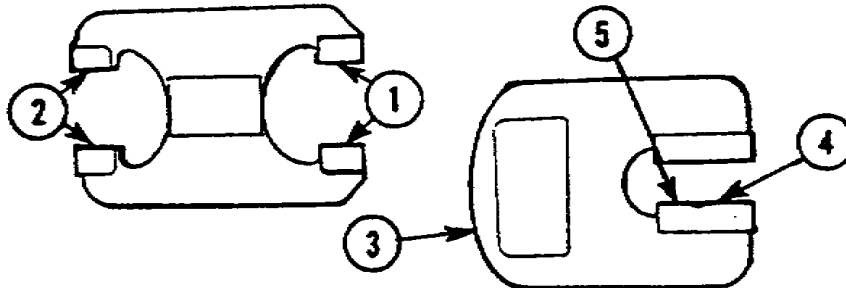
(c) *Adjustable Snap Gages.*

1 Three standard designs of the adjustable type of snap gage are available (figure 14, view B, on the following page), consisting of a light, rigid frame with adjustable gaging pins, buttons, or anvils. These pins or buttons may be securely locked in place after adjustment. The locking screws are tightened to hold the gaging dimensions.

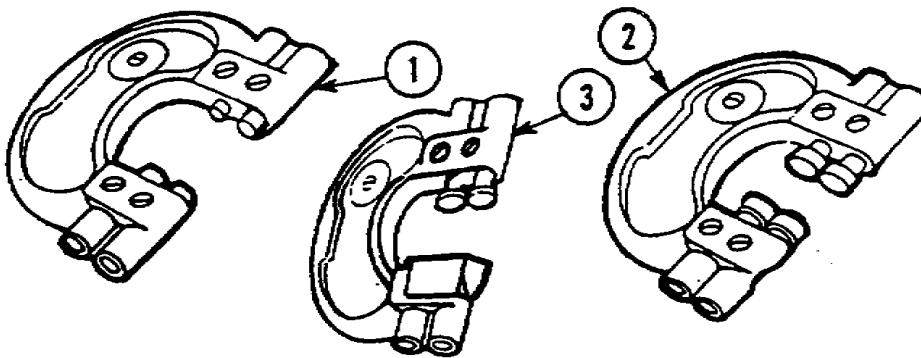
2 One type of adjustable snap gage is made in sizes that range from 1/2 to 12 inches (1). This gage is equipped with four gaging pins and is suitable for checking the dimensions between surfaces. Another type is made in sizes that range from 1/2 to 11 1/4 inches (2). This gage is equipped with four gaging buttons and is suitable for checking flat or cylindrical work.

3 The third type is made in sizes from 1/2 to 11 5/8 inches (3). This type is equipped with two gaging buttons and a single block anvil, and is especially suitable for checking the diameters of shafts, pins, studs, and hubs.

FIGURE 14. SNAP GAGES.



VIEW A. NON ADJUSTABLE SNAP GAGES

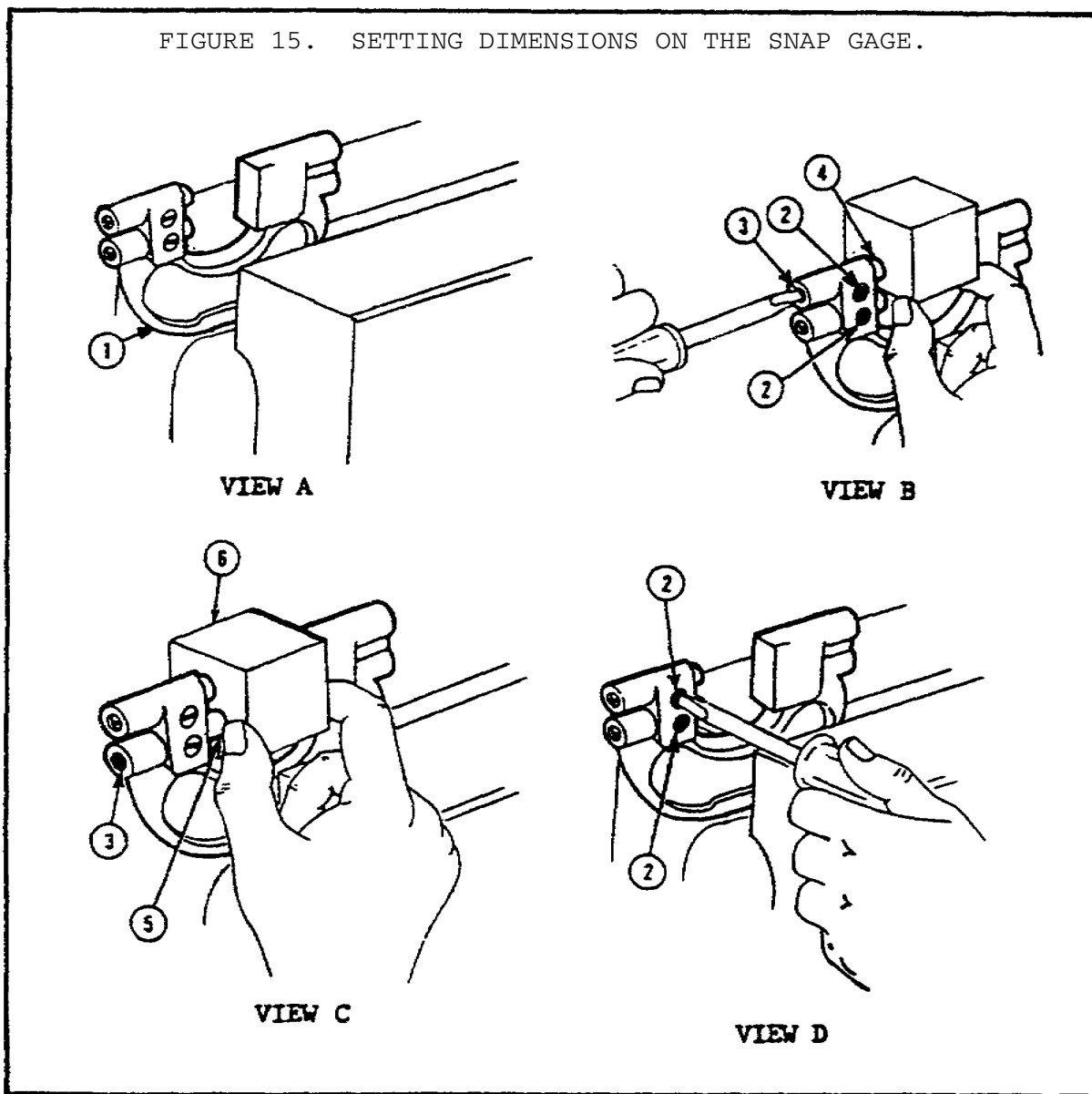


VIEW B. ADJUSTABLE SNAP GAGES

(d) *Using an Adjustable Snap Gage.* Before the snap gage is used to check parts, the GO and NO GO buttons, pins, or anvils must first be set to the proper dimensions (figure 15, views A through D, on the following page indicate the steps used for making the proper settings).

1 To make the proper settings, the snap gage should be clamped in a vise (soft jaws) or a holder (figure 15, view A). Adjust the GO dimension first or, if desired, reverse the procedure and adjust the NO GO dimension first.

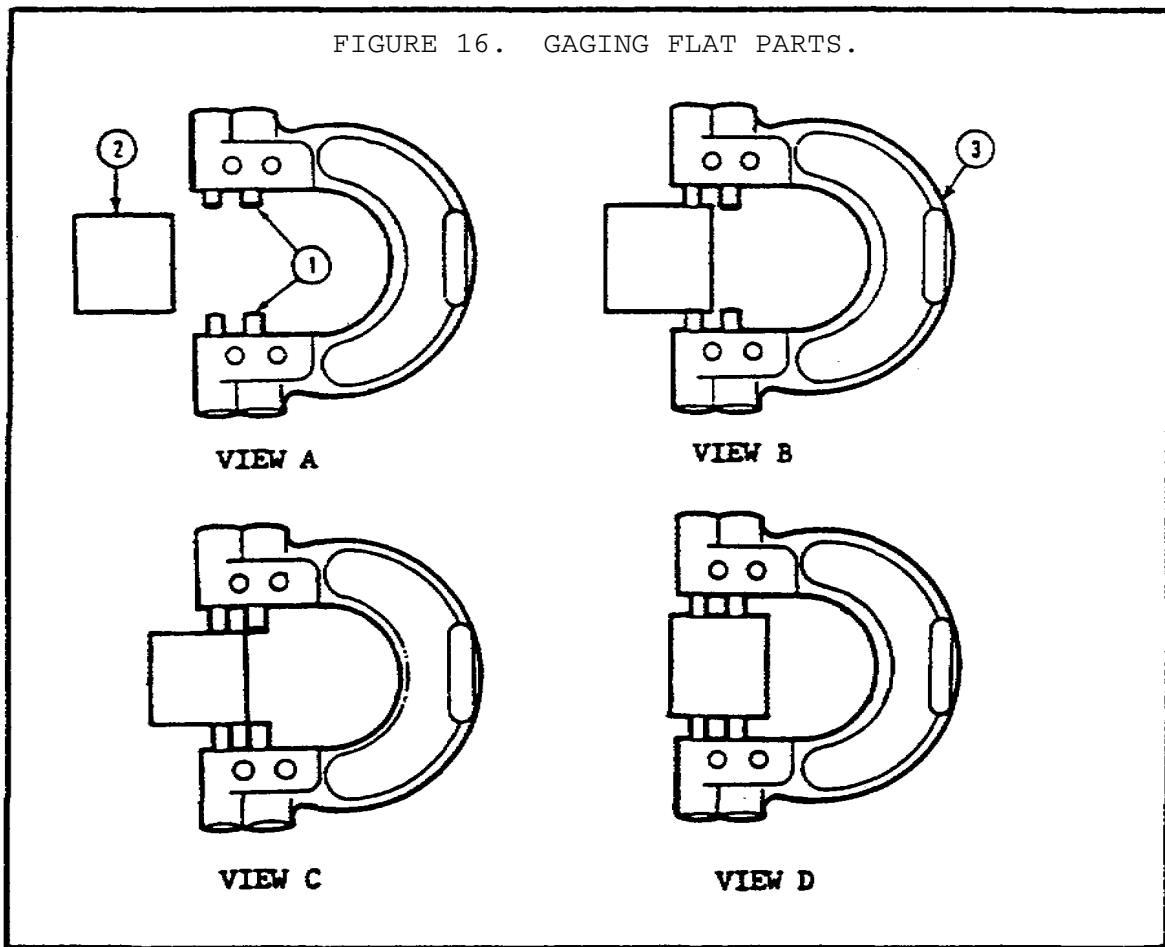
2 After determining the correct dimension, the gage should be set. Select a master disk, a precision gage block, or a master plug of the correct size. Loosen the locking screw (2) (figure 15, view B), and turn the adjusting screw (3) until the dimension (4) is set.



3 Take the gage block selected for the NO GO dimension and check it against the setting (5) (figure 15, view C). If the NO GO dimensions are incorrect, place the gage block in place and turn the other adjusting screw (3) until the NO GO dimension (5) is set.

4 After adjusting the gage for proper dimensions with the master precision piece (6) in place (view C), tighten the locking screws (2) (view D). Recheck to make sure that the dimensions have not changed before the gage is used to check the workpiece.

(e) *Gaging Flat Parts.* Gaging flat parts with the snap gage is illustrated in figure 16, views A through D. Inspection of machined components or parts is vital when they are being matched or assembled with other parts to form a completed unit. Therefore, the inspector must be proficient in the use of gages to be able to accept or reject parts being tested by the GO or NO GO standards.



1 To gage flat parts, position the gage so that the pins or buttons (1) (view A) are square with the flat surfaces on the part (2).

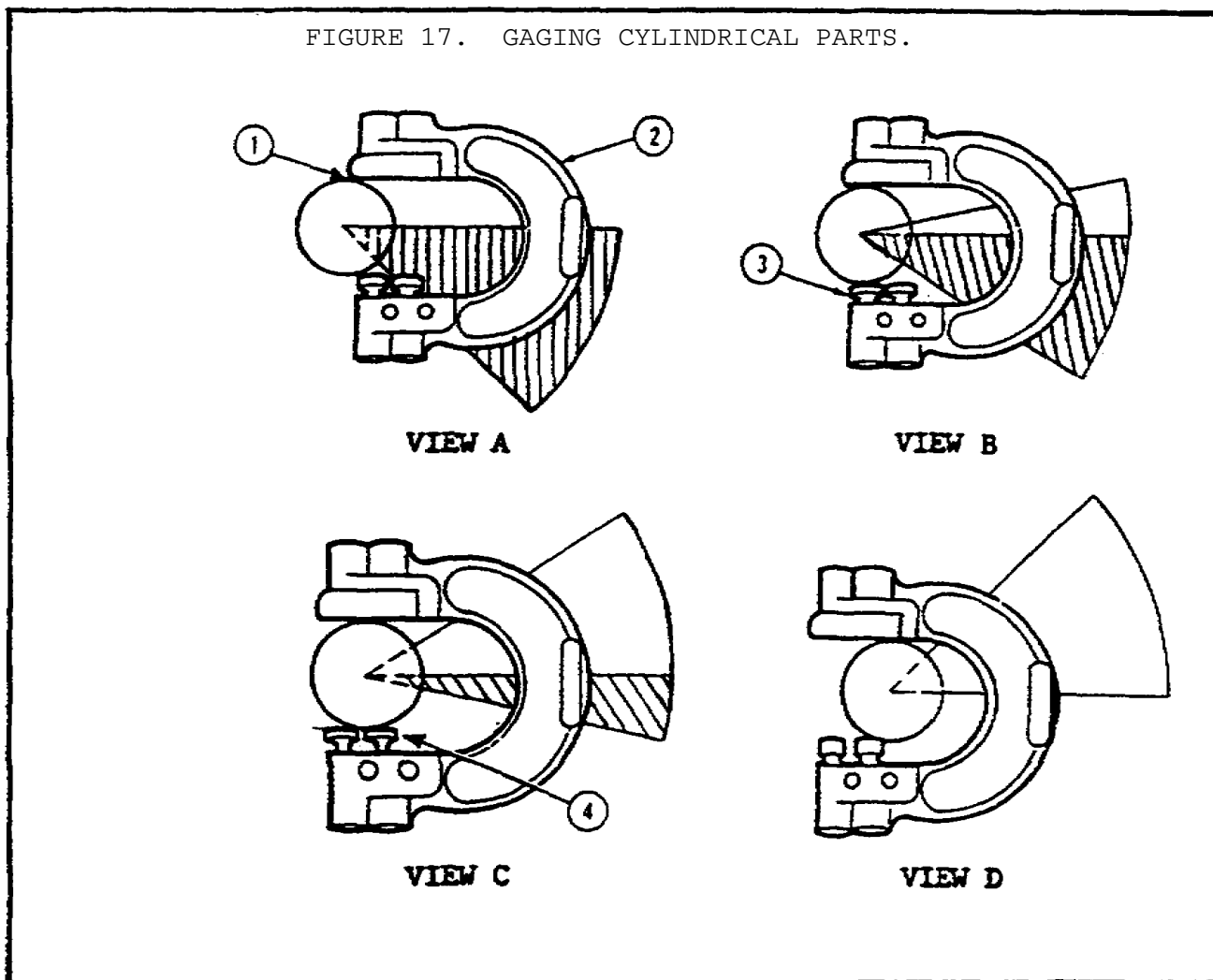
2 Take the work to be measured and place it at the front of the first pin or button. Using a slight hand pressure, push the gage (3) (view B) over the part.

3 If the part is within limits, the NO GO pins will stop the part (view C). However, if the

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part is undersize, it will be possible to push the part past the NO GO pins (view D).

(f) *Gaging Cylindrical Parts.* Figure 17, views A through D, will be used in illustrating gaging cylindrical parts.



1 To gage cylindrical parts, locate the gage on the part with the solid anvil (1) on top (view A). Rock the gage (2) as indicated by the shaded segment in figure 17, view A, where the GO dimension is checked.

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2 If the shaft is not oversize, the first button (3) (view B) on the gage will pass over it easily.

3 Move the gage to the position shown in view C. If the NO GO button (4) stops the gage, the shaft is within limits. However, if the gage can be rocked further, as shown in view D, then the part diameter is too small, since it has passed over the NO GO button. This is known as a reject.

c. *Fixed Gages.* Fixed gages cannot be adjusted. They can generally be divided into two categories, graduated and nongraduated. The accuracy of a machinist's work, when using fixed gages, will depend on the ability to determine the difference between the work and the gage. For example, a skilled machinist can take a dimension accurately to within 0.005 of an inch or less when using a common rule. Practical experience in the use of these gages will increase ones ability to take accurate measurements.

(1) *Rules.*

(a) *Steel Rule.* The steel rule with the holder set (figure 18, view A, on the following page) is convenient for measuring recesses. It has a long tubular handle with a split chuck for holding the ruled blade. The chuck can be adjusted by a knurled nut at the top of the holder, allowing the rule to be set at various angles. The set has rules ranging from 1/4 to 1 inch in length.

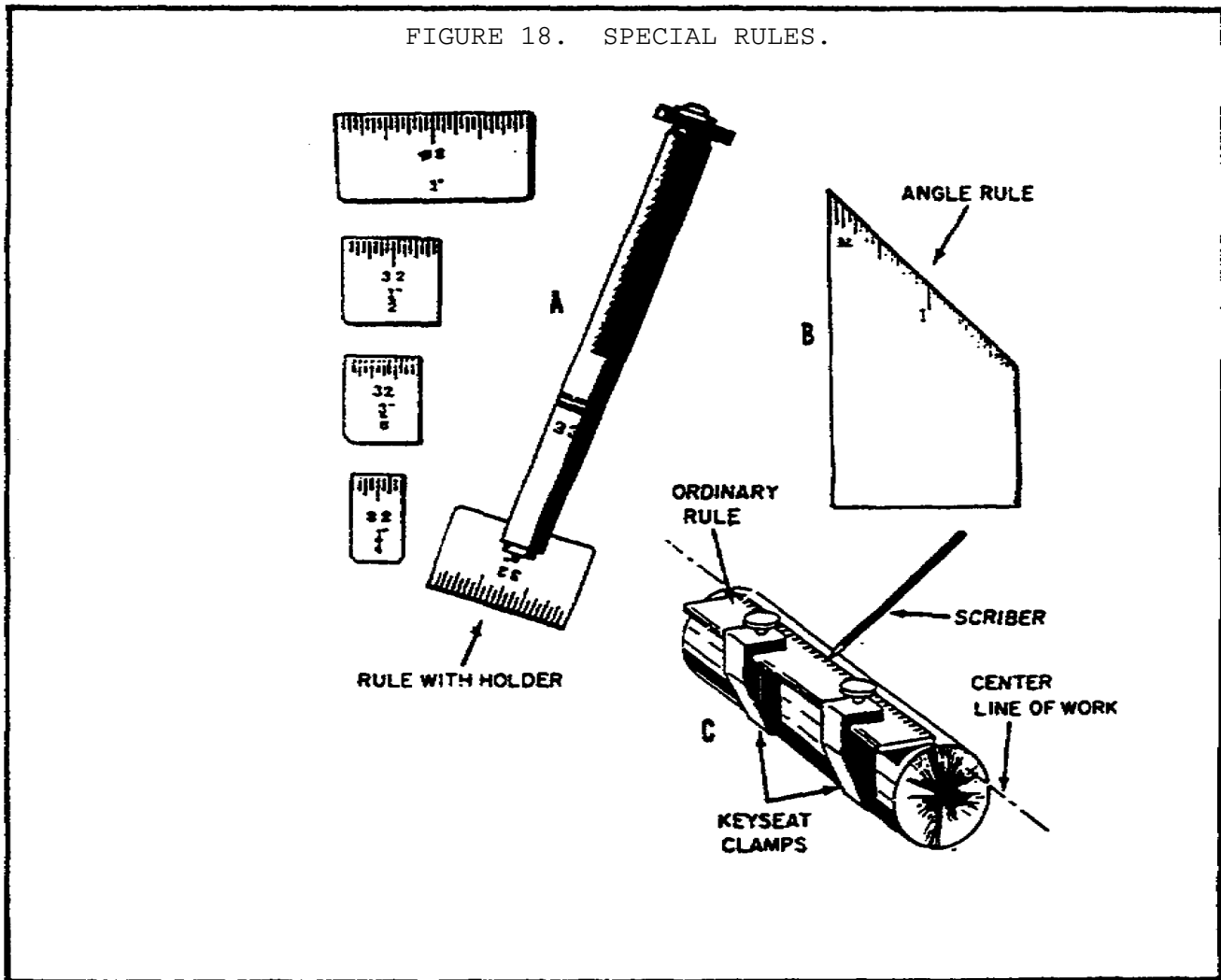
(b) *The Angle Rule.* The angle rule (figure 18, view B) is useful in measuring small work mounted between centers on a lathe. The long side of the rule (ungraduated) is placed even with one shoulder of the work. The graduated angle side of the rule can then be positioned easily over the work.

