Fundamentals of Mechanical Inspection

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Fundamentals of Mechanical Inspection

FOR

Trainees and Junior Inspectors

BY

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PREFACE

The high precision demanded in airplane engine making is illustrated by the fact that 47,000 *gaging operations are needed in making a single Rolls-Royce-Merlin engine.*—NEWS ITEM.

The necessities of present-day industrial production are placing heavy demands on the nation's man power and woman power, resulting in the induction into mechanical trades of tens of thousands whose background and training have been far removed from such a field of endeavor.

For most of these, there is available a vast and ever-increasing library of handbooks, textbooks, and other sources of useful information, which provide in exhaustive detail the essential data regarding any one of a hundred trades. But in the important field of quality control known as *mechanical inspection*, little is found to give the beginner an adequate conception of the why and how of this branch of the machine trades.

This volume is not offered as a definitive and complete handbook of inspection. It is rather a compilation of classroom discussions on some of the more fundamental phases of the subject, wherewith many hundreds of men and women, young and old, have been introduced to and launched upon interesting careers in a highly essential industry. Throughout the country many thousands more will engage in similar work in the near future. The purpose of this handbook is to assist them in gaining a better understanding of their function as inspectors as well as to serve as a ready reference book as they progress.

In the preparation of this book it has been necessary to make extensive use of photographs to illustrate and amplify the text. Valuable assistance in this respect has been rendered by those mentioned below. Following their names, the illustrations they have kindly contributed are listed.

Brown & Sharpe Mfg. Co., for Figs. 29*a*, 29*b*, 33, 50, 53 to 56, 89, 92 to 95, and 98.

The Sheffield Corporation, for Figs. 7, 8, 80 to 83, 87*a*, 87*b*, and 88.

Sperry Gyroscope Co., Inc., for Figs. 20, 43, 70, 71, 97, 99 to 102, 104, and 105.

Federal Products Corporation, for Figs. 70, 72 to 74.

The Trico Co., for Figs. 84, 85 and 86.

Taft-Peirce Mfg. Co., for Figs. 90 and 91.

In addition, the United States Office of Education has supplied many excellent views adapted from their training films for industry, which are gratefully acknowledged with each illustration so obtained.

ROLLAND JENKINS.

BROOKLYN, N.Y.,
December, 1943.

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Fundamentals of Mechanical Inspection

CHAPTER I

MECHANICAL INSPECTION: WHAT AND WHY

The term *inspection* today has a very broad application, and the word is often used without any qualifying adjective better to define its meaning. For the purpose of the present handbook, however, "inspection" refers to the examination of constituent parts of mechanical assemblies both visually and by means of measuring instruments, gages, fine tools, etc., to ensure the proper functioning of those parts when used for the purpose for which they were designed and manufactured.

On the inspector therefore rests the responsibility for determining whether the part meets certain conditions that might be broadly summarized as follows:

1. Is the part correctly formed and accurately dimensioned in accordance with the blueprint specifications?
2. Is the part free from fault as regards defects in the material, improper machining, or accidental injury?
3. Have all the processing and finishing operations been performed?

Careful and intelligent inspection is of the utmost importance in these days. This may be illustrated by many actual cases in which inspectors have failed to exercise the utmost vigilance. Mechanical failure or improper performance at a critical time has resulted, causing destruction of important equipment and even death to valuable military personnel. One such case concerns the crankshaft of an airplane motor, in which there were several drilled holes to permit the circulation of lubricating oil. The blueprint called for the removal of the rough edges left by the drilling operation. These rough edges are known as *burrs*, and every engineer and designer knows that burrs are a frequent source of mechanical failure through fracture of the metal, originating in the tiny cracks that always exist when burrs are present. The machinist failed to smooth off one of the several holes, the inspector failed to note the omission, and when the motor had been in service for a little time the crankshaft broke, the motor failed, and the plane crashed, killing the two pilots. Examination of the motor parts disclosed that, every time the motor had been operated, the strain had caused the fracture in the metal to become a little larger; and, when it had extended a certain distance into the metal, the shaft gave way and the motor was wrecked as a consequence.

Another case concerns a complex mechanism for antiaircraft defense. This instrument controls the pointing of the guns. It is contained in a watertight case to protect the mechanism from rain and dampness. The operators of the instrument, noting that the action was sluggish, decided that some of the parts had been damaged and removed one of the side plates to investigate. Within the case they found a large nest of mud wasps in the midst of the many gears and shafts. This nest was clogging the machine so that the parts could not turn freely. The wasps had found an opening where a loose screw had fallen out. The inspector whose duty it was to check all the screws for tightness had failed to note this one loose screw. Luckily the trouble was discovered and remedied in time to forestall any serious results, but this particular antiaircraft battery was located in one of the most vital areas of the American defense system, and if there had been occasion to repel an air attack before the trouble had been found, the results of the inspector's laxity might have been disastrous.

But, to get back to the purpose of inspection, "Is the part correctly formed and accurately dimensioned?" This brings up several matters for explanation. First of all, the engineer or designer determines the material, shape, and dimensions of each part so that the part should perform its function properly. In order to do this, it has to fit and work with the other component parts with a degree of accuracy which is largely determined by the ultimate precision required of the assembled unit. In the past, if any parts did not fit or function properly, the mechanic in assembling the various parts could make certain corrections and selections of mating parts to bring about satisfactory per-

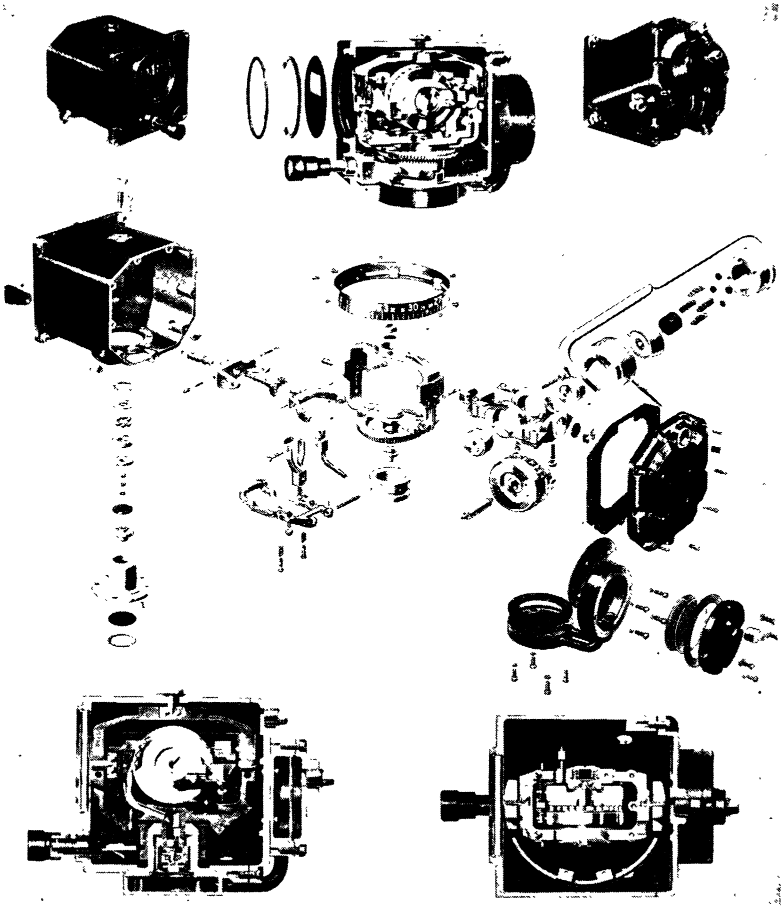


FIG. 1.—"Exploded" view of an aeronautical instrument. (*Courtesy of Ternstedt Manufacturing Division, General Motors Corporation.*)

formance. But today mass production demands that all unnecessary waste of time and material be eliminated. Then too the individual parts are often manufactured in many widely separated places and shipped in to a central assembly point. For this reason it is desirable to have the duplicate parts so accurately dimensioned and so uniform in size and shape that any part will fit properly into any other part or parts for which it is intended. In other words, the various parts should be interchangeable one with another; and, in assembling the complete mechanism, it should not be necessary to match up various parts by the selective, or cut-and-try, method. Consider the instrument illustrated in Fig. 1, for instance. It contains a relatively simple mechanism of about 150 component parts. The most important single part is the rotor of the gyroscope, which in use revolves several thousand times per minute, exerting a considerable force. Naturally, a high degree of precision is necessary to ensure proper operation of the instrument. That means that the parts must be made with great exactitude. In some of the parts, a variation of one-tenth a hair's breadth could not be tolerated. Nevertheless, some of the parts may be made in Ohio, some others in New Jersey, others in New York or Michigan, and they must all be counterparts of the original element of the mechanism.

Here is where the inspector comes into the picture. One of his functions is so to control the accuracy of the finished parts that all of them will interchange. This is known as *interchangeability*, a term not uncommon in everyday life, but in the mechanical industry it has a rather specific meaning, and it is in fact of utmost importance in mass production.

Today almost every industrial plant is engaged in the production of instruments of warfare, especially guns of all types and accessory equipment, and without interchangeable parts production would be enormously curtailed. By a striking coincidence, interchangeable manufacture was first practiced in this country in the production of guns. Eli Whitney, the inventor of the cotton gin, who also had a gun factory, received an order for 15,000 muskets. He determined to make these so that any part of any gun would fit any other of his own guns. Up to that time craftsmen made products in their entirety, fitting each element in its place. No two products were exact duplicates, and when any repairs were needed the device had to be returned to its maker to have a new part fitted. At that time "the thickness of a worn shilling" was judged to be a precise standard. But Whitney set up his own standards, made his own gages, and produced his interchangeable muskets. Of course guns made from the same drawings in another shop were different, and the parts would not interchange, because the other shop did not use the same standards of measurement. By gradual processes, standards were adopted and made available, measuring equipment was developed, and finally gages and instruments appeared that were both speedy and accurate. Modern inspection makes it possible to replace a damaged or missing part with the certainty that the new part will fit into its place without alteration.

To check the accuracy of dimensions, the inspector makes use of various fine tools, measuring instruments, and gages of many types. If the piece is dimensioned according to a system that permits liberal variations in measurement, these dimensions can be checked with "nonprecision" tools such as the 6-in. scale, or outside and inside calipers. (Such dimensions are sometimes referred to as "scale dimensions," and they can be read directly with the unaided eye.)

Finer and more precise dimensions such as thousandths and ten-thousandths of an inch cannot be read without amplifying or magnifying the dimension through various means such as micrometers, and numerous other mechanical, optical, and electrical devices.

One often hears a mechanic claim that he is able to *read* in thousandths of an inch visually, but it is doubtful that anyone has the ability to do this accurately. Perhaps a skilled man can by his sense of feel determine a measurement, with an outside or inside caliper for instance, with an accuracy of plus or minus one or two thousandths of an inch, but *measuring* such dimensions visually is a very different matter. A thousandth of an inch is really a very small dimension. A sheet of cellophane, for instance, such as that used for wrapping cigarettes, is approximately 0.001 in. thick. However, inspectors today are required as a matter of regular routine to measure differences in dimension which amount to only one-tenth the thickness of a sheet of cellophane, or 0.0001 in.

In addition to checking the dimensions of a part, the inspector makes a visual examination to determine if any defects are present, which may be due to blowholes or "inclusions" in a casting, tool marks, burrs, or rough spots on machined surfaces, crossed threads, failure of a surface to "clean up," accidental injuries that may have occurred in handling or transportation, etc.

In most plants, the inspector also checks all tools used for machining purposes and the hand tools used in manufacturing. When a shipment of new micrometers or a quantity of reamers is received, for instance, the inspector checks them against standards and tests for imperfections and any other failure to meet the strict requirements. Periodical checks are also necessary for tools and gages of all types used by machinists and inspectors, to guard against undue wear and damage to or deformation of the tools. Machining jigs and fixtures have to be checked with extreme care when new and at frequent intervals during use. Such precautions tend to prevent the defects and dimensional variations that might result if machining fixtures were used without the inspector's approval or if tools and gages went unchecked.

EXAMPLE OF INSPECTION ROUTINE

How are mechanisms developed? How do they come into being? Perhaps these and similar questions have arisen many times in the minds of people who are not acquainted with the functions of various divisions of a modern manufacturing plant.

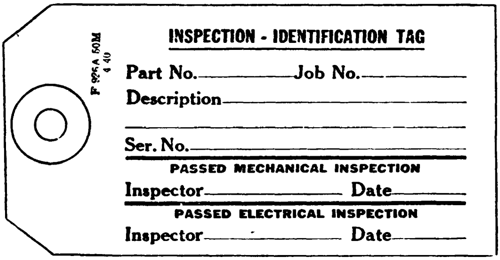
First of all comes the idea in the mind of an inventor or engineer. He writes out a description or possibly makes a rough drawing of the mechanism or device. He then calls in the designer, who, after determining the form and function of the device, makes a drawing of each separate part of the mechanism and assigns each part a number and name. This drawing shows all the necessary details for a machinist to produce the finished part—the material to be used, the form or shape of the part, and its various dimensions. Copies of the drawing, known as *blueprints*, are available to all who work on the part, including the inspectors who examine it. The blueprint is the inspector's source of most information regarding the part. On it is found details of material, dimensions, finish, and in many cases data as to processing.

Seldom does one man make the part, using only one tool or machine. Generally the parts are made step by step, each step being known as an *operation*. The manner in which these operations shall be performed, the machines or tools that shall be used, and the sequence of the operations will usually have been worked out by the methods engineers, and the plan that governs the work is known as an *operation sheet*.

The operation sheet accompanies the blueprint and each lot of parts as it progresses through the shop, serving as a guide for both machinist and inspector. In addition to the machinist's operation sheet, many plants have special operation sheets detailing the inspection procedure, such as a list of necessary tools and gages, the most efficient and accurate method of checking various dimensions, etc. If the plant is large and well organized, the work may also be governed by certain rules known as *standard practice*, which may be, in whole or in part, made up of procedures and methods worked out by the several societies and committees such as the American Standards Association, Society of Automotive Engineers, American Society for Testing Materials, etc.

Each part is identified by a name and a number, which are also shown on the blueprint and operation sheet. When work is started on a "lot" or "job" of a certain part, the "first piece," on which the machinist has performed the first operation, is submitted to an inspector who determines if that operation has been performed in accordance with the information given in the blueprint and operation sheet. If the inspector approves the piece, the workman then proceeds to complete that operation on all the pieces in the lot. If the inspector does not approve the part, the machinist makes whatever corrections are necessary until the piece is proper.

In most cases, the "first piece" inspection is made in the inspection division adjacent to the machines and by the group of inspectors who handle the completed jobs. In some instances, however, when heavy parts are being machined or pieces cannot readily be removed without disturbing the "setup" of the machine, floating or floor inspectors check the operations on the machines. Floating inspectors also check the assembly of large and heavy apparatus.



F 925A 50M
4 40

INSPECTION - IDENTIFICATION TAG

Part No.__________Job No.__________

Description____________________

Ser. No.____________________

PASSED MECHANICAL INSPECTION

Inspector__________ Date__________

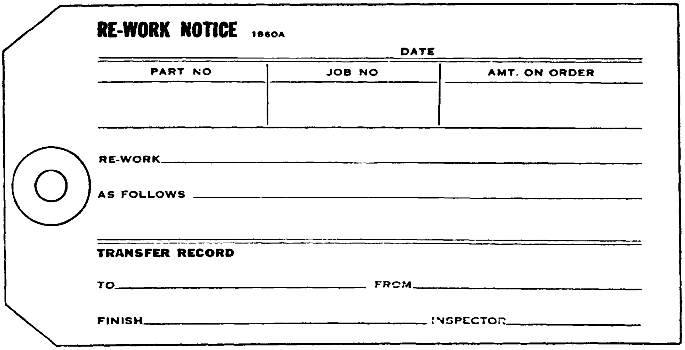
PASSED ELECTRICAL INSPECTION

Inspector__________ Date__________

FIG. 2.—Identification tag for parts in process of inspection.

The work proceeds in the same routine until all the operations are completed or in some cases only until a certain number and type of operations have been finished, and then all the pieces of that lot are sent to the inspection station. Here the inspection foreman decides, on the basis of his previous knowledge of the job and its difficulties, whether it should be given a 100 per cent inspection or a "spot check." The latter is done by selecting a certain percentage of the parts for a complete check, or by checking one or two features of each piece and then deciding by the results of a partial check whether the lot needs a more thorough inspection.

If any pieces are found to be defective in any way, such pieces are tagged with a statement of the defects. If the defects can be corrected, a "rework notice" is attached, and the parts are sent back to the section from which they were received (Fig. 3). If the defects are obviously such that the part cannot be corrected, it is tagged as "rejected material" (Fig. 4), but, if the inspector is uncertain as to the importance of the defects, a report is made to the inspection foreman. He consults with the engineers, and they make a decision as to acceptance or rejection of the part (Fig. 5). All pieces that are acceptable are then signed



RE-WORK NOTICE 1860A

DATE

PART NO	JOB NO	AMT. ON ORDER

RE-WORK

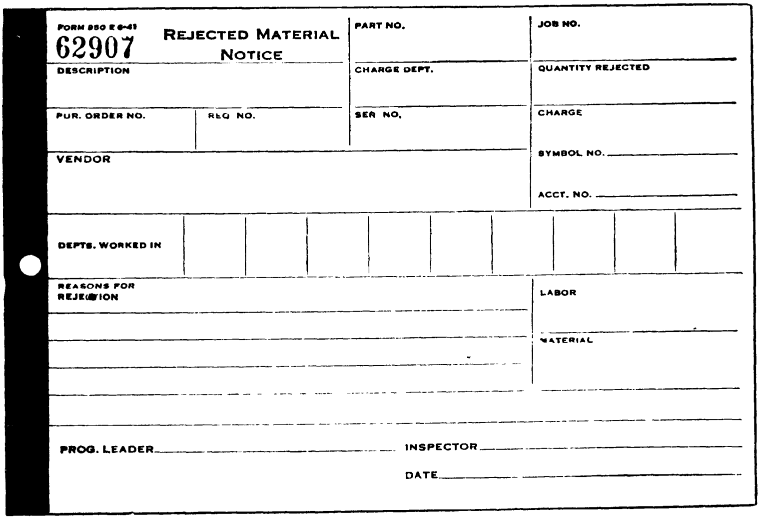
AS FOLLOWS

TRANSFER RECORD

TO FROM

FINISH INSPECTOR

FIG. 3.—Rework tag for incorrect parts that can be made to conform to blueprint specifications.



FORM 850 E 6-41

62907

REJECTED MATERIAL NOTICE

PART NO.

JOB NO.

DESCRIPTION

CHARGE DEPT.

QUANTITY REJECTED

PUR. ORDER NO.

REQ NO.

SER NO.

CHARGE

SYMBOL NO.

VENDOR

ACCT. NO.

DEPTS. WORKED IN

REASONS FOR REJECTION

LABOR

MATERIAL

PROG. LEADER

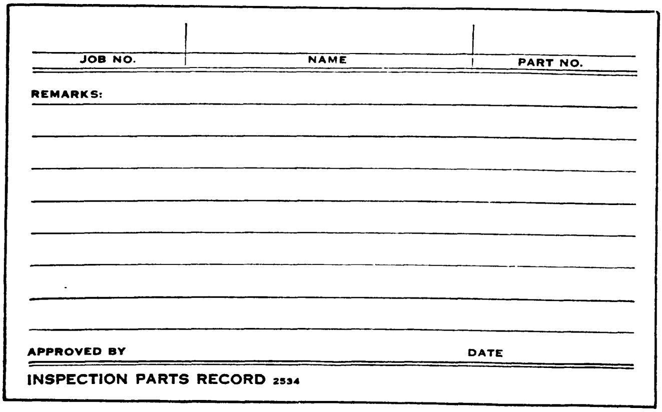
INSPECTOR

DATE

FIG. 4.—Tag to accompany rejected parts.

for by the inspector and routed according to the disposition of the job.

It is quite obvious that inspection is an important function in mass production, and the universal adoption of high-precision methods in manufacture has made inspection one of the most necessary of the many operations involved in modern industrial production. Formerly manufacturers looked upon inspection as a necessary evil, but today, with the need of utmost speed and efficiency in production, the inspector performs an important function in his determination of the accuracy and suitability of the multitude of parts that go to make up the thousands of different mechanisms required for our daily comfort and convenience as well as the more urgently necessary instruments of war.



JOB NO. | NAME | PART NO.

REMARKS:

APPROVED BY

DATE

INSPECTION PARTS RECORD 2534

Fig. 5.—Form to accompany questionable parts.

It is also obvious that inspectors should function as thoroughgoing, careful, and accurate members of their particular organization. The safety and well-being of a whole community or indeed a whole nation could be endangered by a careless or indifferent inspector. Be sure to do your job thoroughly—do all that is required of you, and then some. Lives may depend upon it—and more.

Questions

1. What are the three general requirements that must be surveyed in the inspection of a mechanical part?

2. What source of information describes the requirement of a part?

3. An inspection for visible defects in material and for defects caused by improper machining or accidental injury is called ______ inspection.

4. An inspection with measuring instruments or gages to ensure correctness of dimensions is called a ______ inspection.

5. What is the meaning of *interchangeability?*

6. How is interchangeability made possible?

7. Can a difference of 0.001 in. be measured accurately with a 6-in. steel rule?

8. What is the thickness of a sheet of cellophane?

9. When is a *first-piece inspection* made?

10. The inspection of parts while they are still secured in the processing machines is called ______ inspection.

CHAPTER II

THE BASIS OF MEASUREMENT

For the purpose of inspection, no very extensive knowledge of the development of standards of linear measurement is necessary, because practically all inspection operations that involve the use of measurement of dimensions are based on the inch and fractional and decimal divisions thereof. However, it may not be amiss to give a brief outline of the background upon which our modern system of linear measurement has been built up.

From biblical records, we know that man measured things he made and used, even before the time of written history. The description of the Ark and of Solomon's Temple show the use of a definite system of measurements.

Precision measurement is often considered as a modern development, and in a broad sense this is so. But even today there still exist some examples of the use of precision measurement on a colossal scale, dating back many thousands of years. As one author has expressed it, in these examples we have precision of a type that characterizes the work of modern opticians but on a scale of acres rather than feet and inches. One such example is the Great Pyramid in Egypt, built about 3750 B.C. In laying out and constructing this pyramid, as well as many other structures of that ancient land, some methods of measurement were used which excel all but our most exacting work of today.

If we suppose that drawings were made that served the purpose similar to that of our blueprints, it is quite likely that one of them would have been similar to Fig. 6.

Now, taking the dimension of the four sides, 9,068 in. (755 ft.), we find a variation that amounts proportionately to what we should consider very small today, even in our most precise machine work, which has been ground and lapped. For instance, a variation of 0.6 in. in 9,068 in. is approximately equivalent to 1.00000 in. ±0.00006, which is classified as "superprecision" today. Of course, in laying out four sides of a square, it would not be difficult to measure the length of the sides with great exactness, but the matter of squareness of the corners makes the problem quite difficult.

In mechanical inspection, a vernier protractor is used to lay out and check angular dimensions. Angular dimensions refer to the amount of divergence between two straight lines that form an angle. This divergence is expressed in degrees (°), of which there are 360 in a complete circle. Single degrees are divided in 60 parts or minutes (′), and single minutes are divided into 60 seconds (″). Each second therefore represents 1/1,296,000 of a circle. A vernier protractor has an accuracy of ±5′. The "error" of 12″ which is found in the Great Pyramid is twenty-five times less than an angle one might measure or lay out with a vernier protractor. Then there are other features of the pyramid that are characterized by great accuracy; for instance, the huge stones that formed the facing. These stones, after being surfaced, were placed end to end, and they fit together so closely that a piece of heavy paper about 0.005 in. thick cannot even today be inserted between adjacent surfaces of the stones. Most of these facing stones were removed some hundreds of years ago to construct many of the mosques and other large buildings in the present city of Cairo, but enough remain today to show us what the original job was like.

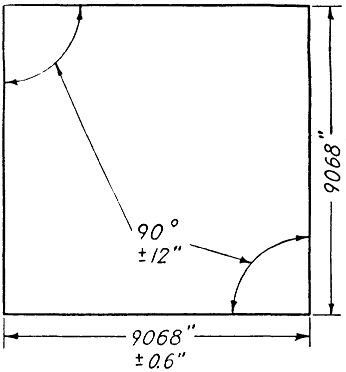


Fig. 6.—Plan view of the base of the Great Pyramid.

Going even further, if we examine the stones forming the walls of the Great Hall inside the Pyramid, we find huge stones that are so accurately finished and set together that there is no apparent joint where the individual stones meet. So here we have a structure weighing eight million tons which has stood for over 5,000 years without deteriorating to any great degree. Surely this is, among other things, a monument of precision measurement on a grand scale.

Behind the knowledge that enabled the pyramid builders to carry out their work with such accuracy, there must have been many hundreds of years of experience; therefore the beginning of precision measurement cannot be dated with any degree of exactness. However, before and during the Middle Ages there was little occasion for precision, and as a consequence we find systems of dimensioning and measuring that in most cases were directly related to parts of the human body. None of these was an unvarying and absolute measurement, because no "standards" existed. In fact the variations must have been quite considerable. As examples we have the following:

Cubit	About 20½ in.
Span	About 9 in.
Palm	About 3 in.
Digit	About ¾ in.
Thumbnail	About 1 in.

and—a little later—foot and yard.

It is quite obvious that these were most unreliable methods of measurement. The cubit was the length of the forearm from the elbow to the tip of the middle finger; the span was the distance covered by the spread fingers; the palm was the width of a hand (the "hand" is still a unit in measuring the height of horses, although the "hand" is four inches instead of three); the digit, the width of a finger; the thumbnail, a twelfth part of a foot (the Latin word for which, *uncia*, by a slight change becomes *inch*). The foot was roughly standardized in England in the sixteenth century by averaging the length of the feet of 16 men. The yard was defined in the twelfth century as the distance from the end of the nose of Henry I of England to the tip of his middle finger. Many of us have seen this method of measurement still being used in recent years in the shops of small towns where we have gone to buy 10 yd. of gingham or some other inexpensive fabric.

However, the first really effective attempt at standardization was made in England during the reign of Queen Elizabeth in 1658, when a bar of bronze about 3 ft. long was made the standard of reference. This was superseded by Bird's yard in 1824, which was destroyed by fire in 1834, and it was not until 20 years later that new imperial standards were established, copies of which were in turn sent to the United States.

Origin of the Meter.—Meanwhile the French were endeavoring to set up a standard that would be as nearly permanent as possible and accurately reproducible if necessity arose. They related their unit of measurement first to the circumference of the earth, but, since this was found to be variable because of certain changes in the earth's crust, they later changed to the wave length of a red line in the spectrum of cadmium metal. Wave lengths of light are, for the purpose of measurement, definite and unchanging quantities that permit an accuracy of one part in ten million. The French unit of length was called the *meter*. In 1893, this was legalized as the standard of linear measurement in the United States, and it has now been accepted as the standard everywhere in the world.

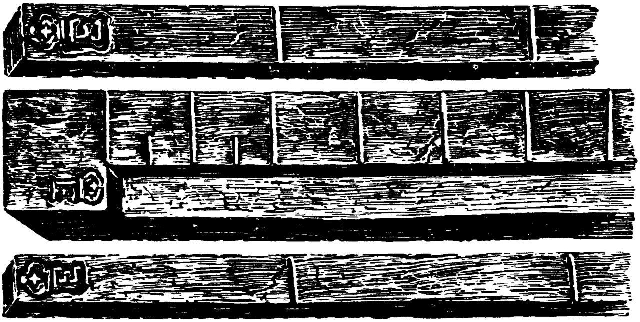


FIG. 7.—Bronze yard standards of Queen Elizabeth.

The national standard of length, called meter 27, is now in the Bureau of Standards in Washington. It is a platinumiridium X-shaped bar (Fig. 8). These two metals have excellent physical properties such as stability and resistance to oxidation or corrosion and are ideal for the purpose.

Although the metric system is used almost entirely in the scientific world, most of the mechanical industries in this country use the English system of feet and inches, and this system is so thoroughly established that it is likely to prevail for years to come. Many difficulties would be dispensed with if the metric system were used throughout industry, but this would involve such a scrapping of valuable tools and instruments that there is no present prospect of any change-over. But to anyone who has used the metric system, the English system seems cumbersome and confusing, with the constant necessity of converting fractions to decimals, and vice versa.

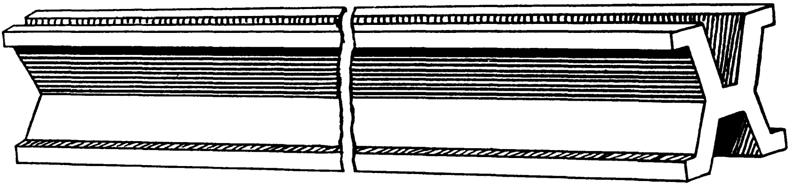


FIG. 8.—Standard meter of the United States.

The Inch as Standard.—In the manufacture of mechanical parts, the *inch* is the standard of dimensional measurement. However, since most dimensions consist of both inches and subdivisions of an inch, it is necessary to make use of suitable systems of dimensioning which will meet the requirements of each specific part of a mechanism or device. For this purpose there are two broad classifications of dimensions known as *nonprecision* and *precision.*

Nonprecision dimensions are those which can be measured accurately with the unaided eye. For all practical purposes a sixty-fourth of an inch is the smallest dimension that can be so read with accuracy by the average person. However, it is quite common to find scales divided in hundredths of an inch being used with a good deal of accuracy, but prolonged use of a scale of this type is very tiring.

As a matter of fact, most blueprints are dimensioned, for nonprecision work, by the so-called "binary system." This system is based on a natural tendency to subdivide by halving, and it consists in first dividing an inch into two equal parts (½ in.), then further dividing this into halves (¼ in.), and so on—⅛ in., $\frac{1}{16}$ in., $\frac{1}{32}$ in., and finally $\frac{1}{64}$ in., the last being the smallest dimension used under this system (Fig. 9).

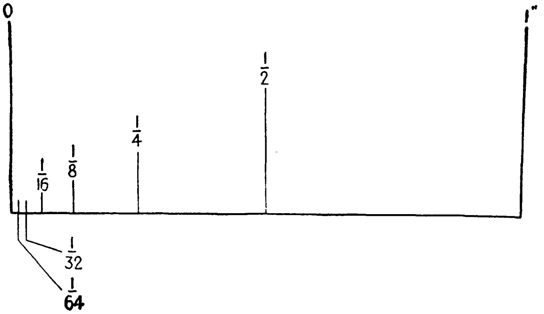


FIG. 9.—The inch divided according to the binary system.

Precision dimensions are used when it is necessary to hold dimensions to a high degree of accuracy, and for this *decimal dimensions* must be used. In this system, three or more "decimal places" are needed to express the dimension.

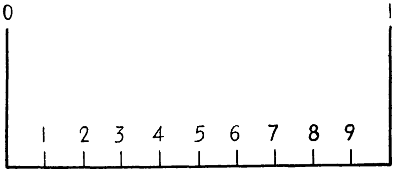


FIG. 10.—The inch divided according to the decimal system.

As the word "decimal" implies, the inch is first divided into 10 parts, following the ancient system of counting on one's fingers groups or parts of 10. Then each tenth of an inch is divided into one hundred parts. As a result, the inch is divided into one thousand parts or "thousandths" and one inch is written as 1.000 in., one and one-half inches as 1.500 in., and so on. However, if a still finer accuracy is called for, the inch is divided into ten thousand parts, and this requires four "decimal places." In this case one inch is written 1.0000 in., an inch and a quarter as 1.2500 in., etc. The figure that occupies the fourth decimal place, which is the "ten-thousandth" position, is expressed as so many "tenths." For instance, .1625 in., which is one hundred sixty-two and one-half thousandths, in shop parlance is "one hundred sixty-two and *five-tenths.*"

In machine shops, it is common practice to use fractions of an inch expressed in decimals, called *decimal equivalents of fractional dimensions.* Large charts containing these tables are found in plain view in every inspection station. For instance, $\frac{1}{8}$ in. is expressed as .125 (one hundred twenty-five thousandths of an inch), or $\frac{1}{4}$ in. as .250 (two hundred fifty thousandths of an inch). The decimal equivalents are arrived at by simple division; for instance, to find one-eighth of one:

$$\begin{array}{r} .125 \\ 8\overline{)1.000} \end{array}$$

Where the results of such a division exceed three or four decimal places, the decimal is usually "rounded off" to meet the conditions of accuracy required in specific instances. Taking $\frac{43}{64}$ as an example, the decimal equivalent is exactly .671875. If we were working to thousandths only, we would use .672 as the rounded-off dimension. If an accuracy of ten-thousandths were required, the decimal would be rounded off at .6719.

The divisions of an inch on the decimal system are

1	1.000	One
1/10	.1	One-tenth
1/100	.01	One-hundredth
1/1,000	.001	One-thousandth
1/10,000	.0001	One ten-thousandth

From the above it is readily understood that *nonprecision dimensions* are those which are expressed in fractions of an inch, the smallest being $\frac{1}{64}$ in., and which can be measured visually without the aid of a magnifying or amplifying devices. *Precision dimensions* theoretically begin where nonprecision dimensions end, but practically they begin at 1/1,000 in., and dimensions that need to be expressed in thousandths of an inch or less require the use of various devices to magnify or amplify the measurement so that it can readily be determined.

Questions

1. What two general systems of measurement are being used today?

2. What is the standard unit of length used in the manufacture of mechanical parts?

3. What part of an inch is considered as a unit of measurement for nonprecision dimensions?

4. In what form is the unit in problem 3 usually expressed?

5. What part of an inch is considered as a unit of measurement for precision dimensions?

6. In what form is the unit in problem 5 usually expressed?

7. Subdivide one inch by halving and make a list of all the resulting fractions up to $\frac{1}{64}$ in.

8. Show the equivalent, in sixty-fourths of an inch, of each of the fractions in problem 7.

9. Find the decimal equivalent of these fractions.

10. Find the decimal equivalent of $1\frac{1}{4}$ in.

CHAPTER III

THE MECHANICAL DRAWING OR BLUEPRINT

Mechanical drawings, or blueprints, as they are commonly called, could well be referred to as a universal picture language by means of which the ideas of an engineer or designer can be conveyed to anyone engaged in producing the mechanism or device which the engineer has conceived. It is of utmost importance, therefore, that an inspector should know how to understand this "language," or, in other words, he should know how to "read" blueprints. By "reading," it is not meant that he should simply know the meaning of the various terms, symbols, and abbreviations, but he should be able to understand and interpret them so fully that he can form a mental picture of the finished product. This is almost as necessary to the inspector as the ability to read or write. This process of forming a mental image of an object from a mechanical drawing or blueprint is known as *visualization.* Until the ability to visualize has been acquired, it is difficult if not impossible to know the real meaning and purpose of blueprints.

In the production of a mechanism, the engineer or designer makes a drawing of each separate part. This drawing shows the material from which the part is to be made, its form and shape, its dimensions, and the various machining operations that are to be performed to make it assume its proper place and function in the final assembly. A copy of this mechanical drawing is the blueprint.

If we made a photograph or a perspective drawing of an object, we would have a view that would not show the exact size, shape, and location of the various parts and details of the object. One reason for this is that in a perspective drawing the lines converge toward what is known as the *horizon point* (Fig. 11).

Therefore if, for instance, we measured a vertical edge representing the height or thickness of an object drawn in perspective, we would find that at the point nearest to us the height might be 4 in., whereas a line representing the back edge or point farthest from the eye would measure only, say 1 in. Of course it would be possible to make a perspective drawing from which, with the aid of detailed dimensions, a machinist could reproduce the part, but such drawings of complicated parts would be extremely difficult to produce and would be correspondingly difficult to read and interpret. Therefore, in mechanical drawings, we make use of several drawings or views, each showing a portion or side of the object as it would appear if one looked directly at it. Of course direct visual observation from a short distance would reveal some portions of other "views," but one should imagine oneself at an infinite distance so that the lines of sight from the eye to the object would be parallel to each other and perpendicular to the plane of the object.

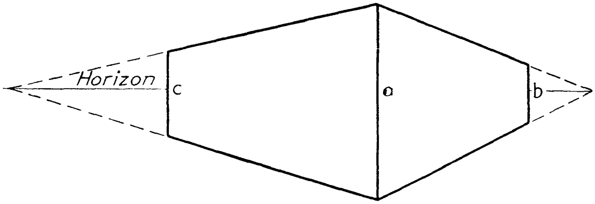


FIG. 11.—Perspective view of a rectangular object. Lines *a*, *b*, and *c* all represent equal dimensions, but all three are unequal in this type of drawing.

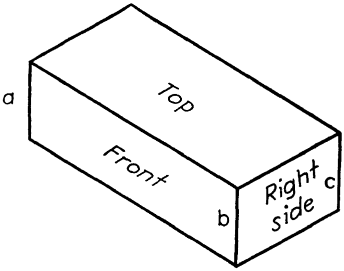


FIG. 12.—Isometric view of a rectangular block. Lines *a*, *b*, and *c* represent equal dimensions that in isometric (equal-measurement) drawing all appear of equal length.

These views, as shown in the blueprint, follow a systematic pattern or sequence. They appear in the same order as they would if the object were completely enclosed in a square box of transparent paper, on the sides of which were drawn "projections" of the various details of the object as seen from that side, the box being then unfolded and laid out flat. Or, to express it in another manner, if the object were swung as a pendulum from side to side and to and fro, the various views would be presented to the eye in the same sequence as on the blueprint. This process can be called *rotation*, and this method is used universally in this country in transferring the various views to the blueprint. Without such a system or method, known as *orthographic projection* (Fig. 13), blueprints would be most confusing, and difficult if not impossible to interpret.

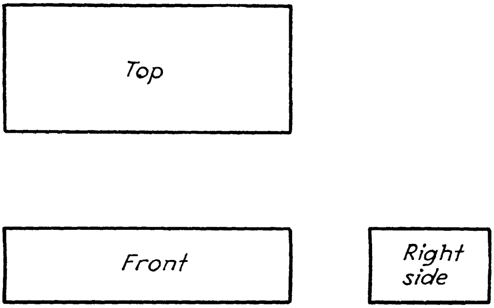


FIG. 13.—Orthographic projection of the object in FIG. 12. The standard method of making mechanical drawings.

If certain fundamentals are known and kept in mind, it is not difficult to visualize an object simply by the study of a mechanical drawing of that object. These fundamentals are

1. Every heavy solid line in a drawing represents a visible edge of some sort.
2. The different views of an object are made according to a definite sequence or "rotation" of the object.
3. In drawing the front of an object, for instance, only the front is shown, leaving the top and sides for other views.
4. A complete understanding of certain standardized signs and symbols which represent various lines, figures, and abbreviations is necessary before it is possible to visualize an object.

Although no attempt is made here to outline all the rules and procedures that govern the making and interpretation of blueprints, the most important of these are given below.

ARRANGEMENT OF VIEWS

In making a mechanical drawing of a part, the draftsman first selects the view that he believes will give the most understandable idea of the general contour or the more characteristic view of the part. This is then shown as the *front view* on the drawing. However, the front view may have no relationship whatever to the actual front of a part as finally used in assembly.

Then other views are drawn. Directly over and in line with the front view is the *top view.* (In the case of cylindrical parts, where the top view would be the same as the front view, the top view is omitted as unnecessary.) Then to the right of the front view and lined up with it is the *right-side view;* similarly where desirable the *left-side view* may be shown in addition to or instead of the right-side view. Where space is limited, the side views may be placed alongside the top view.

A *bottom view* may at times be used to advantage when a part is complicated. This view would be directly under the front view.

If two side views are used, they need not be complete views, provided that together they completely describe the shape of the part. Also, in the case of cylindrical parts, the side view may be omitted if one view adequately represents the part and if the diametrical dimensions are so indicated.

The beginner will soon find that in mechanical drawing there are many instances in which absolutely true and correct representations of objects are not shown. These "violations," or "exceptions," as they are known, cannot be fully described here, and it is recommended that appropriate textbooks be acquired as the learner progresses, beginning with a book such as Weir's "Blueprint Reading for the Machine Trades" (McGraw-Hill), then the two-volume "Advanced Blue Print Reading for Machine Trades" (New York State Education Department). In the latter will be found an extensive list of publications for further detailed study to assist in analyses of blueprints and an understanding of the parts.

It might also be mentioned here that mechanical drawings contain no superfluous or unnecessary details beyond those which are needed to given an adequate portrayal of the part. In other words, where several holes of the same dimension appear, the dimension is usually shown only once, and, where a piece is symmetrical in contour, dimensions of radii and centerline distances are not repeated.

TYPES OF LINES

Visible Outlines.—Every edge, contour, or intersection that can be seen when viewed from top, front, or any side is drawn as a full heavy line. These lines are known as *object lines.*

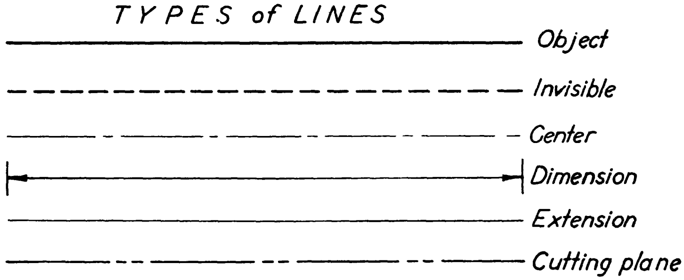


FIG. 14.—Common types of lines used in mechanical drawings.

Invisible Edges.—In any view, there are some parts of an object that cannot be seen because they are concealed by parts closer to the eye. Although these edges, or contours, are invisible, their position must be indicated. This is done by using a series of short dashes known as *invisible lines* or *hidden lines.*

Extension lines are fine solid lines extending outside the view to show the surfaces being dimensioned.

Dimension lines are also fine solid lines drawn between extension lines and terminated by arrowheads at either end. The dimension line is broken in the center, and in this break the dimension is shown.

Center lines indicate the centers of holes and slots, the axes of cylindrical or conical parts, and sometimes the center of symmetrical pieces. Center lines are important because important dimensions are measured to and from these lines. They consist of alternate long and short lines.

TYPES OF DRAWINGS

One-view Drawings.—If a part is uniform in cross section, one view is often sufficient to show all necessary details. This applies chiefly to thin flat pieces or cylindrical work. This not only saves time in drafting but makes the drawing easier to read.

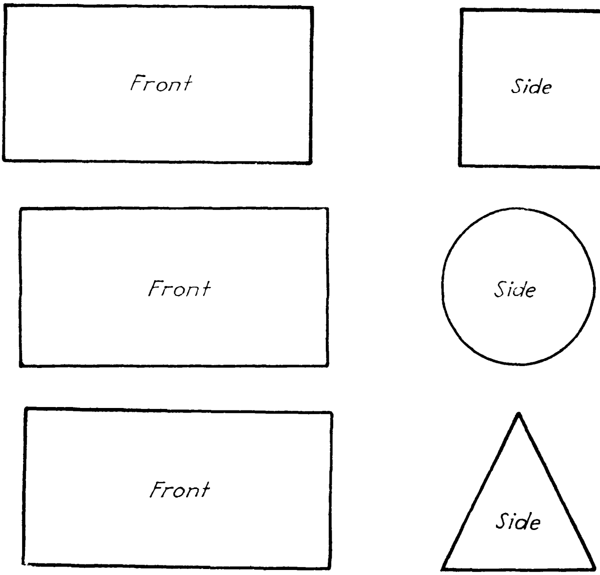


FIG. 15.—Showing why a front view alone is not sufficient to represent an object. (The same front view represents a square, a cylinder, or a triangular object. Many other variations of form are possible.)

Two-view Drawings.—In showing cylindrical pieces, such as shafts and screws or disks, rings, etc., two-view drawings showing the front view and one end or side view are used. As an example of the necessity of side views, see Fig. 15.

Three-view Drawings.—One of the most general methods of drawing is to show an object in three views as the part would be seen when looking directly at the top, front, and right side in turn. In some cases, the left side might be shown also, and in fact all the other views of the piece, if the details of each face are such that it would be desirable to have a separate view to show them.

Detail and Assembly Drawings.—Each single part of a mechanism is shown in a separate *detail* drawing; the *assembly* drawing shows these parts in their correct relationship in the assembled form.

Sectional Views.—Often the interior construction of a part is so complex that the hidden lines would be very confusing and difficult to read. In such a case a part of the object is imagined to be cut or broken away so as to expose the interior. When this is done the path of the cut is indicated in the drawing by a *cutting plane line* consisting of a series of one long and two short lines. At the ends of this line are two short arrows pointing in the direction the object is to be viewed, and each end of the line is lettered *A-A*, *B-B*, etc., to identify the sectional view to which the cut refers. The cut surface is indicated by section lining, known as *crosshatching,* a series of slanted lines equally spaced (Fig. 16).

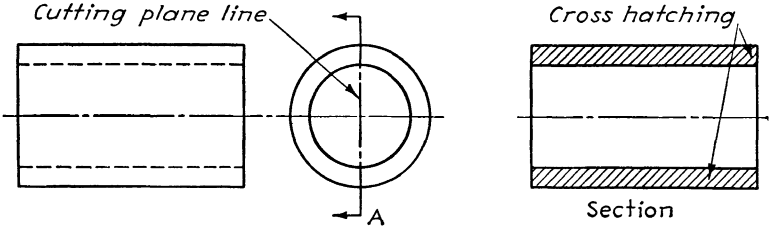


FIG. 16.—Sectional view of a simple object. A hollow cylinder.

A section line does not always cut straight through the piece but may run in two or more directions to bring out certain details.

Half Section.—In some cases, an exterior view and a sectional view can be combined in one drawing. The cut is imagined to extend halfway through the piece, stopping at the center line.

The hidden lines are usually not shown, but they may be if they are necessary for dimensioning (Fig. 17).

Partial Sections.—If only a small portion of the interior needs to be shown, this can be accomplished by "breaking away" a part of the exterior view. This is known as a partial section.

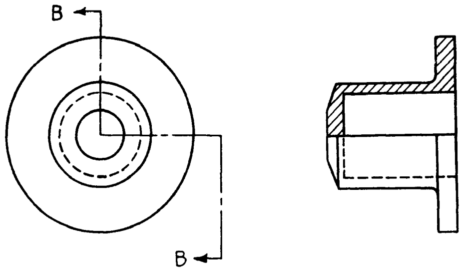


FIG. 17.—Half section of a cylindrical part showing cutting-plane line (*B-B*).

DIMENSIONING

All mechanical drawings are so dimensioned that the part can be made without the necessity of scaling or measuring the drawing. In this connection, the inspector should not under any conditions make measurements of the drawing for use in checking the work. One rarely finds a dimension lacking, but in such an event the matter should be referred back to the engineer to supply the missing information. Sometimes changes are made in a blueprint without altering the drawing, which calls attention to another common habit of the learner—that of trying to match up the finished part by placing it on the blueprint to see if the part coincides with the various views. This is bad practice and serves no useful purpose.

In most cases, dimensions appear in the break at the middle of the dimension line, but, if there is insufficient room, the figures may appear in another position with relation to the dimension line (Fig. 18).

Most mechanical parts that an inspector handles are of relatively small size. For this reason, the blueprints of such parts do not show the symbol for inches (″) along with the dimension, because it is understood that the figures represent inches and parts of an inch. In the event the dimension is more than 72 in., both feet (′) and inches (″) may be shown with the appropriate symbols.

Tolerances to which dimensions must be held are shown either alongside the figures or in the appropriate space in the footnotes. This matter is explained in detail in the section on tolerances.

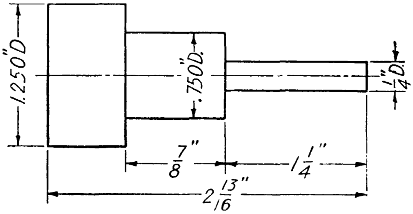


FIG. 18.—Method of dimensioning a cylindrical part. In this one-view drawing no side view is necessary.

Angular Dimensions.—Angles are dimensioned in degrees, each degree being one three-hundred-sixtieth of a circle. The degree may be divided into smaller units called *minutes* (one-sixtieth of a degree) and *seconds* (one-sixtieth of a minute), for example, 10°15′33″. One must not confuse the symbols for minutes and seconds with the symbols for feet and inches, which are exactly

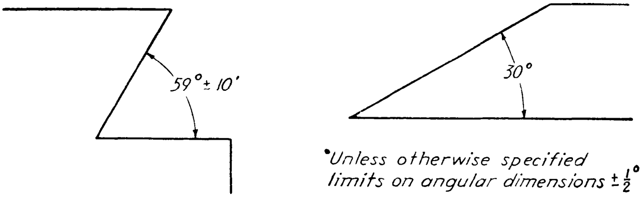


FIG. 19.—Methods of showing angular dimensions.

the same. Angular tolerances may be expressed either with the dimension or in a note on the drawing (Fig. 19).

Scale.—Sometimes a part is so large that a full-sized drawing would be awkward to handle and unnecessarily large. At other times, a part might be so small that it would be difficult to make all the details clear. To provide for such cases, a drawing is scaled down to a fraction of the full size of the part or scaled up to enlarge the details of the part.

All drawings include a notation indicating the relationship between the size of the drawing and the actual size of the part. However, the dimensions shown in the drawing are the actual full-scale dimensions. The scales are indicated thus:

Full size—scale 1:1
Half size—scale ½:1 or 6 = 12
and so on.

COMMON TERMS AND SYMBOLS

Change Notes.—When changes in design or production become necessary, alterations in the drawing to denote the change are identified by a numeral or letter in a circle ("bubble") placed near by. The number or letter refers to the change box on the drawing, which gives a record of the date and the nature of the change. Such changes are important and should be carefully noted by the inspector. Minor changes are often made without altering the drawing, an additional reason for the rule that a piece should never be checked as to dimensions or form by matching it with the blueprint.

Finish Marks.—A surface on which a machining operation is to be performed is indicated by a mark, either *f* or V, placed on the line that represents that surface. However, there are various degrees and types of finish, and in many cases other letters or words appear with the symbol (Fig. 20). Some of these are

*f*r.	Rough	*f*ss.	Semismooth
*f*s.	Smooth	*f*G.	Grind
*f*G & L.	Grind and lap	*f*B.	Buff

There is no uniformity in the designation of finishes, some manufacturers preferring to use code letters or numbers to indicate their own particular needs. However, the American Standards Association is endeavoring to standardize the symbols and abbreviations used in drafting, and the V-shaped character is coming to be widely used. In addition to the symbol, a series of numerical designations of surface roughness or irregularity has been devised. The numbers range from $\overset{\frac{1}{4}}{\mathsf{V}}$ to $\overset{63M}{\mathsf{V}}$ and indicate the roughness measured in micro-inches, or millionths of an inch. Thus $\overset{\frac{1}{4}}{\mathsf{V}}$ specifies a surface irregularity of 0.00000025 and $\overset{16M}{\mathsf{V}}$ an irregularity of 0.016. "Tolerances," or upper and lower limits of roughness, are shown as $\overset{4M}{\mathsf{V}} - \overset{1M}{\mathsf{V}}$.

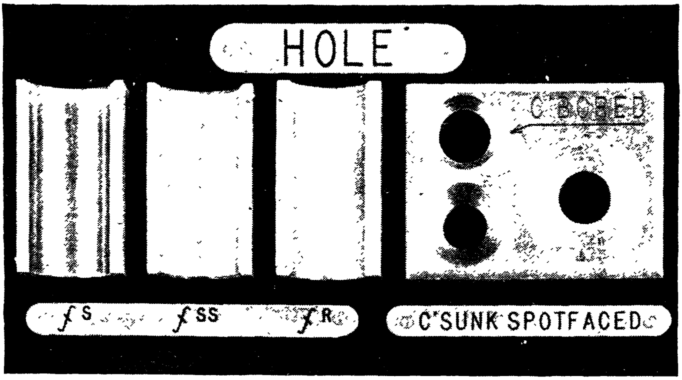


Fig. 20.—Examples of three different types of finished holes; also counterbored, countersunk, and spot-faced holes.

The roughness or irregularity is measured by an instrument that records the variations or profile on a calibrated strip of paper. The extreme variations are averaged by what is known as the *root-mean-square method*, or r.m.s. As an illustration of the r.m.s. value of the more familiar finishes, a ground surface would run from 8 to 250, a lapped surface from 2 to 8, and a milled or turned surface would run from 16 to 250.

Taper.—If a part tends to change size uniformly along its length, it is said to taper. The taper is usually expressed in inches per foot indicating the change in width, thickness, or diameter. A taper of ¾ in. per foot, for instance, would represent the total taper in 1 ft., not the taper relative to the axis or center line.

Chamfering is the process of cutting the edge or corner of a piece. The length and angle of chamfer are generally shown on the drawing. Chamfering is usually done to facilitate the entry of a piece into a mating part or to provide clearance of fillets in the mating part (Fig. 21).

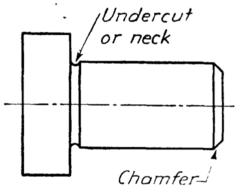
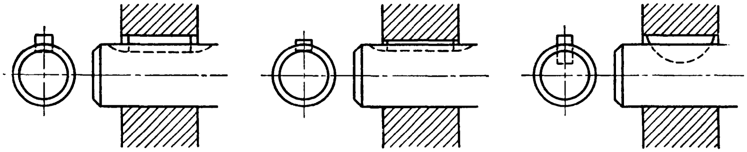


FIG. 21.—Examples of chamfer and undercut of a cylindrical part.

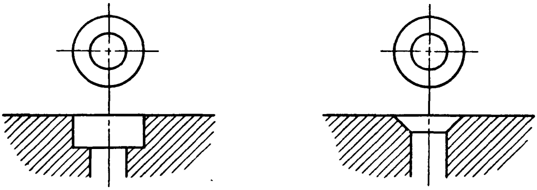
Keys and Keyways.—A keyway is a groove cut into a shaft or a mating part, into which a fastening known as a *key* fits. The purpose of the key is to prevent any relative motion between the shaft and the part. Keys are of different shapes—square, rectangular (flat), or a segment of a circular disk (Woodruff key) (Fig. 22).

Countersink.—When a flathead screw or bolt is to be used in a hole, a conical depression called a countersink is cut to receive the screw or bolt (Fig. 23).



Square Flat Woodruff

FIG. 22.—Three common types of keys and keyways.



Counterbore Countersink

FIG. 23.—Sectional view of counterbore and countersink.

Counterbore.—When a fillister, hexagonal, or similar type of bolt is used, the hole is machined larger to a given depth to receive the bolt head.

Spotface.—When a smooth flat surface is required on a casting or forging to provide a firm seat for a bolt, nut, or washer, the surface around the hole is cut away to a shallow depth. The diameter of the spot face is shown on the drawing, and the depth ranges from $1/64$ to $1/16$.

Necking, or undercutting, is the cutting of a groove or recess in a diameter to provide for subsequent machining operations such as threading or grinding. The width and depth of the cut are not always given, but the depth is usually from 0.002 to 0.005 in. below the finished surface.

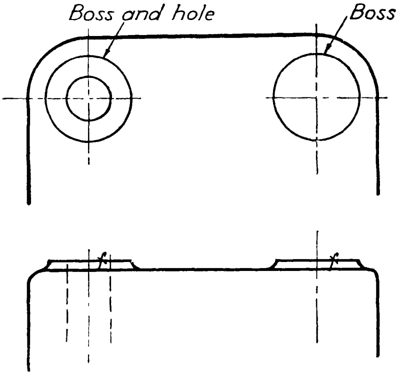


Fig. 24.—Conventional drawings of two bosses. Pads are similarly represented but are not cylindrical in form.

Boss and Pad.—A boss is a cylindrical projection that extends slightly above the surface of a part. Its purpose is to provide a smooth flat surface on which to mount or locate the piece so that it will seat itself closely and firmly.

A pad is a similar projection, other than cylindrical in form (Fig. 24).

Radius.—In geometry, a radius is a straight line drawn from the center of a circle to the circumference. In machine work, a radius is a curved outside surface made to avoid sharp edges or to improve appearance (Fig. 25).

When a radius appears at the inner intersection of two surfaces, it is called a *fillet* ("fill it"). The purpose is to increase the strength of the part by eliminating sharp corners.

Both radii and fillets are dimensioned from a center mark, usually in fractional dimensions.

Slots are used to hold sliding parts together. Two of the more common types are T slots and dovetails.

Tolerances.—See Chap. IV, pages 35–39.

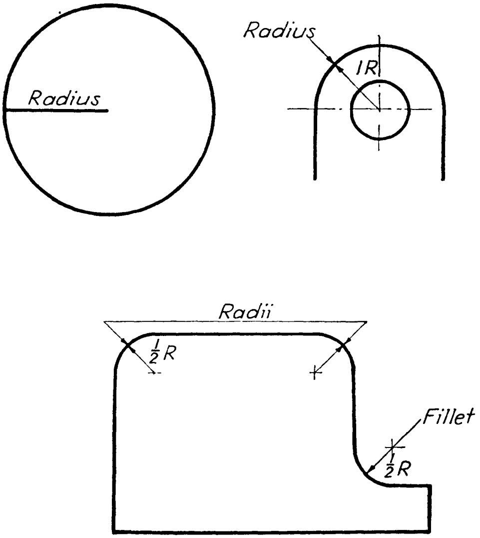


Fig. 25.—Types of radii.

Materials in section are indicated by crosshatching. In some cases, different types or spacings of the crosshatch lines indicate different materials, but this practice is not by any means universal.

Questions

1. The process of forming a mental image of an object from a mechanical drawing or blueprint is known as ______.

2. Name six different types of lines used in mechanical drawings.

3. When may a one-view drawing be used?

4. When is a drawing having three or more views used?

5. Describe a *detail* drawing.

6. Describe an *assembly* drawing.

7. What type of view shows an object as though part of it were cut away?

8. How may such a view be readily identified?

9. How are finished surfaces indicated on a blueprint?

10. A blueprint shows the length of a shaft to be 2 in. Upon actually measuring the length of the blueprint, we find it to be 4 in. What is the scale of the drawing?

CHAPTER IV

TOLERANCES, LIMITS, AND ALLOWANCES

One of the first things an inspector should learn and keep prominently in mind is that *in practice there is no such thing as an exact dimension.* Variations in size can be restricted but cannot be entirely eliminated. One main purpose of inspection is to control variations. It is easy for an engineer to specify, for instance, the diameter of a shaft as 1 in. exactly, but in practice perhaps not one shaft in a million will be *precisely* 1 in. in diameter throughout its length. Some will be larger or smaller, tapered or otherwise variable in part. The question arises, "Just why do these variations occur?" There are many factors on which accuracy of machine work depends. Among these are

1. There may be play in bearings or other working parts.
2. The cutting tool may wear.
3. Internal stresses may distort a part after machining.
4. The material may not be uniform. A hard spot often displaces the setting of a tool.
5. A reamer or drill point may be eccentric.
6. Temperature may cause changes. To anyone who is not familiar with the effects of temperature changes, it may seem far-fetched that even a relatively small temperature change should prevent parts from going together in assembly or should cause rejection of a part in inspection. But it is not unusual to meet with this condition.
7. There are variables in machine operators. Some may misunderstand the setup or machining instructions. Many who have acquired skill will have off days or after a holiday may have to reacquire a fine touch, coordination, etc.
8. Montonous or repetitive work can cause lack of attention.
9. The operators' mental attitude toward the work may cause variations. Some machinists handle their tools, setups, and

controls with gentle care; others adopt a sort of reckless abandon which they hope will be mistaken for adeptness and expert handling.

There are, of course, many other causes for inaccuracy, but those mentioned will tend to show how and why variations in size occur *unintentionally.* An *intentional* variation is also provided for because it is recognized that dimensions will seldom if ever be exactly as specified. It is axiomatic in machine work that, the more precisely a dimension is held, the greater the cost. There is no need to hold certain types of work to close limits, and furthermore, what in certain types of work would be a close limit in other types would be much too great a variation.

This brings us to *tolerances, limits,* and *allowances.* These three terms are very loosely used today, and in many cases they are used interchangeably as though they all had the same meaning. The inspector especially should know the proper meaning of these three terms and use each of them correctly at all times. We shall first define the terms in simple language and then give a more detailed explanation of the meanings.

Tolerance is a permissible variation from a basic dimension, that is, the deviation that may be *tolerated* in a part while still permitting it to function properly when used for its designated purpose. The term *tolerance* applies only to *single parts* and not to an assembly of two or more parts.

Limits are the dimensions beyond which the work must not extend; that is, the largest permissible dimension is the *upper limit,* and the smallest permissible dimension is the *lower limit.* Tolerance is the *difference* between the upper and lower limits.

Allowance is an intentional difference in dimension between two "mating" parts. (By "mating parts," we mean parts that are designed to fit together as an assembly or a part of an assembly.) In fact, the term can be more exactly defined as the difference in size between the *tightest* dimensions of the mating parts. For instance, a shaft with a diameter of $0.250\,^{+0.000}_{-0.002}$ is designed to fit into a hole with a diameter of $0.251\,^{+0.002}_{-0.000}$. In this case, the tightest condition of the *shaft* would be a diameter of 0.250. The tightest condition of the *hole* would be 0.251. The allowance would therefore be 0.001. In some instances, when parts are to be shrink-fitted, a shaft might be slightly larger than the sleeve into which it is to go. The difference in size of the parts is known as a *negative* allowance. The parts might, for instance, be fitted together by placing the shafts in dry ice, heating the sleeves, and then fitting them together when the temperatures are some hundreds of degrees apart. When both parts reach a normal temperature, they become practically one piece.

Recently a further qualification of tolerance has come into general use. Tolerances are now expressed in some cases as *unilateral* or *bilateral.* These terms mean simply "one-sided" and "two-sided." In explanation, it is quite customary, as in the instance cited in the previous paragraph, to limit the size of a *shaft* to the basic dimension with the tolerance on the *minus* side; the *hole* into which the shaft is to fit is dimensioned with a *plus* tolerance only. The reason for this is that in assembly any shaft must fit into any hole without exception. In practice such tolerances are known as unilateral. If a tolerance were permitted on the plus side for the shaft and on the minus side for the hole, there would be some cases where the sizes overlapped and the hole would be smaller than the shaft. Where close fits are not required, the tolerances can be distributed on both sides of the basic dimension; in such cases they are known as bilateral.

Bilateral tolerances apply on most commercial work but are not acceptable on government ordnance work. Ordnance engineers claim unilateral tolerances are more scientific and satisfactory in producing interchangeable parts for ready assembly.

As stated previously, it is generally recognized that a dimension will seldom if ever be *exactly* as specified. We must therefore know how much variation there may be from the mean or basic dimension. Sometimes a fractional dimension is given on the blueprint without an accompanying tolerance. In such cases, it is usually assumed that the tolerance is "plus or minus one sixty-fourth," but this should be confirmed by reference to a note on the blueprint, which would read "Unless otherwise stated, tolerance on fractional dimensions $\pm 1/64$," or a phrase of similar meaning. If however, the blueprint shows such a dimension as $1\frac{5}{8}\,{}^{+\frac{1}{64}}_{-0}$, this means the measurement must not be less than $1\frac{5}{8}$; and, if it is not exactly $1\frac{5}{8}$, it must be greater rather than less, but not more than $\frac{1}{64}$ greater. On the other hand, if the dimension is given as $1\frac{5}{8}\,{}^{+0}_{-\frac{1}{64}}$, the piece must measure no more than $1\frac{5}{8}$ and no less than $1\frac{39}{64}$.