(c) *The Keyseat Rule.* Another useful measuring device is the keyseat rule (figure 18, view C). It has a straightedge and a 6 inch machinist's type rule arranged to form a right angle square. This rule and straightedge combination, when applied to the surface of a cylindrical workpiece, makes an excellent guide for drawing or scribing layout lines parallel to the axis of the work. This

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measuring device is very convenient when making keyseat layouts on shafts.

(d) *Care.* Rules, like any other measuring tool, must be taken care of if accurate measurements are to be obtained. Do not allow them to become battered, covered with rust, or otherwise damaged in such a way that the markings cannot be read easily. Do not use them for scrapers; once rules lose their sharp edges and square corners, their general usefulness is decreased.

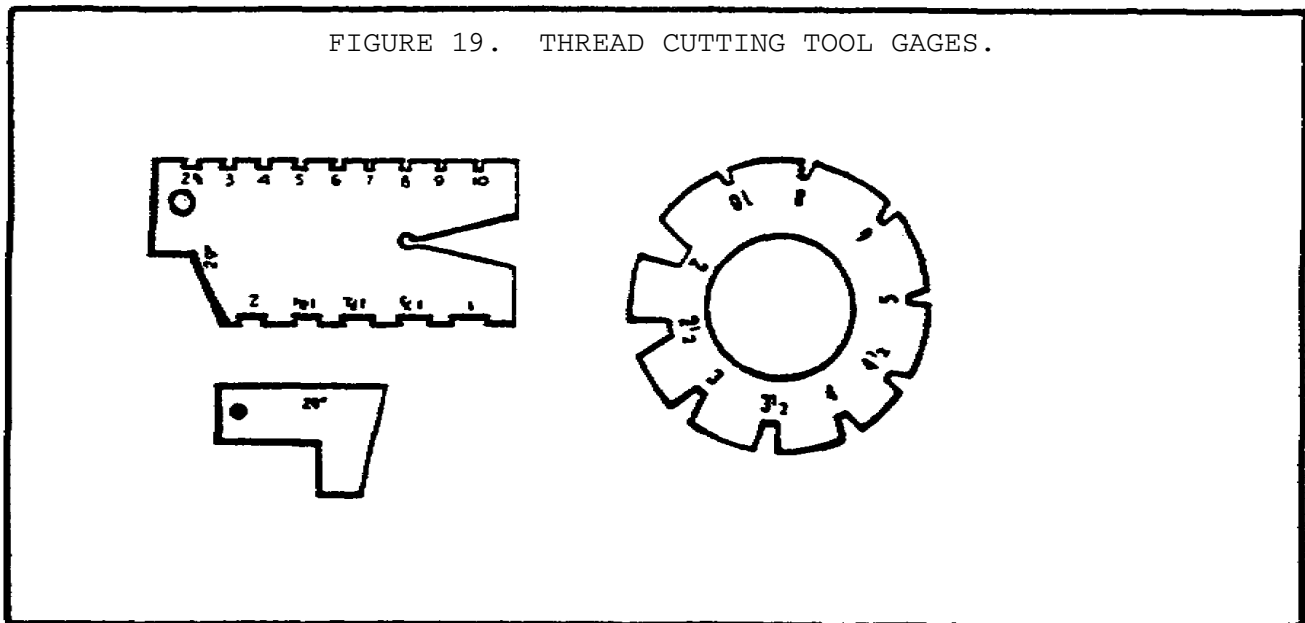


(2) *Scales.* A scale is similar in appearance to a rule, since its surface is graduated into regular spaces. The graduations on a scale, however, differ from those on a rule because they are either smaller or larger than the measurements indicated. For example, a half-size scale is graduated so that 1 inch on the scale is equivalent to an actual measurement of 2 inches. A 12 inch long scale of

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this type is equivalent to 24 inches. A scale, therefore, gives proportional measurements instead of the actual measurements obtained with a rule. Like rules, scales are made of wood, plastic, and metal. They generally range from 6 to 24 inches.

(3) *Acme Thread Tool Gage*. The Acme thread cutting gages (figure 19) are hardened steel plates with cutouts around the perimeter. Each cutout is marked with a number that represents the number of threads per inch. These gages provide a standard for thread cutting tools that are being ground. The tool is also used to align the Acme thread cutting tool prior to machining them on a lathe. The sides of the Acme thread have an included angle of 29° ($14\frac{1}{2}^{\circ}$ on each side) and that is the angle made into the gage. The width of the flat on the point of the tool varies according to the number of threads per inch. The gage provides different slots to use as a guide when grinding the tool. Setting the tool up in the lathe is simple. First, ensure that the tool is centered to the work as far as the height is concerned. Then, with a gage edge laid parallel to the centerline of the work, adjust the side of the tool until it fits the angle on the gage very closely.

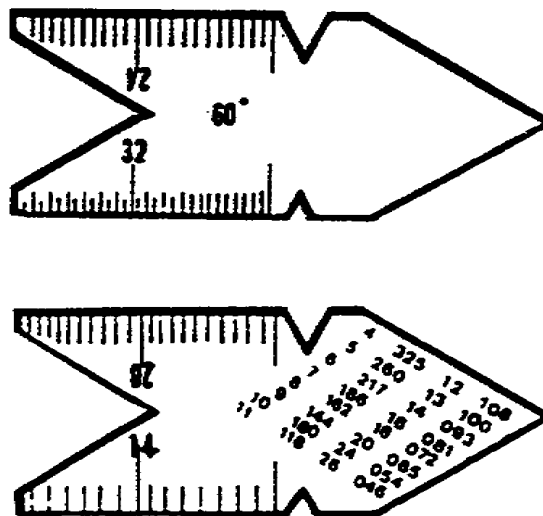


(4) *Center Gage*. The center gage (figure 20 on the following page) is used like the Acme thread gage. Each notch and the point of the gage has an included angle of 60° . The sixty-degree angles of

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the gage are used for checking Unified and American threads, as well as older American National or U.S. Standard threads, and for checking thread cutting tools. The center gage is also used to check the angle of lathe centers. The edges are graduated into $1/4$, $1/24$, $1/32$, and $1/64$ of an inch for ease in determining the pitch of threads on screws. The back of the center gage has a table giving the double depth of the threads in thousandths of inch for each pitch. This information is also useful in determining the size of tap drills.

FIGURE 20. CENTER GAGE.



(5) Thickness (Feeler) Gages.

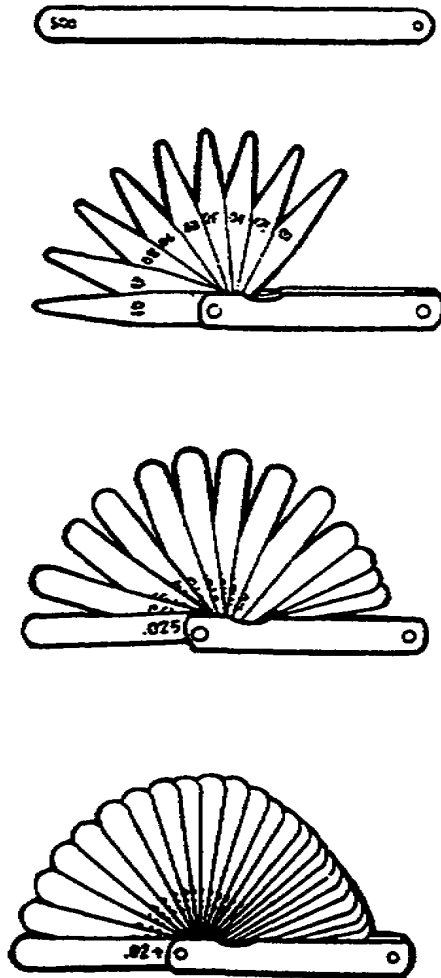
(a) Thickness (feeler) gages (figure 21 on the following page) are used to determine distances between two mating parts. The gages are made in various shapes and sizes; usually 2 to 26 blades are grouped into one tool and graduated in thousandths of an inch.

(b) Most thickness blades are straight, while others are bent at the end at 45 degree and 90 degree angles. Some thickness gages are grouped so that there are several short and several long blades together. Thickness gages are also available in single blades and in strip form for specific measurements.

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(c) Some gages are fixed in leaf form, like a jackknife. This type allows the checking and measuring of small openings such as contact points, narrow slots, and so forth. They are widely used to check the flatness of parts, in straightening and grinding operations, and in squaring objects with a try square.

FIGURE 21. THICKNESS (FEELER) GAGES.



(d) The leaf-type gage can be used with a combination of blades to obtain a desired gage thickness. Always place the thinner blades between the heavier ones to protect the thinner ones and to prevent them from kinking. Do not force the blades into openings which are too small as the blades may

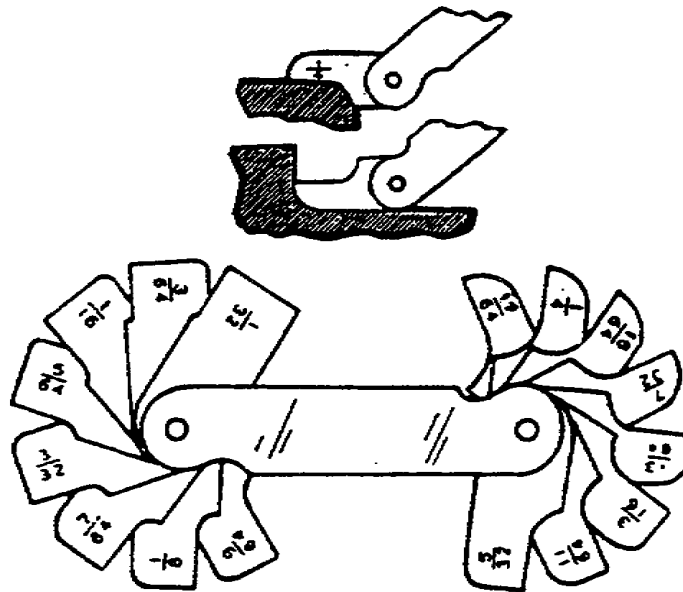
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bend or kink. A good way to get the "feel" of using a thickness gage correctly is to practice with the gage on openings of known measurements.

(6) Radius Gage.

(a) The radius gage (figure 22) is used to check, in any position and at any angle, both inside and outside radii. This gage is often underrated in its usefulness to the machinist. The blades of the fillet and radius gages are made of hard-rolled steel. The double-ended blades of the gage have a lock which holds the blade in position. The inside and outside radii are on one blade on the gage. Each blade of the gage is marked in 64ths. Each gage has 16 blades.

FIGURE 22. FILLET AND RADIUS GAGES.



(b) Whenever possible, the design of most parts includes a radius located at the shoulder formed when a change is made in the diameter. This radius gives the part an added margin of strength at that particular place. When a square shoulder is machined in a place where a radius should have been, the possibility that the part will fail by bending or cracking is increased. The blades of most radius gages have both concave (inside curve)

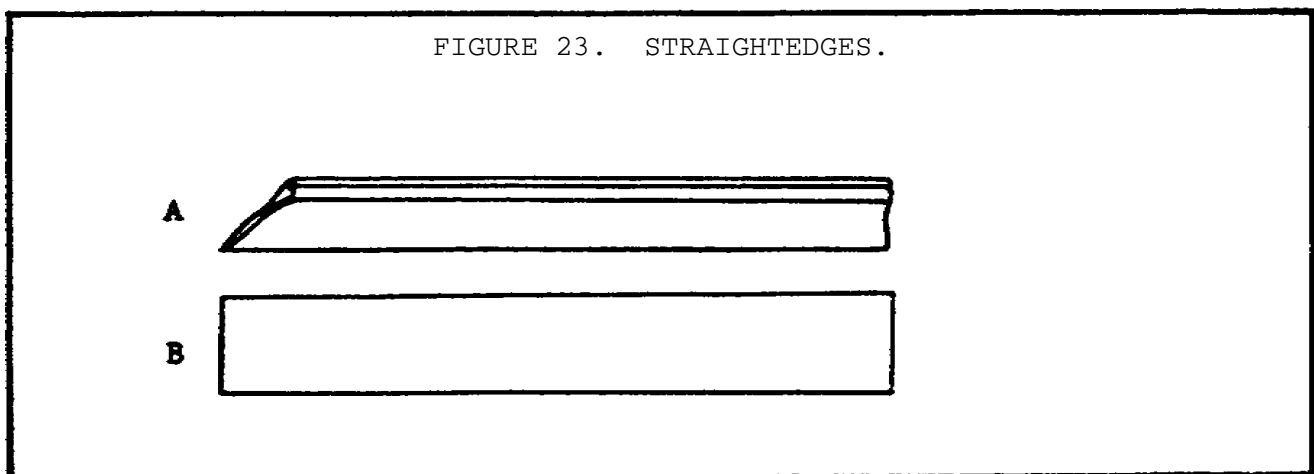
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and convex (outside curve) radii in almost all of the common sizes.

(7) *Straightedges.*

(a) *General.* Straightedges look very much like rules, except that they are not graduated. They are used primarily for checking surfaces for straightness; however, they can also be used as guides for drawing or scribing straight lines. Two types of straightedges are shown in figure 23. View A shows a straightedge made of steel which is hardened on the edges to prevent wear; it is the one the machinist will probably use the most. The straightedge shown in View B has a knife edge and is used for work requiring extreme accuracy.

(b) *Care.* The straightedges should always be kept in a box when they are not in use. Some straightedges are marked with two arrows, one near each end, which indicate the balance points. When a box is not provided, place the resting pads on a flat surface in a storage area where no damage to the straightedge will occur from other tools. Place the straightedge so that the two balance points set on the resting pads.

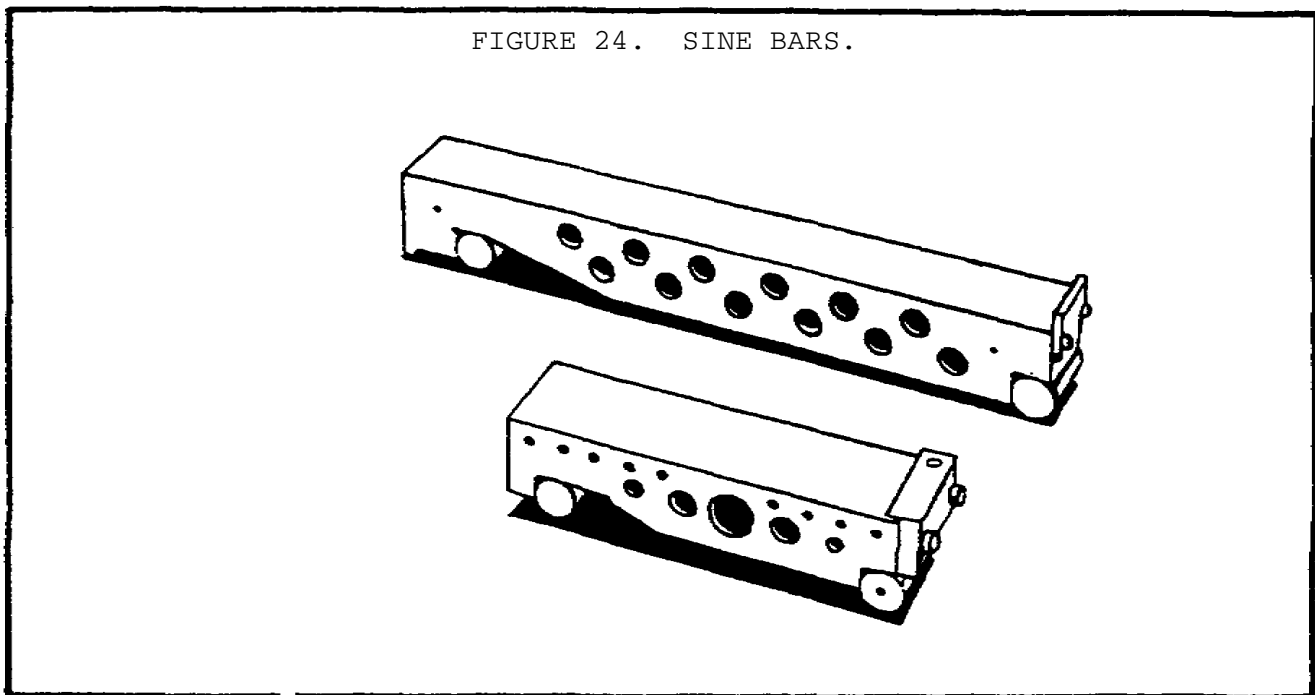


(8) *Machinist's Square.* The most common type of machinist's square is a hardened steel blade securely attached to a beam. The steel blade is not graduated. This instrument is very useful in checking right angles and in setting up work on shapers, milling machines, and drilling machines. The size of the machinist's squares range from 1 1/2 to 36 inches in blade length. The same care should be taken with them as with micrometers.

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(9) *Sine Bar.*

(a) *General.* A sine bar (figure 24) is a precision tool used to establish angles which require extremely close accuracy. When used in conjunction with a surface plate and gage blocks, angles are accurate to within 1 minute ($1/60^\circ$). The sine bar may be used to measure angles on a workpiece and to lay out an angle on the workpiece that is to be machined. Work may be mounted directly to the sine bar for machining. The cylindrical rolls and the parallel bar, which make up the sine bar, are all precision ground and accurately positioned to permit such close measurements. Any scratches, nicks, or other damage should be repaired before the sine bar is used, and care must be exercised in using and storing the sine bar.



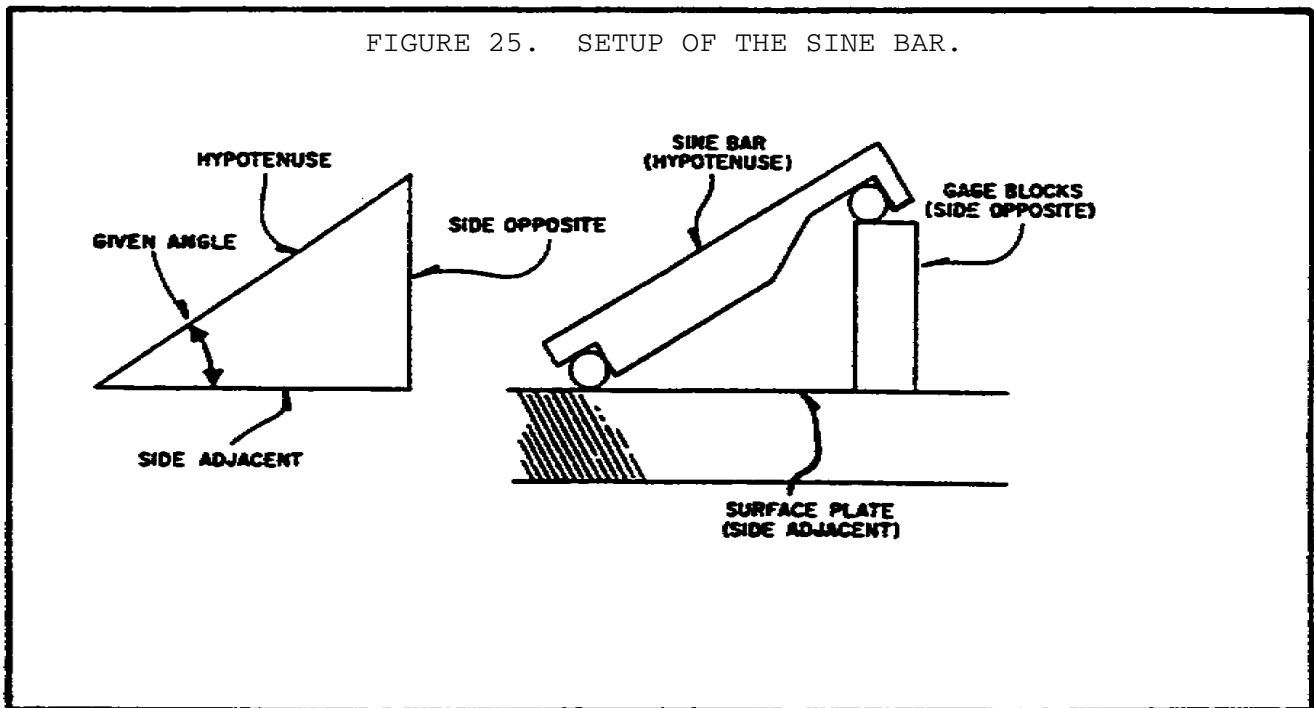
(b) *Use.*

1 A sine bar is a precisely machined tool steel bar used in conjunction with two steel cylinders. In the type shown in figure 25 on the following page, the cylinders establish a precise distance of either 5 inches or 10 inches from the center of one to the center of the other, depending upon the model used. The bar itself has accurately machined parallel sides. The axes of the two

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cylinders are parallel to the adjacent sides of the bar within a close tolerance. Equally close tolerances control the cylinder roundness and freedom from taper. The slots or holes in the bar are for convenience in clamping workpieces to the bar. Although the illustrated bars are typical, there is a wide variety of specialized shapes, widths, and thicknesses.