If the dimension is given as 1, 5, or 12, it is classed as a fractional dimension, and the fractional tolerance is applied even though there is no actual fraction in the number.

When we are dealing with decimal dimensions, we usually find not less than three decimal places, which means that each inch is subdivided into one thousand parts or "thousandths." On the blueprint, one inch would be shown as 1.000, eight inches as 8.000, and twelve inches as 12.000. [On mechanical drawings it is not necessary to show the inch symbol ("), because it is generally understood that all measurements are in inches unless the dimension exceeds 72 in., in which case the dimensions are expressed in feet and inches.]

In using decimal dimensions, the tolerances are also shown in decimals. If a certain dimension is shown as $1.000\,{}^{+0.003}_{-0.000}$, the piece may be not less than 1.000, but it may be greater but not more than 0.003 greater. If a decimal dimension is given without a tolerance, it is usually assumed that the tolerance is ±0.005, but we must verify this by referring to the note covering decimal dimensions on the blueprint.

When dimensions are shown in four decimal places, such as 1.0000, the tolerance must also be expressed in four decimal places.

There are two ways of showing the upper and lower limits of decimal dimensions. One is to express it as $1.250\,{}^{+0.003}_{-0.001}$, for instance, or the same dimension could be written as ${}^{1.253}_{1.249}$, thus indicating the upper and lower limit without a mental calculation of what these would be.

To summarize the method of denoting tolerances:

Fractional Dimensions.—1. No accompanying tolerance, as, for instance, $1\frac{5}{8}$. Part may be $1\frac{5}{8} + \frac{1}{64}$ or $1\frac{5}{8} - \frac{1}{64}$, or any size between these limits.

2. Dimension expressed as $1\frac{5}{8}\,^{+0}_{-1/64}$. Part may be not larger than $1\frac{5}{8}$ or smaller than $1\frac{39}{64}$ ($1\frac{5}{8} - \frac{1}{64}$).

Decimal Dimensions.—1. Dimension shown as 1.250 with no accompanying tolerance. Part may be 1.255 or 1.245, or any size between these limits.

2. Dimension shown as 1.250 ± 0.002. Part may be 1.252 or 1.248 or any size between these limits.

3. Dimension shown as $\frac{1.250}{1.245}$. Part may be 1.250 or 1.245 or any size between these limits.

Questions

1. Define tolerance.

2. A dimension is shown on a blueprint as 1.250 ± 0.005. What is the tolerance?

3. What is meant by limits?

4. What are the limits of the dimension 1.250 ± .005?

5. The difference between the upper and lower limits of a dimension is equal to the ______.

6. What is the difference between unilateral and bilateral tolerances? Give examples of each.

7. A lot of 8 shafts, whose blueprint dimension is 1.000 ± 0.002, were found to measure as follows:

0.999
1.000
1.001
0.996
0.998
0.997
1.002
1.004

Indicate how many would be accepted, how many returned for rework, and how many rejected.

8. What is meant by allowance?

9. How does allowance differ from tolerance?

10. A finished hole is dimensioned $1.250^{+0.002}_{-0.000}$. The shaft to fit into this hole is dimensioned $1.248^{+0.000}_{-0.002}$. What is the allowance?

CHAPTER V

THE NONPRECISION TOOLS

For checking nonprecision or fractional dimensions, the inspector uses a rule or scale, these terms having acquired the same meaning (Fig. 26). Such dimensions are therefore commonly referred to as *scale dimensions.* The 6-in. rule is one of the two indispensable tools of the inspector, the other being the 1-in. micrometer (Fig. 27). However, there are many places where it is not possible to use a 6-in. rule, because of inaccessibility or the interference of other parts of a piece. In this event, use is made of other nonprecision tools, of which the outside and inside calipers, dividers, depth gages, and small rules from 1/4 to 1 in. in length are the most common.

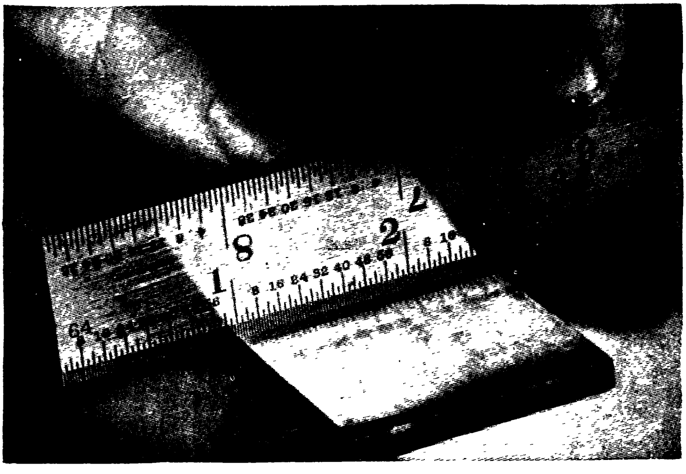


FIG. 26.—A typical steel scale with numbered divisions. *(Courtesy of U.S. Office of Education.)*

THE STEEL SCALE

The steel rule, or scale, is a strip of steel graduated in regular divisions. The term *rule* is generally used to denote a means of drawing straight lines. The term *scale* is defined as "an instrument with one or more sets of spaces graduated and numbered on its surface, for measuring or laying off distances, dimensions, etc."

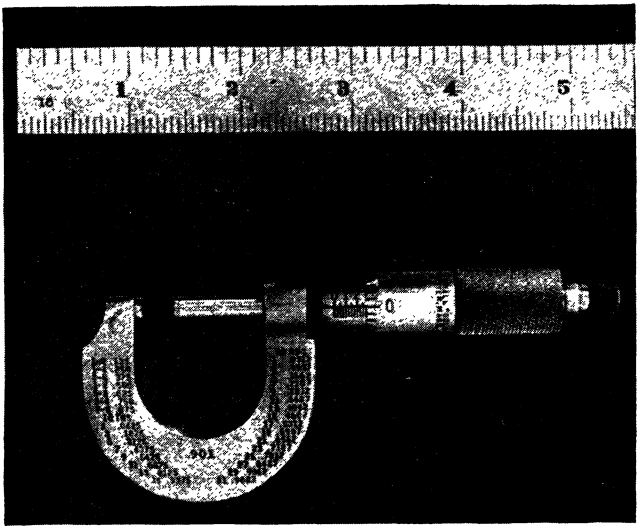


FIG. 27.—The two indispensable inspection tools. (*Courtesy of U.S. Office of Education.*)

Because of the greater variety of applications and also the personal preference of the user, there are many types of steel scales available. These usually have four scales, two on each side, reading in eighths, sixteenths, thirty-seconds, and sixty-fourths. Inspectors should have one of the better quality types with machine-divided graduations. These graduations are cut into the steel and are distinct and clearly readable. On the other hand, the scales of the "five-and-ten" variety have etched divisions which are not always clearly defined, and in fact the graduations are individually so wide that precise readings are impossible.

A scale should be read to the nearest division. If the part being measured does not fall directly on a scale division, read the nearest division; and, if the point of coincidence is midway between two divisions, read the next highest. In any case, the accuracy of measurement with a scale is largely governed by one's aptitude in correctly lining up and reading the graduations.

In writing fractional dimensions, the dimension is always expressed with the least common denominator. In this case, the numerator is always an odd number. For instance, a blueprint never shows dimensions such as $4/8$ or $48/64$. These would be written as $1/2$ and $3/4$, respectively.

Methods of Using the Steel Scale.—In using the steel scale, the readings may be made by

1. Placing the left end of the scale flush with the edge of the piece and reading the dimension on the opposite edge. For maximum accuracy the scale should be held on edge, as shown in Fig. 26, not flat on the work. It should also be held at right angles to the edges from which the measurement is being made; if it is slanting, it will give an incorrect reading.
2. If the ends of the scale are worn or damaged, by placing the 1-in. mark exactly even with one edge of the piece and reading the dimension on the opposite edge, not forgetting to subtract the 1-in. overlap on the left-hand edge.
3. Holding a smooth flat piece of stock or a block against one edge of the part to be measured, placing the steel scale snugly against the stock or the block, with the edge of the scale on the part, and taking the reading. The scale should not be laid flat on the part. The thickness of the rule is likely to affect the reading. If the ends of the piece are faced true, and it is not too long, it can be set upright on a flat surface, and the scale can also be placed on end against it. Be sure the scale is placed against it and is parallel to the center line.

The latter is considered good practice, because the entire attention may be given to reading the scale correctly. It also avoids

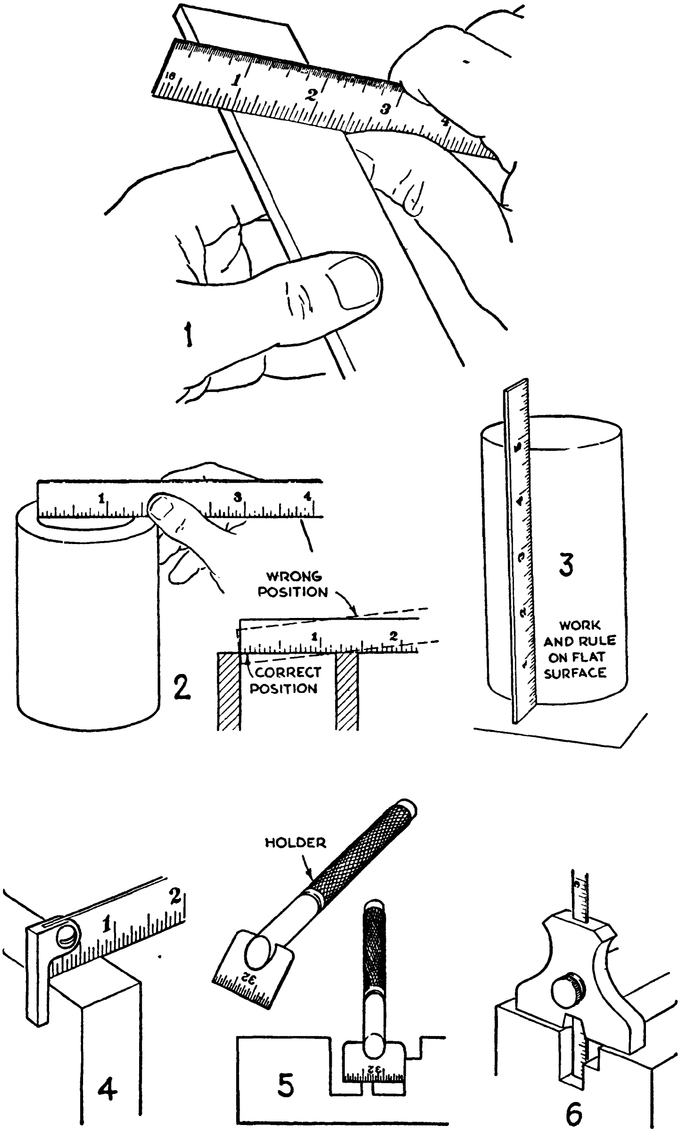


FIG. 28.—Various methods of using steel scales.

errors that might occur is using the first two methods, if the edge of the piece had been "broken" or chamfered (Fig. 28).

In reading diameters of holes or cylindrical pieces, be sure the scale is directly across the center and tilted as little as possible. The largest reading obtained is the correct one and represents the true diameter.

The Depth Gage.—To measure depths of holes and slots where fractional dimensions are involved, the depth gage with its narrow rule or graduated rod is a very convenient tool, although somewhat limited in its application.

Special Scales.—A flexible scale is useful in getting at some places where the ordinary scale cannot be used because of the interference of other parts. A narrow scale is sometimes needed for measurements in slots or holes, and the small steel scales are useful in restricted portions.

CALIPERS

Calipers for inspection should be of the toolmaker's or spring type, both of which have an adjusting nut. The split-nut type, which permits quick adjustment of the legs, has certain advantages, but these are offset by the possibility of rapid wear of the threads. The 6-in. caliper is the most generally useful, but a second set of the 2½- or 3-in. size is often found necessary for smaller work.

"Touch" or "Feel."—The proper use of calipers and, in fact, of many other inspection tools requires the development of a sense of touch or feel. Variations in touch explain why different mechanics will get different readings of the same measurement. In accurate gaging, much depends on getting just the right contact between the tool and the piece being measured. This applies to nonprecision tools as well as micrometers and vernier instruments.

Feel is acquired with practice and experience, and, to get the full benefit of this sense, the measuring tools should be held as lightly as possible with the fingers. The fingertips are extraordinarily sensitive, and this fact is of great assistance in making accurate measurement. Observe an expert machinist or inspector when he is using measuring tools, and you will see that he holds the instrument with the utmost delicacy and never uses force. In fact, two or three fingers will control the use and manipulation of most inspection tools.

If a micrometer or caliper is forced over a piece, the reading obviously will be somewhat less than if the contact points just touch the work as they pass over it. Even the frame of a micrometer, which is quite sturdy, can be sprung several ten-thousandths of an inch with a little pressure, and the jaws of a vernier caliper can be sprung several thousandths of an inch if pressure is used. Proper feel is also necessary in using fixed gages such as plug or snap gages. Even the harder metals are more flexible than the average person realizes, and this lack of rigidity has to be taken into consideration when instruments are used to make measurements of very small dimensions.

Of course, other errors of technique frequently cause inaccurate measurements, but most mistakes are due to lack of proper feel, and correct feel can be acquired in only one way—"practice and more practice." When practicing, a set of precision blocks to check the readings will be very helpful.

Outside Calipers.—To return to the calipers—the outside caliper, as the name implies, is used to make external measurements. The caliper has curved legs to permit its use over outside surfaces. In measuring work, the calipers should first be adjusted to the approximate dimension to be checked. They should then be held in one hand, with the thumb and forefinger grasping the adjusting screw and should be applied *at right angles* to the part and moved back and forth across the work, while the screw is adjusted until the points bear lightly on the work. To determine the measurement, a scale should be held in the left hand with the second finger at the bottom and behind the scale to steady the caliper; then one of the legs should be placed against the end of the rule and the other leg on the graduated face of the scale, in line with the first leg; or the scale may be laid on a surface plate, and the reading may be taken as shown in Fig. 29*b*. Of course, the caliper can first be set on a scale and then used to check dimensions (Fig. 29).

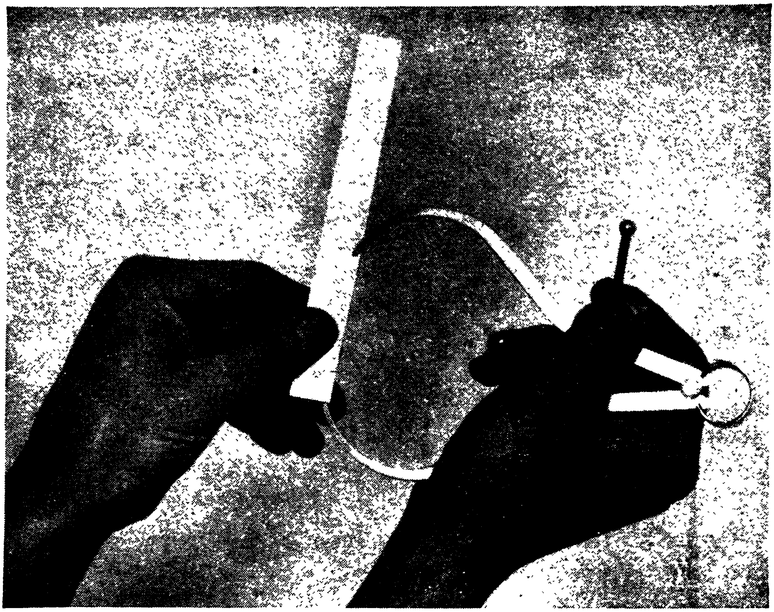


FIG. 29*a*.—Taking the measurement of an outside caliper setting using finger to steady one end of caliper against scale.

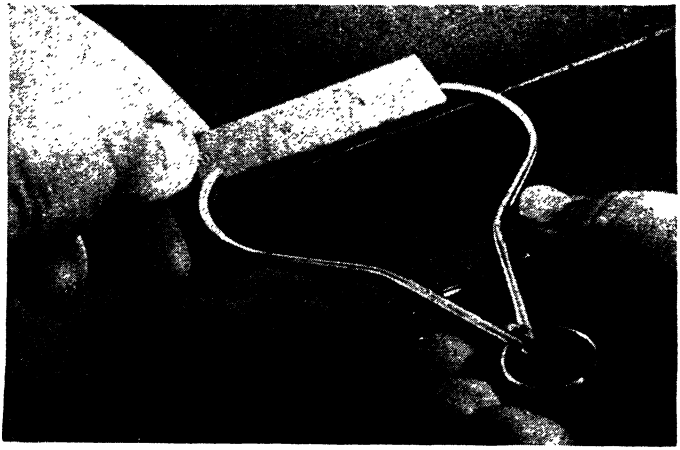


FIG. 29*b*.—Reading or setting outside caliper on flat surface.

Inside Calipers.—Inside calipers have straight legs that are turned outward at the end. They are used for measuring the diameters of holes, widths of slots, distances between surfaces, etc. In taking an inside measurement, the caliper should be held in one hand with the thumb and forefinger grasping the adjusting nut. One leg of the caliper should be rested slightly inside the space to be measured, and the adjusting nut should be turned until contact with the other leg is felt (Fig. 30). The tips of the legs should always be "square" with the work, and this can be determined by "rocking" the caliper slightly. If a hole is being measured, the correct diameter should be found by moving the calipers sidewise; and, if necessary, the nut can be readjusted so that no side motion can be felt.

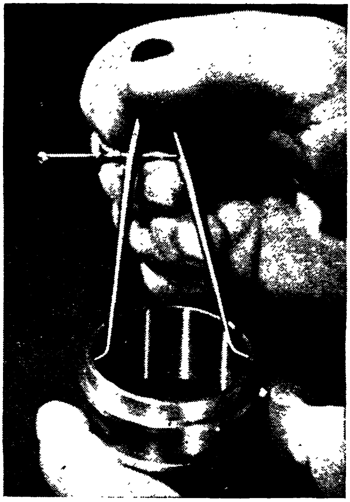


FIG. 30.—Measuring an inside diameter with inside caliper. (*Courtesy of U.S. Office of Education.*)

The dimension is measured by placing one end of a steel scale against a solid surface, holding one caliper leg against the surface at the end of the rule, and then reading the dimension on the scale where the other leg lies (Fig. 31).

In some cases, when measurements of inside diameters are needed, it may be difficult to use the more common precision gages. If the tolerances are not close, the caliper can be used to take the measurement, which is then read with a micrometer. This requires some care in getting the correct feel, not only with the caliper in the hole, but also on taking the reading with the micrometer.

Measurements made in this manner are known as *transfer* measurements and are of course more subject to error than those made with only one instrument.

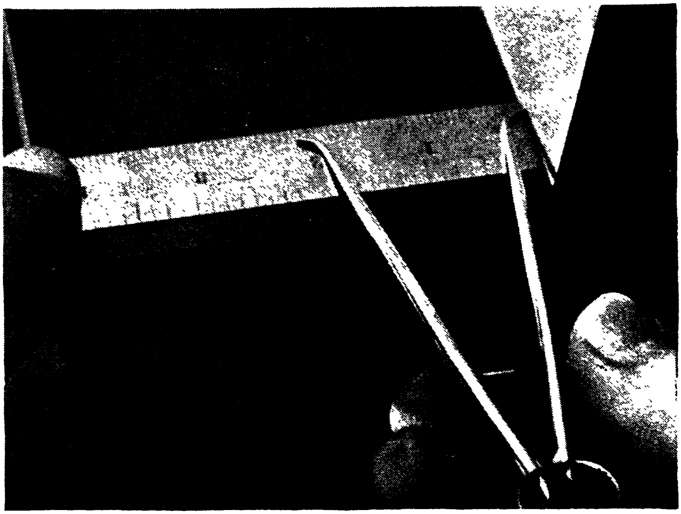


FIG. 31.—Proper method of reading measurement of inside caliper setting. (*Courtesy of U.S. Office of Education.*)

DIVIDERS

A divider is an instrument used in inspection to transfer dimensions for measurement or to lay out or scribe an arc, radius, or circle. It consists of two adjustable straight and sharp-pointed legs, held by a spring. Measurements are checked by

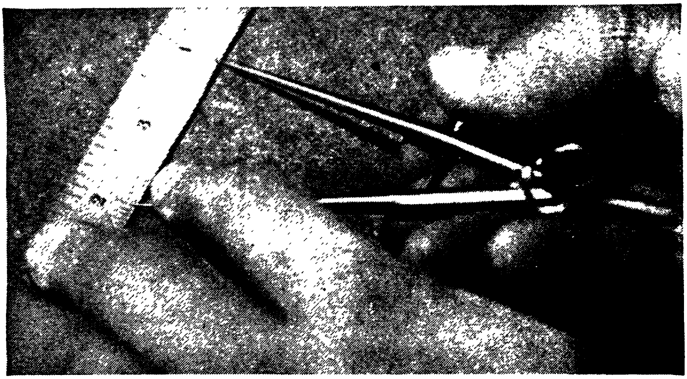


FIG. 32.—Setting a divider. (*Courtesy of U.S. Office of Education.*)

setting one pointed leg in one of the inch graduations of a scale, adjusting the nut so that the other pointed leg falls easily into the correct graduation, and then reading the dimension, not forgetting to deduct the inch from the reading (Fig. 32). The points should always be sharp and straight to do accurate work.

THE COMBINATION SQUARE

The combination square is a measuring instrument used to check squareness of surfaces and to lay out lines at right angles or at 45-deg. angles. The sliding head can be adjusted and locked at any point along the scale. This makes it useful as a height gage or depth gage. The slide also has a spirit level and a steel scriber, which extend its usefulness (Fig. 33).

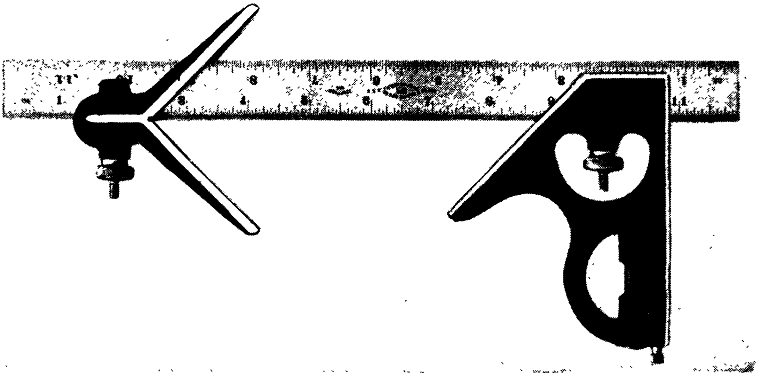


Fig. 33.—Combination square with center gage attachment.

The combination square is also provided with a center head by means of which centers of round or square pieces can be ascertained by scribing two lines at about 90 deg. to each other, along the edge of the steel ruler. The point of intersection is the center point. Some combination squares also have a protractor head for checking and laying out angles where an accuracy of ±1 deg. will serve.

When using any of the accessory slides, one should be careful to tighten the clamping screw; otherwise the steel ruler will not be held firmly in its proper position and will not maintain a true relationship with the other parts.

Altogether, the combination square is a versatile tool but of course is used only for nonprecision work. It serves as a rule, square, miter, depth and height gage, level, center scriber, and protractor.

Questions

1. What are the four common graduations found on a steel rule?

2. What is the accuracy of measurements obtained by the steel rule?

3. The following "scale" measurements were obtained by an inspector.

$$\begin{array}{ccc} \frac{6}{8} & \frac{15}{16} & \frac{24}{32} \\[1ex] \frac{10}{16} & \frac{12}{32} & \frac{48}{64} \end{array}$$

Convert these, where necessary, to their lowest terms.

4. Should the scale be held with the flat side down when taking measurements of work? Why?

5. How would you take a measurement with a scale having worn or rounded corners?

6. What three tools are used to transfer measurements to and from the steel rule?

7. Can these tools also be used to transfer measurements to and from precision tools in order to check a decimal dimension? Under what conditions?

8. The diameter of a hole whose blueprint dimension is $7/8\,{}^{+1/64}_{-0}$ was found to measure $55/64$. Is this passable?

9. What angles can be checked with a combination square?

10. What is the purpose of the center head?

CHAPTER VI

THE MICROMETER

The most important measuring tool in mechanical work is the 1-in. micrometer caliper, or simply *micrometer.* This is used to measure variations in size too small for the unaided eye to see. There are many different types of micrometers, some to measure outside lengths and thicknesses, others to measure inside diameters or widths, and others to measure the depths of slots and holes. However, the principle of each type is the same.

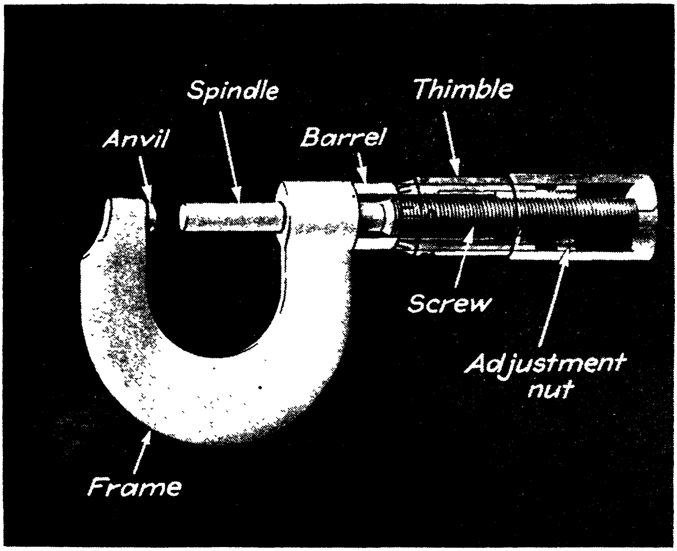


FIG. 34.—The mechanism of a standard micrometer. (*Courtesy of U.S. Office of Education.*)

Mechanism of Micrometer.—The micrometer has a sturdy frame on which is mounted a hardened steel *anvil.* To one side of this frame is attached a *barrel* on which is engraved a scale

1 in. long, divided into 40 equal parts. The mechanism of the micrometer is mostly concealed within the barrel, and for this reason a cutaway view is shown in Fig. 34. Here is seen the micrometer *screw*, which with the *spindle* forms one and the same piece. The *adjustment nut* is permanently attached to the barrel, so that this part, with the barrel, frame, and anvil, is practically one piece. The micrometer screw fits within the fixed nut. The screw is actuated by the *thimble*, which, when turned toward the left, or counterclockwise, moves the spindle away from the anvil and increases the distance between the *measuring faces*. Turning the thimble to the right, or clockwise, "closes" the micrometer or decreases the distance between the measuring faces.

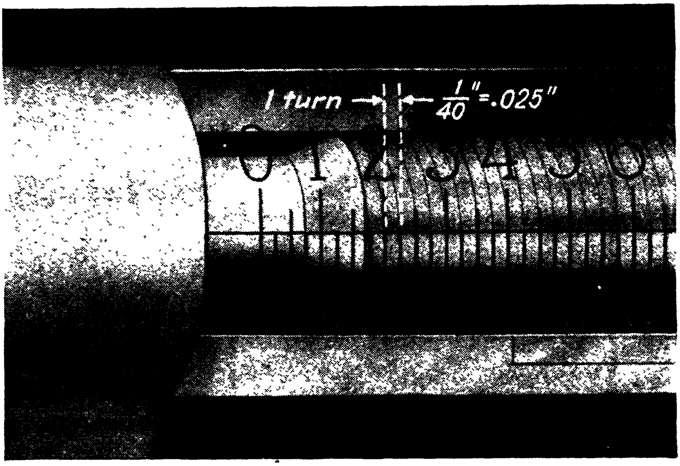


Fig. 35.—The relationship of the lead of a micrometer screw to the barrel graduations. (*Courtesy of U.S. Office of Education.*)

Graduation of Micrometer.—The screw that controls the movement of the spindle has 40 threads to the inch; therefore one complete turn of the spindle moves it exactly $\frac{1}{40}$ in., or .025 (Fig. 35), and changes the distance between the measuring faces by that much (Fig. 36). The lower edge of the thimble is engraved with 25 lines. Every fifth line is numbered, beginning at 0, then 5, 10, 15, 20, and back around the circle to 0, which also counts as 25. The barrel is engraved with a long axial *index line.* This line as mentioned in the preceding paragraph, is divided into 40 equal parts, each of which is .025. Each fourth

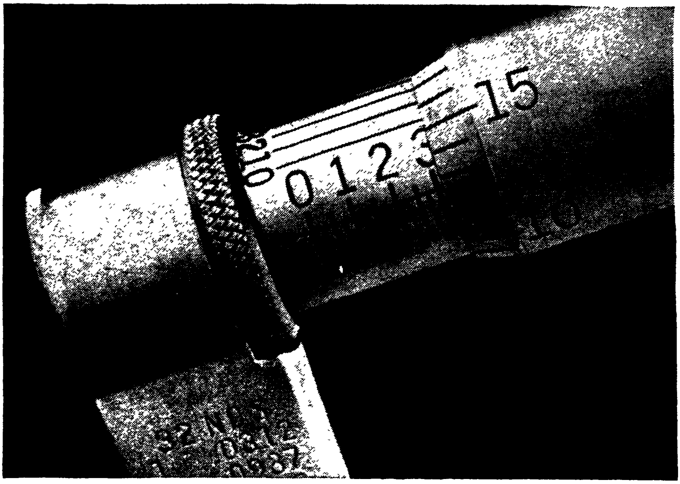


Fig. 36.—The barrel and thimble scales of a micrometer showing index line. (*Courtesy of U.S. Office of Education.*)

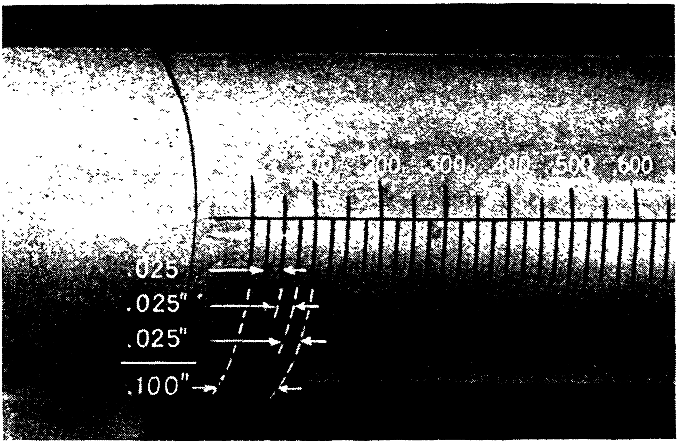


Fig. 37.—What the numbered barrel scale represents. (*Courtesy of U.S. Office of Education.*)

division is numbered 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, and 0. Four divisions of .025 each make .100, so that these numbers really represent .000, .100, .200, .300, .400, .500, .600, .700, .800, .900 and 1.000 (Fig. 37).