2 The sine bar itself is very easy to set up and use. One does not need to have a basic knowledge of trigonometry to understand how it works. When a sine bar is set up, it always forms a triangle. A right triangle has one 90° angle. The base of the triangle formed by the sine bar is the surface plate (figure 25). The side opposite is made up of the gage blocks that raise one end of the sine bar. The hypotenuse is always formed by the sine bar. The height of the gage block setting may be found in two ways. The first method is to multiply the sine of the angle needed by the length of the sine bar. The sine of the angle may be found in any table of trigonometric functions. The second method is to use a table of sine bar constants. These tables give the height setting for any given angle (to the nearest minute) for a 5 inch sine bar. Tables are not normally available for 10 inch bars because it is just as easy to use the sine of the angle and move the decimal point to the right.

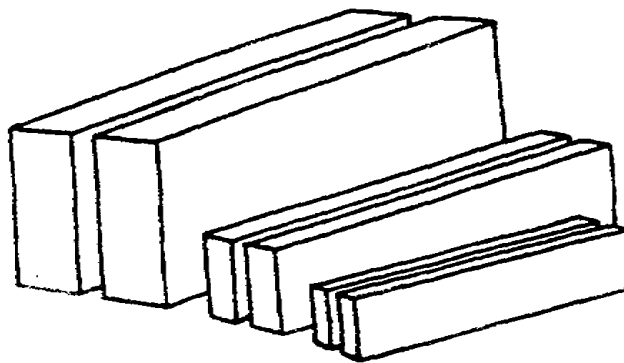


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(c) *Care.* Although sine bars have the appearance of being rugged, they should receive the same care as gage blocks. Because of the nature of their use in relation with other tools or parts that are heavy, they are subject to rough usage. Scratches, nicks, and burrs should be removed or repaired. They should be kept clean of abrasive dirt, sweat, and other corrosive agents. Regular inspection of the sine bar will locate such defects before they are able to affect the accuracy. When sine bars are stored for extended periods, all bare metal surfaces should be cleaned and then covered with a light film of oil. Placing a cover over the sine bar will further prevent accidental damage and discourage corrosion.

(10) *Parallel (Bars) Blocks.* Parallel blocks (figure 26 on the following page) are hardened, ground steel bars that are used in laying out work or setting up work for machining. The surfaces of the parallel blocks are all either parallel or perpendicular, as appropriate, and can be used to position work in a variety of setups with accuracy. They generally come in matched pairs and standard fractional dimensions. Care should be used in storing and handling them to prevent damage. If it becomes necessary to regrind the parallel blocks, be sure to change the size that is stamped on the ends of the blocks.

FIGURE 26. PARALLEL BLOCKS.



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(11) *Ring and Plug Gages.*

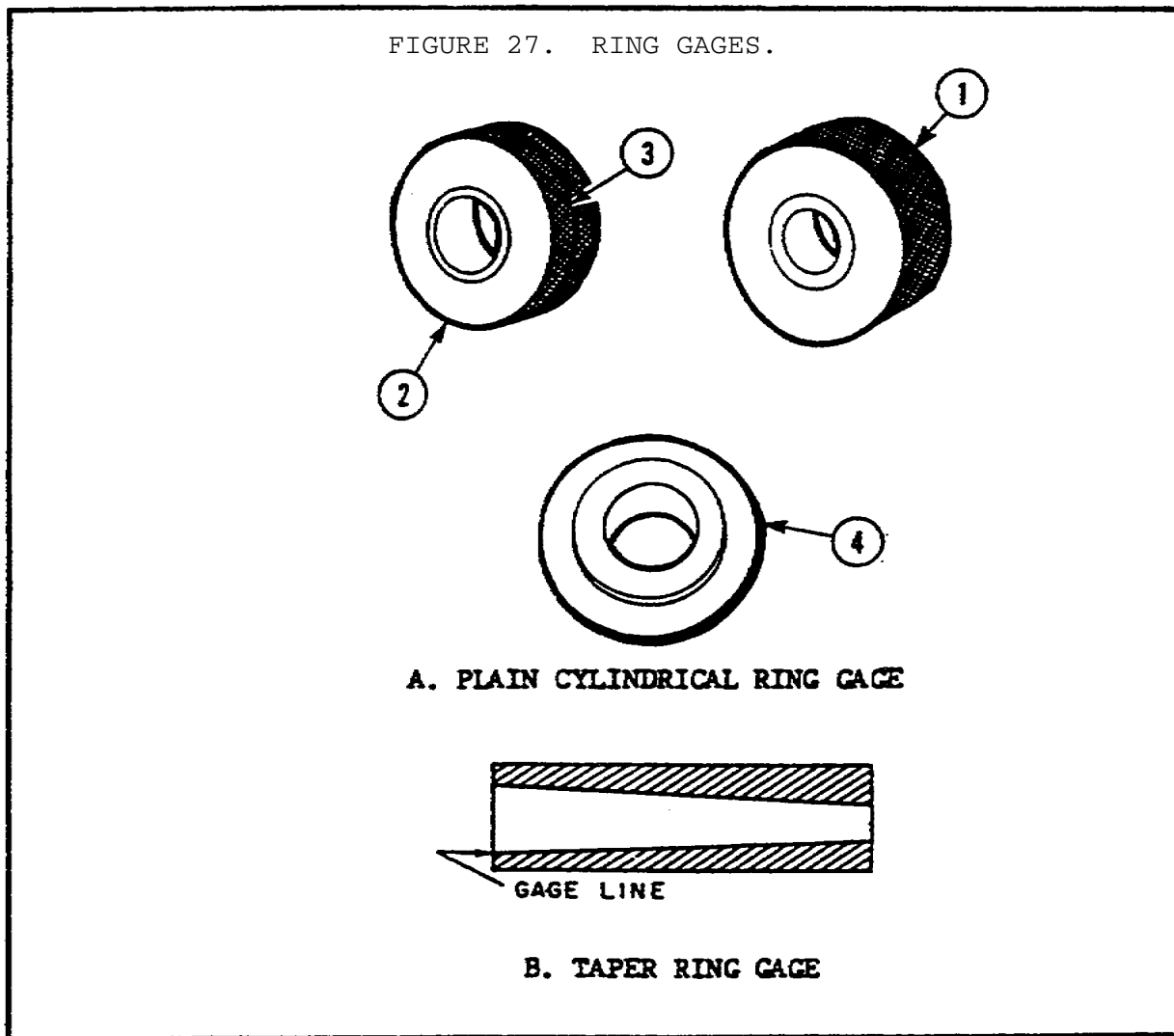
(a) *General.* Ring, plug, snap, and precision gage blocks are used as standards to determine whether or not one or more dimension is within specified limits. Their measurements are included in the construction of each gage, and they are called fixed gages. However, some snap gages are adjustable. Gages are used for a wide range of work, from rough machining to the finest tool and die making. The accuracy required of the same type of gage will be different, depending on their use.

(b) *Ring Gages.*

1 A ring gage (figure 27 on the following page) is a cylindrical-shaped disk that has a precisely ground bore. Ring gages are used to check machined diameters by sliding the gage over the surface. Straight, tapered, and threaded diameters can be checked by using the appropriate gage. The ring gage is also used to set other measuring instruments to the basic dimension that is required for their particular operation. Normally, ring gages are available with a GO and a NO GO size that represents the tolerance allowed for that particular size or job.

2 The plain gage is an external gage of the circular form. For sizes between 0.059 and 0.510 inch, ring gages are made with a hardened steel bushing and pressed into a soft metal body. The thickness of the gage will range from 3/16 to 1 5/16 inches. On ring gages, the GO gage (1) is larger than the NO GO gage (2). The GO and the NO GO ring gages are separate units. They can be distinguished from each other by an annular groove (3) cut in the knurled outer surface of the NO GO gage. Ring gages made for diameters of 0.510 to 1.510 inches are the same as those in figure 27, except that there is no bushing; they are made all in one piece. Ring gages, sized from 1.510 to 5.510 inches are made with a flange (4). This design reduces the weight, making the larger sizes easier to handle.

3 Ring gages are used more often in the inspection of finished parts than of parts in process. The reason for this is that the finished parts are usually readily accessible; whereas parts in a machine that are supported at both ends would have to be removed to be checked.

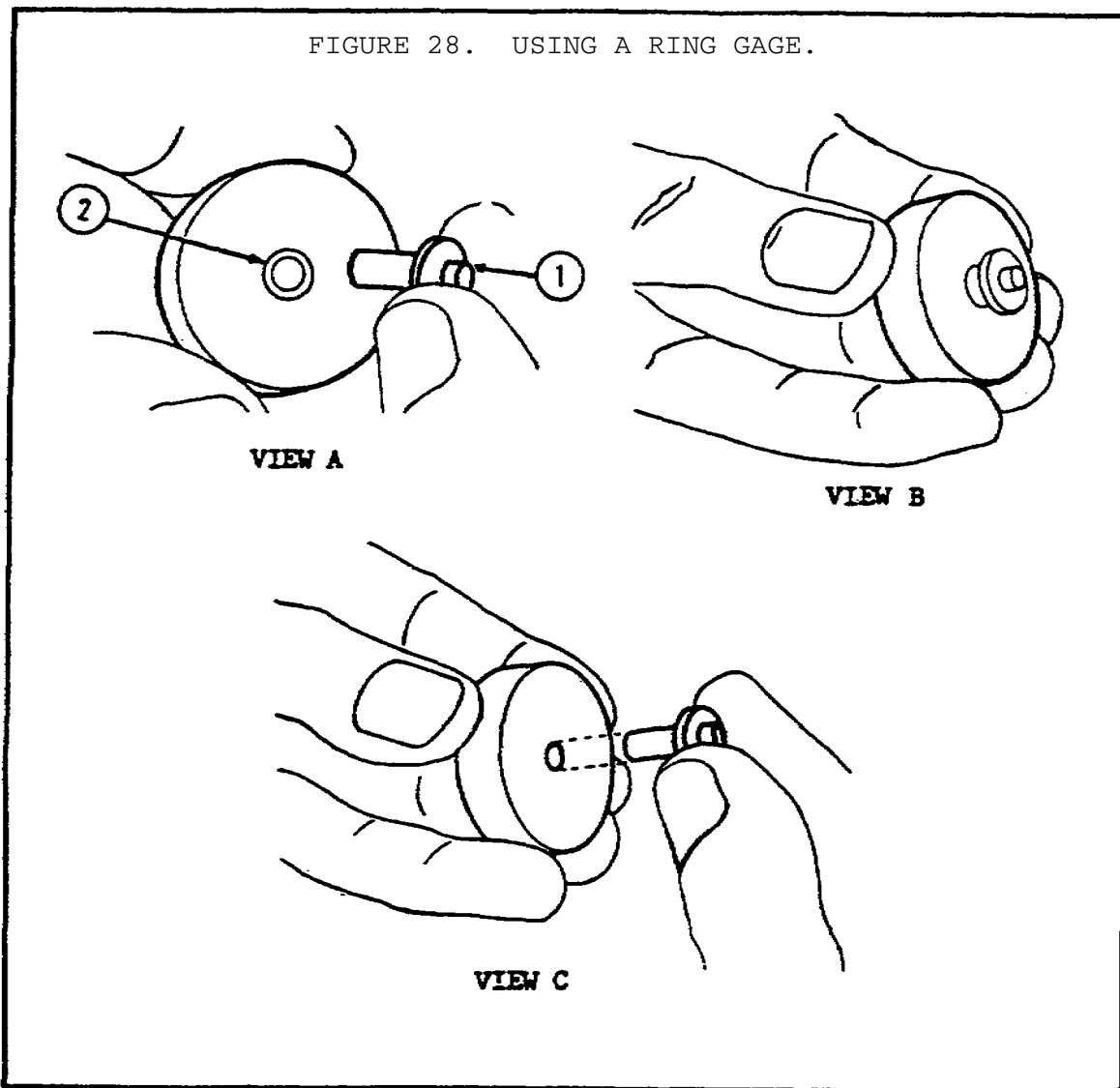


4 The use of the ring gage (figure 28 on the following page) is an important function when checking the accuracy of parts. Proper use of the ring gage requires a sensitive sense of feel by the individual inspecting the finished parts.

5 To check the shank diameter of a pivot stud (figure 28) line the stud (view A) (1) up with the hole (2) and press it in gently. If the stud will not go in, the shank is too large. With the stud in the hole (view B), check the piece for taper and out-of-roundness by sensing any wobble.

6 After checking the part in the GO gage, check it in the NO GO gage. The stud must not enter this gage to establish it as being between the desired limits.

FIGURE 28. USING A RING GAGE.



NOTE

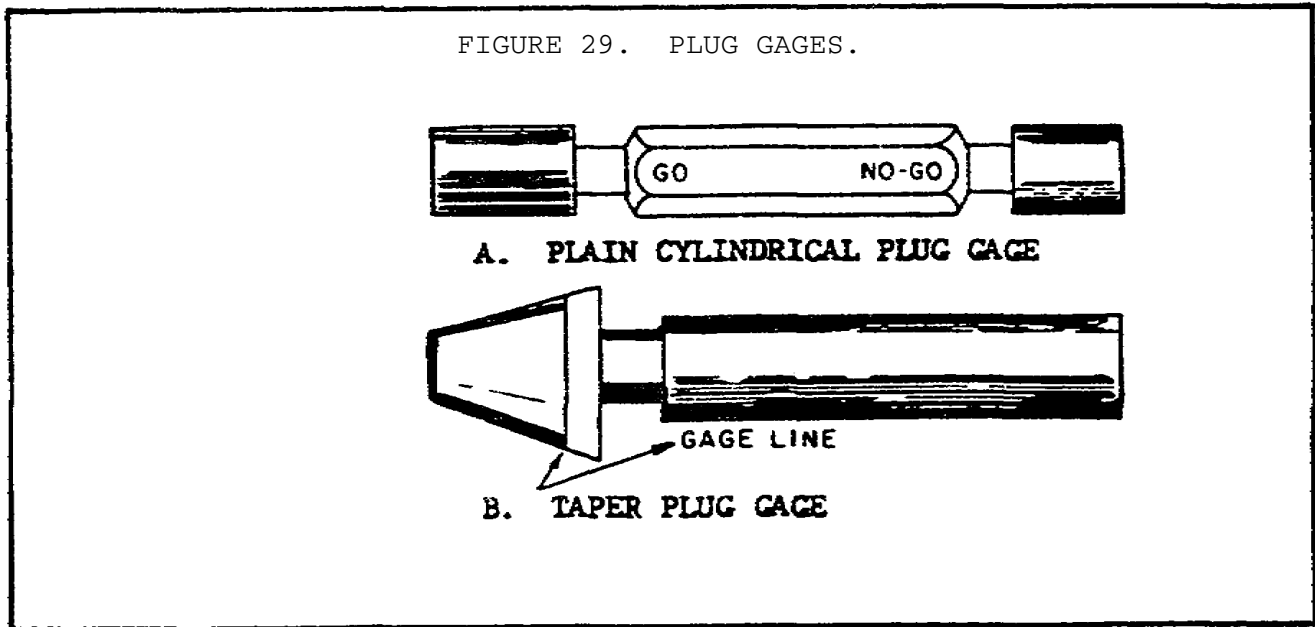
The GO ring gage controls the maximum dimension of a part and the NO GO plug gages control the minimum dimension of a hole. Therefore, GO gages control the tightness of the fit of the mating parts and the NO GO gages control the looseness of the fit of the mating parts.

(c) *Plug Gages.* A plug gage (figure 29 on the following page) is used for the same type of jobs as a ring gage except that it is a solid

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shaft-shaped bar that has a precisely ground diameter for checking inside diameters or bores.

(12) *Micrometer Standards.* Micrometer standards are either disk or tubular shaped gages that are used to check outside micrometers for accuracy. Standards are made in sizes so that any size micrometer can be checked. They should be used on a micrometer on a regular basis to ensure continued accuracy.



(13) *Gage Blocks.*

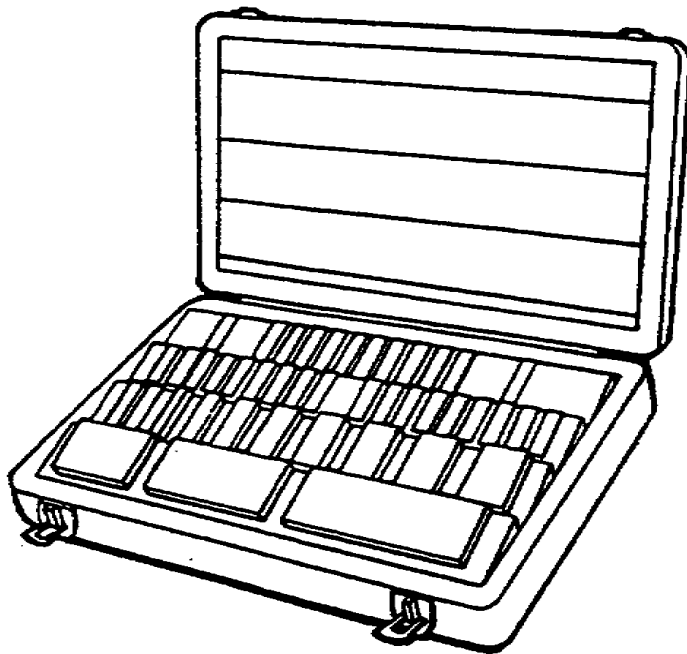
(a) Gage blocks (figure 30 on the following page) are available in sets from 5 to 85 blocks of different dimensions. Precision gage blocks are made from a special alloy steel. They are hardened, ground, and then stabilized over a period of time to reduce subsequent waxing. They are rectangular in shape with measuring surfaces on opposite sides. The measuring surfaces are lapped and polished to an optical flat surface and the distance between them is the measuring dimension. The dimension may range from 0.010 of an inch up to 20 inches.

(b) Gage blocks are used as master gages to set and check other gages and instruments. They are accurate from eight millionths (0.000008) of an inch to two millionths (0.000002) of an inch, depending on the grade of the set. To visualize this minute amount, consider that the thickness of

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a human hair divided by 1,500 equals 0.000002 of an inch. The degree of accuracy applies to the thickness of the gage block, the parallelism of the sides, and the flatness of the surfaces. The gages are lapped so smooth and flat that when they are "wrung" or placed one on top of the other in the proper manner, one cannot separate them by pulling them straight out; they have to be slipped to the side and then off. A set of gage blocks has enough different size blocks that any measurement can be established within the accuracy and range of the set. As one might expect, anything so accurate requires exceptional care to prevent damage and to ensure continued accuracy. A dust-free temperature-controlled atmosphere is preferred. After the gage blocks are used, each block should be wiped clean of all fingerprints and coated with a thin layer of white petroleum to prevent them from rusting.

FIGURE 30. GAGE BLOCKS.



(c) Gage blocks are used for various precision measurements. Before using a set of new gage blocks, remove the coat of rust preventing compound with a chamois or a piece of cleaning tissue, or by cleaning them with an approved solvent. Gage

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blocks and any other measuring tool used with them must be free of grease, oil, dirt, and any other foreign matter to avoid a lapping action whenever the block is moved, and to ensure accurate measurement. When using gage blocks, take particular care when measuring hardened workpieces to avoid scratching the measuring surfaces.

NOTE

When building gage blocks (wringing them together) to obtain a desired dimension, care should be exercised to avoid damaging them.

Step 1. To build or stack precision gage blocks (figure 31 on the following page) to take measurements, bring the blocks together (view A) and move them slightly back and forth. This minimizes scratching, as it will detect any foreign particles between the surfaces.

Step 2. Shift the blocks. If the blocks are clean, they will begin to take hold.

Step 3. Slide the two blocks together (view B), using a slight pressure and a rotary motion.

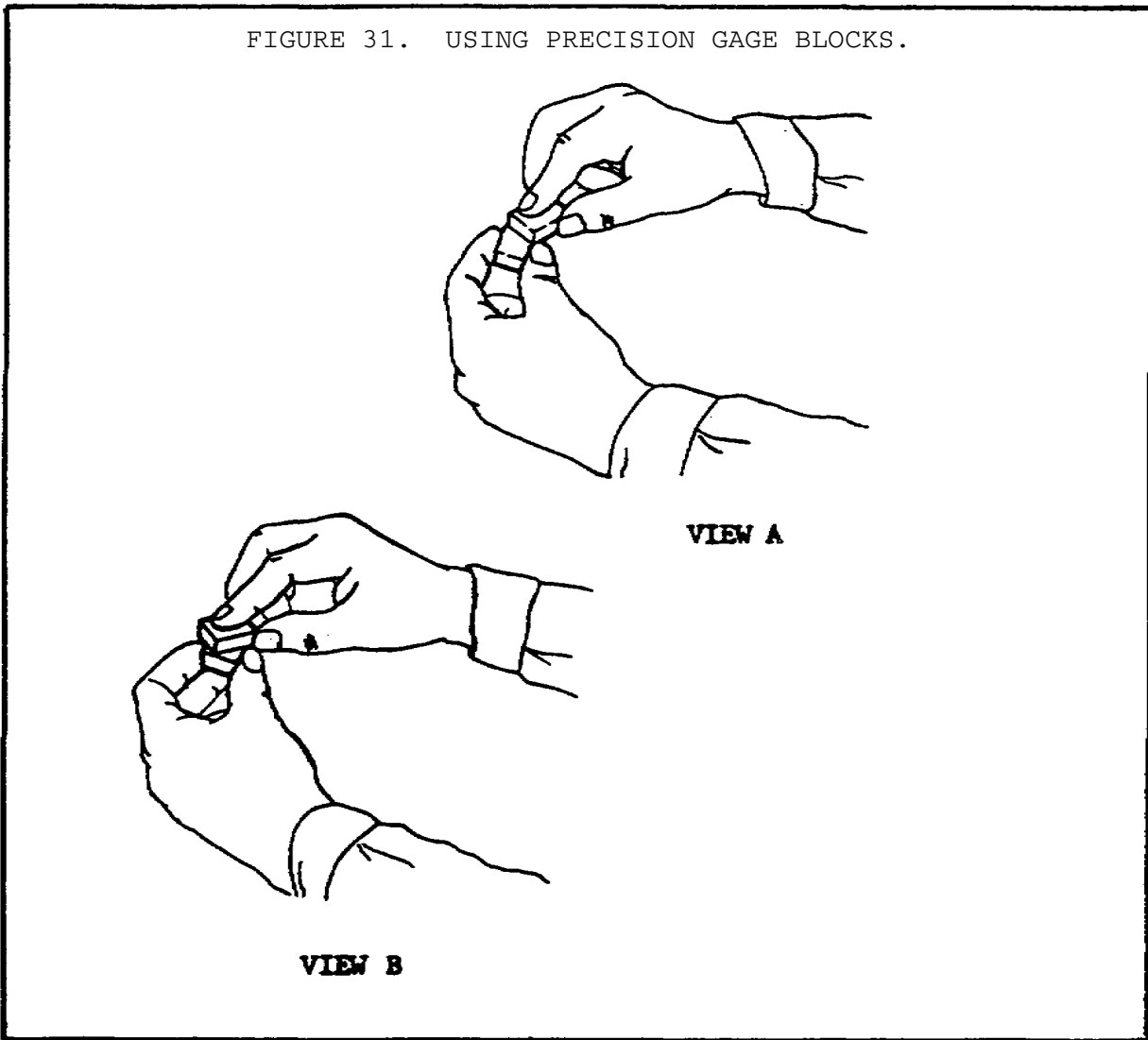
Step 4. Shift the gage blocks so that the sides are in line. Any combination of the gage blocks may be stacked together in this manner. The combination will be as solid as a single block.

NOTE

The adhesive force that binds the two gage blocks together is a combination of molecular attraction and the suction cup action due to the film of oil or moisture on the surfaces being wrung together.

Separate the gage blocks by sliding them apart, using the same movement as when wringing them together.

FIGURE 31. USING PRECISION GAGE BLOCKS.



CAUTION

Do not leave blocks wrung together for long periods of time since the surfaces in contact will tend to corrode.

(d) Ordinary changes in temperature have a significant effect on the measurements made with precision gage blocks. The standard measuring temperature is 68°F, which is just a little lower than the average temperature in most shops. Since the room temperature affects the work as well as the block, the expansion in the work will be matched in most cases by a similar expansion in the block. The coefficient of expansion of several metals and blocks are listed below:

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Material	Millionths of an inch
Steel	5.5 to 7.2 per degree F
Iron	5.5 to 6.7
Phosphor bronze	9.3
Aluminum	12.8
Copper	9.4
Gage blocks	6.36 to 7.0

(e) Handle blocks only when they must be moved and hold them between the tips of your fingers so that the area of contact is small. Hold them for short periods of time only.

NOTE

Avoid conducting body heat into the block by careless handling. Body heat may raise the temperature of the block, causing serious error in a measurement, particularly if a long stack of blocks is being handled.

(f) When using gage blocks, consider the source of error resulting from the temperature. Metals other than iron and steel (such as aluminum) have a much different coefficient of linear expansion, which will result in a difference between the room measurement and the standard measuring temperature measurement. Careless handling of gage blocks may produce an error of several millionths of an inch, and this error increases proportionally with the dimension of the block.

(g) The temperature of the work may be either lower or higher than the room temperature as a result of a machining operation. This difference may be sufficient to cause a sizable error.

(h) Theoretically, the measuring pressure should increase proportionally with the area of contact. For practical purposes, it is better to use a standard measuring pressure. The most commonly used pressure is 1/2 to 2 pounds.

(i) Gage blocks are used in the layout and checking of tools, dies, and fixtures. They are also used in machine setups, in checking parts in the process of being manufactured, and finished parts.

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(j) Gage blocks are commonly used in setting adjustable instruments and indicating gages and verifying inspection gages. Gage blocks are used to verify the accuracy of ring and snap gages and many other special-purpose gages. The classification of blocks depends largely on the accuracy required. Typical classification is as follows:

Class	Work	Error range millionths of an inch
I	Verification gages, setting instruments, and tool inspection	5 to 20
II	Layout of jigs, fixtures and dies, setting instruments, and tool inspection	20 to 40
III	Setup of grinding, milling and drilling machines, and parts inspection	40 to 100

(14) Care. The following steps should be followed when caring for precision gage blocks:

Step 1. Observe particular care when using gage blocks to measure hardened work. The danger of scratching is increased when the work is as hard as the block, or harder.

Step 2. Never touch the measuring surfaces of the blocks any more than necessary. The moisture from one's hands contains acid which, if not removed, will eventually stain the blocks.

Step 3. Before using the gage blocks, ensure that there is no grease, oil, dirt, or other foreign substances on the block.

Step 4. Every time a set of blocks is used, all of the blocks which have been cleaned for use must be covered with a light film of acid-free oil, such as boiled petroleum, before they are put away. Wipe them with an oiled chamois as the blocks are returned back to their places in the case.

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(15) *Classes and Standards for all Makes of Gages.*

Class X - Precision lapped to close tolerances for many types of masters and the highest quality working and inspection gages.

Class Y - Good lapped finish to slightly increased tolerances for inspection and working gages.

Class ZZ - (Ring gages only). Ground only to meet the demand for an inexpensive gage, where quantities are small and tolerances liberal.

Table 1 below lists the tolerances for ring gages in each class:

TABLE 1. TOLERANCES FOR RING GAGES.

ABOVE	TO AND INCL	X	Y	Z	RING GAGES ZZ
0.029	0.825	0.00004	0.00007	0.00010	0.00020
0.825	1.510	0.00006	0.00009	0.00012	0.00024
1.510	2.510	0.00008	0.00012	0.00016	0.00032
2.510	4.510	0.00010	0.00015	0.00020	0.00040
4.510	6.510	0.00013	0.00019	0.00025	0.00050
6.510	9.010	0.00016	0.00024	0.00032	0.00064
9.010	12.010	0.00020	0.00030	0.00040	0.00080

X Precision lapped

Y Lapped

Z Ground or polished (grinding marks may be in evidence)

ZZ Ground only

(16) *Thread Measuring Wires.*

The most accurate method of measuring the fit or pitch diameter of threads, without the use of the expensive and sophisticated optical and comparator equipment, employs thread measuring wires. These wires are accurately sized, depending on the number of threads per inch, so that when they are laid over the threads in a position that allows an outside micrometer to measure the distance between

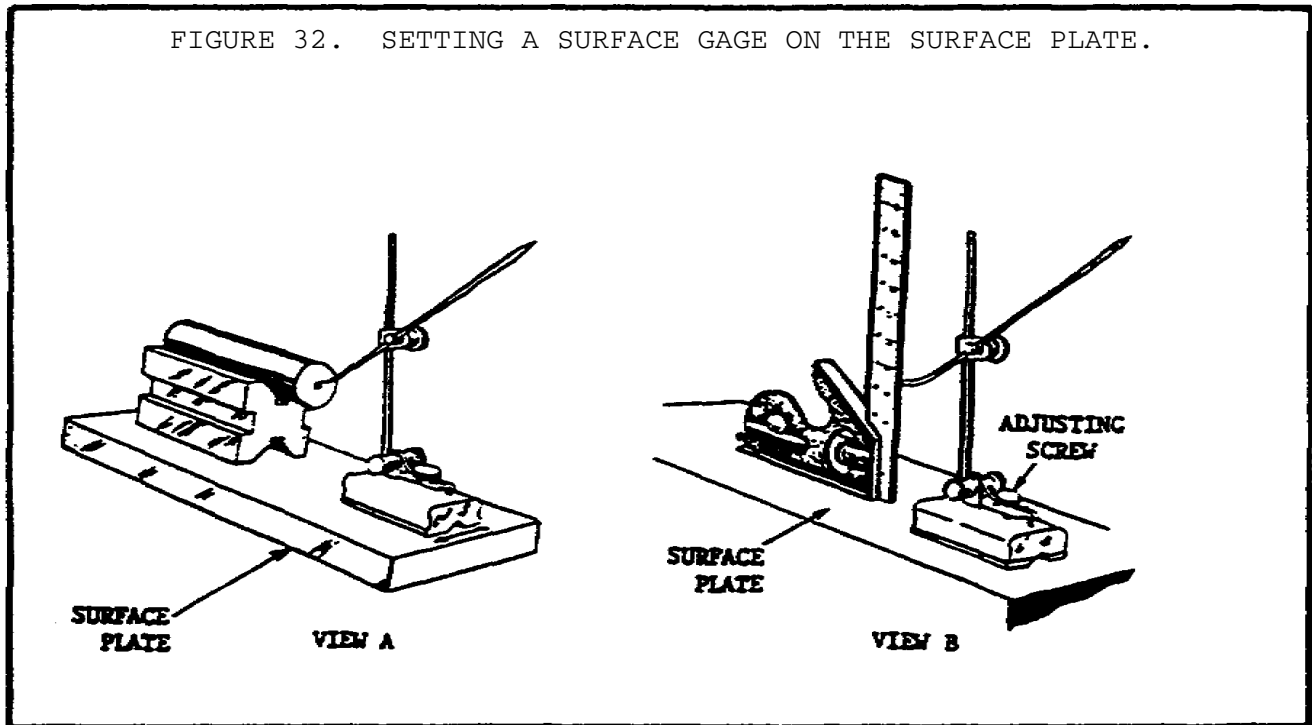
them, the pitch diameter of the threads can be determined. Sets are available that contain all the more common sizes. Detailed information on computing and using the wire method is covered in most machinist and technical manuals.

(17) *Surface Plate.*

(a) *General.* A surface plate (figure 32) provides a true, smooth, plane surface. It is often used as a level base for surface and height gages from which to make accurate measurements. Surface plates are usually made of close grain cast iron, are rectangular in shape, and come in a variety of sizes.

(b) *Uses.* The surface plate is used with such tools as parallels, squares, surface gages, angle plates, and sine bar in making layout lines. Angle plates are used to mount work at an angle on the surface plate.

FIGURE 32. SETTING A SURFACE GAGE ON THE SURFACE PLATE.



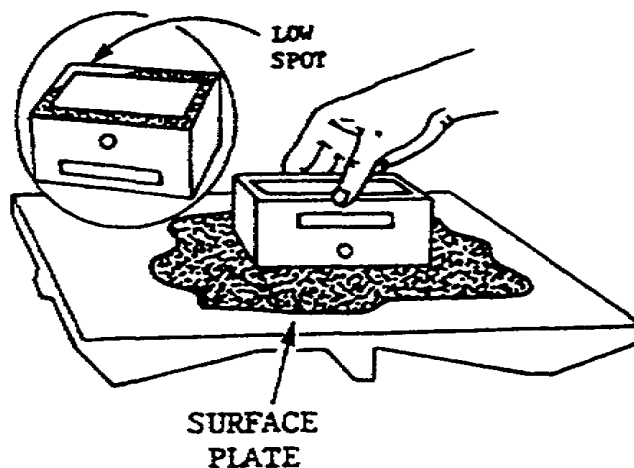
1 View A of figure 32 shows a surface gage and a V-block combination used in laying out a piece of stock. To set the surface gage for height, first clean the top of the surface plate and the bottom of the surface gage. Then, place the squaring head of a combination square as shown in view B of figure 32. The scale is secured in

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the square head so that it does not move and is in contact with the surface of the plate. Settings are then made on the surface gage to be transferred to the workpiece.

2 The surface plate is also used for checking surfaces that are being scraped for flatness (figure 33). To perform this operation, a surface plate and nondrying prussian blue are used. The plate is covered with a light coat of blue. The workpiece is placed on top of the plate and blue, and moved over the surface. The blue will stick to the high spots on the workpiece, revealing the areas that are to be scraped. Once the blue areas are scraped, the piece is checked again. This process is continued until the blue coloring shows on the entire surface of the workpiece.

FIGURE 33. CHECKING A SURFACE ON THE SURFACE PLATE.



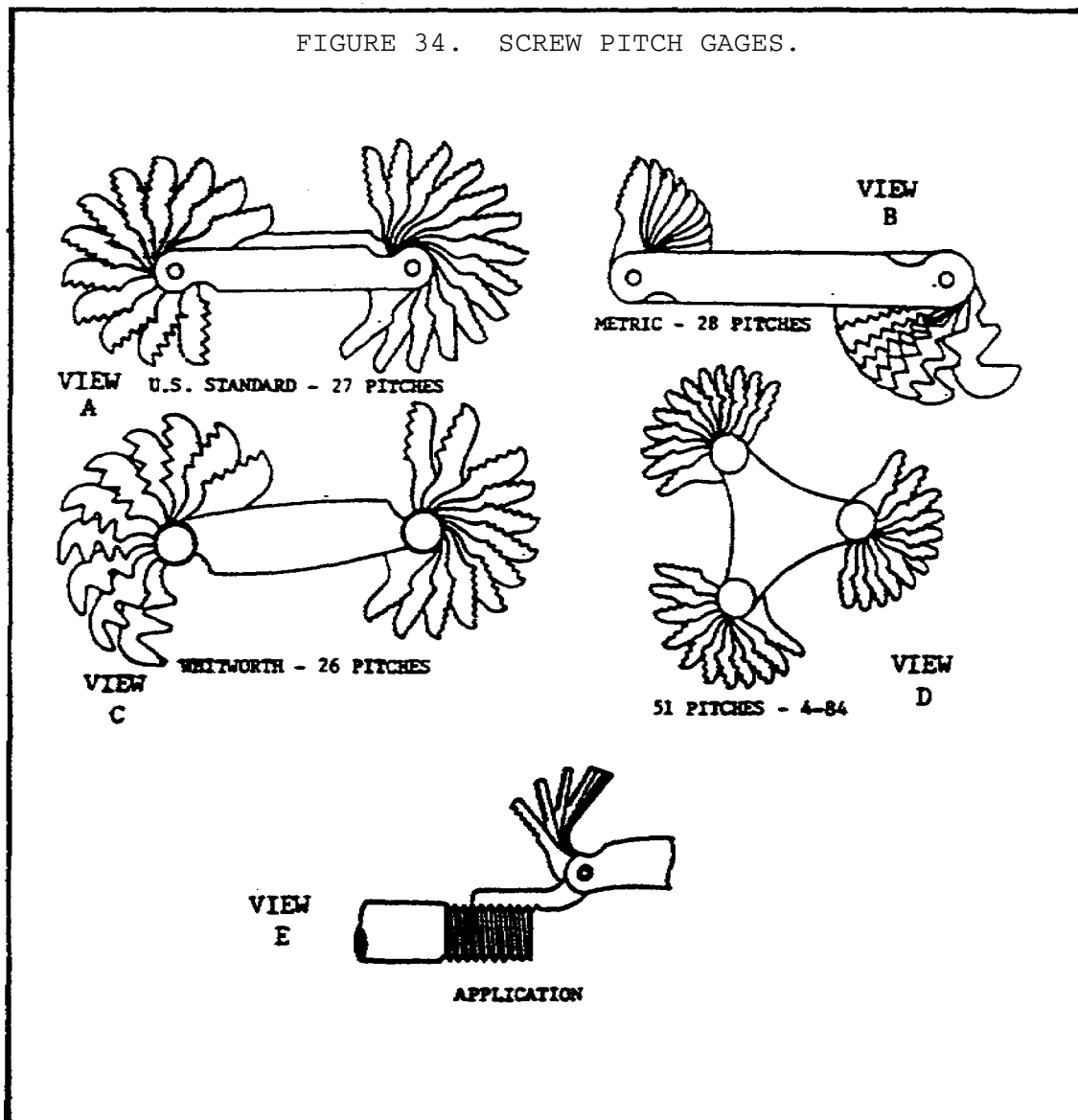
(18) Screw Pitch Gage.

(a) *General.* Screw pitch gages (figure 34 on the following page) are made for checking the pitch of U.S. Standard, Metric, National Form, and Whitworth cut threads. These gages are grouped and retailed in a case or handle, as are the thickness gages. The number of threads per inch is stamped on each blade, in which are cut the exact form of threads of the various pitches. Some types are

equipped with blade locks. The triangular shaped gage has 51 blades covering a wide range of pitches, including 11 1/2 and 27 threads-per-inch for V-form threads.

(b) Screw pitch gages are used to determine the pitch of an unknown thread by setting one of the pitch blades (one that matches the threads) against the threads that have already been cut (figure 34, view E). The pitch of a screw thread is the distance between the center of one tooth to the center of the next tooth.

FIGURE 34. SCREW PITCH GAGES.

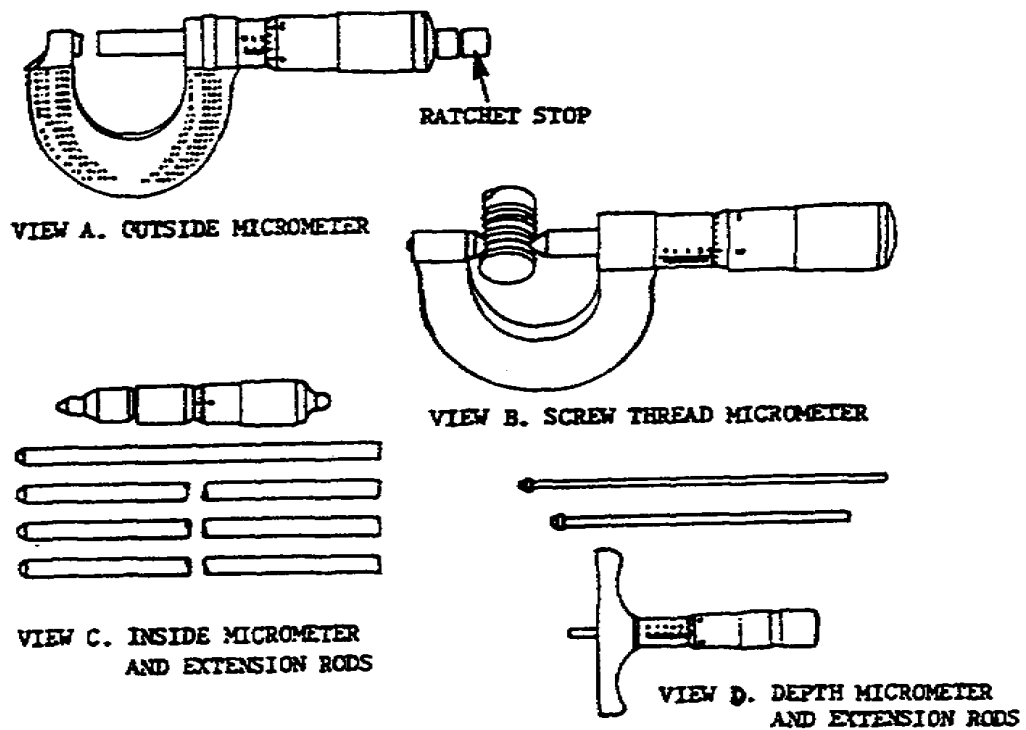


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3. Precision Measuring Tools

a. *General.* Micrometer calipers (figure 35) are probably the most often used precision instruments in a machine shop. There are many different types, each having been designed to permit measurement of surfaces for various applications and configurations of workpieces. The degree of accuracy obtainable from a micrometer also varies. The most common graduations on the micrometer are from one thousandth (0.001) of an inch to one ten thousandths (0.0001) of an inch. The measurement is usually expressed as a decimal. There are three types of micrometers which are commonly used: The outside micrometer, the inside micrometer, and the depth micrometer.