A micrometer should be closed easily so that the measuring surfaces are in contact. If the micrometer is in correct adjustment and the measuring surfaces are clean, the edge of the thimble will just cover the zero line on the barrel, and the zero line on the thimble will just match with the index line on the barrel. This measurement is zero. When the thimble is turned slightly to the left so that the first graduation on the thimble coincides with the index line, the distance between the measuring faces is one one-thousandth of an inch (.001). Continuing to turn the thimble to the left, each succeeding line on the edge of the thimble, as it lines up with the index line, marks another thousandth of an inch between the measuring faces. When the thimble makes just one complete revolution and the zero line of the thimble again lines up with the index line, the opening

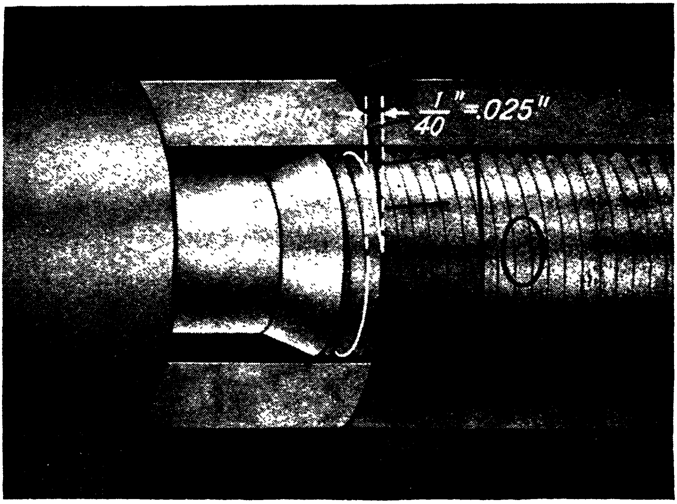


FIG. 38.—An imaginary thread wrapped around a micrometer screw. (*Courtesy of U.S. Office of Education.*)

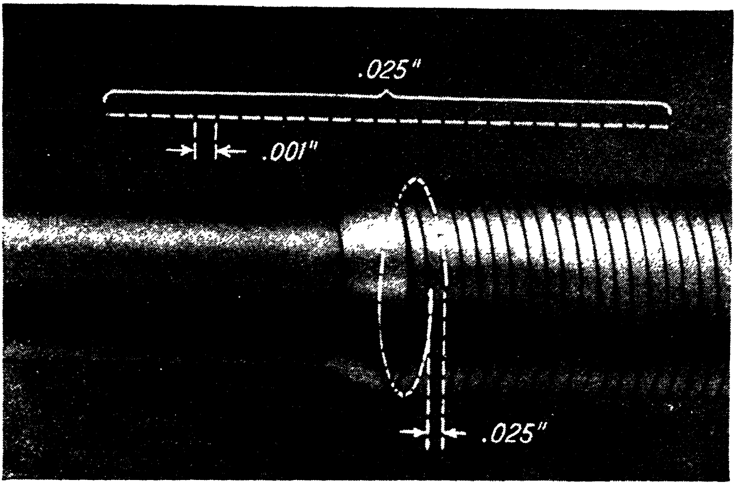


FIG. 39.—The thread divided into 25 equal parts and extended. (*Courtesy of U.S. Office of Education.*)

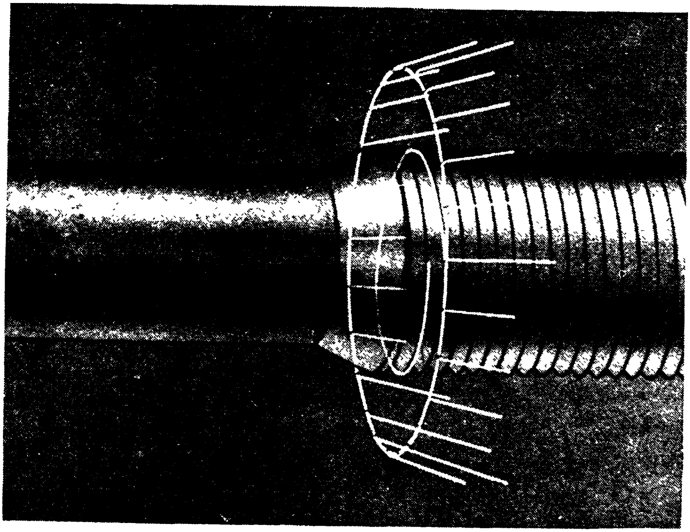


FIG. 40.—Relationship of thimble scale to imaginary thread. (*Courtesy of U.S. Office of Education.*)

is twenty-five thousandths (.025), and the first line on the barrel just begins to come into view (Figs. 38–40). Thus it will be seen that the lines on the barrel mark the number of complete revolutions of the thimble.

Reading the Micrometer.—Reading the micrometer is relatively easy if we think of the scale as representing $10 worth of quarters and pennies. Then each graduation on the barrel would represent a quarter. Four of them would represent $1. The fourth division on the barrel is marked 1, and this would be counted as $1. Each of the groups of four is marked with its proper number. The pennies would be represented by the lines on the edge of the thimble, and these of course really indicate thousandths of an inch. With these suggestions in mind, a little study of the settings in Fig. 41*a* will give the reading.

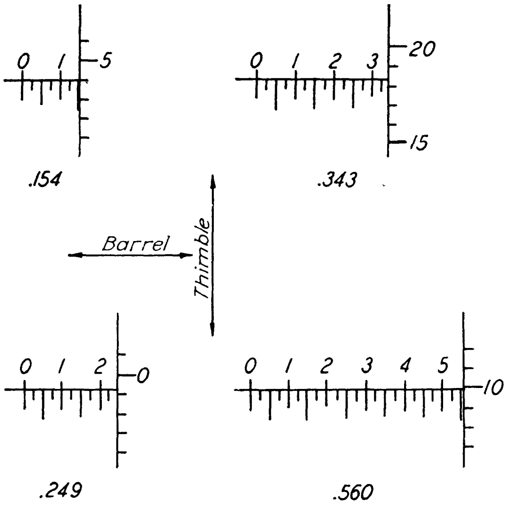


FIG. 41*a*.—Reading in thousandths.

Vernier Scale.—Up to this point, we have been considering readings in thousandths of an inch only; but, for the fine precision required for a great deal of mechanical work today, it is necessary to read to closer dimensions, that is, ten-thousandths of an inch. Turn the micrometer, and you will see a number of parallel lines numbered 0, 9, 8, 7, 6, 5, 4, 3, 2, 1, and 0. These lines are *vernier lines*, and the numbers are *vernier numbers.* If the thimble is carefully turned, it will be seen that both the zero vernier lines can be set so that they match lines on the thimble and that, when the thimble is in this position, the index line just matches a line on the thimble. This means that the reading is an exact number of thousandths; there are no tenths of a thousandth to be added. In this position, it will be noted that no other two lines of the vernier will coincide with graduations of the thimble at the same time. This is so because 10 spaces on the vernier just equal the span of 9 spaces on the thimble. If a more detailed explanation of the vernier principle is desired, it will be found in a succeeding chapter. However, the diagrams in Fig. 42 will enable the reader to test his ability to read correctly to an accuracy of a ten-thousandth of an inch. These views show a vernier opened out flat.

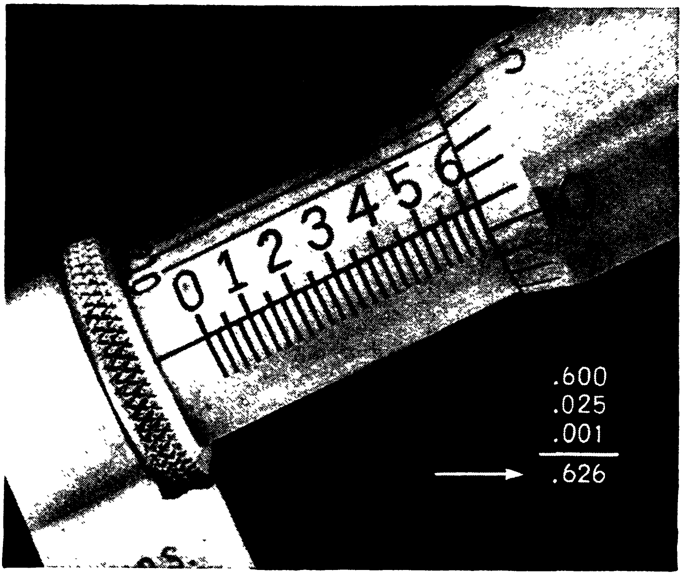


FIG. 41*b*.—Micrometer set at .626 in. (*Courtesy of U.S. Office of Education.*)

In reading a micrometer, first read the twenty-five thousandth divisions from the barrel and then the additional number of whole thousandths shown on the thimble. Then turn to the vernier and observe the number of the vernier division which matches any graduation on the thimble. The number of that line is the number of tenths of thousandths that must be added to the reading.

Micrometers are made in all sizes up to 12 in. but in most cases they are limited to a measurement of 1 in. only. For instance, a 3-in. micrometer is adapted to parts measuring between 2 and 3 in. only. Most of these larger micrometers can be read in thousandths only as they have no vernier.

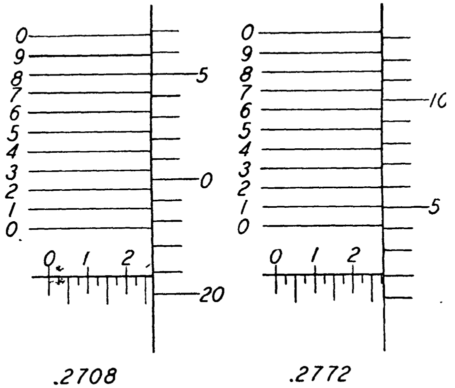


FIG. 42.—Readings in "tenths" with vernier scale.

Manipulation of Micrometer.—A few minutes of daily practice will enable one to read the micrometer with ease and accuracy. There are one or two points, however, that should be stressed in order to avoid any difficulty in obtaining correct results. First and most important is the acquisition of proper feel or touch, the meaning of which is explained in a preceding chapter. Proper holding and manipulation of the micrometer will materially assist to this end. The instrument should be held lightly but firmly in the hollow of the hand, with the third or little finger hooked through the curve of the frame. The thumb and forefinger are used to turn the thimble (Fig. 43). When the pieces being measured can be held in the left hand, the left thumb can be used to advantage to steady the micrometer if it is pressed against the frame near the anvil. This assists in "squaring" the micrometer to the surface of contact and enables one to use a more delicate touch with the adjustment of the thimble. The thimble should be turned slowly and easily until contact is felt. Then the thumb and forefinger should merely *rub* the knurled section of the thimble, without grasping it, until the proper measuring pressure is obtained. It can easily be demonstrated how a slight variation of the measuring pressure will give different readings of the same dimension; but, with the acquisition of an exact touch, readings of ±.0001 are possible, and this accuracy is the closest possible with any micrometer.

FIG.43.—How to hold micrometer.

Errors in Reading.—A common error in reading made when first learning to use the micrometer is the incorrect count of the small graduations, which represent .025. The reason for this is that the graduation is just beginning to appear when the zero is on or close to the index line and is not fully visible at this point. Another frequent error in reading to ten-thousandths is the practice of counting a graduation on the thimble before it reaches or passes the index line. For instance, if a dimension of .3258 or .3259 is being measured, the graduation that would indicate .326 is very close to the index line, and there is a tendency to count this graduation and then add the value of the vernier reading. This would give a reading of .3268 or .3269, which is of course erroneous.

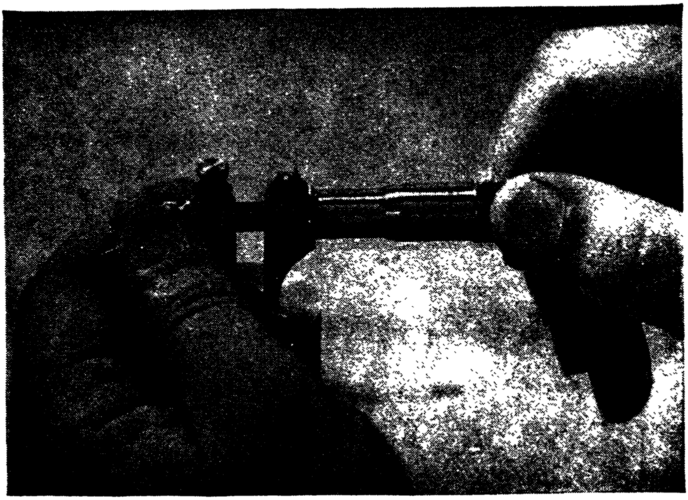


FIG. 44.—Measuring diameter of a hole with inside micrometer. (*Courtesy of U.S. Office of Education.*)

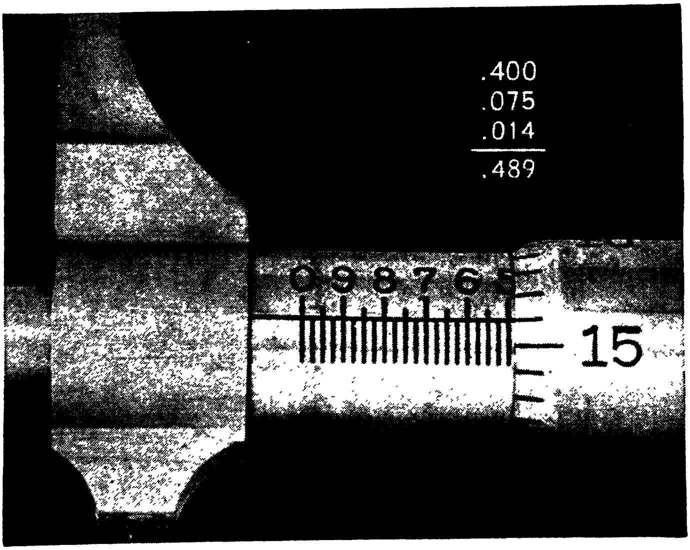


FIG. 45.—The scale of the inside micrometer is reversed, requiring care in reading. (*Courtesy of U.S. Office of Education.*)

Although a micrometer looks strong and rigid, it should be used with a great deal of care. Detailed suggestions on this subject are found in the chapter on the Use and Care of Tools and Instruments.

Inside Micrometer.—A companion tool to the outside micrometer is the inside micrometer, which is provided with jaws or points that move apart to fit the part to be measured (Figs. 44 and 45). Care should be used to see that the instrument is square with the inside surfaces of the work and that measurements are taken across the center of the hole. Another type of inside micrometer uses interchangeable rods to measure the diameter of large holes (Fig. 46). These rods are of various lengths and are selected and inserted into the screw section according to the diameter of the hole to be measured. This type of micrometer cannot be used on holes of less than 2 in. in diameter (Fig. 47). Another disadvantage in using any precision instrument that has interchangeable rods is the possibility that the rods may not be properly seated because of dirt or chips under the shoulder of the rod. The small sleeves or collars sometimes used in conjunction with these rods are also subject

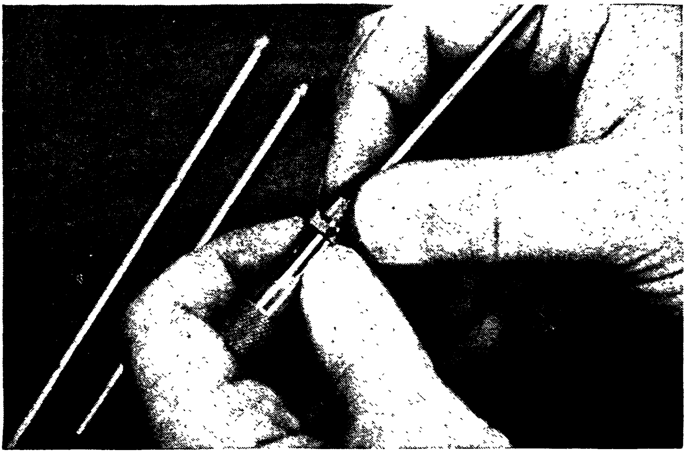


FIG. 46.—Inside micrometer with extension rods. (*Courtesy of U.S. Office of Education.*)

to error from this cause. After the micrometer is assembled, it should be checked for accuracy before measurements are made. But, whenever possible, the inside micrometers of fixed range should be used in preference to the adjustable type.

Depth Micrometer.—Another type of micrometer is the depth micrometer used for the measurement of holes, slots, and other depressions below a finished surface (Fig. 48). The depth micrometer has a slender rod that enters easily into small holes and slots, and rods of various lengths adapt the instrument to measuring holes of various depths (Fig. 49). Depth micrometers, however, are not generally used unless a small hole or narrow slot is involved, for the vernier depth gage is a much more rapid measuring instrument.

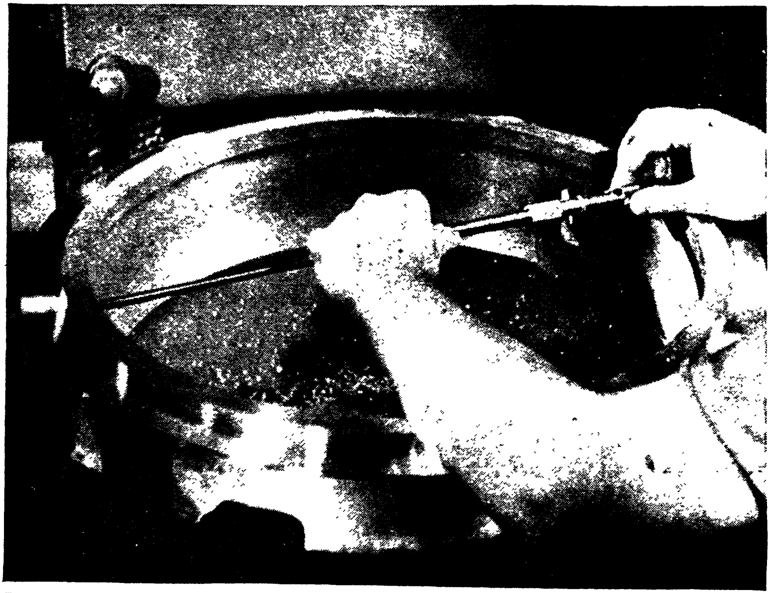


FIG. 47.—Using inside micrometer for measuring large bore. (*Courtesy of U.S. Office of Education.*)

Glare-proofing a Micrometer.—Under the best conditions, the prolonged use of a micrometer often induces severe eyestrain, especially when readings of "tenths" are necessary. In many plants, the windows are blacked out, making it necessary to use artificial light at all times. The wider use of the tubular form of fluorescent lights adds another difficulty in reading a micrometer, for the reflection of the long narrow lights on the surface of the barrel and spindle causes a decided glare from the brightly finished surface of those parts of the micrometer.

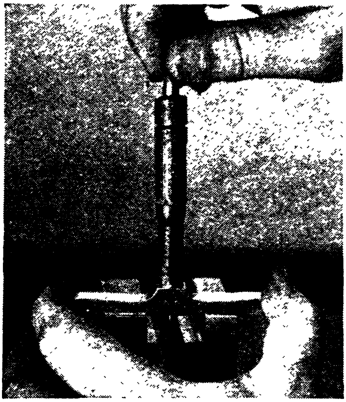


FIG. 48.—Using a depth micrometer. (*Courtesy of U.S. Office of Education.*)

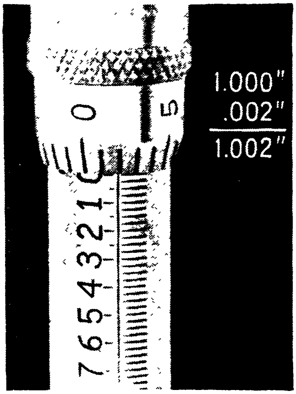


FIG. 49.—The scale of a depth micrometer is read backward. Here a 1-in. extension rod was used. (*Courtesy of U.S. Office of Education.*)

Long observation has shown a vast improvement in ability to make readings quickly and easily when the bright finish is dulled, or "glareproofed." Occasionally this is done by the manufacturer, but, if not, the inspector can glareproof his own micrometer in a very few minutes. First turn the spindle until it is open to the extreme measurement, which is just beyond the 0 indicating a full inch. Then place one drop of instrument oil under the edge of the thimble. Take a small piece of emery polishing paper No. 0 grade, fold it to form a square, and rub the edge along the barrel with lengthwise strokes slowly and evenly until the entire surface is dulled; then do the same to that part of the thimble where the graduations and figures appear. If desired, the portion of the thimble between the figures and the knurled section can be masked with adhesive tape.

After the surfaces are uniformly dulled, wipe them thoroughly with a soft cloth and remove the oil under the edge of the thimble. The purpose of the oil is to trap any small abrasive particles that might be detached from the polishing paper and keep them from getting into the screw. This possibility is remote, but the oil will serve to prevent any damage.

Questions

1. What are the three general types of micrometers?

2. Does the principle of the screw control the movement of the spindle in all three types?

3. What is the range of a micrometer screw?

4. How much does each of the divisions on the barrel represent? How many such divisions are there?

5. How many does each of the numbered divisions of a barrel represent? How many such divisions are there?

6. How much does each of the divisions on the thimble represent? How many such divisions are there?

7. How much does each of the divisions on the vernier scale represent? How many such divisions are there?

8. What are the readings for the following micrometer settings?

	Barrel scale reading	Thimble reading	Vernier reading
a	Between 0.100 and 0.125	Between 5 and 6	7
b	Between 0.800 and 0.825	Between 10 and 11	4
c	Between 0.225 and 0.250	Between 7 and 8	3
d	Between 0.000 and 0.025	Between 3 and 4	6
e	Between 0.995 and 1.000	Between 24 and 25	9

9. Why should the reading of a micrometer be taken before it is removed from the work?

10. What is the accuracy of a micrometer that is not equipped with a vernier scale?

CHAPTER VII

THE VERNIER INSTRUMENTS

VERNIER HEIGHT GAGES

One of the most important instruments for inspection purposes is the vernier height gage. In fact it is indispensable for certain purposes, such as the checking of jigs and fixtures and the layout of castings. As will be seen from the illustration in Fig. 50, the height gage consists of a vertical blade rigidly fixed to a base. The scale on the blade is graduated in inches and tenths of an inch (.100), and the tenths in turn are subdivided into four smaller graduations, each of which represents .025. Thus the main scale of the height gage is substantially the same as the scale of a micrometer. A slide, which moves up and down along the blade, consists of a gaging jaw and clamping bar, which are connected by an adjusting screw, the purpose of which is to impart a slow or fine adjustment motion to the gaging jaw. The gaging jaw contains a vernier scale.

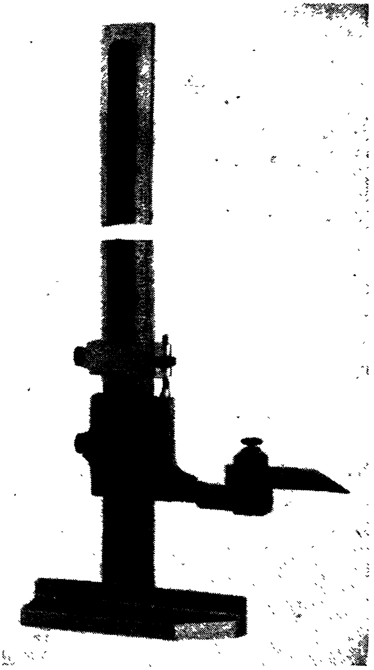


FIG. 50.—Vernier height gage.

Principle of Vernier.—Inasmuch as the vernier height gage is the most widely used of the vernier instruments, the vernier principle will be explained. There are several other vernier instruments, but the method of reading and the principle involved are the same with all these tools. The general rule that covers all verniers is as follows: A vernier scale can divide each main scale division into fractional parts. The denominator of the fraction is the number of divisions on the vernier scale, and the numerator of the fraction is the number of the vernier graduation that lines up with any main scale division. Figure 51 shows a 10-part vernier. Here the vernier scale has 10 divisions, which span the same distance as the nine divisions on the main (fixed) scale. A 10-part vernier is used on the vernier micrometer. In this case, the vernier scale engraved on the barrel spans the same distance as nine divisions on the main, or thimble, scale.

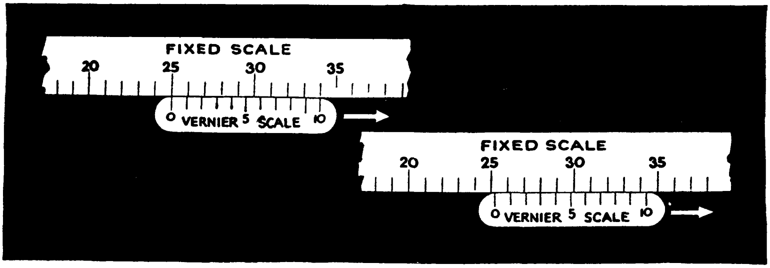


FIG. 51.—A simple vernier (10-part).

If we move the main scale so that it lines up with number 3 index on the vernier scale, we add $\frac{3}{10}$ to the reading, which becomes $25\frac{3}{10}$. As we move the scale so that the number 4 vernier division lines up with a main scale division, the reading becomes $25\frac{4}{10}$, and so on, until number 10 division lines up, when it will be noticed that the 0 division also lines up, and in this position only the main scale is read. Always remember that the point of reading the main scale is the point where the 0 on the vernier comes to rest.

Reading the Height Gage.—To return to the vernier height gage—the vernier scale on this instrument has 25 divisions, which span 24 divisions on the main scale. The vernier scale is numbered at every fifth division, beginning at zero—5, 10, 15, 20, and 25, and, when the 25th division lines up with a main scale division, it will be found that the 0 also lines up, and in this position the full reading is made on the main scale. Since each main scale division equals .025 and each vernier division is $^{24}\!/_{25}$ths of a main scale division, a movement sufficient to cause, say vernier division 3, to line up with a main scale division when vernier division 0 previously lined up with a main scale division is a movement equaling .003. The diagrams on Fig. 52 will illustrate various readings.

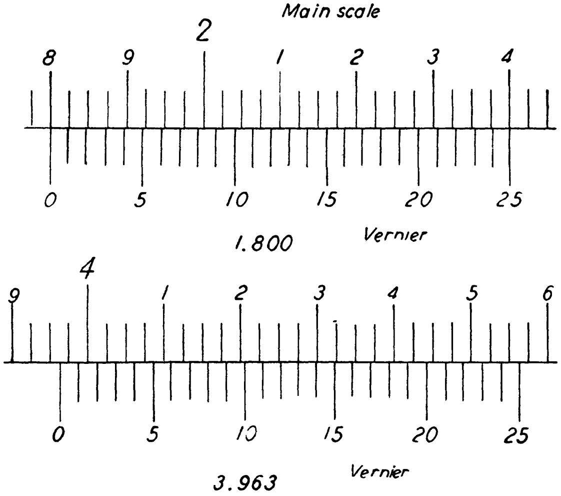


Fig. 52.—Scales of vernier height gage.

VERNIER CALIPER

Another vernier instrument that employs the same main scale and vernier scale as the height gage is the vernier caliper. This is an important measuring instrument, for it can be used for either small measurements with the 6-in. model or dimensions as great as 48 in. with the larger models. It can also be used to take both outside and inside measurements, for it is provided with two scales, one on each side of the blade, and in using it for inside measurements one should be careful to take the reading on the side marked "inside."

Manipulation of Vernier Caliper.—This is one vernier instrument where feel is important, for the measuring faces must be correctly placed on the piece to secure correct readings. In measuring an outside diameter, for instance, the fixed jaw is held firmly against the piece and the movable jaw is brought into contact with the other side, taking care that the caliper is held square. After contact is made, if any play is noted between the measuring jaws and the piece, the clamp should be tightened and the final adjustment of the movable jaw made by means of the adjusting screw. When the feel is just right, the locking screw on the slide is tightened, the feel is rechecked, and the reading is taken. A magnifier, such as a jeweler's loupe, will greatly facilitate readings with this and all vernier instruments.

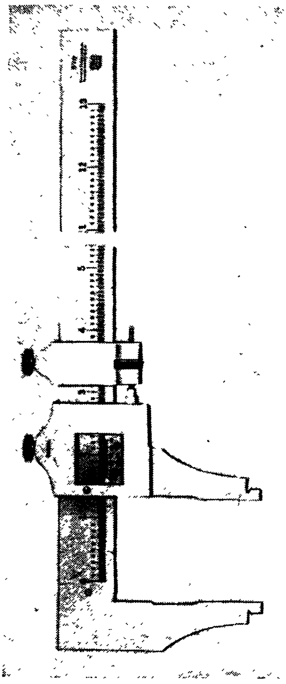


FIG. 53.—Vernier caliper.

In making measurements of inside dimensions, the same technique is observed, that is, the outside of the jaws is brought into proper contact with the work; and, after the feel is checked, the reading is made on the side of the slide marked "inside."

On the "outside" face of the slide will be observed a small depression that might be mistaken for an oil hole. There is also a dot in a small circle just to the left of the 0 division on the blade. These marks are used for the purpose of setting dividers accurately, by inserting one point of the divider in one hole and adjusting the screw until the other point falls into the other hole.

In moving the slide from one position to another, grasp the slide with the fingers at the point where it moves over the blade, not at the end of the movable jaw. The jaws are easily sprung so that they are not parallel, in which case readings are incorrect. To detect an out-of-parallel condition, bring the measuring faces together, and hold the instrument to the light to see if any light shows through at any point where the faces should be in close contact. If light does show through, the caliper must be repaired, preferably by the makers of the instrument.

Another point to observe carefully, with this and all other instruments having clamp screws, is that these screws should not be tightened too firmly; to do so will cause uneven wear and bring about an undesirable side play. Further, when any clamping screws have been tightened, the feel should be rechecked to see if the sliding member changed its position when the clamp screw was tightened.

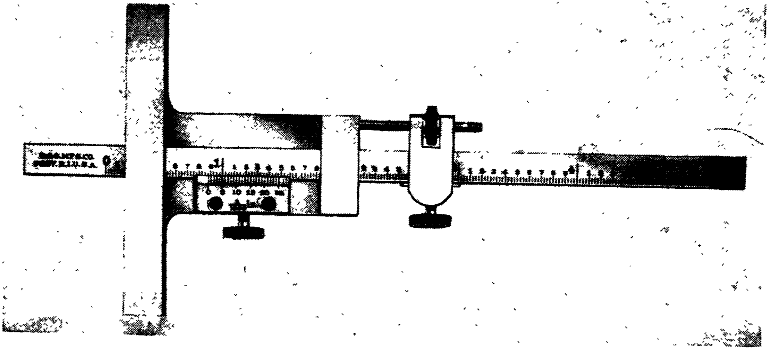


Fig. 54.—Vernier depth gage.

VERNIER DEPTH GAGES

For accurate measurement between surfaces, the vernier depth gage is a handy, rapid, and versatile instrument (Fig. 54). The principle is exactly the same as the height gage and the vernier caliper, and the main scale and vernier are the same in all these instruments. Feel does not enter into the use of the depth gage, but care should be taken to see that the surfaces are clean and free from chips and that the gage is resting firmly on its base. Then the blade should be run down until it makes gentle contact with the surface to be measured, the clamp screw should be set, and the reading taken.

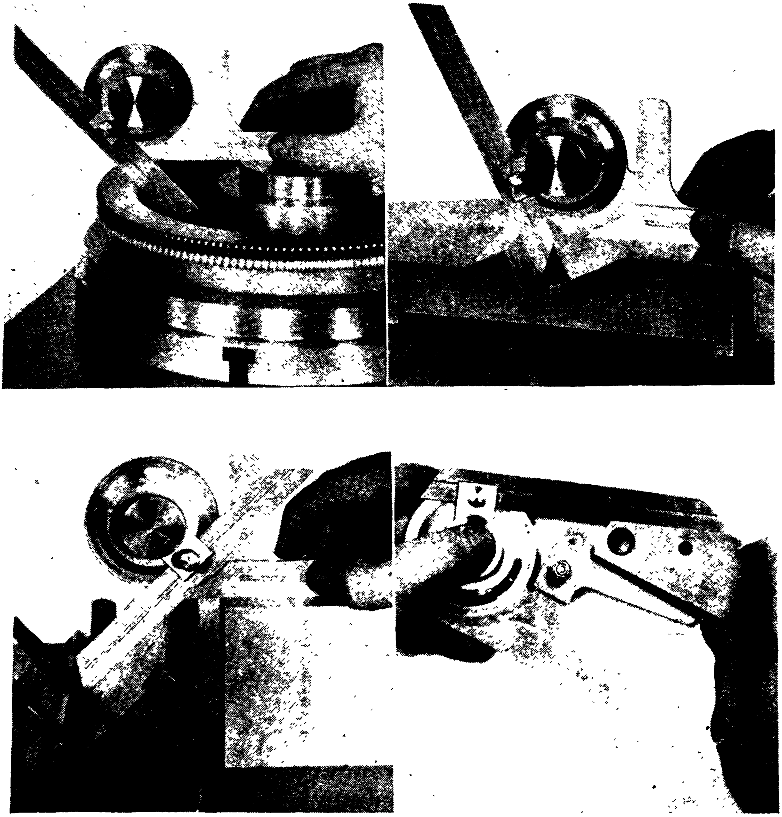


FIG. 55.—Vernier protractor showing some methods of use.