FIGURE 35. COMMON TYPES OF MICROMETERS.



b. *Outside Micrometer.*

(1) *General.* An outside micrometer (figure 36 on the following page) often called a micrometer caliper, or mike, is used to measure the thickness or the outside diameter of various parts. They are available in sizes ranging from 1 inch to about 96

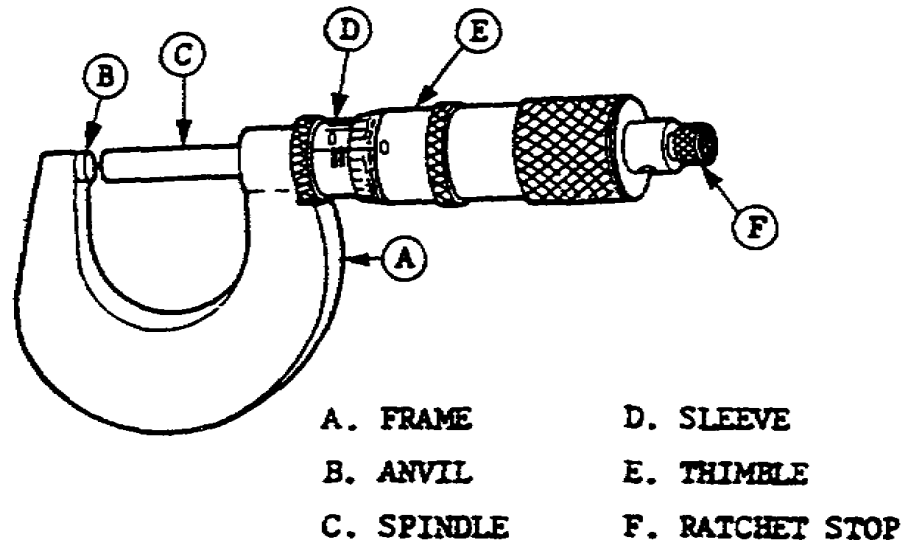
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inches, in steps of 1 inch; or in sets graduated to read in units of the metric system, from 0 to 25 millimeters by hundredths of a millimeter. However, in most shops, standard sets up to 24 inches are more common. The larger sizes normally come as a set with interchangeable anvils which provide a range of several inches. The anvils have an adjusting nut and a locking nut to permit setting the micrometer with a micrometer standard. Regardless of the degree of accuracy designed into the micrometer, the skill applied by each individual is the primary factor in determining the accuracy and reliability of measurements. Training and practice will result in proficiency when using this tool.

(2) The types of micrometer commonly used are made so that the longest movement possible between the anvil and the spindle is 1 inch. This movement is called the "range". The frames of the micrometer, however, are available in a wide variety of sizes, from 1 inch up to as large as 24 inches. The range of a 1 inch micrometer is from 0 to 1 inch. In other words, it can be used to measure work where the part to be measured is 1 inch or less. A 2 inch micrometer will only measure work between 1 and 2 inches thick. A 6 inch micrometer has a range of from 5 to 6 inches, and will only measure work between 5 and 6 inches thick. It is necessary, therefore, that the machinist first find the approximate size of the work to the nearest inch, and then select a micrometer that will fit it. For example, to find the exact diameter of a piece of round stock use a rule and first find the approximate diameter of that stock. If it is found to be approximately 3 1/4 inches, a micrometer with a 3 to 4 inch range would be required to measure the exact diameter. Similarly, with the inside and the depth micrometers, rods of suitable lengths must be fitted into the tool to get the approximate dimension within an inch, after which the exact measurement is read by turning the thimble. The size of a micrometer indicates the size of the largest work it will measure.

(3) On some outside micrometers, the frame can be smaller, so that the range of the micrometer is only 0 to 1/2 inch or 0 to 13 millimeters; or it can be larger, so that the range is 23 to 24 inches. The head has a constant range of 0 to 1 inch. The shape of the frame may be varied to

FIGURE 36. NOMENCLATURE OF THE OUTSIDE MICROMETER.



adapt to the physical requirements of some types of work. For example:

(a) The frame back of the anvil may be cut away to allow the anvil to be placed in a narrow slot.

(b) The frame may have a deep throat to permit it to reach into the center sections of a piece of sheet metal (sheet metal or paper gage).

(c) The frame may be in the form of a base so that the gage can be used as a bench micrometer.

(d) The frame may have a wooden handle and may be of extra-heavy construction for use in steel mills for gaging hot sheet metal.

(4) The spindle and anvil may vary in design to accommodate special physical requirements. For example:

(a) The spindle and anvil may be chamfered so that the micrometer gage can slide on and off the work easily, as when gaging hot metal.

(b) The ball-shaped anvil is convenient in measuring the thickness of a pipe section of small diameter.

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(c) The V-shaped anvil is necessary on the screw thread micrometer caliper to mesh properly with the screw thread. The spindle of the screw thread micrometer is cone-shaped. This micrometer measures the pitch diameter of the thread.

(d) The interchangeable anvils of various lengths make it possible to reduce the range of the micrometer. A micrometer having a range of 5 to 6 inches can be changed to one having a 4 to 5, or a 3 to 4 inch range by inserting a special anvil of the proper length.

(5) *Design of Micrometers.* The micrometer makes use of the relation of the circular movement of a screw to its axial movement. The amount of axial movement of a screw per revolution depends on the thread, and is known as the lead. If a circular nut, on a screw, has its circumference divided into 25 equal spaces and if the nut advances axially $1/40$ th of an inch for each revolution, each space will represent $1/25 \times 1/40$, or $1/1000$ of an inch. In the micrometer, the nut is stationary and the screw moves forward axially a distance proportionate to the amount it is turned. The screw on a micrometer has 40 threads per inch, and the thimble has its circumference divided into 25 parts, so 1 division on the thimble represents an advancement of $1/1000$ of an inch axially.

(6) *Construction.*

(a) The steel frame is U-shaped, and one end holds the stationary anvil. The stationary anvil is a hardened button, either pressed or screwed into the frame.

(b) The steel spindle is actually the unthreaded part of the screw. It is the spindle that advances or retracts to open or close the open side of the U-frame. The spindle bearing is a plain bearing and is part of the frame.

(c) The hollow barrel extends from this bearing, and on the side of the barrel is the micrometer scale, which is graduated in tenths of an inch, then divided into subdivisions of 0.025 of an inch. The end of the barrel supports the nut which engages the screw. This nut is slotted and its outer surface has a taper thread and a nut which makes it possible to adjust the diameter of the slotted nut, within limits, to compensate for wear.

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(d) The thimble is attached to the screw and is a sleeve that fits over the barrel. The front edge of the thimble carries a scale divided into 25 parts. This scale indicates parts of a revolution, where the scale on the barrel indicates the number of revolutions. The thimble is connected to the screw through a sleeve that permits it to be slipped in relation to the screw for the purpose of adjustment. The inner sleeve is sweated to the screw. The outer sleeve is clamped to the inner one by the thimble cap. Loosening the cap makes it possible to slip one in relation to the other.

(e) On top of the thimble cap there may be a ratchet. This device consists of an overriding clutch held together by a spring in such a way that when the spindle is brought up against the work, the clutch will slip when the correct measuring pressure is reached. The purpose of the ratchet is to eliminate any difference in personal touch, and so reduce the possibility of error due to a difference in measuring pressure. Not all micrometers have ratchets.

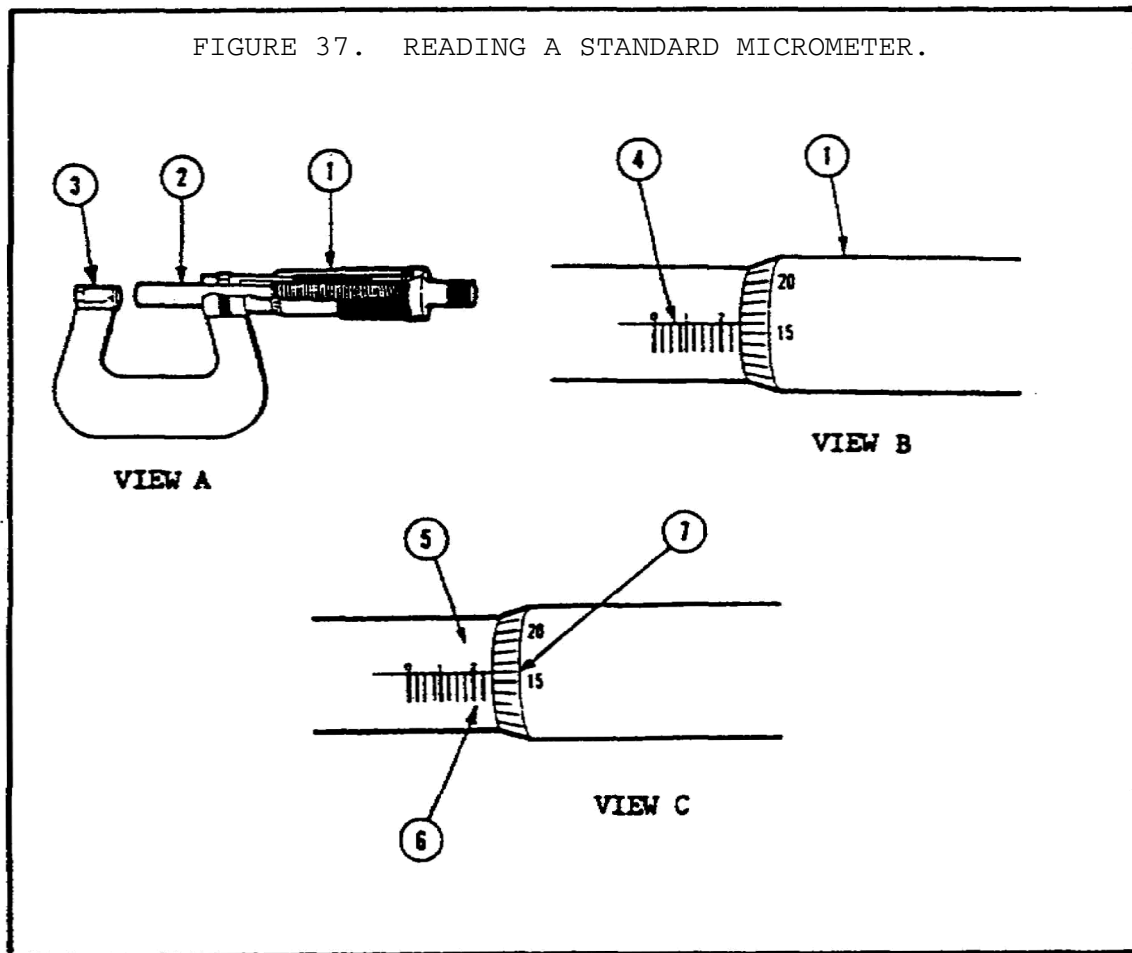
(f) A clamp ring or locknut is located in the center of the spindle bearing on those micrometers equipped with it. This clamping makes it possible to lock the spindle in any position to preserve a setting.

(7) *Use of Micrometers.*

(a) *Reading a Standard Micrometer.*

1 Reading a micrometer (figure 37 on the following page) is only a matter of reading the micrometer scale or counting the revolutions of the thimble and adding to this any fraction of a revolution. The micrometer screw has 40 threads per inch. This means that one complete revolution of the micrometer screw (1), view A, moves the spindle (2) away from or toward the anvil (3) exactly $1/40$ or 0.025 inch.

2 The lines on the barrel, view B, (4) conform to the pitch of the micrometer screw (1), each line indicating 0.025 of an inch, and each fourth line being numbered 1, 2, 3, and so forth.



3 The beveled edge of the thimble is graduated into 25 equal parts. Each line indicates 0.001 of an inch, and one complete and exact revolution of the micrometer screw and the thimble moves the spindle away from or toward the anvil exactly 0.025 of an inch. Every fifth line on the thimble is numbered to read a measurement in thousandths of an inch.

4 To read a measurement on the standard micrometer use figure 37, view C, and perform the following:

- a Read the highest figure visible
on the barrel (5).....2 = 0.200 in.
- b Number of lines visible between
the No. 2 and the thimble
edge (6).....1 = 0.025 in.

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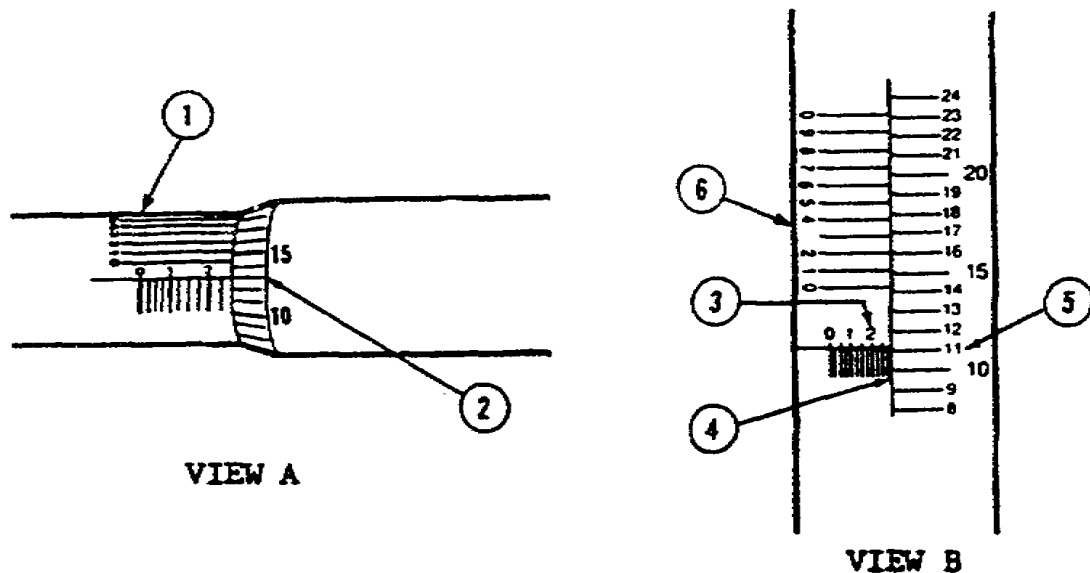
c The line of the thimble that coincides with or has passed the revolution or long line in the barrel (7).....16 = 0.016 in.

TOTAL _____
= 0.241 in.

(b) Reading a Vernier Micrometer.

1 Reading the vernier micrometer (figure 38) is the same as reading the standard micrometer, except that an additional step must be taken, which is to add the vernier reading to the regular dimensions. This allows for precise measurements which are accurate to ten-thousandths (0.0001) of an inch. This scale furnishes the fine readings between the lines on the thimble rather than making an estimate as one would make on a standard micrometer.

FIGURE 38. READING A VERNIER MICROMETER.



2 There are ten spaces on the vernier micrometer, (figure 38, view A, (1)). Therefore, each unit on the vernier scale is equal to 0.0009 of an inch, and the difference between the sizes of the units on each scale is 0.0001 of an inch.

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3 To read a measurement on the vernier micrometer, use figure 38, view B and perform the following:

4 Read the highest figure
visible on the barrel (3).....2 = 0.200 in.

Number of lines visible
between the No. 2 and the
thimble edge (4).....3 = 0.075 in.

The line on the thimble
that coincides with or is
nearest the revolution or
long line on
the barrel (5).....11 = 0.011 in.

The line on the vernier
scale that coincides
with a line on the
thimble (6).....2 = 0.0002 in.

TOTAL _____
= 0.2862 in.

(c) *Reading a Metric Micrometer.* The same principle is applied in reading the metric graduated micrometer, but the following changes in graduations are used:

1 The pitch of the micrometer screw is 0.05 mm. One revolution of the spindle advances or withdraws the screw a distance equal to 0.5mm.

2 The barrel (figure 39, view A, on the following page) (1) is graduated in millimeters from 0 to 25. It takes two revolutions of the spindle to move the barrel 1mm.

3 The thimble (2) is graduated in 50 divisions with every fifth line being numbered. Rotating the thimble from one graduation to the next moves the spindle 1/50 of 0.5mm, or 1/100mm. Two graduations equal 2/100mm, and so forth.

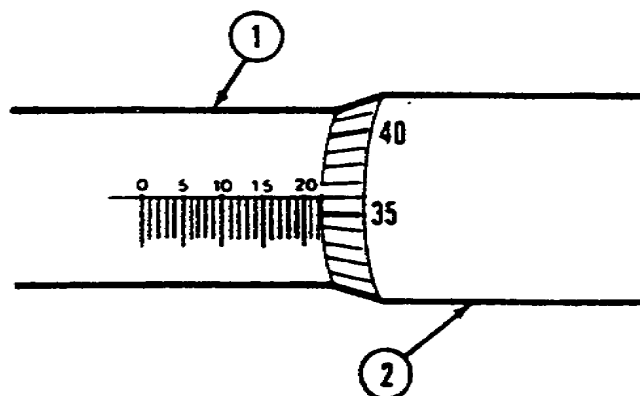
4 To read a measurement on the metric micrometer, use figure 39, view B, and perform the following:

5 Read the highest
figure visible on
the barrel (1).....20 = 20.0mm

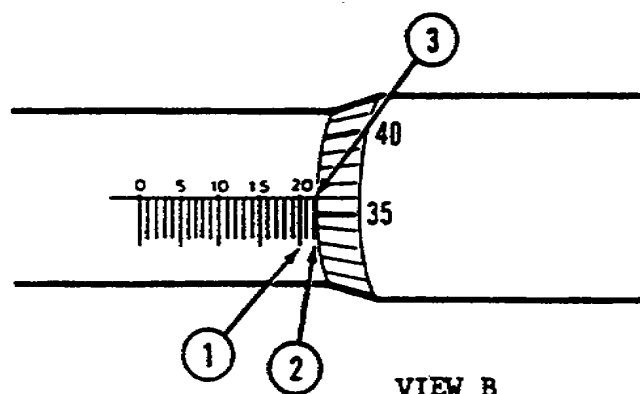
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- 6 Number of lines visible
between the NO. 20 and
the thimble edge (2).....2 = 2.0mm
- 7 The line on the thimble
that coincides with or
has passed the revolution
or long line in the
barrel (3).....36 = 36/100 (.36)mm
- Measurement reading.....TOTAL 22.36mm

FIGURE 39. READING A METRIC MICROMETER.



VIEW A



VIEW B

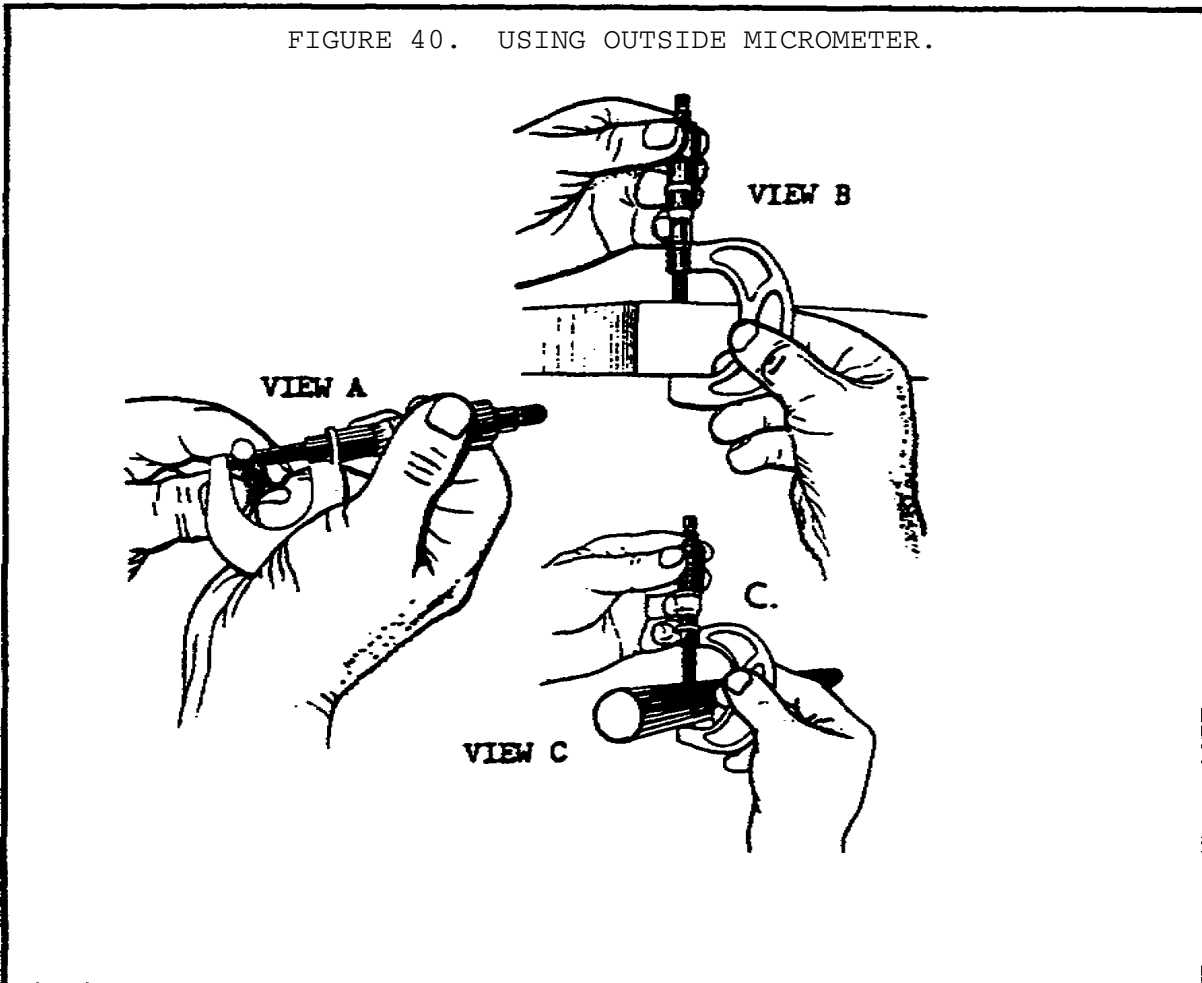
NOTE

Remember that 1 complete revolution of the thimble is 0.5mm. It takes two complete revolutions to advance it to 1mm.