The side of the blade should not rest against any surface while a measurement is taken and in fact should be kept at least 1/8 in. away from the piece, in the event that a fillet has to be cleared which might otherwise cause a wrong reading.

VERNIER PROTRACTOR

For measuring angles other than 90 deg. (which is done with a solid square) the bevel protractor is used (Fig. 55). This consists of a disk graduated in 360 deg. (four quadrants of 90 deg. each) in which rotates an arm to which is clamped an adjustable blade. The blade is clamped by an eccentric stud and may slide along its full length or may be turned to any angle and firmly clamped. Because of this, it can be used to measure angles of many types and locations. Owing to the relatively small size

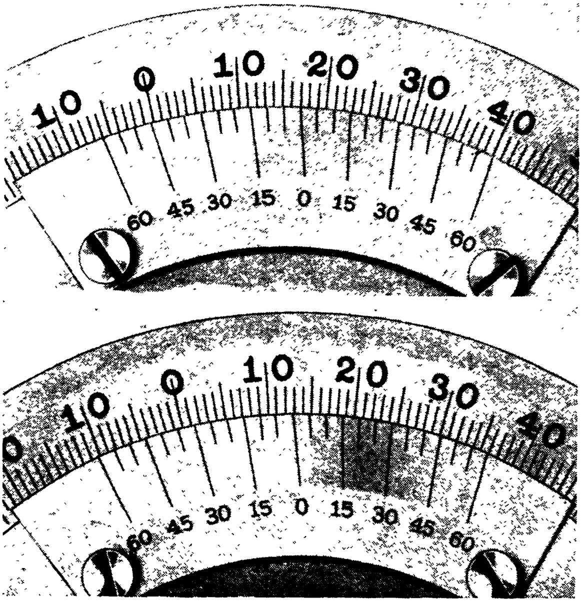


FIG. 56.—Vernier protractor scales.

of the graduated disk, however, the accuracy of the bevel protractor is limited to ±5 minutes, and for this purpose a vernier is provided which is graduated in 12 divisions on each side of a central zero point (Fig. 56). As in other vernier instruments, the reading is taken at the point where the zero rests. Twelve divisions on the vernier span 23 deg. on the disk; therefore the difference in width of one of the 12 spaces on the vernier and one of the degree graduations is $\frac{1}{12}$ deg., or 5 minutes.

To read the protractor, note on the disk the number of whole degrees between 0 on the disk and 0 on the vernier; then count *in the same direction* the number of spaces from 0 on the vernier to a line that coincides with a line on the disk. Multiply this by 5, and the product is the number of minutes to be added to the number of whole degrees.

In some cases, it may be impossible to apply the protractor to an angle that has been machined. In this event it will often serve to use a piece of heavy paper or thin metal stock, scribe the proper angle with the assistance of a protractor, and cut out the paper or metal along the scribed lines. This piece can then be applied to the angle-cut, to check its correctness.

Questions

1. What are the three principal vernier instruments? What is the purpose of each?

2. What is the accuracy of these instruments?

3. Is there any similarity between the main scale of a vernier instrument and the barrel scale of a micrometer?

4. What is the similarity between the vernier scale of a vernier instrument and the thimble scale of a micrometer?

5. Is there any similarity in the purpose they serve?

6. What instrument would you employ to check a shaft diameter of $0.6875 \begin{smallmatrix}+0.0000\\-0.0005\end{smallmatrix}$?

7. What precaution must be taken when tightening the clamp screw of a vernier instrument?

8. Explain, in proper sequence, the steps necessary to set a vernier caliper to 4.780 to take an outside measurement.

9. What vernier instrument is used to measure angles?

10. What is the accuracy of this instrument?

CHAPTER VIII

GAGES AND GAGING

Gages are the most essential single factor in mass production. They provide the only means of assuring interchangeability of component parts. To quote the National Screw Thread Commission,

> The final result sought by gaging is to secure interchangeability, that is, the assembly of mating parts without selection or fitting of one part to another, and to ensure that the product conforms to the specified dimensions within the limits of variation establishing the closest and loosest conditions of fit permissible in any given case. Gaging should be as much employed to prevent unsatisfactory parts from being produced as to sort out the correct from the incorrect parts.

Broadly speaking, any tool or instrument used for measurement might be called a *gage*, but more specifically a gage is a tool of a fixed dimension not provided with graduations or adjustment for measuring various dimensions. Gages are used for checking sizes of various details of mechanical parts. The following definitions of gaging terms are those adopted by the American Gage Design Committee:

The term *anvil* designates the gaging member of a snap gage when constructed as a fixed nonadjustable block, or as the integral jaw of the gage (Fig. 57).

The *drift hole* or *drift slot* is a small hole or slot provided in the side of a taper lock gage handle near the "go" end, through which a pin or drift may be inserted for the purpose of ejecting the gaging member from the handle (see Fig. 60).

The *flange* is that external portion of a large ring gage which is reduced in section for the purpose of lightening the gage.

The *frame* of a snap gage is the body portion of the gage as distinct from the gaging pins, gaging buttons, anvils, and adjusting or locking mechanism (Fig. 58).

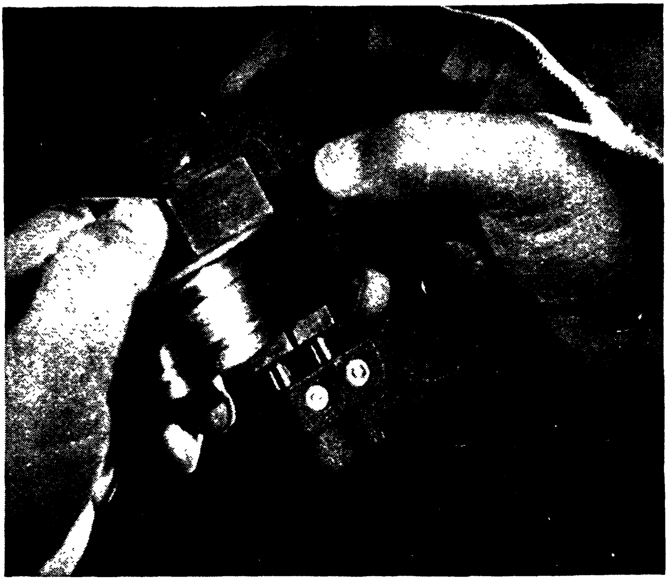


FIG. 57.—Snap gage showing anvil. (*Courtesy of U.S. Office of Education.*)

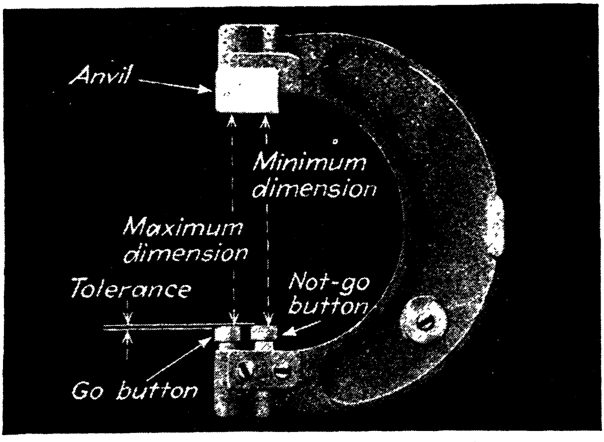


FIG. 58.—Snap gage showing frame, gaging buttons (adjustable), and locking screws. (*Courtesy of U.S. Office of Education.*)

A *gaging button* is an adjustable gaging member of a snap gage consisting of a shank and a flanged portion, the latter constituting the gaging section.

A *marking disk* is a plate that can be attached to a gage frame to provide, when suitably marked, a means of identification for the gage (Fig. 59).

The *gaging member* is that integral unit of a gage which is accurately finished to size and is employed for size control of the work. In taper lock plug gages, the gaging member consists of a shank and a gaging section.

FIG. 59.—Marking disk of snap gage. (*Courtesy of U.S. Office of Education.*)

The *handle* is that portion of a gage which is employed as supporting means for the gaging member or members. In the American Gage Design Standards, three types of handles are employed, *viz.*, the taper lock design, the reversible design, and the ball handle.

Lightening holes are unfinished drilled holes provided in heavier sizes of gaging members for the sole purpose of reducing weight of the gage.

A *plain cylindrical plug gage* is a complete unthreaded internal gage of single- or double-ended type for the size control of holes. It consists of handle and gaging member or members, with suitable locking means. The term *taper lock* designates that construction in which the gaging member has a taper shank, which is forced into a taper hole in the handle. This design is standard for all plug gages in the range above 0.059 in. to and including 1.510 in., and for pipe-thread plug gages up to and including 2-in. nominal pipe size (Fig. 60). The *shank* is that portion of the gaging member which is used to fix the gaging member in the handle.

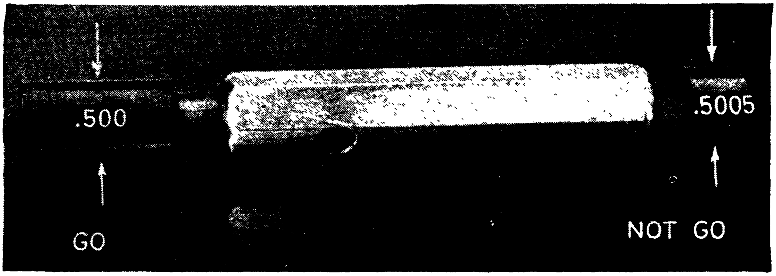


FIG. 60.—Taper lock cylindrical plug gage showing go and no-go plugs and handle with drift hole. (*Courtesy of U.S. Office of Education.*)

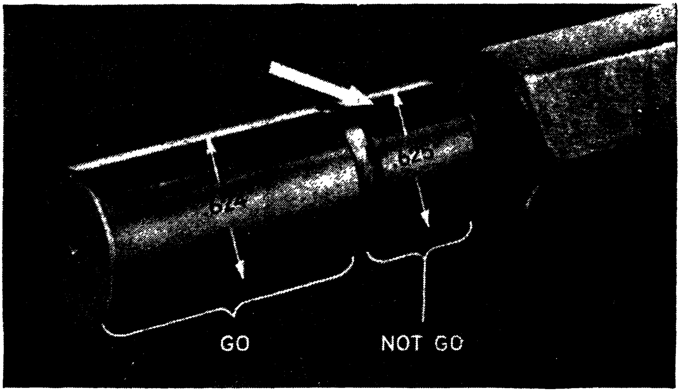


FIG. 61.—A "progressive" plug gage which checks the diameter of a hole with one operation. (*Courtesy of U.S. Office of Education.*)

A *progressive cylindrical plug gage* is a complete unthreaded internal gage consisting of handle and gaging member in which the "go" and "no-go" gaging sections are combined in a single unit in one end of the handle (Fig. 61).

A *reversible plug gage* is a plug gage in which three wedge-shaped locking prongs on the handle are forced into corresponding locking grooves in the gaging member by means of a single through screw, thus providing a self-centering support with a positive lock. This design is standard for all plug gages in the ranges above 1.510 to and including 8.010 in., with the exception of pipe thread plug gages, for which it is standard in the ranges above 2-in. nominal pipe size, to and including 6-in.

A *plain ring gage* is an unthreaded external gage of circular form employed for the size control of external diameters. Smaller sizes consist of a gage body into which is pressed a bushing, the latter being accurately finished to size for gaging purposes.

A *plain adjustable snap gage* is a complete external caliper gage employed for the size control of plain external dimensions, comprising an open frame, in both jaws of which gaging members are provided, one or more pairs of which can be set and locked to any predetermined size within the range of adjustment (see Fig. 58).

A *plain solid snap gage* is a complete external caliper gage employed for the size control of plain external dimensions, comprising an open frame and jaws, the latter carrying gaging members in the form of fixed, parallel nonadjustable anvils.

A *snap gage adjusting screw* is a threaded member employed for adjusting to any predetermined setting, the gaging pins or gaging buttons of an adjustable snap or length gage.

The *snap gage locking device* is that portion of an adjustable snap or length gage which is employed for locking the adjustable gaging members in fixed position. It comprises a locking screw, a locking bushing, and a locking nut.

Adjusting slots are radial slots provided in thread ring gages in order to facilitate expansion and contraction of gage size by means of the adjusting device. An adjusting slot always terminates in an adjusting slot terminal hole (see Fig. 70).

THE FIXED GAGES

Most of the measuring tools used in mass production are fixed gages. Fixed gages differ from other measuring instruments in that a fixed gage is not adjustable while in use. Some fixed gages can be adjusted within a narrow range of settings, but the settings made remain fixed. There are many types of fixed precision gages. They include plug gages for internal dimensions, ring and snap gages for external dimensions, taper plug and ring gages for checking taper, etc.

A fixed gage sustains a slight wearing action every time it is used. A plug gage gets slightly smaller and a ring gage slightly larger, so that after a few thousand pieces are checked a gage becomes so worn that it is no longer useful for precise work.

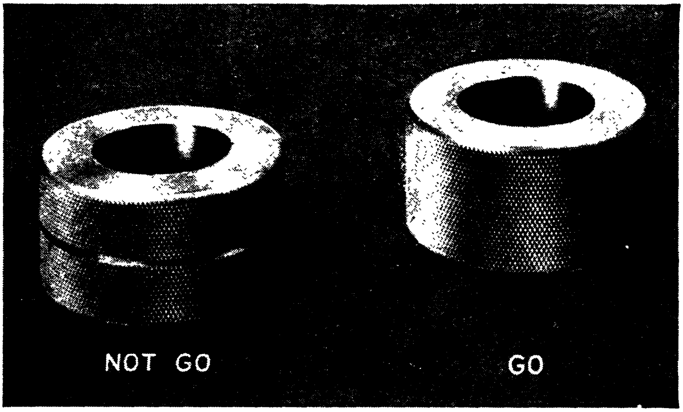


Fig. 62.—Go and no-go ring gages. (*Courtesy of U.S. Office of Education.*)

Many of these gages are made to within a few hundred-thousandths of an inch of their rated size. To maintain such a degree of accuracy in the gage demands the greatest care in its use. The work should be clean and free from burrs or chips. If not, the surfaces of the gage may become scratched and worn. A gage should never be forced over or into the work.

Plug Gages.—Plug gages are used ordinarily for checking holes, not only for dimension but also for detecting other conditions such as taper, out-of-round, etc. A common type of plug gage is shown in Fig. 60. The single plug type is used for a single fixed dimension and is not intended for work that has to be gaged between tolerance limits. The double-ended gage, with go, no-go plugs, is capable of checking a hole within the limits set up by the gage. The size of each gaging member is clearly marked. The go end should enter the hole freely; the no-go end, the shorter of the two, should not enter. Feel is quite important in a plug gage, which for that reason should never be inserted in a vise or used with a wrench, for the feel is thereby lost. A plug gage should never be used dry; a coating of light oil will prevent sticking of the gage and injury to the gage or hole.

FIG. 63.—Using a ring gage. (*Courtesy of U.S. Office of Education.*)

Bell mouth is an enlargement of a hole at one end. The plug gage starts loosely, tightening as it enters the hole only a short distance. Taper differs from bell mouth in that the hole reduces or increases in size evenly from end to end.

Out-of-round condition exists when the gage appears to be firm in the hole but will move sideways in one direction. In such cases, the gage fits firmly at right angles to the loose fit.

Ring Gages.—Ring gages are used to check external diameters of shafts, arbors, etc. (Fig. 62). The main advantage of the ring gage over other methods of checking is that, at one operation, it will check for size, taper, and out-of-round condition (Fig. 63), whereas other types of gages have to be applied at several points. If the gage passes over the part freely and smoothly with light pressure, the part is acceptable with respect to maximum size, and the no-go gage should then be tried. Ring gages are necessarily made very heavy relative to their size, in order to give stability, which will prevent distortion while they are being used. Except in experienced hands they do not permit rapid inspection, although they do check several features of the finished surface at one time.

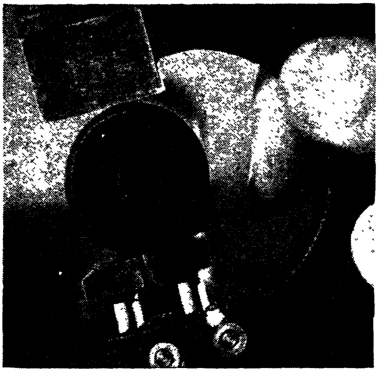


FIG. 64.—Snap gaging a shaft. (*Courtesy of U.S. Office of Education.*)

Snap Gages.—Snap gages are fixed gages for checking outside measurements. They are made in a wide variety, one of which is shown in Fig. 58. Some of those illustrated are of a type which is adjustable through a small range. The principle

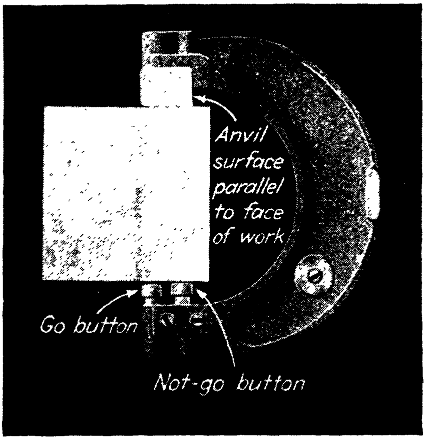


FIG. 65.—Snap gaging a piece with parallel surfaces (piece is undersize). (*Courtesy of U.S. Office of Education.*)

of these gages is that the gaging buttons are so spaced that, if the piece is of the proper dimension, it will pass through the first set of buttons or anvils (the go member) but will be stopped by the second pair (the no-go member). In other words, suppose a piece is dimensioned on the blueprint 0.500 ± 0.002. The go member would be set at 0.502 and would permit any piece up to this dimension to enter the gage. If the piece were 0.503, it would be stopped as over the permissible dimension of 0.502. If the piece passed through the go gage and if it were not smaller than 0.498 (the smallest permissible dimension), it would be stopped by the no-go member. If, however, it passed through the no-go member, it would measure less than 0.498 and would have to be rejected.

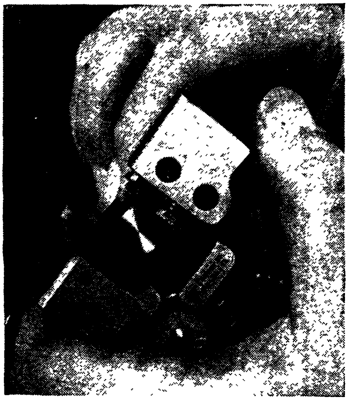


FIG. 66.—Snap gaging a small cylindrical part. (*Courtesy of U.S. Office of Education.*)

Snap gages should be used with great care to reduce wear and to maintain accuracy. The correct way to gage a cylindrical piece is to place the anvil, or top button, of the snap gage gently on the work and with a simple rocking motion push the go button past the work. If it stops at the no-go button, as shown in Fig. 64, it passes inspection; and, if it passes through, the piece is too small. Remember the go button is set out as far as the tolerance will allow and forcing it past an oversized part may damage the gage.

To gage parallel surfaces, the gage should approach the piece so that the gaging buttons are "square." Only a light hand pressure should be used. If the piece is between the limits set up in the gage, the no-go buttons will not pass the work (Fig. 65). However, if the piece is undersized, the no-go buttons will slide by. This usually indicates the piece must be rejected.

In gaging small cylindrical parts, the work should be rolled on the anvil toward the gaging buttons (Fig. 66).

Flush pin gages in the simplest form consist of a solid steel body and a movable pin. The body rests on one surface, the pin moves until it contacts another surface, and the distance between the surfaces is indicated by the position of the pin

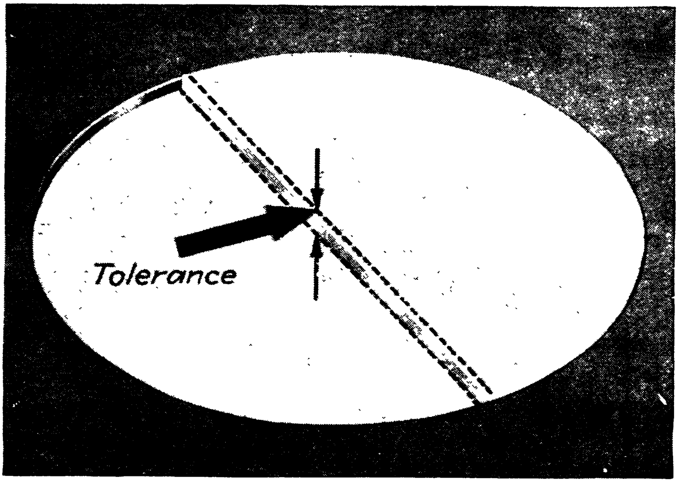


FIG. 67.—The "steps" of a flush pin gage. (*Courtesy of U.S. Office of Education.*)

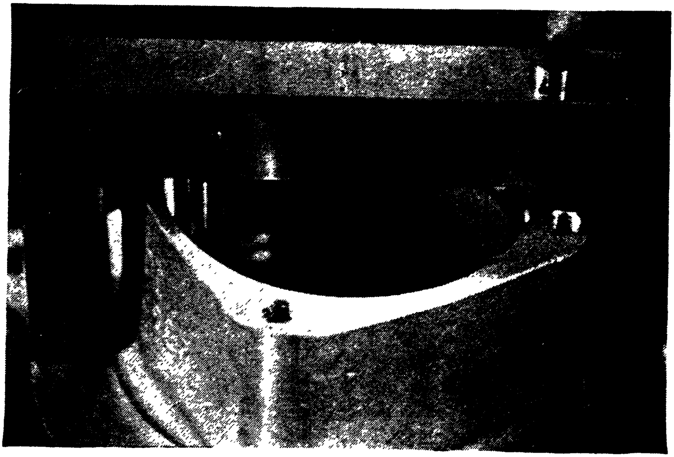


FIG. 68.—Checking three dimensions at once with a flush pin gage. (*Courtesy of U.S. Office of Education.*)

relative to the body, especially the upper part of the pin, which usually protrudes slightly from the body in such a way that its position can be determined in respect to one or more steps, by feel. The accompanying sketch (Fig. 67) shows the principle and the steps normally indicate the maximum and minimum limits of the protrusion of the pin when positioned on the surface to be measured.

Flush pin gages are adaptable to many types of inspection gaging which ordinarily would present many difficulties, but the flush pin type is not only accurate to about 0.001, if well made, but it is also rugged and not subject to unusual wear.

By using more than one pin, it is possible to extend the usefulness of the flush pin gage to the determination not only of one dimension relative to two surfaces, but of more than one dimension relative to other surfaces and to each other (Fig. 68).

Questions

1. What is the basic reason for using gages?

2. Name two types of gages suitable for checking outside dimensions of cylindrical parts.

3. In what ways could a worn plug gage be made again serviceable?

4. What does a ring gage check besides the diameter of a part?

5. What are the two general types of snap gage?

6. What is the chief advantage of an adjustable snap gage?

7. How may an out-of-round condition of a hole be detected with a plug gage?

8. What does the height of the step in a flush-pin gage represent?

CHAPTER IX

SCREW THREADS

In a recent issue of a well-known weekly magazine, there appeared an advertisement of a prominent manufacturer of industrial materials. The illustration showed an army pilot in a dive bomber, and the caption read, "He flies a plane held together with a thread." To the layman this was a rather startling statement and not readily understood until he read the text of the advertisement, which revealed that the thread referred to was not a sewing thread but a screw thread. The advertisement further stressed that accurately formed threads were of utmost importance in modern machines.

The inspection of screw threads is one phase of quality control that requires a fairly thorough understanding of the principles that govern the function and forming of screw threads. To begin with, we have a somewhat formidable set of terms and definitions of various details and characteristics of a screw thread. First of all is the definition of a screw thread as "a ridge of uniform section in the form of a helix on the surface of a cylinder or cone." Then we have various standards to which screw threads must conform.

There are many types of screw threads, and what appears to be a relatively simple operation in forming a screw thread is in fact subject to a number of rules and methods of machining. However, for the purpose of an inspector, it is not necessary to go into great detail regarding the procedure, but there are a few characteristics of a screw thread that an inspector should understand thoroughly.

Thread Form.—The form of threads used in most machine work has been established as the *American National Form.* This supersedes the old U.S. Standard, which has been changed to the American National Coarse Series; the old SAE (Society of Automotive Engineers) thread, which is now the American National Fine Series, and the sharp V thread, which was very easily nicked or burred and was very hard on the taps and dies used to cut the thread.

Thread Series.—The term thread series might be explained by stating that, in most cases, threads of a given major diameter (outside diameter) may be formed with two or three different numbers of threads per inch.

For instance, a 1/4 in. major diameter thread may be made with 20, 28, or 32 threads per inch.

The fewer threads per inch on any given thread diameter, the coarser the individual thread. Therefore the 1/4-in. screw thread with 20 threads per inch is known as the *National Coarse* (NC), the one with 28 threads per inch is the *National Fine* (NF), and the one with 32 threads per inch (seldom used) is *Extra Fine* (EF).

In addition, there is a thread series known as *National Special* (NS) which, as the term implies, is used for special purposes. Then there is the 8-, 10-, and 12-pitch series in which all diameters have the number of threads per inch specified in the particular series. This is in contrast to the coarse and fine series, in which the number of threads per inch decreases as the diameters increase.

Thread Fits.—The type of *fit* of a screw thread is specified by a number, beginning with No. 1 for a poor or loose fit. The method of designating fits is, of course, subject to somewhat broad interpretation, but generally speaking a No. 1 fit is one in which the mating parts turn freely and loosely one with another; a No. 2 fit is a free fit in which the parts turn easily with little or no "shake"; a No. 3 fit is a medium fit in which there is no shake and the parts can be worked together with the fingers; a No. 4 fit is a close fit in which pliers or a wrench is needed. This type of fit is a precision fit used in a mechanism that is subject to severe vibration.

Various types of fits are used in accordance with the specific needs of the mechanism. For instance, it is not necessary to have a high-quality fit in a stove bolt, but in an airplane motor, which is subjected to varying strains and extreme vibration, a precise fit is essential.

There is also a stud fit which provides for a tight fit between one end of a screw stud and a tapped hole in which the stud is intended to remain permanently.

Thread Terminology.—The diagram (Fig. 69) shows certain characteristics, which, however, do not include all the terms applied to thread formation but show all the features necessary for ordinary mechanical inspection. These are

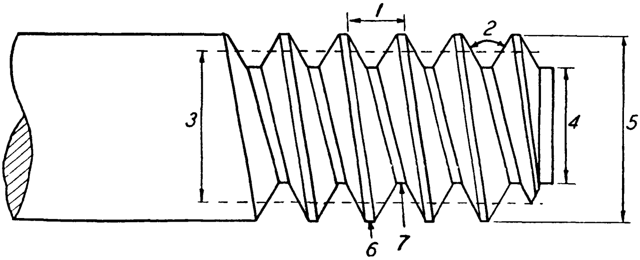


FIG. 69.—Diagram of screw thread.

Screw Thread.—A ridge of uniform section in the form of a helix on the surface of a cylinder or cone.

External and Internal Threads.—An external thread is a thread on the outside of a member. *Example:* A threaded plug.

An internal thread is a thread on the inside of a member. *Example:* A threaded hole.

Major Diameter (formerly known as "outside diameter").—The largest diameter of the thread of the screw or nut [Fig. 69(5)]. The term *major diameter* replaces the term *outside diameter* as applied to the thread of a screw and also the term *full diameter* as applied to the thread of a nut.

Minor Diameter (formerly known as "core diameter").—The smallest diameter of the thread of the screw or nut [Fig. 69(4)]. The term *minor diameter* replaces the term *core diameter* as applied to the thread of a screw and also the term *inside diameter* as applied to the thread of a nut.

Pitch Diameter.—On a straight screw thread, the diameter of an imaginary cylinder, the surface of which would pass through the threads at such points as to make equal the width of the threads and the width of the spaces cut by the surface of the cylinder [Fig. 69(3)]. On a taper screw thread, the diameter, at a given distance from a reference plane perpendicular to the axis of an imaginary cone, the surface of which would pass through the threads at such points as to make equal the width of the threads and the width of the spaces cut by the surface of the cone.

Pitch.—The distance from a point on a screw thread to a corresponding point on the next thread measured parallel to axis [Fig. 69(1)].

$$\text{Pitch in inches} = \frac{1}{\text{number of threads per inch}}$$

Lead.—The distance a screw thread advances axially in one turn. On a single-thread screw, the lead and pitch are identical; on a double-thread screw, the lead is twice the pitch; on a triple-thread screw, the lead is three times the pitch, etc.

Angle of Thread.—The angle included between the sides of the thread measured in an axial plane [Fig. 69(2)]. In the American National Form, this is 60 deg.

Helix Angle.—The angle made by the helix of the thread at the pitch diameter with a plane perpendicular to the axis.

Crest.—The flat top surface joining the two sides of a thread [Fig. 69(6)].

Root.—The flat bottom surface joining the sides of two adjacent threads [Fig. 69(7)]. (These "flats" prevent the damage that would result if the edges were sharp and also give a firmer fit, with the mating part.)

Side.—The surface of the thread which connects the crest with the root. The sides of the thread are the bearing surfaces for any thrust or strain to which the screw is subjected.

Axis of a Screw.—The longitudinal central line through the screw.

Base of Thread.—The bottom section of the thread; the greatest section between the two adjacent roots.

Depth of Thread.—The distance between the crest and the base of thread measured normal to the axis.

Number of Threads.—Number of threads in 1 in. of length.

Length of Engagement.—The length of contact between two mating parts, measured axially.

Depth of Engagement.—The depth of thread contact of two mating parts, measured radially.

Pitch Line.—An element of the imaginary cylinder or cone specified in the definition of pitch diameter (page 87).

Thickness of Thread.—The distance between the adjacent sides of the thread measured along or parallel to the pitch line.

Right- and Left-hand.—When viewed end on, a thread usually runs from left to right or clockwise, but in some cases the thread runs from right to left or counterclockwise. The latter are known as left-hand threads, abbreviated L.H. In the absence of this designation, the thread is assumed to be a right-hand thread.

THREAD GAGES

In the section relating to plug and ring gages for checking holes, shafts, etc., it was shown that the main function of these gages is to check the dimension or diameter. In dealing with thread gages, however, we have a more complex problem, because a screw thread must be formed in accordance with certain established practices, as outlined on the pages just preceding. For this reason, a thread gage is designed to check at one time the major or outside diameter, the minor or smallest diameter, the pitch or distance between two adjacent threads, and also whether the threads have been properly formed to ensure a correct fit. The go gage checks all these features, but the no-go gage checks only one thing, that is, whether the threads are so cut as to make a proper contact or fit with the mating part when assembled. This depends on whether or not the pitch diameter is properly dimensioned. For this reason, it is always necessary to use the no-go gage when checking threads.

Until recently no more than one and one-half turns of the no-go gage were permissible for acceptance of the part; but, under new provisions of the National Bureau of Standards, a no-go thread plug gage may enter a threaded hole for the full length of the gage and still be acceptable, provided the gage fits snugly after three full turns. Likewise a thread ring gage may engage an external thread for its full width, provided there is no shake after four full turns.

This applies to a No. 3 fit. For No. 1 and No. 2, three and one-half turns are permitted for internal threads and four and one-half turns for external threads. For a No. 4 fit two turns are allowed and for a stud fit one and one-half turns.

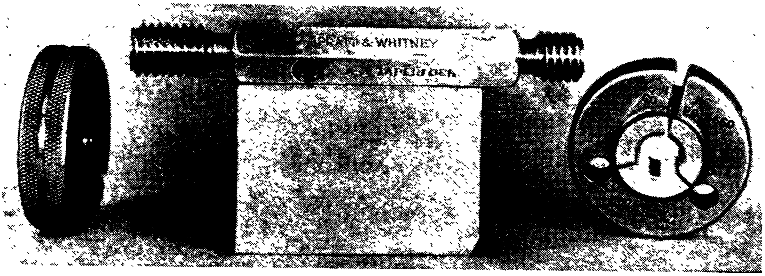


Fig. 70.—Thread plug and ring gages showing adjusting slots of ring gage.

Thread plug gages, used for checking internal screw threads, usually have a chip groove cut the full length of the gage to pick up any loose chips of metal or bits of dirt in the threads. However, if the hole appears not to be clean, it should be cleaned out with a brush or an air jet before the gage is used. Be sure there are no burrs on the work, for they might prevent the gage from entering and might damage both the gage and the work. The gage should enter the hole easily and be run down to the bottom of the hole. The gage should not rock or show a loose fit. Be sure you are using the proper gage for the class of thread fit specified for the thread; otherwise an improper conclusion regarding the fitness of the work is almost certain to result.

When the gage is in the hole, see if the handle of the gage is square with the work. If not, the hole has been improperly drilled at an angle. When a hole does not go completely through a piece, check to see if it has been cut as deep as the blueprint specifies.

Thread ring gages are the counterpart of the thread plug gage and are used to check external threads. A convenient tool widely used for gaging external threads is the roll thread snap gage. This is capable of much more rapid use than other types. The work should pass the go rolls freely and of course should be stopped by the no-go rolls.

Go and No-go Thread Gages (Fig. 70).—Like the straight plug gage, the go end of a thread plug gage is longer than the no-go end. Unlike the straight plug gage, where the no-go end is larger in diameter than the go end, the no-go end of a thread plug gage is smaller in major, or outside, diameter, because the chief function of the no-go gage is to check pitch diameter, and for this reason the threads are truncated or ground down so that they will clear the "flats" at the crest of the threads being gaged.

The no-go ring gage is distinguished from the go gage by a groove cut in the knurled surface around the outside of the gage.

How to Select the Proper Thread Gage.—For threads with a major (outside) diameter of less than ¼ in., the blueprint dimension is always shown as a decimal. However, the thread gages for these dimensions are designated by a number instead of a dimension. For this reason, an inspector sometimes is at a loss to know which gage to select to match the dimension of the thread he is to check. It will be noted that the dimensions of the major diameter follow a regular system beginning at .060 (the smallest standard industrial thread) and increasing in intervals of .013. For instance, .060, .073, .086, .099, etc. An .060 diameter is known as No. 0, .073 as No. 1, .086 as No. 2, etc.

Therefore, to select the proper thread gage first subtract .060 from the dimension shown on the blueprint, then divide the remainder by .013. The result will be the number of the gage to be used.

PIPE THREADS

Pipe threads like the regular American Standard are cut with an angle of 60 deg., and the thread is truncated at crest and root.

Pipe threads taper ¾ in. per foot, and this makes them very useful when a tight joint is desired for air, liquids under pressure, etc.

Pipe threads begin at a nominal size of ⅛ in. and increase by ⅛ in. steps to ½ in., thence by ¼-in. steps to 1½ in., thence by ½-in. steps to 5 in. For internal threads, three gages are used (Fig. 71), one of which checks the normal hand engagement between internal and external threads. A gaging notch shows the distance the plug should enter, one turn over or under this notch being allowable. A supplementary gage checks the thread length and taper.

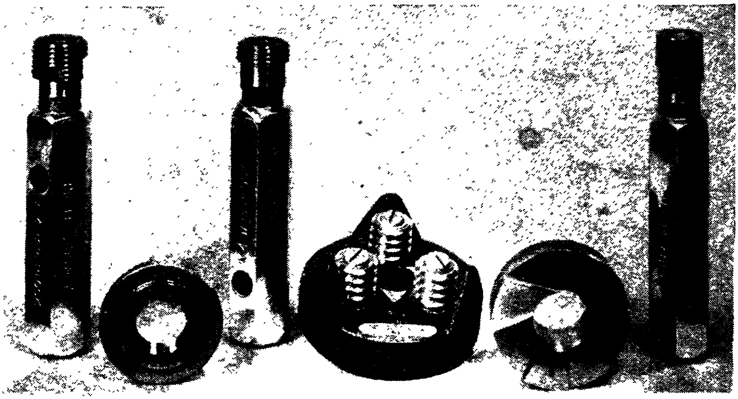


FIG. 71.—Set of pipe thread gages.

The plain taper gage checks for minor diameter truncation, the correctness of the thread being determined by the amount of shake between gage and thread, when the extreme end of the boss or fitting is between the maximum and minimum steps of the gage.

For external pipe threads, three gages are also used. The tri-roll gage checks the thread sizes. The taper ring thread gage checks for length of normal hand engagement. The end of the pipe should be flush with the face of the gage, with plus or minus one turn being permissible. The other gage is a plain taper gage which has steps indicating the basic size, and other steps for minimum and maximum dimensions.

GLASS GAGES

In the quest for new devices and improved methods to simplify inspection practice, several new developments have been brought forward. One of these is the use of glass for gages of the fixed type, such as plug, ring, and snap gages.

Many advantages are claimed for glass gages, which are summarized as follows:

1. There is a saving of valuable tool steel.

2. Glass gages afford visibility in inspection.

3. Extended use of glass gages will release for other production machine-hours and man-hours now consumed in annealing, machining, heat-treating, and eliminating distortion of steel gages.

4. Glass gages are not subject to corrosion.

5. Since glass does not rust, greasings and degreasings necessary with steel gages during shipment and storage are eliminated.

6. Because thermal conductivity of glass is less than steel, body heat of inspectors will not be transmitted so rapidly to the gage to affect gaging dimensions.

7. Scratches and slight chipping on glass neither burr the gages nor change their gaging functions.

8. Where the part being inspected is very near the size of the gage, there is less tendency for it to seize or gall on glass than on steel.

9. Sense of feel is more pronounced when using a glass gage.

10. The use of glass will teach inspectors to handle gages carefully.

11. Glass appears to have abrasion-resisting qualities better than steel for gaging applications.

12. When a steel gage is dropped, it may spring or deform, and its gaging functions will thereby be impaired. A glass gage either breaks or remains dimensionally unchanged.

Exhaustive tests are being made to ascertain whether these claims are justified. Some of them definitely are correct, while others are debatable. At the present time, it has been shown that, within certain size limits, when tolerances are not too close, glass gages are acceptable substitutes for steel gages. However, undue wear has occurred in precision fits with close tolerances, owing probably to the abrasive action of such metals as aluminum.

Undoubtedly many improvements will be made in the production and use of glass gages. Certainly the saving of time in filling orders, and the economy of both material and labor in production warrant their use wherever possible.

Questions

1. Is the thread on a bolt external or internal?

2. What is the standard term for the outside diameter of a screw thread?

3. What is the term that denotes the smallest diameter of a screw thread?

4. What is the relation between the lead of a single thread and the pitch? The lead of a double thread?

5. What is the thread angle of the American National form?

6. How many classes of thread fit are there?

7. What is the standard taper on a pipe thread?

8. What does a go thread gage check?

9. What does the no-go thread gage check?

10. The thickness of a thread is measured at what point?

CHAPTER X

DIAL INSTRUMENTS AND MECHANICAL COMPARATORS

A dial instrument is one in which a dimension or variation from a dimension is read directly from a graduated and numbered dial. Some of these instruments are designed to measure a full dimension directly, whereas other types will measure only variations of a dimension from the fixed or standard measurement to which the instrument is adjusted. The latter type is known as a *mechanical comparator*, because it is a mechanical device for *comparing* proper dimensions.

In other words, comparators contain within themselves no definite standard, but they do have a reasonably precise scale covering a plus or minus range from the zero point. The "sensitivity" of comparators, that is, the relative movement of the pointer on the scale due to a given displacement of the contact point, depends largely on the purpose for which the instrument is used.

Most of these instruments are designed to measure variations in size of a thousandth (.001) or a ten-thousandth (.0001) of an inch, but some of them can detect variations as small as one five-hundred-thousandth (1/500,000, or .000002). This is a very small dimension indeed. If you could split a sheet of cellophane into 10 equally thick sheets, each would be 1/10,000 in. thick, but to conceive such a sheet split into 500 equally thick sheets or 1/500,000 in. is practically impossible. However, such a small dimension can be measured by mechanical means, and a few hundred-thousandths can be of much consequence in certain types of precision mechanisms.

The Indicator.—A typical dial instrument is shown in Fig. 72. This instrument is better known as an indicator. It is said to have been originated by two mechanics who were employed by a large watch manufacturer. They made some dial indicators for their own use from watch parts and later began the manufacture of indicators on a commercial basis because of the demand for an instrument of this kind. The indicator is not in itself a complete gage. It must be supported on an arm or clamped to a fixture to be held firmly in a fixed position. The indicator is a comparator in that it cannot measure dimensions but registers only the difference between the piece being checked and the master or standard to which it is set.

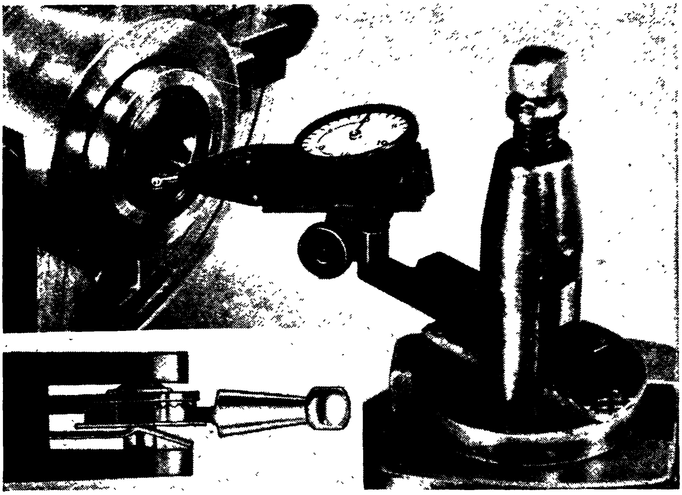


FIG. 72.—Dial indicator. Inset shows index point. (*Courtesy of Federal Products Corporation.*)

The scale on the dial is graduated so that, as the pointer moves to either the right or the left of zero, the divisions read in the same manner, that is, as plus or minus from the basic dimension. In using indicators, the inspector should be careful to check the sensitivity of the instrument by referring to the fraction which appears on the face. Usually this is 1/1,000, which means that a movement of the ball point of 1/1,000 in. would cause the pointer to move just one division on the dial. The most commonly used dial is the one shown in Fig. 73.

The more sensitive type of indicator will give readings to an accuracy of 1/10,000, in which case a dial similar to that in Fig. 74 will be used.

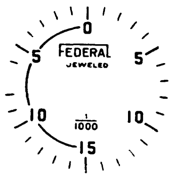


Fig. 73.—Dial of indicator .001 in.

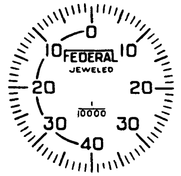


Fig. 74.—Dial of indicator .0001 in.

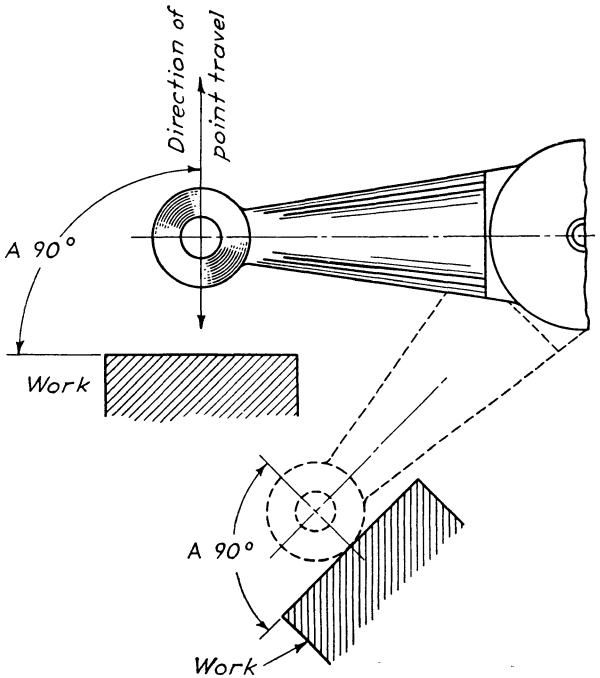


Fig. 75.—Proper position of ball lever.

Position of Lever.—In using an indicator, there are two or three points that should be kept carefully in mind to secure correct readings. One is to see that the lever on which the ball is located should be approximately parallel with the surface being measured (Fig. 75). If the lever is turned from this parallel position, it alters the relation of the lever movement with the pointer movement and thereby gives wrong values.

Many an experienced inspector is not aware of this and therefore fails to caution the learner against the use of an indicator with the ball lever turned so that it is not approximately parallel to the surface of the work. However, a study of the diagram in Fig. 76 will show why incorrect readings are obtained when the ball lever is not in its proper position.

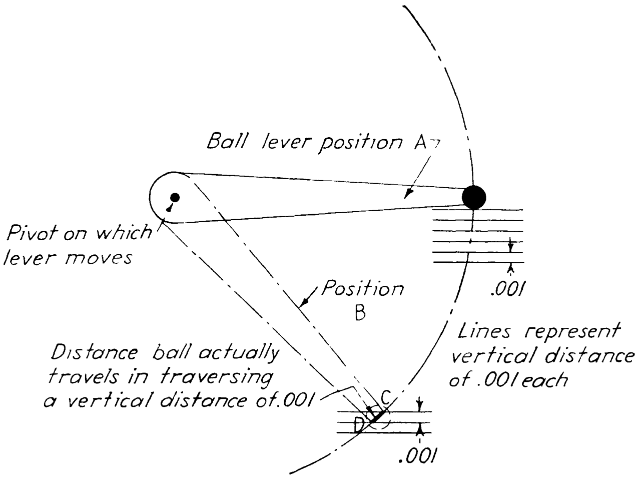


FIG. 76.—Diagram showing effect of nonparallel position of lever arm.

Inasmuch as the ball lever is mounted on a pivot, the ball moves in a circular path. If, for instance, a small variation in height is being measured and the ball is in position *A*, a vertical displacement of the lever of .001 will register .001 on the dial. In the diagram, several horizontal lines represent vertical intervals of .001. Suppose the ball lever were in position *B*. A vertical displacement of the ball of .001 would then cause it to follow the path *C-D*, which is obviously greater than the distance between the horizontal lines and the dial would show a movement of about .0015.

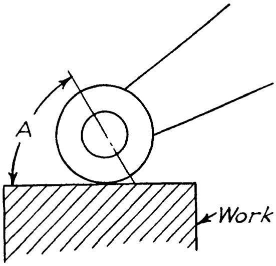


FIG. 77.—Showing angle *A*.

For instance, referring to Fig. 77, if the ball lever is applied to the work in such a manner that angle A is 60 deg., a correction factor of .866 is necessary to obtain the actual measurement. Therefore, if the indicator reading is .0056, the correction would be .0056 × .866. The correct measurement is .0049. If angle A is 30 deg., the factor is .5. In this case .0056 × .5 equals .0028. The correct measurement is .0028.

Special Levers.—Another cause for incorrect indicator readings is the use of levers other than those regularly supplied by the manufacturer. It must be kept in mind that the indicator is designed for a lever of a *specific length,* applied to the work so that the lever is *approximately parallel* with the surface of the work. If either the length of the lever or the parallel condition is altered, the readings are also changed to an untrue value. Therefore, in using longer or shorter levers, the lever ratio is incorrect and must be compensated for.

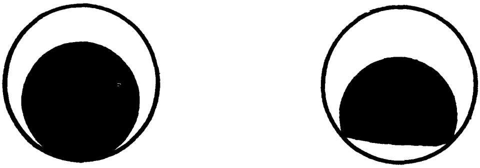


FIG. 78.—Showing effect of worn ball in hole.

Indicating Holes.—Still another point to observe is to be careful in measuring from the bottoms of holes, especially small holes, to see that the ball point is not worn on the bottom surface. If it is worn somewhat flat, it may "bridge" the bottom of a hole, as shown in Fig. 78, and the resulting reading will be incorrect. Some indicators are provided with a removable ball lever that permits easy replacement of the ball when it becomes worn, but other indicators are so made that the ball points are not interchangeable. Of course, when measuring dimensions between holes or between a surface and a hole, it is desirable to take the indicator reading over the top surface of a plug gage rather than at the bottom of a hole, but suitable plug gages are not always readily available or convenient to use. When a measurement is taken at the bottom of a hole, the ball point should rest at the bottom of the hole and not on the sloping surface to one side of the bottom. In order to make sure of this, the indicator should be shifted slowly from side to side while movement of the pointer of the dial is observed to see when it reaches the greatest "minus" position, which indicates that the bottom has been reached.

Reversing Lever.—If for any reason it is necessary to use the indicator so that the ball must contact the under surface of a part, the movement of the ball point can be reversed by shifting the reversing lever on the side of the indicator to the upward position. In using this reversing lever, however, the inspector should be sure to move it all the way up or down, for if this is not done the mechanism works sluggishly and the pointer appears to stick at various positions on the dial.

Setting the Zero Point.—In using a dial indicator with a height gage, be careful to see that all clamps and setscrews are firm but not excessively tightened. Set the vernier scale at 2 in. Then, using a 2-in. size block or an accurate parallel, adjust the position of the indicator so that a zero reading is attained with the pointer swinging not less than 10 graduations. This must be done with some care, and the final exact adjustment of the zero point can be accomplished by rotating the dial cover of the indicator, the outside of which is knurled.

Setting at zero with the vernier reading at the same dimension as the size block gives direct readings on the height gage, measured from the surface plate, without any calculations. This is known as a "true zero" setting. In some cases, however, the graduation of height gages does not permit this adjustment unless the indicator is slanted at a sharp angle. In this event, an "arbitrary zero" can be established, with the indicator in a convenient position, by using a block of accurate size, adjusting the zero point of the indicator by means of the fine adjustment of the slide on the height gage, and taking the reading. Then, by deducting the height of the size block, we have a figure that represents the plane of the surface plate, but this figure must be deducted from all future readings to obtain the true distance from the surface plate. Despite the necessity of an additional calculation, this method is by far the most common one used by experienced inspectors, because it saves the time and trouble necessary to set a "true zero," and, if the setting of the indicator should be disturbed, it is only necessary to take a new reading on a size block before resuming measurements.

These methods might be compared to the mileage register of an automobile. The first method would be equivalent to setting the trip mileage at zero before starting a journey. The second method would be equivalent to taking the reading of the total mileage before starting and then deducting this from the mileage at the end of the journey to ascertain the trip mileage.

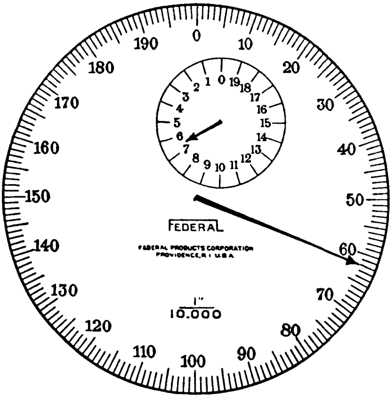


FIG. 79.—Dial of measuring instrument.

In either case, after the zero is set, the position of the indicator or the ball lever should not be altered in any way during the measurements. The instrument should also be rechecked on a size block at intervals. Sometimes, if the ball is applied to a surface quickly, the lever is slightly displaced, and incorrect readings result. Care must also be taken when vernier readings are made to keep the indicator away from the body, so that the ball point will not be displaced by contact with the clothing.

Of course, if measurements are being taken between points without any reference to the surface plate, it is not necessary to make any preliminary zero adjustments; simply record the reading of the height gage at the various surfaces and then add or subtract the readings, as the case may be.

Dial micrometers are somewhat similar to the comparator instruments in appearance; they are not comparators but measuring instruments, because they show the actual dimension of the part. For this reason, they are permanently mounted on a pedestal, and, when measurements are taken, the pointer moves only in one direction (clockwise). As these instruments usually measure in thousandths, one complete revolution of the pointer might indicate a dimension of only 1/10 in. Therefore a second dial is provided, the purpose of which is to record the number of revolutions made by the main pointer. Figure 79 shows a typical dial. The pointer on the small dial shows that the large hand has made six revolutions. One revolution indicates a dimension of 200/10,000, or .02. Six revolutions would measure 6 × .02, or .12. The large pointer rests on 62 indicating .0062; therefore the total reading is .12 + .0062, or .1262.

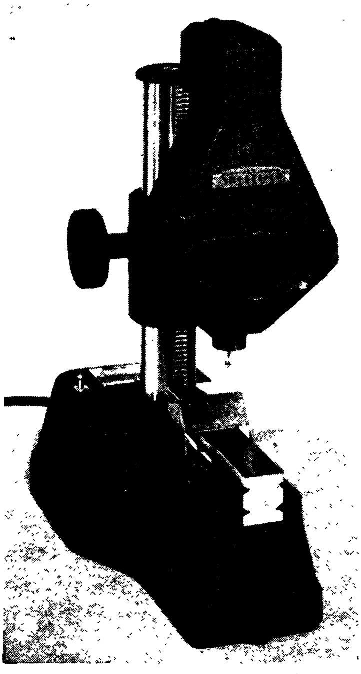


FIG. 80.—A Sheffield visual gage.

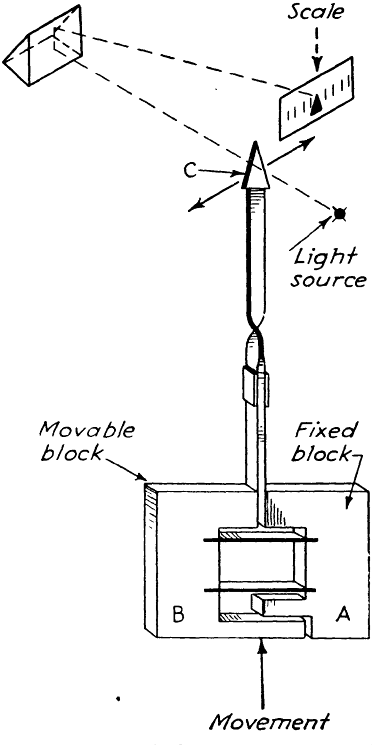


FIG. 81.—Optical system of visual gage.

There are of course many more types of dial instruments used in inspection, but those described are typical of most. These instruments should be handled with as much care as a good watch, for the mechanism is precise; and, if it is damaged by rough usage, it will be useless.

The Visual Gage.—We now come to a widely used type of mechanical comparator which operates not on a system of gears but through an optical system, as shown in Fig. 81. This diagram shows how a movement of the spindle (which rests on the piece being measured) will cause a metal shield or target to move back and forth in the path of a beam of light and throw a shadow on a graduated scale. These instruments are very simple in their operation, being "set up" so that, when the spindle is resting on the standard (which may be a plug gage, a size block, a precision block, or a part which is to be checked and which has previously been accurately measured), the shadow is exactly on the zero mark. Before the work is begun, however, the light should burn for about 10 min. before the final adjustment is made, for the heat of the lamp sometimes causes sufficient expansion of the parts of the mechanism to cause the shadow to "drift" away from zero. If this occurs, the fine adjustment sleeve can be turned carefully to bring the shadow back to zero.

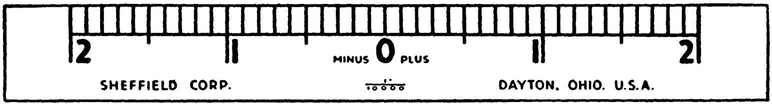


FIG. 82.—Scale of visual gage with 1/10,000 sensitivity.

Types of Scales.—The fractional values of the scale may range from 1/10,000 to 2/1,000,000 on different models. The former scale is shown in Fig. 82. This shows four major divisions, two on each side of zero. Each of these major divisions is subdivided into 10 parts. This means that each small division has a value of 1/10,000 in., or .0001, and each *numbered* division has a value of .001. Therefore, with a piece in place on the anvil of the instrument, if the shadow rested on the first *small* division to the right of the No. 1 graduation on the *plus* side, the piece would be +.0011. If a piece caused the shadow to fall on the first *longer* division to the left of No. 1 graduation on the *minus* side, the piece would be −.0015. It would then rest with the inspector to compare these readings with the tolerances given on the blueprint and to accept or reject the piece accordingly.

The second scale (Fig. 83) shows a fraction of 2/1,000,000; therefore each smallest division has a value of .000002 (fifty millionths or one five-hundred-thousandth); and each *numbered* division, being subdivided into five parts, has a value of .00001.

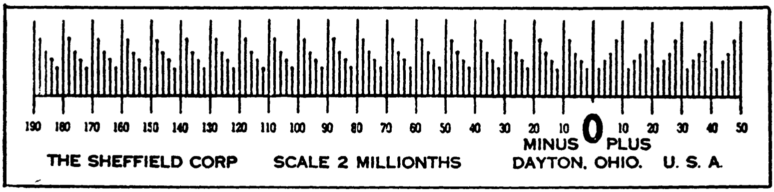


FIG. 83.—Scale of visual gage with 2/1,000,000 sensitivity.

If a piece in place on the anvil caused the shadow to fall on the division numbered 100 on the minus side, the piece would be −.0001 (division No. 100 being 50 of the small spaces—50 × .000002 = .0001. If a piece caused the shadow to rest on No. 40 graduation on the plus side, the piece would measure 20 × .000002 = .00004).

The Micro-Chek.—Owing to the scarcity of skilled workers and the shortage and delay in delivery of the more familiar gages such as snap and ring gages, depth gages, etc., it is gratifying to find that new types of inspection instruments are being developed which not only serve as acceptable substitutes for these gages but, because of their wide range and adaptability coupled with a moderate original cost, make for increased efficiency and speed in checking mass-production parts.

Typical of these new instruments is the one illustrated in Fig. 84, which is known as the Micro-Chek. This device contains very few moving parts, a distinct advantage in an instrument designed for repetitious work, and the moving parts are limited to levers that pivot on hardened knife-edges. The wear is negligible and is compensated by resetting the tolerance markers.

The principle involved is multiplication through a series of levers so that a motion of the contact point of, say .001 in., will produce a movement of the indicator 200 times greater, or about

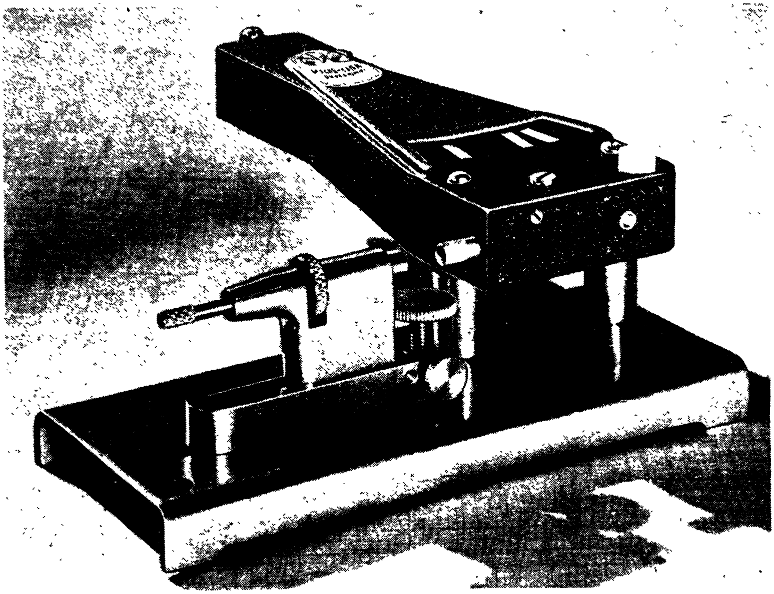


FIG. 84.—Micro-Chek instrument with adjustable anvil.

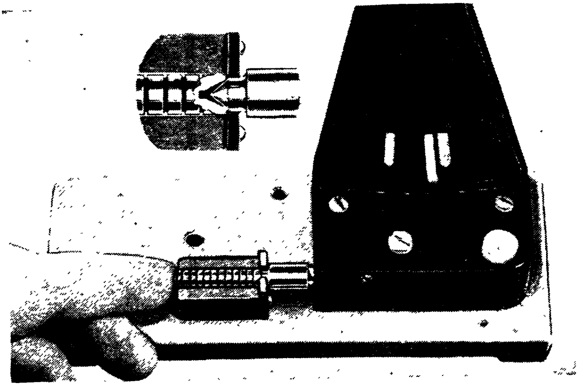


FIG. 85.—Checking tapered center with special fixture.

⅕ in., and by estimation a movement of the contact point of .0002 or .0003 can be read quite accurately. This makes the instrument suitable for high-precision work that would ordinarily call for the use of much more elaborate and expensive apparatus.

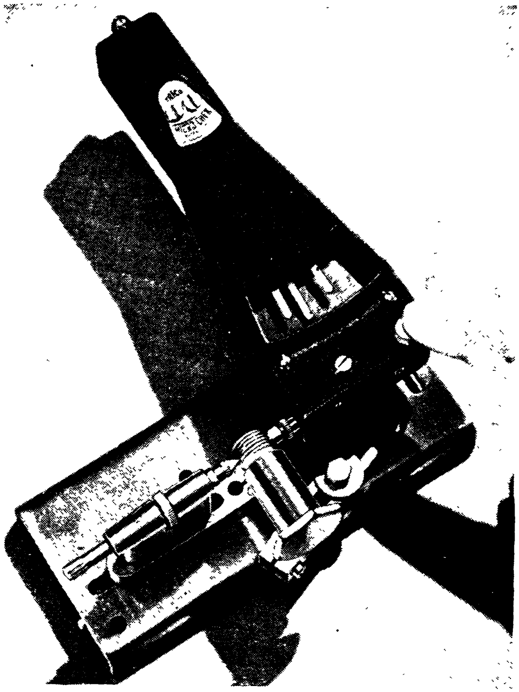


FIG. 86.—Thread checking fixture.

As with all comparators, it is necessary to "set up" the instrument with a master gage or precision blocks, adjust the tolerance indicators so that they will mark the high and low limits, and then proceed to check the parts. This can be done with great rapidity because the pointer comes to rest immediately; and, if it is anywhere between the two tolerance indicators, the piece is properly dimensioned.

By using accessory fixtures of simple design, such as those shown in Fig. 85, the application of the instrument to the checking of what would otherwise be difficult and in some case inaccessible for gaging is made very easy.

One of these accessory fixtures of unusual type is a thread-gaging anvil for measuring the pitch diameter of external threads. The setting of the contact points is effected by the use of the proper thread setting plug (Fig. 86).

Questions

1. Why should the pointer of an indicator not be set to start at zero?

2. Does an extension attachment on the ball lever of an indicator increase or decrease the sensitivity?

3. If the indicator pointer moves sluggishly, what is the probable cause?

4. What is the purpose of the small inner dial found on some dial instruments?

5. What precautions are necessary in indicating the bottom of a hole?

6. Is an indicator a measuring instrument or a comparator?

7. Is a dial micrometer a comparator?

CHAPTER XI

AIR GAGES

It would not seem possible on first thought that accurate gaging could be done by measuring the amount of air that escapes between a gaging fixture and a machined surface. However, air gages of various types have been used for many years on work with relatively large tolerances, and the need for more precise work and finer dimensions has been met by the development of vastly improved instruments based on the air-pressure principle.