(d) *Measuring With The Micrometer.*

1 When checking a small part with the use of a micrometer (figure 40, view A, hold the part in one hand. Hold the micrometer in the other hand so that the thimble rests between the thumb and the forefinger. The third finger is then in a position to hold the frame against the palm of the hand. The frame is supported in this manner making it easy to guide the work over the anvil. The thumb and the forefinger are in position to turn the thimble either directly or through the ratchet, bringing the spindle down against the work.

FIGURE 40. USING OUTSIDE MICROMETER.



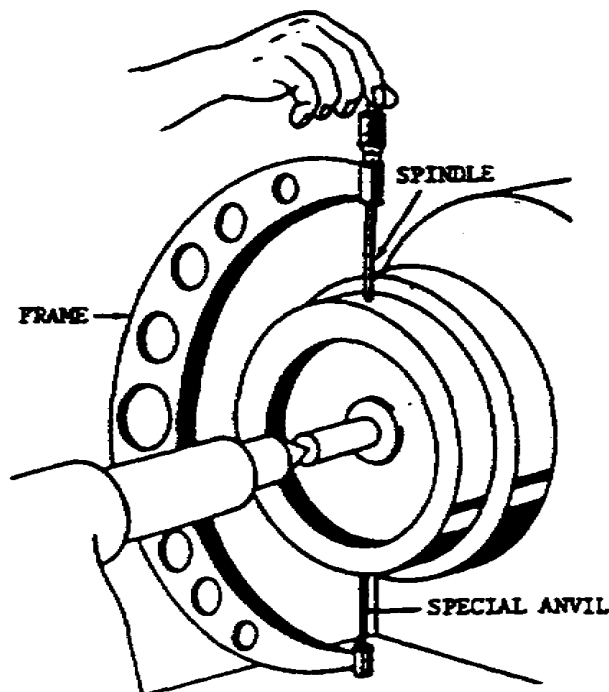
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2 On larger work, it is necessary to have the work stationary and positioned to permit access to the micrometer. The proper method of holding a micrometer when holding a part too large to be held in one hand is shown in figure 40, view B, on the previous page. The frame is held by one hand to position it and locate it square to the measured surface. The other hand operates the thimble either directly or through the ratchet. A large flat part should be checked in several places to determine the amount of variation.

3 To measure a shaft as shown in figure 40, view C, the frame is held by one hand while the thimble is operated by the other. In measuring a cylindrical part with a micrometer, it is necessary to "feel" the setting to be sure that the spindle is on the diameter, and also to check the diameter in several places to determine the out-of-roundness.

4 For measuring very large diameters, micrometer calipers are made in various sizes up to 168 inches. A pulley is being checked (figure 41)

FIGURE 41. MEASURING LARGE DIAMETERS.



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with a micrometer whose range has been reduced by a special anvil which has been screwed into the frame. A set of different length anvils permits the use of the micrometer over a wide range of sizes; yet the spindle only moves 1 inch. This micrometer has been lightened in weight by the I-section construction and by boring holes in the frame.

c. *Inside Micrometer.*

(1) *General.* An inside micrometer (figure 42 on the following page) is used to measure inside diameters or between parallel surfaces. They are available in sizes ranging from 0.200 inch to about 107 inches. However, the average inside micrometer set has a range that extends from 2 to 10 inches. The various steps in covering this range are obtained by means of extension rods. The minimum dimension that can be checked is determined by the length of the unit with its shortest anvil in place and the screw set to zero. It consists of an ordinary micrometer head, except that the outer end of the sleeve carries a contact point attached to a measuring rod. The micrometer set may also contain a collar for splitting the inch step between the rods. The collar, which is 1/2 inch long, extends the rod another 1/2 inch so that the range of each step can be made to overlap the next. The range of the micrometer screw itself is very short when compared to its measuring range. The smallest models have a 1/4 inch screw, and the largest has only a 1 inch screw.

(2) *Extension Rods.* The individual interchangeable extension rods that are assembled to the micrometer head vary in size by 1 inch. A small sleeve or bushing, which is 0.500 inch long, is used with these rods in most inside micrometer sets to provide the complete range of sizes. Using the inside micrometer is slightly more difficult than using the outside micrometer, primarily because there is more chance of not getting the same "feel" or measurement each time the surface is checked.

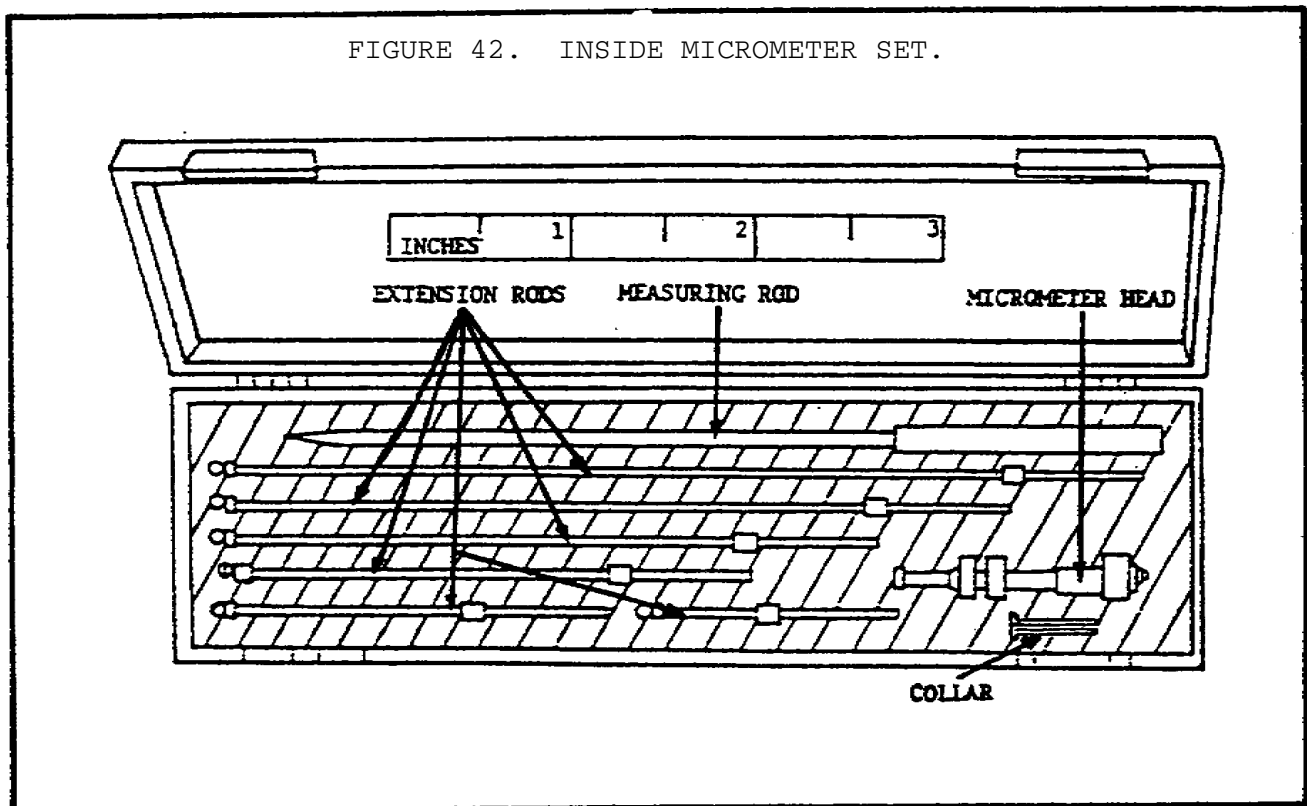
(3) *Using an Inside Micrometer.*

(a) The correct way to measure an inside diameter is to hold the micrometer in place with one hand and "feel" for the maximum possible setting of the micrometer by rocking the extension

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rod from left to right and in and out of the hole. The micrometer is adjusted to a slightly larger measurement after each series of rocking movements until no rocking from left to right is possible and a very slight drag is felt on the in and out rocking movement. There are no specific guidelines on the number of positions within a hole that should be measured. When checking for a taper, the measurements should be made as far apart as possible within the hole. When checking for roundness or concentricity of a hole, several measurements should be taken at different angular positions in the same area of the hole. A reading can be taken directly from the inside micrometer head, or an outside micrometer may be used to measure the inside micrometer.

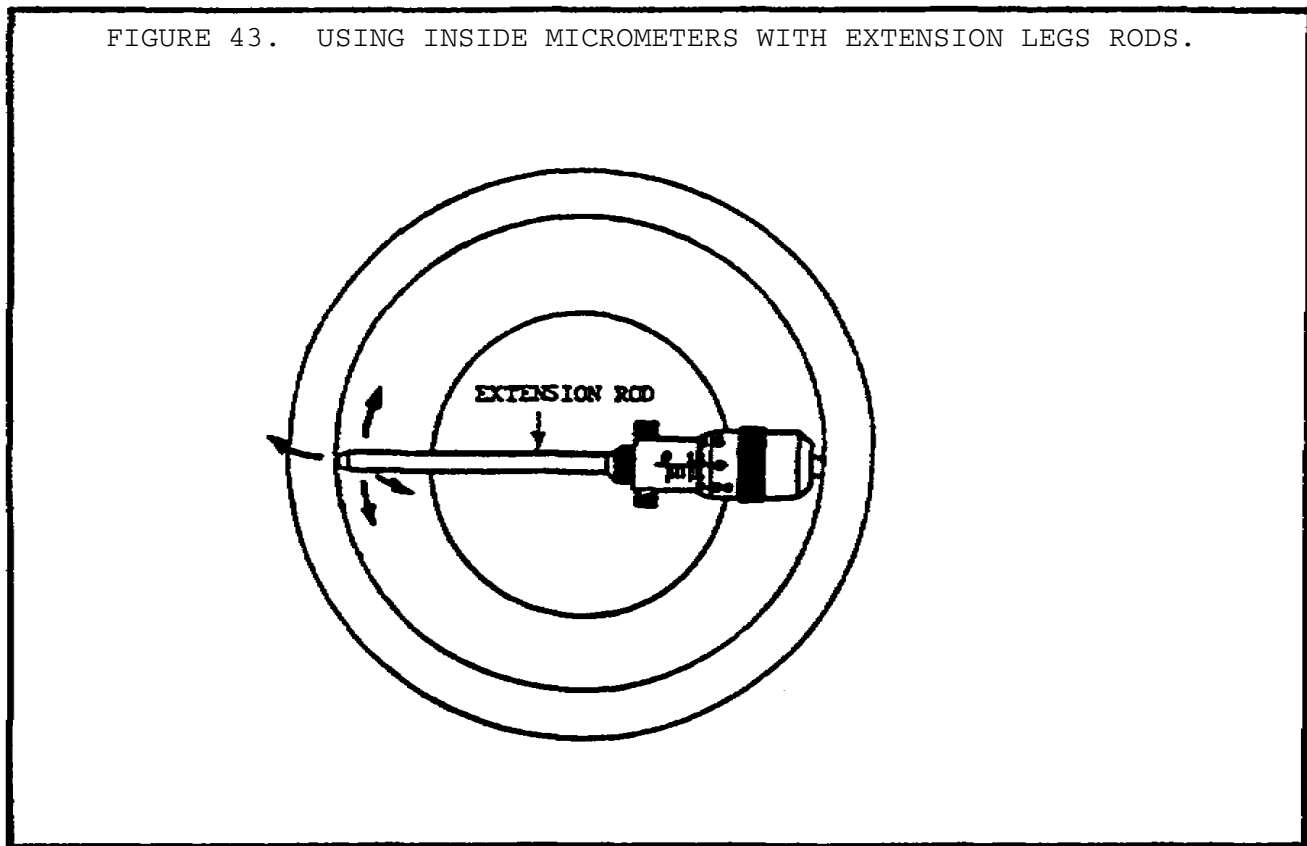
FIGURE 42. INSIDE MICROMETER SET.



(b) The normal procedure in using an inside micrometer is to set it across a diameter or between the inside surfaces, remove it, then read the dimension. For this reason, the thimble on an inside micrometer is much stiffer than the one used on an outside micrometer and it holds the dimensions well. It helps at times to verify the reading of an inside micrometer by measuring it with an outside micrometer.

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1 Figure 43, on the following page, shows an inside micrometer with an extension rod being used to check the diameter of a bored hole. Note the arrows which indicate the direction the operator is feeling for the largest dimension horizontally and the smallest dimension vertically. Inside micrometers have spherical contact points which require more practice to "feel" the full diametrical measurement. One contact point is generally held in a fixed position and the other rocked in different directions to be sure that the tool is spanning the true diameter of the hole or the correct width of a slot.



2 For probing a deep hole or in a restricted place, a handle attachment may be used. The handle clamps onto the body of the micrometer.

(4) *Transferring Measurements.* To transfer a measurement from an inside to an outside micrometer, the following steps can be followed:

Step 1. After setting the inside micrometer or an inside caliper to the work, hold the outside micrometer with one hand and the inside micrometer with the other hand.

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Step 2. Turn the thimble of the outside micrometer with the thumb and the forefinger until you feel the inside tool legs lightly contact the anvil and the spindle of the outside micrometer. Hold the tips of the inside tool legs parallel to the axis of the outside micrometer spindle.

Step 3. The outside micrometer will be accurately set when the inside tool will just pass between the anvil and the spindle of the outside micrometer on its own weight.

d. *Depth Micrometer.* A depth micrometer is used to measure the depth of holes, slots, counterbores, recesses, and the distance from a surface to some recessed part. This type of micrometer is read exactly opposite to the method used to read an outside micrometer. The zero is located toward the closed end of the thimble. The measurement is read in reverse and increases in amount (depth) as the thimble moves toward the base of the instrument. The extension rods come either round or flat (blade like) to permit measuring a narrow, deep recess or groove.

e. *Thread Micrometers.*

(1) Thread micrometers are used to measure the pitch diameter of threads. They are graduated and read in the same manner as ordinary micrometers. However, the anvil and spindle are ground to the shape of a thread.

(2) Thread micrometers are used to measure the depth of threads that have an included angle of 60° . The measurement obtained represents the pitch diameter of the thread. They are available in sizes that measure pitch diameters up to 2 inches. Each micrometer has a given range of the number of threads per inch that can be measured correctly.

f. *Ball Micrometer.* This type of micrometer has a rounded anvil and a flat spindle. It can be used to check the wall thickness of cylinders, sleeves, rings, and other parts that have a hole bored in a piece of material. The rounded anvil is placed inside the hole and the spindle is brought in contact with the outside diameter. Ball attachments are available to fit over the anvil of regular outside micrometers. When these attachments are used, compensation for the diameter of the ball must be added to the regular reading.

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g. *Blade Micrometer.* A blade micrometer has an anvil and a spindle that are thin and flat. The spindle does not rotate. This micrometer is especially useful in measuring the depth of narrow grooves, such as an O-ring seat, on outside diameters.

h. *Groove Micrometers.* A groove micrometer looks like an inside micrometer with two flat disks. The distance between the disks increases as the thimble on the micrometer is turned. It is used to measure the width of grooves or recesses on either the outside or the inside diameter. The width of an internal O-ring groove is an excellent example.

i. *Care of Micrometers.* The micrometer is one of the most used, and often one of the most abused, precision instruments in the shops. Careful observation of the do's and don'ts listed below will enable machinists to take better care of the micrometers they use.

(1) Always stop the workpiece before taking a measurement. Do not measure moving parts because the micrometer may get caught in the rotating workpiece and be severely damaged.

(2) Always open a micrometer by holding the frame with one hand and turning the knurled sleeve or thimble with the other hand. Never open a micrometer by twirling the frame, because such practice will put unnecessary strain on the instrument and cause excessive wear of the threads.

(3) Apply only moderate force to the knurled thimble when taking a measurement. Always use the friction slip ratchet if there is one on the instrument. Too much pressure on the knurled sleeve will not only result in an inaccurate reading, but may also cause the frame to spring, forcing the measuring surfaces out of line.

(4) When a micrometer is not in use, place it where it is not likely to be dropped. Dropping a micrometer can cause the frame to spring; if dropped, the instrument should be checked for accuracy.

(5) Before a micrometer is returned to storage, the spindle should be backed away from the anvil. Wipe all exterior surfaces with a clean, soft cloth, and coat the surfaces with a light oil. Do

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not reset the measuring surfaces to close contact because the projecting film of oil will be squeezed out.

j. *Maintenance of Micrometers.* A micrometer should be checked for zero setting (and adjusted when necessary) as a matter of routine to ensure that reliable readings are being obtained. To do this, proceed as follows:

(1) Wipe the measuring faces with a clean soft cloth, making sure that they are perfectly clean. Use the same moderate force that is ordinarily used when a measurement is taken and bring the spindle into contact with the anvil. The reading should be zero; if it is not, the micrometer needs further checking.

(2) If the reading is more than zero, examine the edges of the measuring faces for burrs. Should burrs be present, remove them with a small slip of oilstone. Clean the surfaces again, then recheck the micrometer setting for zero.

(3) If the reading is less than zero, or if a zero reading is not obtained after making the correction described in (2) above, the relation between the spindle and the thimble will have to be adjusted. The method for setting zero differs considerably between the makes of micrometers. Some makes have a thimble cap which locks the thimble to the spindle; some have a rotatable sleeve on the barrel that can be unlocked; and some have an adjustable anvil.

(4) *Methods For Setting Zero.*

(a) To adjust the thimble-cap type, back the spindle away from the anvil, release the cap with the small spanner wrench provided for that purpose, and bring the spindle in contact with the anvil. Hold the spindle firmly with one hand and rotate the thimble to zero with the other. After zero relation has been established, rotate the spindle counterclockwise to open the micrometer, then tighten the thimble cap. After tightening the cap, check the zero setting again to be sure that the thimble-spindle relation was not disturbed while the cap was being tightened.

(b) To adjust the rotatable-sleeve type, unlock the barrel sleeve with the small spanner wrench

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provided for that purpose. Bring the spindle into contact with the anvil and rotate the sleeve into alignment with the zero mark on the thimble. After alignment is made, back the spindle away from the anvil, and retighten the barrel sleeve locking nut. Recheck for zero setting to be sure that the thimble spindle relation was not disturbed while the locking nut was being tightened.

(c) To set zero on the adjustable-anvil type, bring the thimble to a zero reading. Lock the spindle, if a spindle lock is available, and loosen the anvil lock screw. After the lock screw is loosened, bring the anvil in contact with the spindle making sure that the thimble is still set on zero. Tighten the anvil setscrew lock nut slightly, unlock the spindle, and back the spindle away from the anvil; then lock the anvil setscrew firmly. After locking the setscrew, check the micrometer for zero setting to make sure that the anvil was not moved out of position while the set screw was being tightened.