Figure 87 shows a typical instrument designed for checking parts that cannot conveniently be brought to the inspectors' bench. Other types are used to check parts that are applied to a gaging arm attached directly to the indicating instrument.

Principle of Air Gages.—These gages are actuated by the velocity or flow of air. For this reason there is no time lag in gage action. In a column of air flowing at constant pressure, the quantity of air, by weight, passing any point at any instant is the same, regardless of how long the column may be.

Consequently it makes no difference how far it is between the gaging spindle and the indicating instrument. The gaging spindle is at the end of a long length of flexible tubing.

In all models, compressed air from the regular plant supply enters the gage through an automatic compensating pressure regulator and passes through a vertical transparent indicator tube and out through the orifice in the gaging spindle. This constitutes the air column.

The volume and velocity of air flowing at any given instant during the gaging operation depend only on the clearance between the gaging spindle and the sides of the bore being gaged. The greater this clearance, the higher is the velocity of air that passes between the sides of the spindle and the internal surface of the bore.

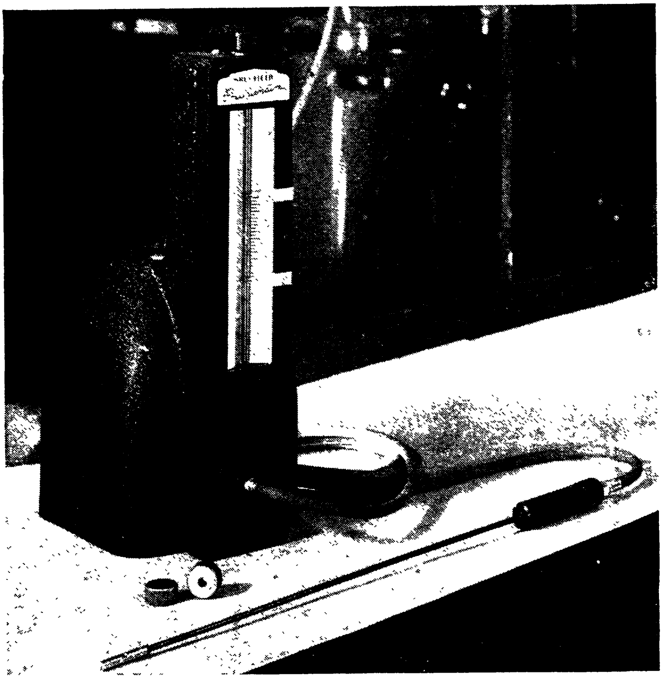


FIG. 87*a*.—Air gage with master gages for setting.

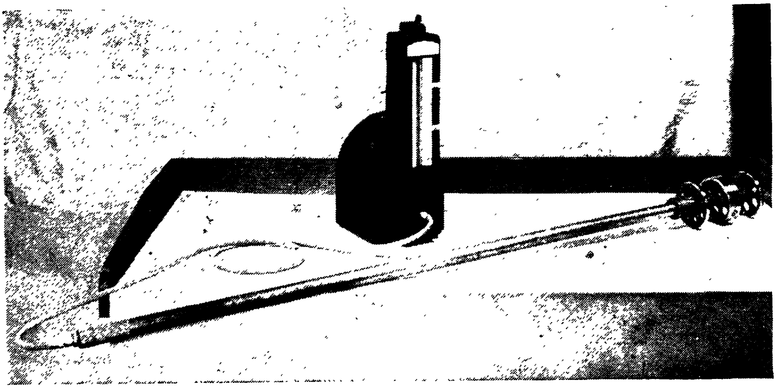


FIG. 87*b*.—Air gage for checking gun bore and rifling.

An indicator float in the transparent tube is free to move up and down in response to changes in velocity of the air passing through the tube and around the float. The greater this velocity, the higher the float rises in the tube.

Any practical degree of magnification is available by making suitable changes in the equipment.

With air pressure on, a minimum master ring is slipped over the gaging spindle, causing the indicator float to come to rest at a point in the central zone of the tube. One of the adjustable markers is then set opposite the float's position. Substituting the maximum master ring sends the indicator float higher in the tube. Another marker is used to mark this second float position. The distance between the two markers now represents the magnified difference in diameter between the maximum and minimum master rings or the tolerance zone of the work to be gaged. Whenever the float comes to rest between these markers, the work being checked is within tolerance.

This length of tube between the two markers may be divided or calibrated on the adjacent scale in any number of divisions desired, by the use of additional setting rings. Thus, for classification inspection, the position of the indicator float shows the actual diameter of the piece being gaged, and the gage becomes an indicating comparator that is very easy for the inspector to read.

The spindle takes one of several forms, depending on the nature of the part to be inspected (Fig. 87). Essentially, it is a cylindrical plug having a central air channel that terminates in one or more jets in the side of the spindle. One type is designed for checking actual diameter, out-of-round, taper or bellmouth conditions and another checks average diameter. Air gages operating on this principle have a wide application in the inspection of:

1. Gun barrels, before and after rifling.
2. Finished holes too small to check by other means or holes that might be vulnerable to scoring with the use of other gages.
3. Deep blind holes.
4. Engine cylinders and liners connecting rod and camshaft bearings.

GUN-BARREL INSPECTION

The proper checking of gun barrels is obviously most important. At the same time, the urgency for fast production calls for simple, speedy, and by all means accurate checking. For many years, the conventional method of checking gun barrels has been a slow and difficult operation, in which readings are made at intervals from breech to muzzle—an operation calling for great skill in maintaining a true alignment of the main shaft of the gage with the axis of the bore.

FIG. 88.—Checking gun barrels with air gage.

The air gage permits both rapid and precise checking of gun barrels (Fig. 88). In checking the bore or rifle grooves of a gun barrel, the gaging spindle is carried at the end of a flexible extension connected to the indicating instrument by flexible tubing. The extension may be graduated along its entire length, so that any dimensional error discovered in inspection can be accurately located in the piece being checked.

The flexibility of the extension eliminates any error that might otherwise result from a misalignment of the spindle in its passage through the bore. The flexibility of the extension also causes the spindle to center itself.

In routine inspection, the inspector passes the gaging spindle through the bore in one continuous pass, watching the indicator float as he does so. He is thus able to inspect the diameter of every increment of length throughout the bore without the necessity of taking a series of separate readings. Any variation in bore diameter causes the indicator float to change its position instantly. If the float remains between the markers on the scale, the barrel is within tolerance and acceptable. If the float fails to reach the lower marker, the bore is undersize. If it rises above the top markers, it is oversize.

After rifling, a second gaging spindle is used to check the diameter of the rifling grooves. The gaging spindle used to check the rifling in a gun barrel has jets that terminate in bosses raised beyond the regular surface of the spindle cylinder. The rifling spindle is inserted into a gun bore with these raised bosses in register with the rifling grooves. Each set of grooves is checked in the same way. This gage is applicable to any bore from the smallest rifle or pistol to the largest gun tube, provided the specified tolerance does not exceed 0.005 in. The same instrument may also be used on any number of bore diameters merely by a change in the gaging spindle. Other cases in which an air gage serves where standard gages would not function properly or might be unsuitable are as follows:

Blind holes long enough to cause an air cushion that would prevent the complete entry of a plug gage or where a plug gage would be too short to reach the far end.

Thin-walled cylinders that have a critical inside diameter and are easily distorted. The air gage exerts so little pressure that there is no distortion of the walls, and the diameter of the cylinder can be measured from end to end.

Avoidance of Surface Scratches.—In artillery recoil or shock-absorber cylinders, the interior finish must be unscored to ensure proper functioning. The air gage has no hard contact points and will not cause scratches.

CHAPTER XII

ACCESSORY EQUIPMENT FOR INSPECTION

Surface Plates.—In a great many routine inspection operations, it is necessary to have a firm, solid, and plane surface on which to rest the instruments and tools while checking and measuring machined parts. This purpose is served by *surface plates* (Fig. 89), which are heavy cast-iron plates, flat and plane on one side and heavily ribbed on the other side to prevent distortion. Surface plates come in various sizes, ranging from the small bench plates to the large tablelike plates 36 by 68 in. When new the plates usually have scraped surfaces, which give a mottled effect. Scraping serves to remove any high spots which appear during the processing of the surface and also counteracts the tendency of some tools with flat surfaces to stick to the surface plate. As the plates become worn, however, the scrape marks disappear, and the surfaces appear smooth. If the surface should become worn to such a degree that there are high and low spots in excess of 0.001 in., the plates should be resurfaced if precise work is required.

FIG. 89.—Surface plate.

A recent innovation in surface plates is the appearance of glass and marble plates. Although, because of their more fragile nature, they do not possess all the advantages of the cast-iron plates, they are nevertheless very satisfactory for many purposes.

One advantage is their relatively low cost. Another is the saving of metal and labor, as well as prompter deliveries. The metal surface plates have to be "aged" to relieve casting and machining strains that might distort the surface after scraping.

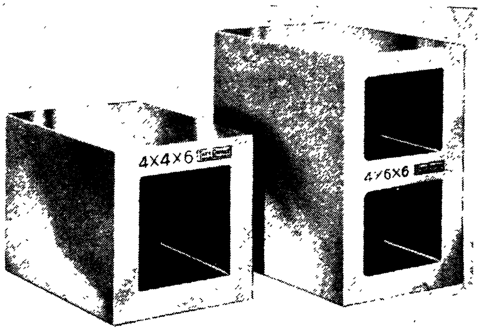


Fig. 90.—Box parallels. (*Courtesy of Taft-Feirce Manufacturing Company.*)

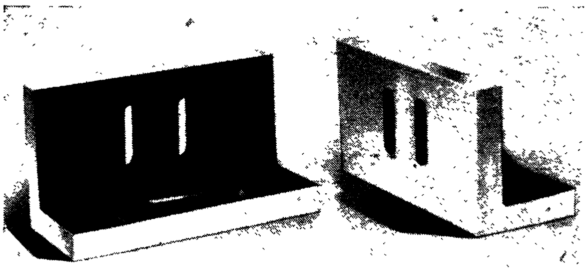


Fig. 91.—Angle irons. (*Courtesy of Taft-Peirce Manufacturing Company.*)

Care must be exercised with the glass and marble plates to protect the surface from rough parts that would scratch the surface and also to guard against dropping of tools on the finished surface. However, similar precautions are necessary with the iron plates.

Box parallels (Fig. 90), sometimes called *subway blocks*, are rectangular iron blocks with large cored holes (for lightening purposes), which have six finished surfaces, square to each other with a high degree of accuracy. They serve as supports for work in process of inspection.

All surface plates should be covered when not in use and before use should be wiped clean to remove any dirt or grit. After use, the surface should be cleaned and oiled. Burrs should be removed from any work before it is placed on the plate. When rough castings are being laid out, they should be supported above the surface. When blocks and parallels are being used, they should be slid onto the plate from the edge.

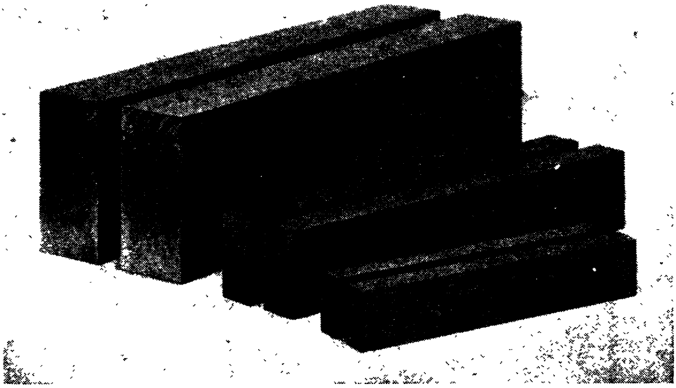


FIG. 92.—Parallels.

Angle irons are used to provide a vertical surface on or against which work may be supported for inspection or layout (Fig. 91). There are several types of angle irons for various purposes and of various sizes. One of these, the universal type, permits the shifting of work to three different planes without unclamping.

Parallels.—Parallels are square or rectangular bars of hardened steel, carefully ground for accuracy (Fig. 92). They are made in pairs of various sizes, and the sides are parallel to a very fine degree. (The ends are not finished, and the bars should therefore not be rested on them.)

Parallels are used in inspection for a great many purposes, such as mounting work parallel to the surface plate, leveling work when the contour prevents locating the piece directly on the surface plate, etc. These bars are quite heavy and have rather sharp edges, so they should be handled very carefully to avoid hitting the edges and thereby causing burrs, which would affect their accuracy. If burrs are found, they should be carefully rubbed down with an Arkansas stone.

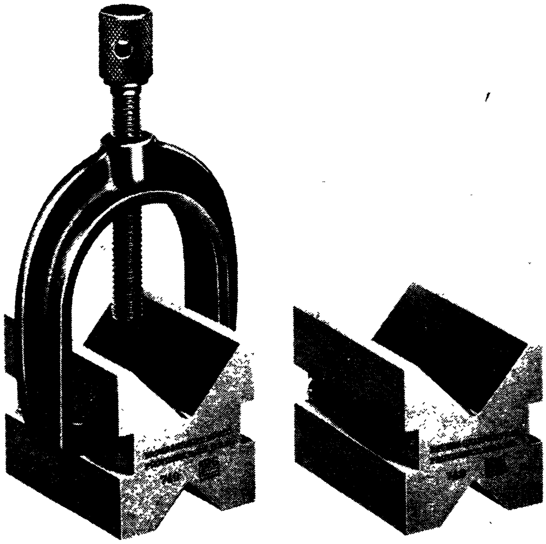


Fig. 93.—V-blocks.

To test parallels for burrs or high spots, they should be laid on a surface plate and rubbed slowly against the plate to establish close contact. Then, with one end held in the fingers, they should be moved from side to side. If the bar "pivots" at the other end, the parallel is correct; but if it should pivot elsewhere than at the end, it has either a burr or a high spot.

V blocks are made of cast iron or steel in various sizes and are finished with various degrees of accuracy (Fig. 93). They are, as the name indicates, machined with a 90-deg. V-shaped slot (sometimes two) with provision to clamp parts firmly in place by means of a screw clamp. When blocks are used in pairs, the identification numbers should be the same on both.

The surface gage is a very useful and versatile instrument, employed mainly to transfer measurements and to check the level of surfaces in layout work and, with an indicator, to determine the accuracy and parallelism of surfaces.

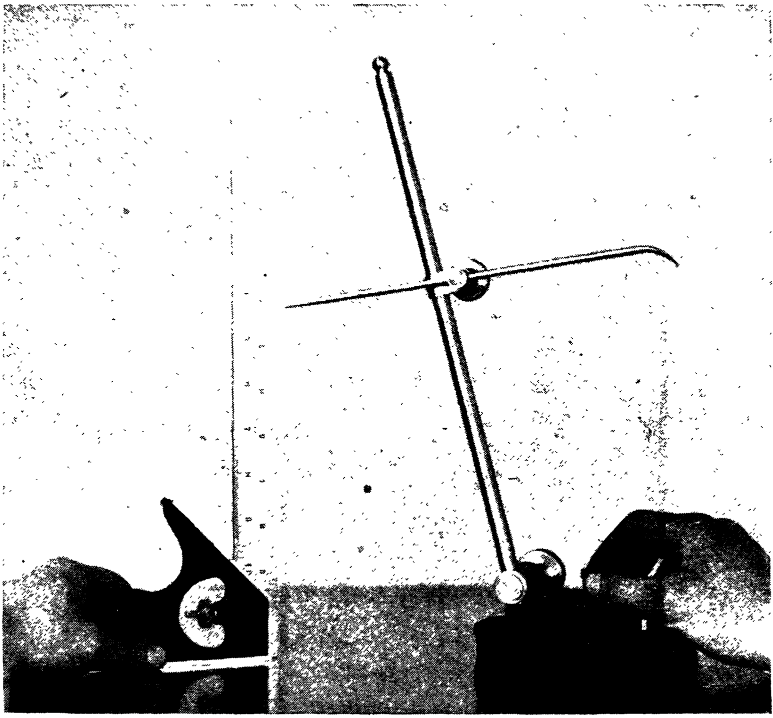


FIG. 94.—Setting a surface gage.

The gage consists of a heavy base and an adjustable arm on which may be mounted a scriber, an indicator, or a measuring instrument. A V-shaped groove is provided in the bottom to permit the use of the gage on cylindrical work. Used as a support for dial instruments it is adaptable to many conditions and positions of work and is in many ways more convenient than a height gage. One of the chief uses is to scribe lines in the layout of castings and similar work. A pivoted spindle can be adjusted to various positions and clamped, and a fine adjustment screw is provided for small movements of the spindle. The scriber can be moved along the spindle and clamped, or it may be removed altogether when instruments are used on the spindle.

Planer Gage.—An exceedingly useful inspection tool is the planer gage. Originally designed for setting tools on machine tools such as planers, it is what might be called an "adjustable size block." It consists of a slide running on an accurate inclined plane (Fig. 95). The slide has two or three plane surfaces parallel to the two base surfaces. By running the slide up and down the inclined plane, a dimension as small as ¼ in. can be set; and, by use of extensions, dimensions up to 8½ in. can be "set up." The planer gage is exceptionally useful in the checking of parts that have been milled on several planes. The gage can be "set up" by using a micrometer or a vernier caliper that has

Fig. 95.—Setting a planer gage.

been clamped at the required dimension and by adjusting the slide to this dimension.

Telescoping Gages.—Some holes are difficult to get at with the commoner measuring instruments. Large holes for which plug gages are not readily available often have to be measured with a better accuracy than is possible with a vernier caliper. For these, and other purposes, telescoping gages are used (Fig. 96).

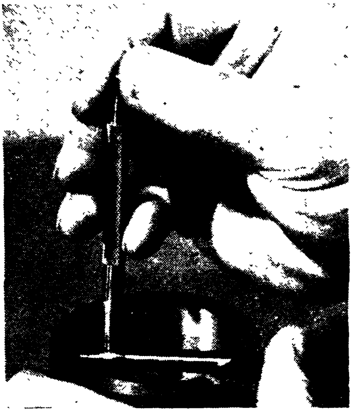


FIG. 96.—Setting a telescoping gage. (*Courtesy of U.S. Office of Education.*)

These gages come in several ranges of size from ½ to 6 in. They are T-shaped and have a knurled handle and a crosspiece that telescopes. The sliding member is pushed in as far as it will go, the lock screw is tightened, and then the gage is applied to the piece and the screw loosened. This causes the sliding member to spring out and make contact with the sides of the hole. The screw is tightened, locking the sliding member in place. The gage is then removed, and the reading is made with a micrometer.

CHAPTER XIII

CHECKING CONCENTRICITY

The concentricity of cylindrical parts is nearly always of utmost importance in machine work, and there are several methods of checking for this, depending upon the form of the part.

V blocks are commonly used, especially when the part does not have working centers or a central hole. A shaft with only two diameters can be tested in a single V block. With three or more diameters, paired V blocks should be used.

The blocks should bear the same manufacturer's identification number. Place them on a surface plate against a parallel that has been clamped to the plate. (In clamping tools with accurate surfaces, such as parallels, always be sure to place a piece of heavy paper or cardboard between the clamp screw and the tool. Otherwise the tool might be damaged by the action of the clamp.) This brings the blocks into correct alignment, which is essential. The part to be checked should be placed in the V blocks so that the piece is supported on the end diameters; then the indicator should be applied to each of the various diameters in turn, and the maximum swing of the pointer should be noted. This swing denotes the "runout," which amounts to twice the actual eccentricity of the centers. The inspector determines whether this runout is excessive, from the blueprint or the standard practice of his shop. In some plants, the actual eccentricity is used; in others, the total runout is deemed the measure of eccentricity.

Figure 97 shows a part being checked in V blocks. In this connection, this and certain other photographs used to illustrate methods of checking concentricity show a height gage being used as a support for the indicator. In many cases, this is not good practice, because it ties up an expensive instrument while the tests are being made and also causes unnecessary wear of the instrument. Ordinarily the indicator should be supported on the arm of a surface gage, as illustrated in Fig. 98, especially when dimensions between surfaces are not being checked, an operation that would require a height gage. The height gage is a very convenient instrument, and it is a natural tendency to follow the line of least resistance and use one when other instruments would serve as well; but, on the other hand, tools that are expensive and somewhat scarce should be used only when some of the less valuable instruments will not serve the purpose.

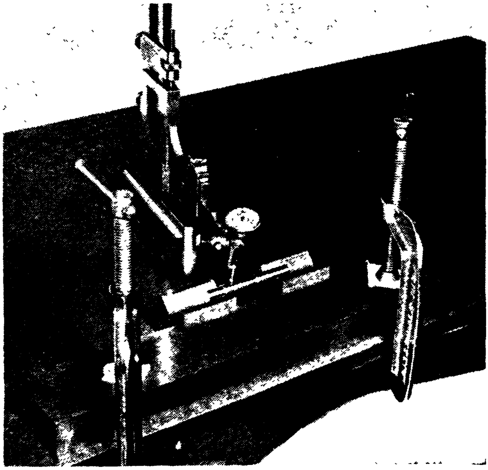


Fig. 97.—Checking concentricity in V blocks.

Concentricity of a center hole with an outside diameter, such as a gear blank, can be tested in a V block, using a plug gage upon which to mount and rotate the part. The indicator should rest against the outside surface, and the runout should be noted.

In precise mechanisms, it is important that bevel gears should operate smoothly and accurately, but, if the blank beveled surface is not true with the center hole, the finished gear will not be smooth-running. One method of determining wobble, or lateral motion of a bevel-gear blank, is shown in Fig. 99. Here the blank is mounted on a plug gage, which in turn is clamped into a V block, with the machined under surface of the blank resting against the side of the V block. The ball point of an indicator is placed carefully against the beveled surface. The blank is slowly rotated, and, if any variation of the pointer is noted, it indicates an out-of-true condition. This should not be more than the permissible runout specified in the blueprint.

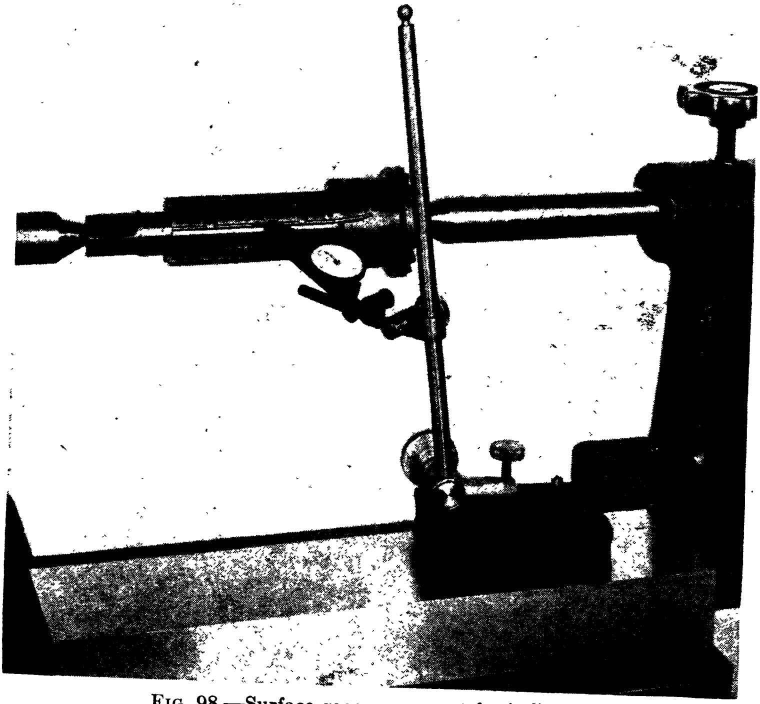


FIG. 98.—Surface gage as support for indicator.

Bench centers are used with pieces that have working centers or central holes (Fig. 100). In the latter case, a mandrel of the same size as the hole should be used upon which to mount the part. The indicator should rest against the outside surface, as

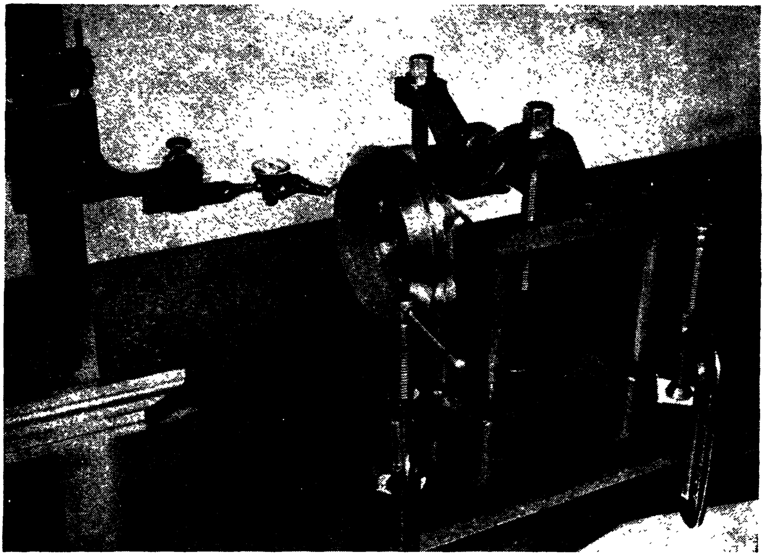


FIG. 99.—Bevel gear block in V block.

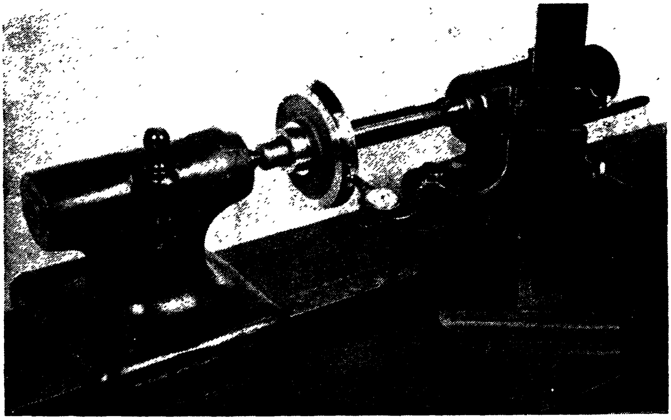


FIG. 100.—Worm-gear blank on bench center.

shown in Fig. 100, which shows a blank of a worm gear being tested.

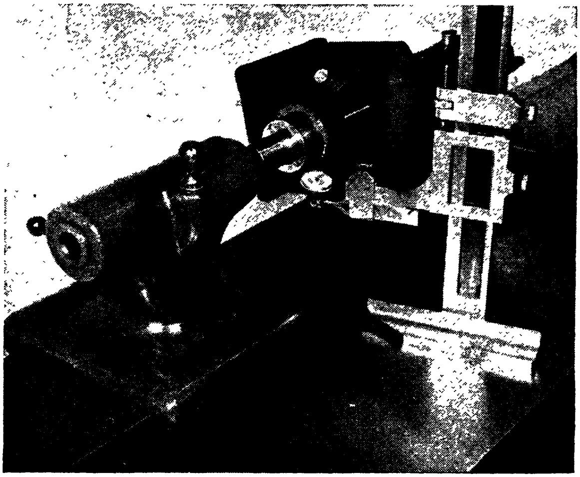


FIG. 101.—Checking holes of different diameters for concentricity.

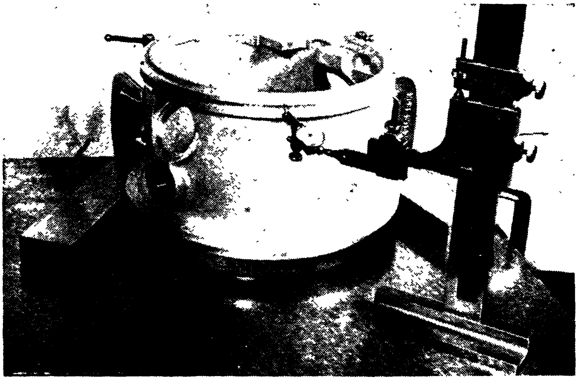


FIG. 102.—Large hollow piece being checked for concentricity of several large diameters.

Figure 101 shows a part being tested for concentricity of two holes of different size. This requires a specially made arbor upon which the piece is mounted, and the indicator rests against a machined surface of the piece at right angles to the axis of the arbor or the center line of the holes.

Figure 102 shows a large piece, which has several machined diameters that are required to be concentric. As the piece is hollow and too large to be mounted on a bench center, a special setup is needed. Two parallels are set at an angle less than 90 deg. to each other and clamped to the surface plate. One of the machined external surfaces rests against these parallels, and the indicator is applied to one of the surfaces at the top. The piece is rotated slowly and carefully by hand, and the part is maintained firmly against the parallels at all times.

CHECKING DEPTH OF KEYWAYS, SLOTS, GRADUATIONS, ETC.

It is frequently necessary to check the depth of keyways, slots, etc., where the width of the cut will not permit the use of a depth gage, depth micrometer, or other inspection tools.

One easy and accurate method is to use a disk that is slightly narrower than the slot. Measure the over-all thickness or diameter of the piece with a micrometer (Fig. 103); then measure the outside diameter of the disk. Add these, then insert the disk in the slot, and measure the over-all dimension of the two parts together. Subtract this from the sum of the two dimensions measured separately, which will give the depth of the slot. This method will also apply when the keyway has a curved bottom, provided the disk is of slightly smaller curvature than the keyway.

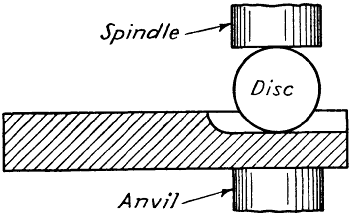


FIG. 103.—One method of measuring depth of keyway.

In some plants, instead of the depth of keyway, the blueprint shows the dimension of the remaining stock, that is, the distance from the bottom of the keyway to the outer surface of the shaft directly opposite the keyway. In such cases, the readings would consist of the diameter of the disk subtracted from the over-all measurement of the disk and shaft when the disk is in the keyway.

CHAPTER XIV

ASSEMBLY INSPECTION

Assembly inspection as practiced today consists of a careful examination and checking, with tools and instruments, of a complete mechanism or of various assembled components of that mechanism known as subassemblies. A large and complex instrument is made up of several units, and it is obviously essential that each of these units must function perfectly in itself; otherwise the completed assembly cannot be expected to perform satisfactorily. It is therefore good practice to check the various units individually before installing them in the complete instrument, so that any inaccuracy or imperfection can be remedied.

Figure 104 is a view of a representative subassembly unit. Although each individual part of this was inspected and checked prior to use in the subassembly, the latter must be checked and tested thoroughly before it is incorporated in the next assembly unit (Fig. 105).

Some comments on the importance of subassembly inspection in the manufacture of a complex mechanism follow:

> Now let us look at another piece of apparatus which is in active production. This is the antiaircraft director or predictor. Here is an instrument which, exclusive of hardware such as screws, nuts, washers, etc., has 2,516 machined parts, 230 of which are castings mostly of irregular or intricate shape. In addition there are 765 complete ball bearings, a number of Selsyn motors, automatic and hand switches. In addition to the castings, the machined parts consist chiefly of gears (bevel, spur, worm, and helical), gear racks, lead screws, slides, dials, cams (spiral and three-dimensional) and many special-purpose parts. The most common tolerance on machined dimensions is .001 in. Very few exceed this, and a great many are expressed in the fourth decimal place. All this material assembles into a compact unit whose external dimensions are equal to about a 30-in. cube. The total weight is about

725 lb. Why all this precision? Well, it is just one of Uncle Sam's defense measures against enemy air attacks. Try to imagine shooting at an aerial target that is flying at a speed of from 300 to 350 miles per hour and expecting to hit it without considering where it is likely to be at the instant the shell is supposed to burst. It is likely to be at least a mile away from its original position. This is where the predictor comes in. It is used to track an aerial target in elevation and azimuth and to generate data continuously for the pointing of the guns and cutting of fuses so that the target and shell will meet in space. It is effective at distances greater than the range of any present-day anti-aircraft gun. All computations of the mechanism must be such that the maximum allowable error in predicting the future position of the target will not exceed 24 yd. This means that the accumulative error in the entire mechanism must not exceed .003 in.