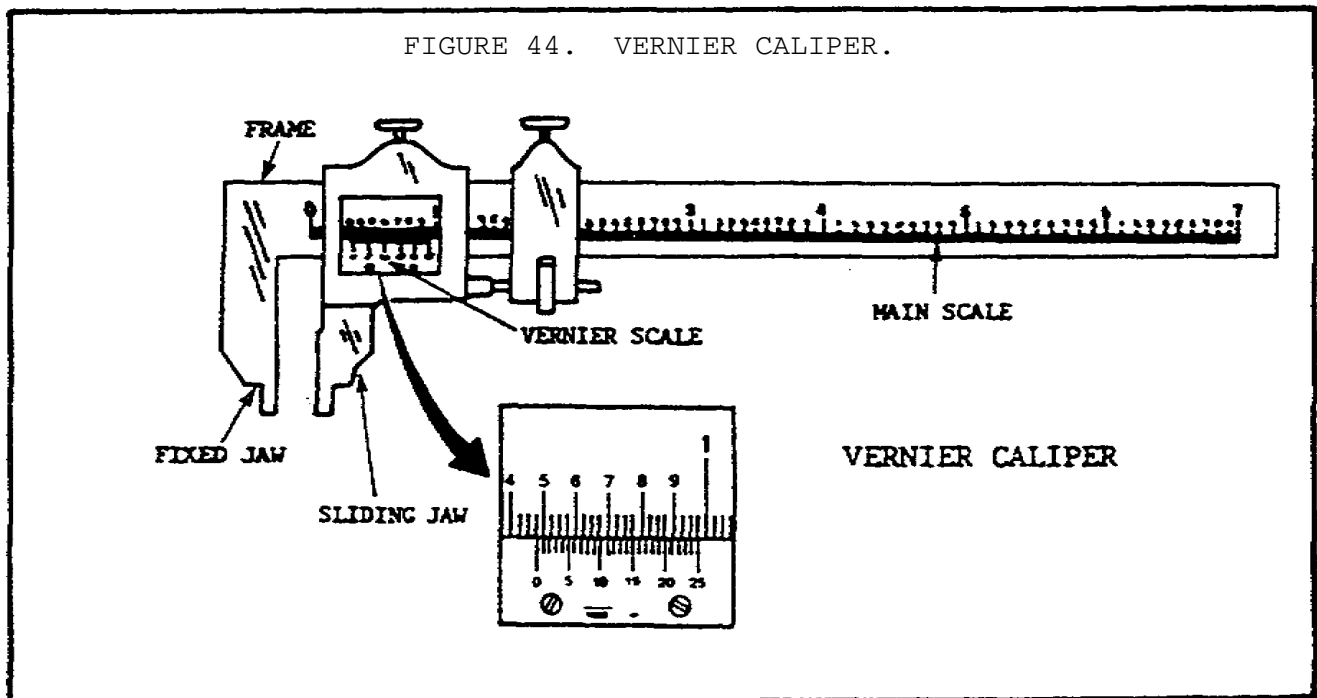
(d) The zero check and methods of adjustment apply directly to micrometers that will measure to zero. The procedures for larger micrometers is essentially the same, except that a standard must be placed between the anvil and the spindle in order to get a zero measuring reference. For example, a 2 inch micrometer is furnished with a 1 inch standard. To check for zero setting, place the standard between the spindle and the anvil and measure the standard. If zero is not indicated, the micrometer needs adjusting.

(e) All micrometers should be disassembled periodically for cleaning and lubrication of internal parts. When this is performed, each part should be cleaned in a noncorrosive solvent, completely dried, then given a light coat of watchmaker's oil or a similar light oil.

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k. Vernier Calipers.

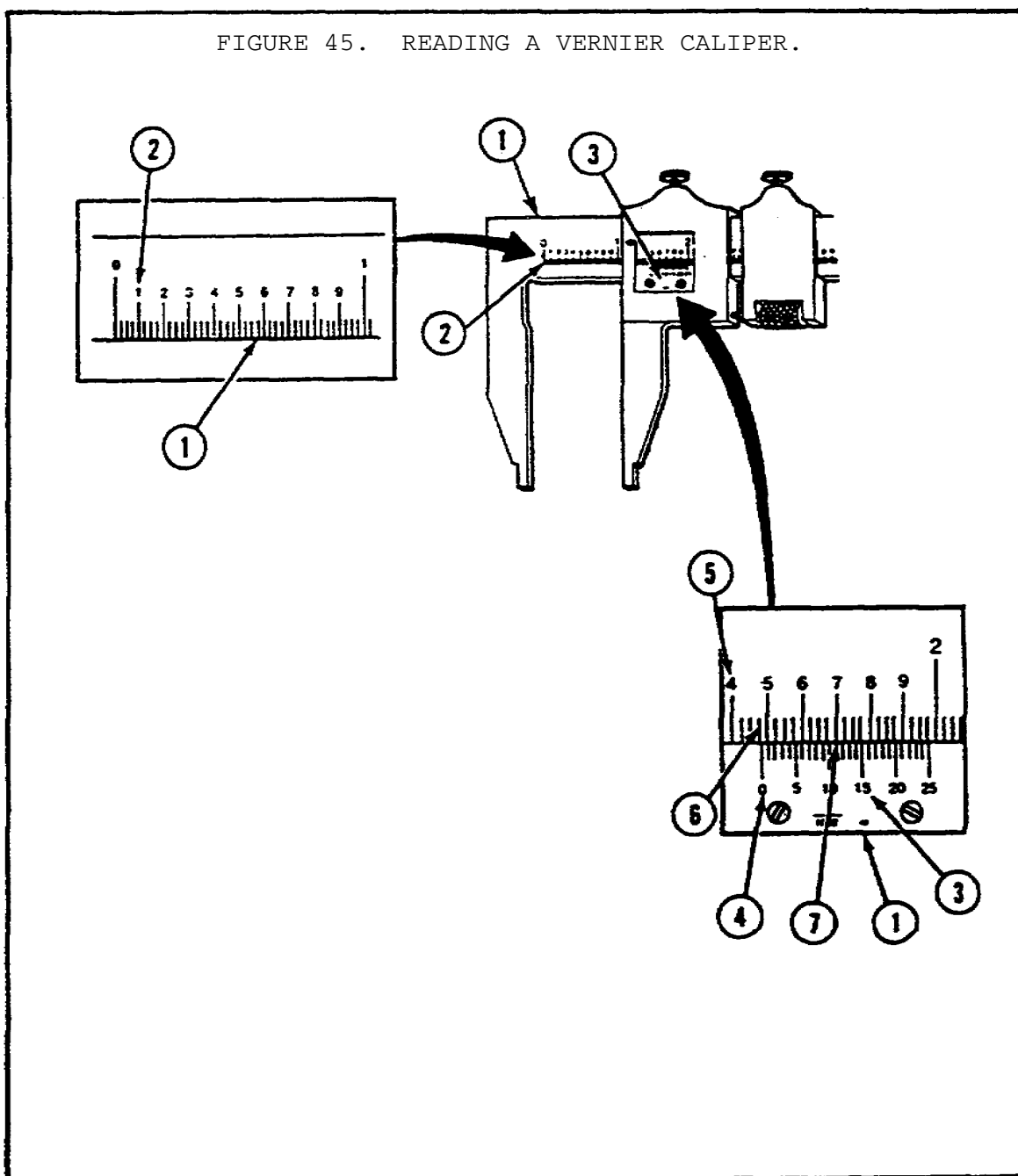
(1) *General.* This type of caliper (figure 44) uses the vernier scale. The vernier scale consists of a short auxiliary scale usually having one more graduation in the same length as the longer main scale. The vernier caliper consists of an L-shaped frame, the end of which is a fixed jaw; the long arm of the L is inscribed with the main true scale or fixed scale. The sliding jaw carries the vernier scale on either side. The scale on the front side is for outside measurements; the scale on the back is for inside measurements. On some vernier calipers, the metric system of measurement is placed on the back side of the caliper in lieu of a scale used for inside measurements. In such cases, add the thickness of the nibs to the reading when making inside measurements. The tips of the jaws are formed so that inside measurements can be taken. The thickness of the measuring points is automatically compensated for on the inside scale. The length of the jaws will range from 1 1/4 inches to 3 1/2 inches, and the minimum inside measurement with the smallest caliper is 1/4 inch or 6 millimeters. Vernier calipers are made in standard sizes of 6, 12, 24, 36, and 48 inches, and 150, 300, 600, and 900 millimeters. The jaws of all vernier calipers, except the larger sizes, have two center points, which are particularly useful in setting the dividers to the exact dimensions.



(2) *Reading a Vernier Caliper.*

(a) To read a vernier caliper (figure 45), one must be able to understand both the steel rule and the vernier scales. The steel rule (1) is graduated in 0.025 of an inch. Every fourth division (2) (representing a tenth of an inch) is numbered. (b) The vernier scale (3) is graduated in 0.001 of an inch. Every fifth division (4) is numbered. The vernier scale (3) is graduated in 0.001 of an inch. Every fifth division (4) is numbered. The vernier scale (3) is graduated in 0.001 of an inch. Every fifth division (4) is numbered.

FIGURE 45. READING A VERNIER CALIPER.



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(b) The vernier scale (3) is divided into 25 parts and numbered 0, 5, 10, 15, 20, and 25. These 25 parts are equal to 24 parts on the steel or main rule (1). The difference between the width of one of the 25 spaces on the vernier scale and one of the 24 spaces on the main rule (1) is 1/1000 (0.001) of an inch.

(c) Read the measurement in figure 45 on the previous page as illustrated below:

Read the number of whole
inches on the top scale (1) to
the left of the vernier zero
index (4) and record.....1.000 inch

Read the number of tenths (5)
to the left of the vernier
zero index (4) and record.....0.400 inch

Read the number of twenty-fifths (6)
between the tenths mark (5) and
the zero index (4)
and record.....3 X .025 = .075 inch

Read the highest line on the
vernier scale (3) which lines up
with a line on the top scale (7)
and record. (Remember $1/25 = .001$
inch).....11/25 or 0.011 inch

TOTAL 1.486 inches

(d) Most vernier calipers read OUTSIDE on one side and INSIDE on the other side. If a scale isn't marked, and an inside measurement is to be taken, read the scale as you would for an outside diameter. Then add the measuring point allowance by referring to manufacturer's instructions or the following table.

<i>Size of Caliper</i>	<i>English Measure</i>	<i>Metric Measure</i>
6 inch or 150mm	Add 0.250 inch	Add 6.35mm
12 inch or 300mm	.300 inch	7.62mm
24 inch or 600mm	.300 inch	7.62mm
36 inch or 600mm	.500 inch	12.70mm

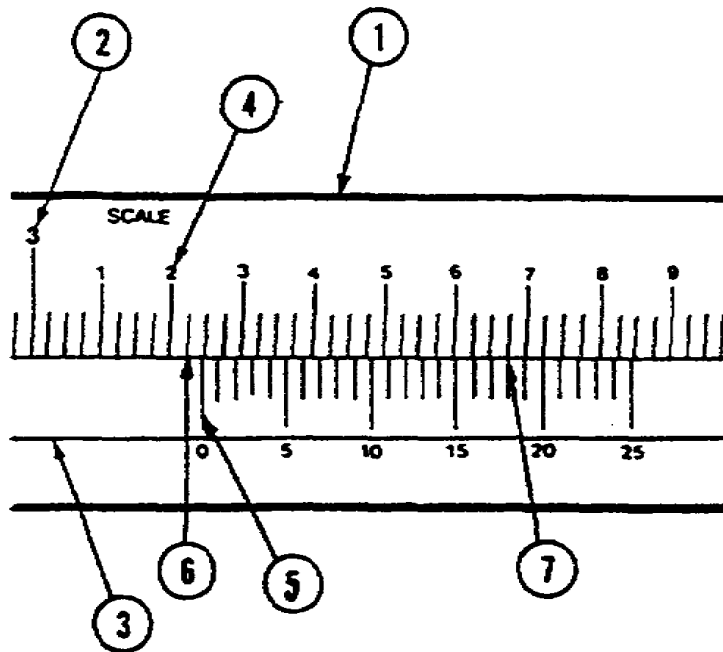
(e) *Reading a Metric Caliper* (figure 46 on the following page). The same principle is applied in

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reading the metric graduated vernier; however, the following differences should be noted:

1 The steel rule or main scale (1) is divided into centimeters (cm) (2) and the longest lines represent 10 millimeters each instead of inches. Each millimeter is divided into quarters or fourths.

FIGURE 46. READING A METRIC CALIPER.



2 The metric vernier scale (3) is divided into 25 equal parts and is numbered 0, 5, 10, 20, and 25.

Read the total number of millimeters (4) to the left of the vernier zero index (5) and record..... 32.00mm

Read the number of quarters (6) between the millimeter mark and the zero index and record..... .25mm = (1 quarter)

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Read the highest line on
the vernier scale (3) which
lines up with a line on
the scale (7) and record..... .18mm

TOTAL 32.43mm

(3) *Use and Application.* The vernier caliper has a wide range of measurement applications, and the shape of the measuring jaws and their position with respect to the scale makes this tool more adaptable than a micrometer. However, the vernier caliper does not have the accuracy of a micrometer. In any 1 inch of its length, a vernier caliper should be accurate within 0.001 of an inch. In any 12 inches, it should be accurate within 0.002 of an inch. Inaccuracy increases about 0.001 of an inch for every additional 12 inches. The accuracy of measurements made with a vernier caliper is dependent on the user's ability to feel the measurement. Because the jaws are long, and there is the possibility of play in the adjustable jaw, especially if an excessive measuring pressure is used, it is necessary that one develop an ability to handle the vernier caliper. This touch may be acquired by measuring such known standards as gage blocks and plug gages. There are various applications of the vernier caliper. In figure 47, view A, on the following page, the machinist is checking the outside diameter of a part. One hand is holding the stationary jaw to locate it, while the other hand operates the adjusting nut and moves the sliding jaw to the workpiece. The same procedure is used in view B in checking the inside dimension.

(4) *Care.*

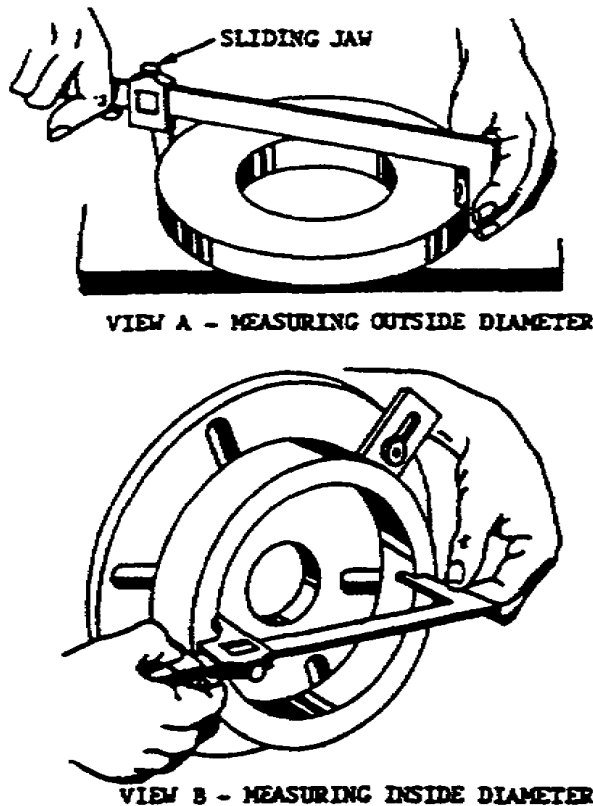
(a) The accuracy of the vernier caliper depends on the condition of fit of the sliding jaw, and on the wear and distortion in the measuring surfaces. The fit of the sliding jaw should be such that it can be moved easily and still not have any play. It may be adjusted by removing the gib in the sliding jaw assembly and bending it. The function of the gib is to hold the adjusting jaw against the inside surface of the blade with just the right amount of pressure to give it the proper friction.

(b) Wear on the jaws of the vernier caliper is mostly at the tips where most of the measurements

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are made. A certain amount of this wear may be taken up by adjusting the vernier scale itself. This scale is mounted with screws in elongated holes which permit it to be adjusted slightly to compensate for wear and distortion. When the error exceeds 0.0002 of an inch, either in parallelism or flatness, the caliper should be returned to the manufacturer for reconditioning. Wear on the jaws can best be checked by visual means and by using measuring rolls or rings of known dimensions.

FIGURE 47. USING A VERNIER CALIPER.



(c) When the machinist is finished using the verniers for the day, he should coat all metal parts with a light coat of oil to prevent them from rusting. Calipers should be stored in separate containers that are provided for them. The graduations and markings on all calipers should be kept clean and legible.

(d) Care should be taken to prevent dropping any caliper, as small nicks or scratches can cause

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inaccurate measurements. Also protect the vernier caliper points from damage.

(e) Vernier gages also require careful handling and proper maintenance if they are to remain accurate. The following instructions apply to vernier in general:

1 Always loosen the binding screws before attempting to move the sliding arms.

2 Never force a gage into position. Forcing, besides causing an inaccurate reading, is likely to force the arms out of alignment.

3 When taking a measurement, use only gentle pressure on the fine adjustment screw. Heavy pressure will force the two scales out of parallel.

4 Prior to putting a vernier gage away, wipe it clean and give it a light coating of oil. (Perspiration from the hands will cause the instrument to corrode rapidly.)

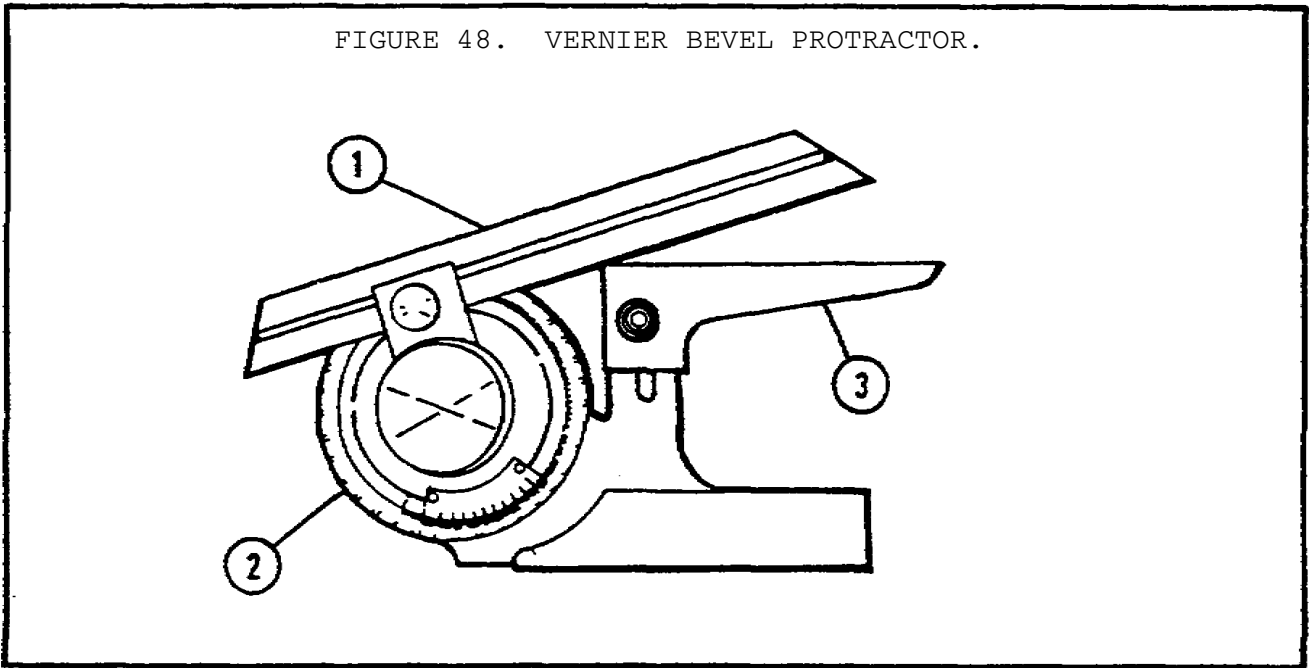
1. *Universal Vernier Bevel Protractor.*

(1) *General.* The universal vernier bevel protractor (figure 48 on the following page) is used to lay out or measure angles on a workpiece to very close tolerances. It reads to 5 minutes or $1/20^\circ$ and can be used completely through 360° . The protractor is made up of an adjustable blade (1) and a graduated dial (2) which contains a vernier scale. The bevel protractor is used to establish an angle and determine its relationship to the other surfaces. The acute angle attachment (3) is used for measuring acute angles separately. The tool can be laid flat upon paper or on the workpiece. The dial is held rigidly in position and the blade can be moved back and forth and clamped independently of the dial. Interpreting the reading on the protractor is similar to the method used on the vernier caliper.

(2) *Reading the Protractor Vernier Scale.*

(a) *General.* The protractor vernier scale indicates every five minutes ($5''$) or $1/20^\circ$. Each space on the vernier scale is 5 minutes less than two spaces on the main scale. When the zero on the vernier scale exactly coincides with a graduation

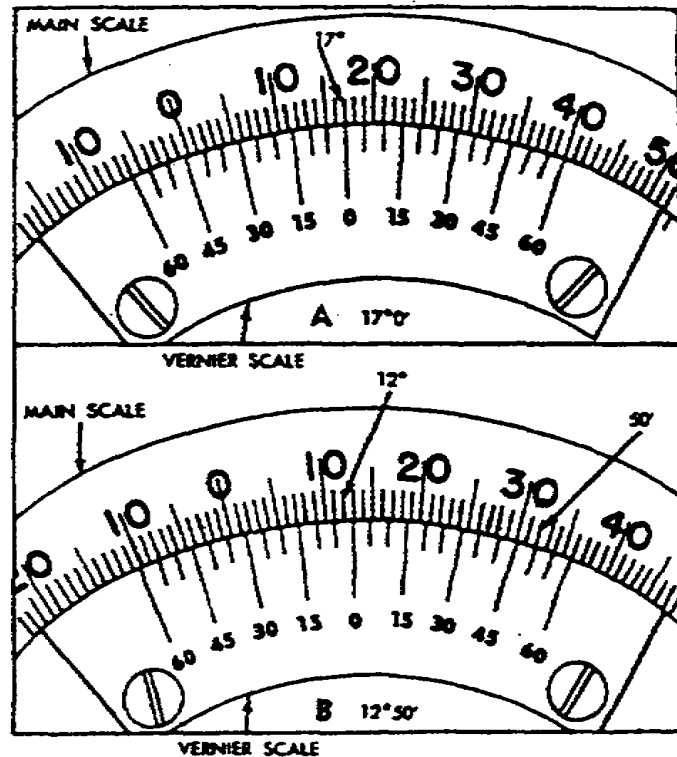
FIGURE 48. VERNIER BEVEL PROTRACTOR.



on the main scale, the reading is in exact degrees, as shown in figure 49, view A, on the following page. When the zero of the vernier scale does not exactly coincide with a graduation on the main scale, check the graduations on the vernier and locate one that lines up with a graduation on the main scale.

(b) Once this graduation is located it will indicate the number of 12ths of a degree in units of 5 minutes that is to be added to the whole degree reading. Example: Figure 49, view B, shows the zero on the vernier between 12° and 13° on the main scale. Counting to the right from the 0 on the main scale, the 0 on the vernier has moved 12 whole degrees. Reading in the same direction (to the right), note that the 10th line of the vernier scale coincides exactly with a line on the main scale. The tenth line of the vernier indicates 50 minutes ($50''$), since each line indicates 5 minutes. Now add 50 minutes to the 12° and the final reading is 12° and 50 minutes. Since the spaces, both on the main scale and the vernier scale, are numbered both to the right and to the left from zero, any angle can be measured. The readings can be taken either to the right or to the left, according to the direction in which the zero on the main scale is moved.

FIGURE 49. PROTRACTOR VERNIER SCALE READINGS.



(3) *Use and Application.* The bevel protractor is used to measure the angular clearance on a ring gear (figure 50, view A, on the following page). The bevel protractor can be used to establish an angle and determine its relationship to other surfaces as shown in figure 50, view B. The acute angle attachment is connected to the slotted extension of the dial and is used to accurately measure acute angles as shown in figure 50, view C.

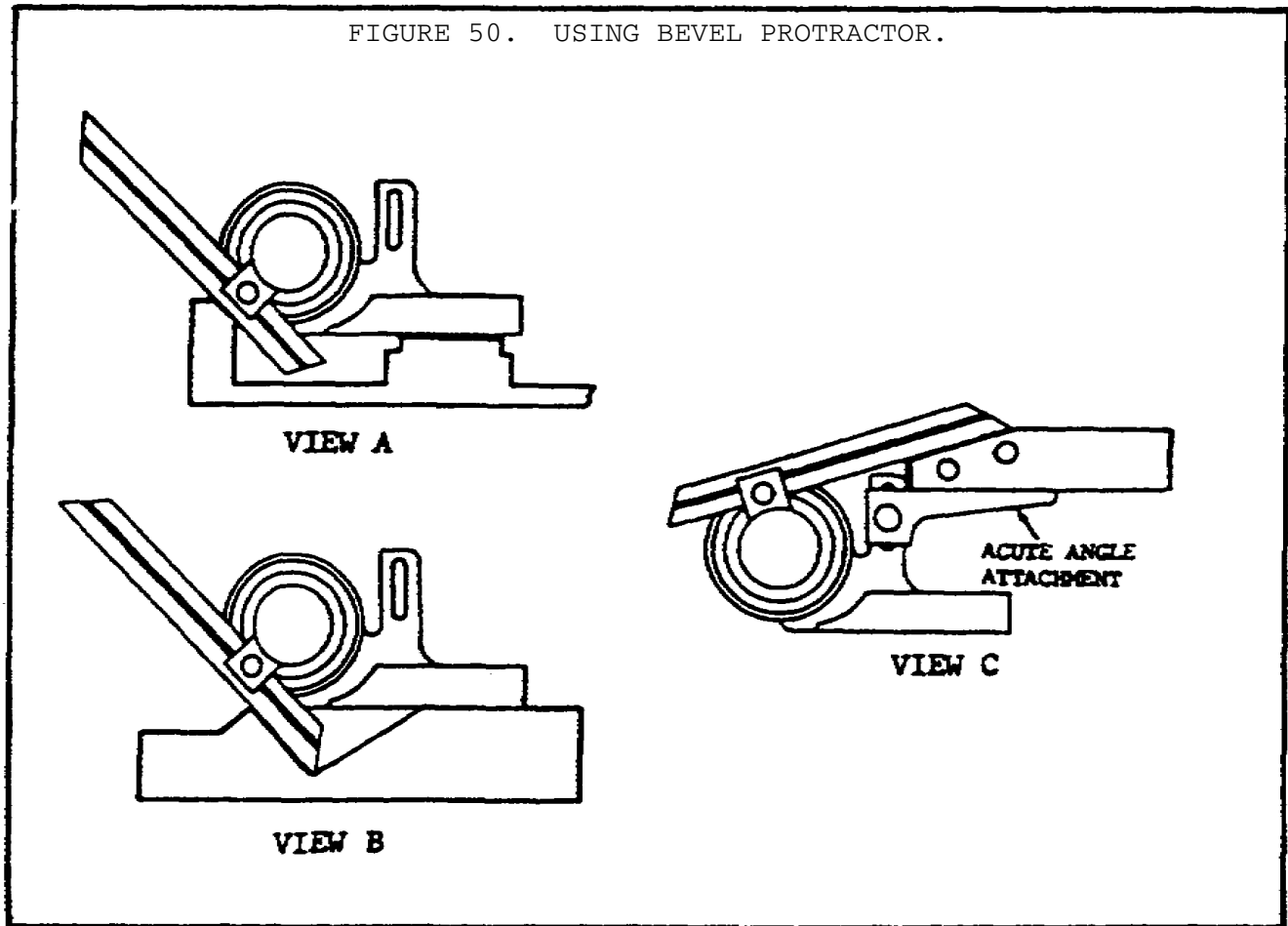
m. *Gear Tooth Vernier Caliper.*

(1) A gear tooth vernier (figure 51, views A and B, on page 80) is used to measure the chordal thickness of a gear tooth on the pitch circle and the distance from the top of the tooth to the pitch chord (chordal addendum) at the same time. The vernier scale on this tool is read in the same way as other verniers, except that graduations on the main scale are 0.020 inch apart instead of 0.025 of an inch.

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(2) In order to understand measurements made with the gear tooth vernier, the machinist should know gear tooth terminology. The following terms (figure 52 on page 81) are used to describe gear and gear teeth (symbols in parentheses are standard gear nomenclature symbols).

(a) *Outside Circle (OC)*: The circle formed by the tops of the gear teeth.



(b) *Outside Diameter (OD)*: The diameter the gear blank is machined to; the overall diameter of the gear.

(c) *Pitch Circle (PC)*: (1) Contact point of the mating gears, basis of all tooth dimensions. (2) Imaginary circle one addendum distance down the tooth.

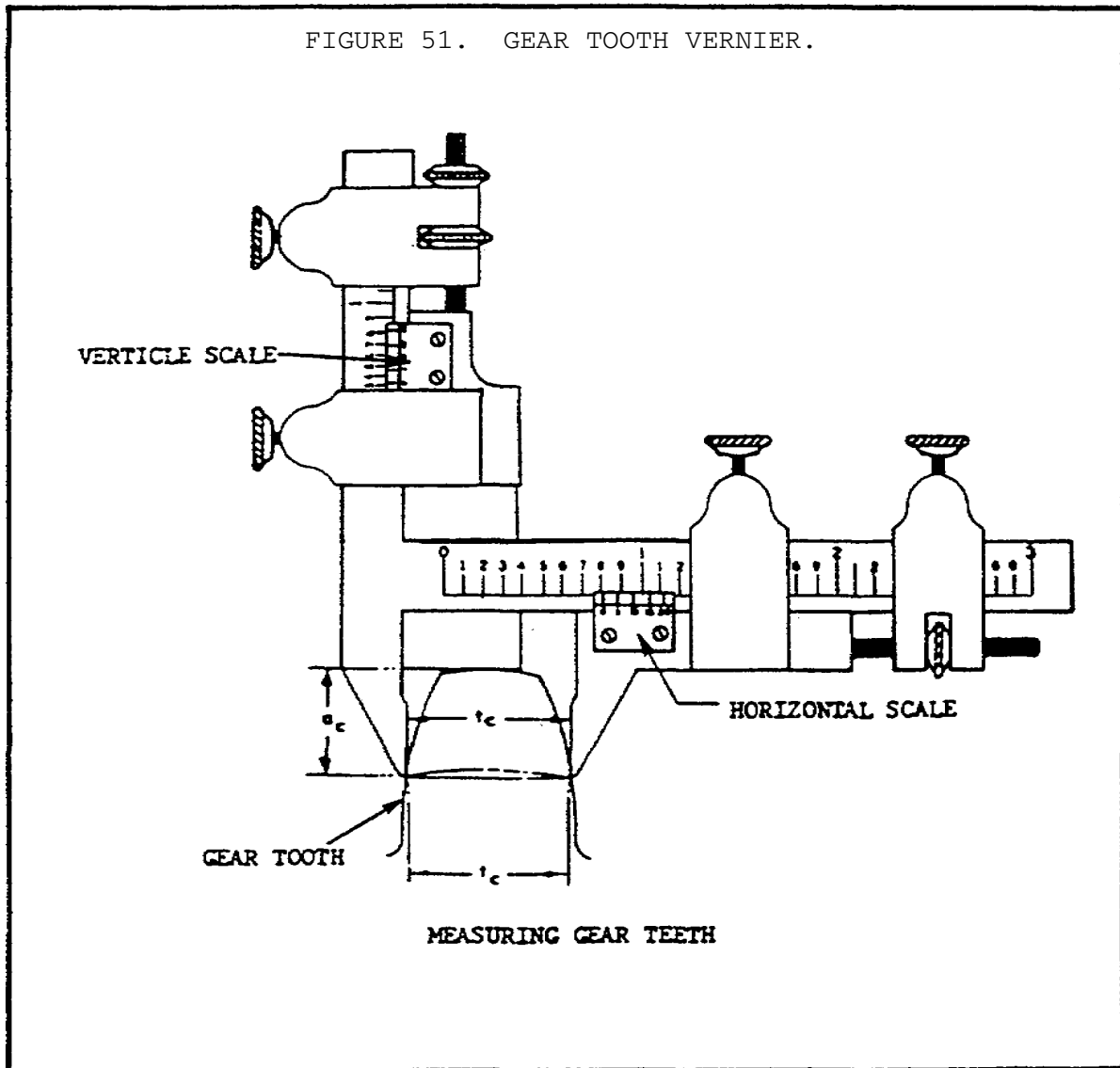
(d) *Pitch Diameter (PD)*: (1) The diameter of the pitch circle. (2) In parallel shaft gears, the pitch diameter can be determined directly from the center to center distance and the number of teeth.

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(e) *Root Circle (RC)*: The circle formed by the bottoms of the gear teeth.

(f) *Root Diameter (RD)*: The distance from one side of the root circle to the opposite side passing through the center of the gear.

(g) *Addendum (ADD)*: The height of that part of the tooth extending outside the pitch circle.



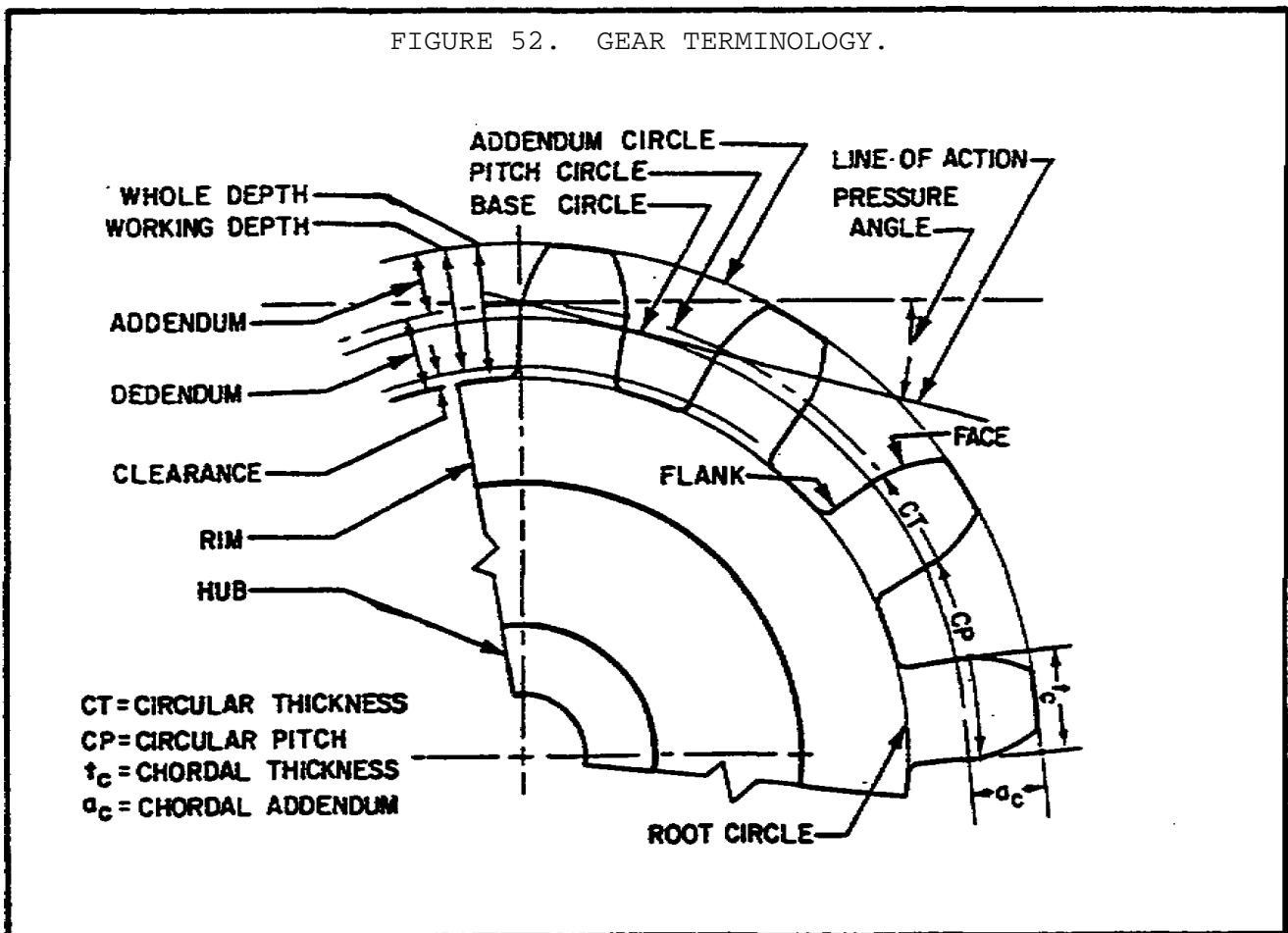
(h) *Circular Pitch (CP)*: The distance from a point on one tooth to a corresponding point on the next tooth is measured on the pitch circle.

(i) *Circular Thickness (CT)*: (1) One-half of the circular pitch.
 (2) The length of the arc between the two sides of a gear tooth on the pitch circle.

(j) *Clearance (CL)*: The space between the top of the tooth of one gear and the bottom of the tooth of the mating gear.

(k) *Dedendum (DED)*: (1) The depth of the tooth inside of the pitch circle.
 (2) The radial distance between the root circle and the pitch circle.

(l) *Whole Depth (WD)*: The radial depth between the circle that bounds the top of the gear teeth and that which bounds the bottom.



(m) *Working Depth (WKD)*: (1) The whole depth minus the clearance.
 (2) The depth of the engagement of the two mating gears; the sum of their addendums.

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(n) *Chordal Thickness (t_c)*: (1) The thickness of the tooth measured at the pitch circle. (2) The section of the tooth that is measured to see if the gear is cut correctly.

(o) *Chord Addendum (a_c)*: The distance from the top of a gear tooth to a chord (pitch chord) subtending (to extend under) the intersections of the tooth thickness arc and the sides of the tooth (used for setting the gear tooth vernier calipers for measuring tooth thickness).

(p) *Diametral Pitch (DP)*: (1) The most important calculation, it regulates the tooth size. (2) The ratio of the number of inches of the pitch diameter. (3) The number of teeth that will go into each inch of the pitch diameter evenly.

(q) *Number of Teeth (NT)*: The actual number of teeth of the gear.

(r) *Backlash (B)*: The difference between the tooth thickness and the tooth space of the engaged gear teeth at the pitch circle.

(3) *Use and Application*. When selecting gear cutters for a gear having 24 teeth, a number 5 cutter would be used. The reason for this is that this particular cutter will cut all gears containing from 21 to 25 teeth. However, for measuring these teeth, certain values must be known. To check the dimensional accuracy of gear teeth, a gear tooth vernier caliper is used (figure 51, view B, on page 80). The vertical scale is adjusted to the *Chordal Addendum (a_c)*, and the horizontal scale is used for finding the *Chordal Thickness (t_c)*. Before calculating the chordal addendum and performing any measurements, the tooth thickness (t) and addendum (a) must first be determined. The following formulas must be applied:

(a) The formula for the addendum is

$$ADD = \frac{PD}{NT}$$

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(b) The formula for the chordal thickness is

$$t_c = PD \sin \left(\frac{90^\circ}{NT} \right)$$

4. Conclusion

Measuring workpieces and determining the correct amount of material needed to be removed is one of the tasks performed by the machinist. The machine, with the use of a machine tool, can only remove the correct amount of stock as determined and programmed by the operator. Therefore, as a machinist, it is essential that one becomes proficient in the use and care of precision measuring tools and gages in order to machine parts and components to the correct degree of accuracy. Undersized or oversized work is not acceptable in most machine shops and waste amounts to money lost. It is hoped that the information in this lesson will enlighten you on the proper use and care of the various measuring tools and gages.

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PRACTICAL EXERCISE 1

1. Instructions

On a plain piece of paper, respond to the requirement below.

2. Requirement

Successful completion of this exercise provides indication of success in the subcourse. Check your answers against those provided on the answer page following the questions.

- a. What is the definition of a fit?
- b. Running or clearance fits have how many classes?
- c. What are three types of transitional fits?
- d. What is the general rule for determining how much is allowed for a force or a shrink fit of internally bored parts?
- e. On an interference allowance fit between mating parts, which component can be smaller but not larger than the basic dimension?
- f. What is a gage?
- g. Which device is the vernier height gage placed on to achieve the most accurate results in transferring measurements?
- h. Which gage is used to gage larger holes and transfer their measurements to be checked by an outside micrometer?
- i. What type of GO, NO GO gage is provided with four pins to check dimensions between flat parallel or cylindrical work?
- j. How does the "scale" differ from the rule?
- k. Which angles are checked by the center gage?
- l. Which tool is used to check an inside cylinder for out-of-roundness?

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- m. Which type of gage is used to check cylindrical shaped machined diameters by sliding the gage over the surface?
- n. Which measuring tool is used to check outside micrometers for accuracy?
- o. What factor has a sizable affect on the readings of gage blocks?
- p. What is another name for an outside micrometer?
- q. How many threads per inch does a standard micrometer have?
- r. Which type micrometer is used to check the wall thickness of bored cylinders?
- s. When reading a standard vernier caliper, the steel rule or the main scale is graduated into how many thousandths of an inch?

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LESSON 1. PRACTICAL EXERCISE - ANSWERS

Requirement

- a. The amount of tightness or looseness between two mating parts.
- b. They range from class 1 to class 9.
- c. Locational clearance, locational transitional, and locational interference fits
- d. Approximately 0.0015 inch per inch of diameter
- e. The opening for the shaft
- f. Any device which can be used to determine the size or shape of an object
- g. Surface plate
- h. Telescoping gage
- i. Snap gage
- j. The rule is graduated into regular spaces, where the graduations on the scale are either smaller or larger than the measurements indicated.
- k. Sixty-degree threads and lathe centers
- l. Dial boregage
- m. Ring gage
- n. Standard
- o. Temperature
- p. "Mike"
- q. 40 threads per inch
- r. Ball micrometer
- s. 0.025 of an inch (25)

REFERENCES

PRECISION MEASURING AND GAGING - OD1642 - REFERENCES

REFERENCES

The following documents were used as resource materials in developing this subcourse:

DA Pam 738-750
TM 9-243