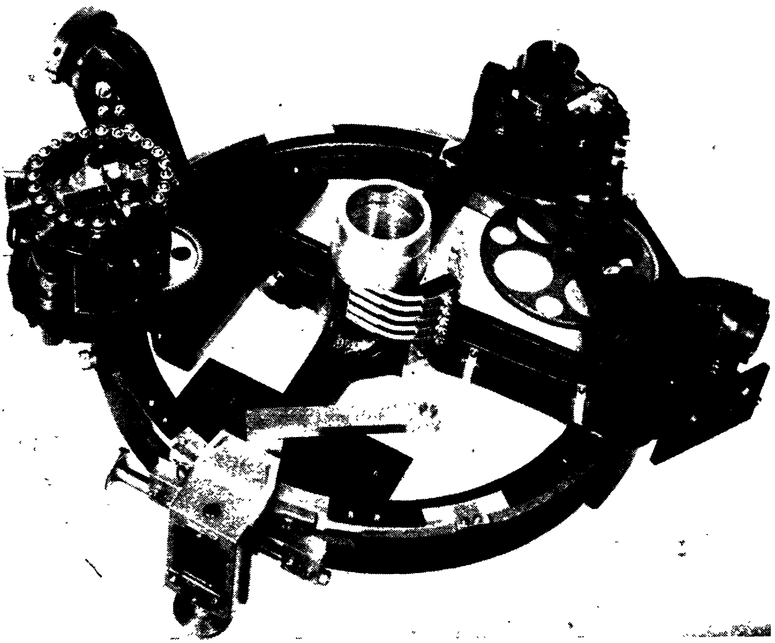


FIG. 104.—Subassembly of marine gyrocompass.

It costs hundreds of dollars to assemble this unit. If on final test the computations err because of an inaccuracy or unseen defect in some part in the core of the instrument, the predictor must be torn down, the part replaced, and the instrument reassembled.

The Check List.—It would of course be impossible to detail an inspection procedure that would suit more than a very few conditions; therefore the most that can be done is to outline a typical subassembly check list, which is the inspector's guide in examining and checking a mechanism of an precision instrument:

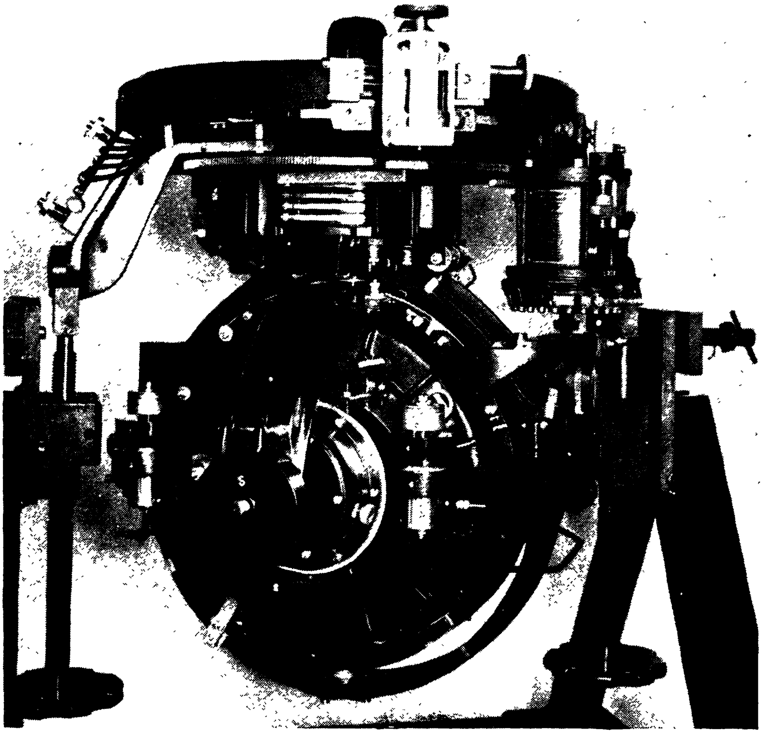


FIG. 105.—Assembly of gyrocompass unit.

1. Camshafts 134 and 299, end play 0.001.
2. Check setting of cams 426 and 585.
3. Drive to move freely, cam train smooth—no rumble.
4. Check $3/16$ and $1\frac{1}{32}$ dimensions as per blueprint.

5. Gear 3559 to clear casting.
6. Bracket 6775 to clear retainer 4672.
7. Runout of shaft 37845 not to exceed 0.001.
8. Gears 7995 and 36725 free running—backlash permitted.
9. Dial to pass 1250 right and left.
10. Dial screws tight—check lock washers.
11. Shafts 7993 and 41157 free running, 0.002 end-play maximum.
12. Check for cleanliness.
13. Cams to have thin coat of lubricant No. 11.
14. Four copper pins in cover plate.
15. Total backlash and end play to be within blueprint tolerances.

CHAPTER XV

THE USE AND CARE OF TOOLS AND INSTRUMENTS

As mentioned elsewhere (and it deserves repetition here), the manner in which an inspector handles and cares for the tools he uses in his work identifies him as a good craftsman or a poor mechanic. An expert inspector always gives the same careful attention to the simpler tools, such as steel rules, dividers, and other similar instruments, as he does to the more delicate precision instruments, because he knows that the quality of his work depends as much on the accuracy and good condition of his tools as it does on his personal skill in using the equipment.

Novices sometimes unwittingly misuse and possibly abuse an instrument. Such faults are usually self-correcting with experience, but there is no excuse for any inspector to be careless with the tools of his trade, especially when, as is usually the case, the tools are not his own and others will use them when he has finished his immediate job. An inspector will seldom drop his own micrometer or use his scriber as a prick punch, and he should not be any less careful of tools that do not belong to him.

The nonprecision instruments are mostly of rugged design and with proper care will last indefinitely, but the following are some of the more noticeable abuses:

1. Permitting rust to develop by failure to keep the surfaces protected with a film of oil, allowing abrasive grit to collect, neglecting to examine and recondition instruments occasionally.
2. Using an instrument for a purpose other than that for which it was intended, such as removing a burr with a steel rule; using a plug gage as a hammer; digging grease and chips out of a hole with a scriber or divider.
3. Unduly wearing surfaces by using a heavier measuring pressure than is necessary, damaging the points of scribers or dividers by bearing too hard.

4. Forcing an instrument, springing dividers and calipers beyond their capacity or setting, forcing a bound screw, making setscrews or clamps too tight.

5. Piling tools in a disorderly heap; storing them in bench drawers with a miscellaneous assortment of other items of equipment and personal belongings, such as lunch kits, etc.

Quite naturally the precision instruments and gages are more susceptible to damage through abuse than are the nonprecision tools. In the case of fixed gages, particularly the plug and thread gages, one important factor to consider is the abrasive action on the gage of the part being tested. Whenever a gage is used in or over a part, a thin layer of the gage is worn off; and, if the material being checked is sand-cast, special care should be exercised, for such materials often have sand inclusions, and the very nature of the material itself makes it more abrasive than other materials. Cast iron, cast aluminum alloys, and brass are likely to be the most abrasive of the common metals.

No gage should ever be forced.—This practice is not only detrimental to the gage, but the use of force has a tendency to score and in some cases to tear the surfaces being gaged, sometimes making the piece useless.

The lubricant used in machining operations tends to catch abrasive dirt, chips, etc., which collect in holes and on other surfaces; and, if these surfaces are not thoroughly cleaned previous to gaging, the dirt or chips may become caught in the space between the entering edge of the gage and the wall. If a plug gage is forced under such conditions, it will be worn rapidly and may even be damaged.

Never use a thread gage to finish the threads of an incomplete undersized or oversized machining or tapping operation.

Never use a gage dry.—A light coating of instrument oil will tend to eliminate freezing, scoring, or loaded gage conditions. The maximum wrist force permitted on plug gages, ring gages, or thread gages should not exceed the force required to wind an average spring-driven clock.

Generally speaking, it is not good practice to use a wrench on a plug gage or to place the gage in a vise, because the inspector thus loses the "feel" and may use too much force. Furthermore, a plug gage not only checks the size of the hole but also detects out-of-round condition, taper, and other undesirable conditions that are determined largely by the sense conveyed through the fingers.

When the fixed gages are not in use, they should be stored away from contact with other tools; they belong in racks or compartments if they are available; otherwise they should be kept in individual boxes.

MICROMETERS

The maintenance of the accuracy of micrometers is of utmost importance, and this can be accomplished only by constant care. There are many rules and suggestions that may be observed to this end.

1. The micrometer should first of all be kept clean and free from all abrasive dirt and rust. When not in use, it should be placed in a tool kit or in the box in which it was received.

2. The micrometer should never be left for a length of time with the measuring faces in contact, for lapped surfaces tend to pit and corrode when left in close contact, and further, a decided temperature change might cause damage to the threads because of thermal expansion of the instrument. When a micrometer is stored, it should be covered with a coat of instrument oil or some good rust preventive and wrapped in an oil-saturated cloth.

3. Oil is needed in only one place—on the screw, and nothing but a light instrument oil should be used. Heavy oil tends to become gummy and might make the instrument insensitive and heavy to the touch.

4. In traversing from one position to another, never grasp the thimble and twirl the frame, for this is injurious to the screw and will in time cause an uneven error in it. Rapid traversal can be accomplished by rolling the knurled thimble along the hand or forearm.

5. The micrometer should never be used as a snap gage. The practice of locking the clamp ring at a certain dimension and then

checking parts for conformance to this dimension is extremely injurious, for it wears the anvil and spindle on only one side and will very soon wear both these faces so that accuracy is impossible. Also, with the spindle locked, one cannot judge whether the piece is correct or not, and there is real danger of springing the frame or mechanism in gaging a slightly oversize part. Another practice to avoid is that of removing the micrometer from the piece being measured in order to take the reading. This need never be done—in fact it is next to impossible without disturbing the reading, unless we are concerned with thousandths only, and the wear of the measuring faces is just as injurious as in using the micrometer as a snap gage. Thus both inaccuracy and wear result.

6. The measuring pressure of the individual inspector is not always constant or correct. Practice with precision gage blocks or some other accurate standard will tend to maintain the individual uniformity and ensure correct pressure at all times.

7. Before a micrometer is used, the measuring faces should be wiped clean with a soft cloth or parchment paper. The presence of dirt or small metal chips on the faces will cause incorrect readings. Small chips often cling to the measuring faces without being noticeable on casual examination. The micrometer mechanism should also be cleaned whenever it becomes gummy from a lubricant.

8. The micrometer screw should run freely and with no play at any point of its travel. If it does not, the slotted adjustable nut that serves to tighten the threaded sleeve can be used to remedy this condition. If the screw binds at one point and runs loosely at another, it cannot be corrected. It has been worn unevenly and must be returned to the manufacturer. This is a common trouble with micrometers.

VERNIER CALIPERS

The accuracy of the vernier caliper is largely dependent on the fit of the sliding jaw and the wear or distortion of the measuring surfaces. The fit of the sliding jaw should be such that it moves easily and still does not have any play. This condition is maintained by a small, slightly springy metal insert called the *gib*, which holds the sliding jaw against the blade with just the right pressure to give it the proper friction. If the jaw slides too freely, the gib may be removed and bent slightly to increase its pressure against the blade. Here again a word of caution might be said about the tendency to set the clamping screws too tightly against the blade. These screws should be tightened just enough to maintain the position of the slide. Too much force causes undue wear of the top of the blade against which they act.

Most of the wear of a vernier caliper naturally takes place at the tips of the measuring faces. It is an easy matter to spring the jaws of a vernier caliper to such an extent that the measuring surfaces are out of parallel. This condition can be detected by closing the jaws, holding them to the light, and noting if any light can be seen where the jaws fail to meet. Checking for wear can be done in the same way, if the vernier setting is exactly on zero. When errors caused by wear or distortion exceed 0.0002, the instrument should be reconditioned, unless a high degree of accuracy is not required.

CHAPTER XVI

INSPECTION PROCEDURE

Interchangeable manufacture requires that definite standards of dimensions, finish, and freedom from defects must be maintained in order that each part may be an acceptable component of the finished product.

Therefore every inspector should maintain an orderly method of procedure in his work. First of all, no job should be inspected without the blueprint of the part. The *blueprint* is the authority for most information regarding the part. It contains the dimensions, finish, material, and sometimes information regarding processing.

Look carefully for any **change notes** on the blueprint. Check the **part numbers** of all the accompanying records to see if everything agrees. **Never mark on the blueprint,** and never inspect a job on which penciled changes have been made in the blueprint, without first consulting your leader.

Organize your work.—When you receive a "lot" of parts, analyze the job to determine the most efficient method of inspection. **Select the most suitable tools and gages,** bearing in mind that nonprecision dimensions should not be checked with precision tools, and vice versa. Line up the work in the available space so as to avoid unnecessary effort and waste motion in checking. *Do not pile the parts one on another.* This often causes burrs or nicks or otherwise injures the part. Piled up parts also frequently fall over with a slight jar. Do not stand shafts or long cylindrical pieces on end, for they may easily fall over.

Arrange the tools and gages to make the sequence of operations easy. Have suitable tote boxes or containers ready for any rejected parts or parts to be reworked or questioned. **Check the**

operations to be inspected. In most cases, the processing is done by several different machines, and each operation or group of operations is checked before the job is transferred to the next department.

Check the count. Check the material from which the part is made. Examine the part visually for blowholes, porous spots, tool marks, burrs. Look for torn or damaged threads. Are the threads full?

Ascertain from the leader if the job is to be "spot checked" or inspected 100 per cent. In spot checks, a certain number of pieces are usually checked 100 per cent.

Determine from the operation sheet if **special checking tools** or fixtures have been provided. If so, use them—that is what they are for.

Check cylindrical parts for **concentricity.** Check the major diameter of external screw threads and the minor diameter of tapped holes, with the proper ring and plug gages. Check to see that threaded holes are not tapped out of square.

In drilling operations, confirm if the jig has been approved by the tool inspector.

Complete the inspection before making your written report. Identify your acceptable, rejected, rework, or questioned parts clearly. Word your report explicitly and understandably, using a vocabulary that conforms to the shop terms that describe parts and operations.

See that the *routing* of accepted material is correct. All fragile parts should be carefully stowed in suitable containers to avoid damage in transfer. Protect all steel parts from rust with proper protective material. Parts made of magnesium oxidize rapidly, and machined surfaces should be protected with a coating of oil. Machined surfaces should be protected from injury in transit by wrapping or packing in suitable boxes or trays.

Sign all documents clearly.—Return all tools and gages to their **proper place** as soon as you are finished with them. Never let them lie around unused—they must be protected from possible damage.

As opportunity permits, **familiarize yourself with manufacturing operations.** Knowledge of things other than your immediate job is always helpful—it often pays dividends.

Know the machines and operators, the sequence of operations. This will help you discover chronic troubles in time to prevent them. **Study your job** with an eye toward improvement in processing or inspection routine. **Turn in constructive suggestions;** if they are feasible many plants offer a reward. In any event your leaders will know you are alert to discover better methods, and this is often an important factor when better jobs are being passed out.

Know your tools, their functions and their limitations. Wear, damage, and improper adjustment must be guarded against by frequent checking.

Getting along with your associates is an important asset, but do not let your friendly attitude toward operators overshadow your obligation to maintain proper quality of work. The respect of your fellow employees and your own prestige are rapidly dissipated by your overlooking poor work or by your irresponsible and immature conduct on the job.

CHAPTER XVII

METALS AND MATERIALS

Although most inspectors are never called upon to determine the composition of the various materials used for mechanical parts (this is done in the materials laboratory), it is always helpful to know some of the characteristics of these materials. A brief description of the most commonly used materials therefore follows:

Aluminum.—The huge demand for lightweight metals due to the enormous increase in aeronautical construction has made aluminum one of the most important of industrial materials. It will probably surprise many students to know that aluminum is the most abundant of all industrial metals—many may have considered iron the most plentiful. Next to oxygen and silicon, it is the commonest element, making up about 10 per cent of the earth's crust. The derivation of the term from the Latin *alumen* (meaning clay) indicates its wide distribution, although it is never found in nature in its metallic form. The generally used "clay," or bauxite, is chemically purified and prepared and then placed in an electrolytic cell where a powerful electric current changes the material into metallic aluminum.

As used in machine work, aluminum is nearly always alloyed with other metals, which improve its casting and machining qualities. Copper, silicon, magnesium, and manganese are commonly used. A system of code letters and numbers is used to designate most of these alloys. For instance, duralumin is one of the oldest and strongest of the alloys. This is known as 17S and consists of aluminum, copper, magnesium, and manganese. There are dozens of other aluminum alloys, each with definite characteristics for specific purposes.

Magnesium is even lighter in weight than aluminum (by one-third). There are deposits of ore from which magnesium can be extracted, but by far the most common source is sea water, or brine from subterranean salt deposits. The metal is obtained through evaporation of the water and electrolysis.

Magnesium is a very "active" metal in that it corrodes readily, and, in a finely divided state, such as powder or fine chips or shavings, it is very inflammable. It is used extensively for incendiary bombs and aerial flares. From an inspector's point of view, care should be taken to see that freshly machined finished surfaces are protected from corrosion by a coating of oil, especially if the part is not being assembled very soon after machining.

Brass and Bronze.—Brass is an alloy of copper and zinc, and bronze was known for hundreds of years as an alloy of copper and tin. However, in late years bronze as a name has lost its significance and is now defined as "an alloy with a typical bronze color." It is now common practice to connect with the term bronze an adjective descriptive of the accompanying alloy, such as manganese or aluminum.

Cast Iron.—An iron that contains more than 2.2 per cent of carbon is classified as cast iron. The commercial metal has between 3 and 4 per cent of carbon. If the carbon is in the form of graphite, the metal is known as *gray cast iron;* if the carbon is in other forms, it is known as *white cast iron.*

Inspection tools such as surface plates, angle plates, box parallels, etc., are commonly made of cast iron.

STEELS

Carbon steel is a tool steel that contains no alloys such as nickel, tungsten, chromium, etc., but has a carbon content ranging from 0.05 to about 1 per cent. The percentage of carbon is usually referred to as "points." Thus 0.05 per cent would be a "5-point steel," 0.45 per cent as "45-point steel," etc.

Alloy steels contain some metallic element other than iron, such as nickel, chromium, or tungsten. Small percentages of various metals give steel distinct properties and characteristics.

SAE System of Steel Classification.—Blueprints sometimes designate material with a number without giving any details of the composition. These numbers refer to steel with various alloys. One can readily understand that, with the wide use of steel, a method had to be found whereby the numerous alloys could be specified without the necessity of using a long formula of the constituent metals and proportions. After long study, the Society of Automotive Engineers devised a system of numbers that are partly descriptive of the materials. The first digit of the number refers to the type of steel. There are eight of these types, the first numbers of which are shown below.

1. Carbon
2. Nickel
3. Nickel-chromium
4. Molybdenum
5. Chromium
6. Chromium-vanadium
7. Tungsten
9. Silicon-manganese

The last two figures indicate the average carbon content in "points," or hundredths of one per cent. For instance, a material designated as "SAE 1015" indicates a carbon steel with a content of 15 points, or 0.15 per cent of carbon, average. SAE 2345 indicates a nickel steel, the first number (2) standing for nickel and the second number (3) indicating a content of approximately 3 per cent of the predominant alloy and an average carbon content of 0.45 per cent. SAE 71360 refers to a tungsten steel with about 13 per cent tungsten and 0.60 per cent carbon average.

PLASTICS

The term *plastic* means capable of being molded, but today, with the necessity of finding suitable substitutes for metals, plastics are being used extensively in machined forms. Even when metals again become plentiful, it is quite certain that plastics will supersede metal in a great many applications.

There are two basic types of plastic materials—thermoplastics and thermosetting plastics. The former term refers to plastics that are softened by heat and harden when cooled but can be softened again by the application of heat. Thermosetting plastics are those which are molded with heat but become permanently hard in the process.

Nearly all types of plastics are available in the form of sheets, rods, and tubes for machining.

METAL CASTINGS

Metal castings play a very important part in mechanical industries today, and the types of castings have been enormously increased with the huge expansion of the aeronautical industry. The necessity for minimum weight of the propelling and operating mechanism and the ever-increasing variety of flight and control instruments have resulted in the design and manufacture of hundreds of new casting shapes, ranging from small supports or brackets to large housings.

In the production of mechanical parts, the material in its rough state usually comes to the machinist in the form of bar stock, metal plate, or castings. When parts of irregular or odd-shaped contour are called for, the method used is to make a pattern or model of the part, from which a casting may be made. Such castings come under two general classifications—sand castings and die castings. Sand castings are produced by impressing the pattern in sand and then pouring into this impression molten metal, which, when solidified, forms a casting of the part. Die castings are produced by forcing molten metal into an impression or cavity in a metal mold known as a *die* and then cooling the metal rapidly.

Sand Castings.—In sand castings, the molding sand is placed in a boxlike frame called a *flask*. The flask is made up of two sections, the bottom section being the drag and the top section the cope. When the pattern is a relatively simple one, the mold is formed in the drag, the pattern is removed, and the cope is placed on top, after some openings have been formed into and along which the molten metal is to run. The hot metal is poured into a sprue, then follows into the mold through gates. In order that the trapped air and gases may escape from the mold, a riser is provided so that the metal can penetrate freely into every part of the mold.

When a hole or cavity is necessary, it is formed by the use of a core, which is a separate mold of the cavity baked hard and placed in proper position in the main mold. The molten metal flows around this core, and, when the metal hardens and is removed from the mold, the core is broken out, leaving a cavity in the casting. Cores are used for reasons of accessibility to interior portions and for economy. Cores provide openings so that machining operations may be carried on inside the casting, and in other cases the cores serve to save metal and lighten the casting.

Many castings are not simple, and, as the pattern becomes more complex and odd-shaped, some difficulties are introduced, such as the removal of the pattern from the mold without disturbing the impression in the sand. The use of split patterns, set cores, and other devices helps to simplify the process. In many cases, also, it is necessary to make a pattern impression in the upper part of the mold or cope, so that when the cope is set in place the two impressions fit together in such a way that the cavity is an exact duplicate of the pattern.

Die Castings.—Die castings are used in the production of many of the smaller and lighter parts used in the metal industries. These castings not only are light and strong but they can be made to such exact dimensions that subsequent machining is reduced to a minimum. Other details such as threaded holes, which ordinarily require a separate machining operation, may also be produced by die casting. Intricate parts and thin sections that cannot be made by other casting methods can be produced by this method. By using a steel mold or die, there is little chance of distortion of the casting, fine sharp details can be reproduced, and the casting time is much shortened because of the quick chilling of the molten metal. The same mold can be used indefinitely.

The dies are made in two sections, which are locked together to form the mold. The molten metal is forced in through a gate, and vents are provided for the escape of air and gases. Water is circulated through the dies to solidify the metal rapidly. The die casting metals are usually alloys of aluminum, tin, lead, and zinc. The zinc alloys are widely used because of various desirable physical properties, such as fluidity of the molten metal and minimum shrinkage on cooling, which permits close dimensional limits.

Three phases of the molding and machining of castings are of importance to the inspector—casting defects, abrasiveness of metals, and layout of rough castings.

Casting Defects.—Casting defects consist mostly of blowholes, inclusions, shifted cores, and distortion. Blowholes and inclusions are the almost inevitable results of the casting process. Most aluminum and brass castings are made in a sand mold. As a binder for the sand, various substances are used, and flour sometimes is dusted on the surfaces of the mold. When hot metal is poured into the mold, these substances together with the moisture from the dampened sand form a gas, most of which escapes through the gates of the mold, but some of this gas is trapped before it can escape, and, as the metal hardens it forms a pocket, or "blowhole." Sometimes the gas carries along with it particles of the sand, which form "inclusions."

Blowholes and inclusions may be easily discovered before a casting is machined, but often they are not seen until some or all of the machining operations are performed. If the blowholes are not in reamed or threaded holes or on bearing surfaces or at a point that has to withstand strain in use, they may be disregarded, but this is a matter for the inspector, the foreman, or the engineer to decide. Inclusions are likely to be harmful to gages because of abrasive action, and, if they are present on any bearing surface, they are sources of damage or causes of improper functioning.

COLOR CODES

Although the chief concern of the inspector is to check dimensions and to detect imperfections, he should always be sure that the parts are made of the material specified on the blueprint. This does not mean that he should be able to check the various types of steel, for instance. That is a function of the materials laboratory, but he can with little experience learn the main characteristics of various metals so that differentiations may be made between aluminum and magnesium, brass and copper, and the various types of iron and steel.

However, he may sometimes find designations of material which are puzzling, such as "Dural (pink)." This does not refer to a color characteristic of the metal itself but to a code that has been devised for ready identification of various metals and alloys in stockrooms, foundry, etc. As examples, red paint is used on the stock to identify 1025 carbon steel, and a combination of orange and green paint identifies a 1345 manganese steel. A complete list of these designations may be found in various handbooks on metal and machinery.

CHAPTER XVIII

MACHINING OPERATIONS

Although it is not necessary for an inspector to have been a machine operator, a knowledge of machining operations will help considerably in making him more competent and expert in his work. Machine operations are not always mentioned specifically in the blueprint, but, on the other hand, the inspector has to ascertain whether machining has been done properly to bring about the desired finish and dimension.

Machining is done by *machine tools*, which are power-driven machines that progressively remove metal in the form of chips, and the actual cutting edge has characteristics common to all machine tools. Some of them remove metal in the form of long spiral shavings, and with others, such as grinders, the chip is microscopic in size.

To begin with, a rough casting or forging nearly always has to be machined on at least one face in order to "locate" the piece in a machine for the subsequent operations. Finish marks are indicated by a symbol placed on the edge line of the surface to be finished. One of these symbols, and the more common one, is *f*; the other one is V. The meaning of these marks is explained more fully in another section.

If the piece is cylindrical in shape, the first operation would probably be to turn it. *Turning* (Fig. 106) is done on a lathe, of which there are many types, principally the engine lathe and the turret lathe. The work revolves, and a cutting tool is brought into contact with its surface. Turning operations are those which work on the outside surface. One of these is *facing*, or machining a flat surface on the end of a shaft or shoulder, or on the side of a flange or disk. *Roughing* is reducing the work as quickly as possible to almost the specified size. *Finishing* leaves the part relatively smooth and usually of definite size. Internal holes are often formed by the operation known as *boring*.

Boring (Fig. 107) is done by a boring tool and produces a straight and fairly smooth hole. Either turning or boring can produce a finish accurate to a thousandth of an inch or better.

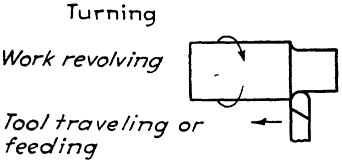


FIG. 106.—Principle of turning.

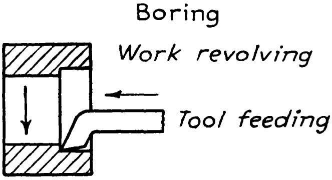


FIG. 107.—Principle of boring.

When a smoother and more accurate hole is needed, a reamer is used after the hole has been drilled or bored slightly undersize.

Reaming is a finishing operation that produces a hole that is smooth, round, and straight. A principal difference between boring and reaming is that a hole may be bored to any desired size, while reaming is limited to the sizes of available reamers.

When great accuracy and a smooth surface are needed, the piece is *ground* with an abrasive wheel, which turns at high speed over the surface as the piece turns slowly in the grinding machine or lathe.

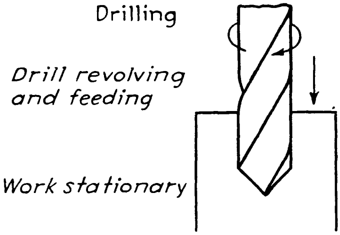


FIG. 108.—Principle of drilling.

Holes are formed by several methods. If the hole need not be accurate or smooth and is of fairly large diameter, it is usually made by using a "core" in the casting process. The core is a cylinder of sand or refractory material placed in the mold, and such holes are known as *cored holes*. If a more accurate hole is called for, a *drill* is used, in either a lathe or a drill press. Such holes are quite accurate but not especially smooth, and they frequently require reaming or boring to obtain a smooth finish.

Drilling (Fig. 108) is mostly done in a drill press, a machine with a vertical spindle holding a drill, which is fed into the work by *pressure*—hence the name *drill press.* To expedite output, drill presses are sometimes provided with multiple spindles so that several holes can be formed at one time.

Milling (Fig. 109) is the process of removing metal from a rigidly held piece by means of revolving cutters. These cutters may be straight or curved, and, since it is possible to use a series of cutters at one time, there is almost no limit to the variety of forms that may be made on this machine. Some milling machines have vertical spindles that may be moved about at will to form contours. This process is known as *profiling.*

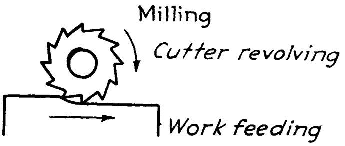


Fig. 109.—Principle of milling.

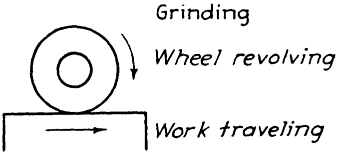


Fig. 110.—Principle of grinding.

Grinding (Fig. 110) employs an abrasive wheel for producing accurate surfaces, either cylindrical, conical, or plane. The grinding wheel is made up of millions of "single-point tools" (abrasive crystals), which remove minute chips. There are many types of grinders—surface grinders, cylindrical grinders, thread grinders, etc.

Lapping is the process of producing a very smooth, plane, and accurate surface by means of a fine abrasive. This is usually done after grinding, to remove the grind marks.

Hobbing is a machine process for generating gear teeth. The most common method of forming gear teeth is to mill them with formed cutters, moving the gear blank the proper distance for each tooth cut; in hobbing, the gear blank revolves continuously at a uniform rate and the hob cuts the teeth at the same time.

Tapping is the process of cutting internal threads in a hole that has been previously drilled. The tool used is known as a *tap*—a fluted tool with the threads cut on it.

CHAPTER XIX

THE MATHEMATICS OF INSPECTION

It is natural to assume that, in dealing with measurements that are sometimes of a complex and precise nature, an extensive knowledge of mathematics is necessary. But this is not so; in fact, for almost any inspection problem, it is quite sufficient to understand how to add, multiply, subtract, and divide simple fractions and decimals and also to know a few of the simpler formulas for dealing with the measurements of triangles.

Because many of us have been out of high school for several years, it is quite common to find that through disuse we have forgotten some of the procedures needed to solve simple arithmetical problems.

Fractions.—First of all, as noted elsewhere, in mechanical work fractional measurements are expressed in six types of fractions, *viz.*, halves, quarters, eighths, sixteenths, thirty-seconds, and sixty-fourths. This simplifies the method a good deal, as will be seen. To illustrate the nature of fractions, suppose we divide a circle into equal parts, as in Fig. 111, and continue, in each operation, doubling the number of equal parts until we have sixty-four. This involves only six fractions—$1/2$, $1/4$, $1/8$, $1/16$, $1/32$, and $1/64$, all of which are divisors of 64. The number of parts into which the circle is divided represents the *denominator* of the fraction. The number of these parts *used* represents the *numerator* of the fraction. In dealing with fractions, it must be remembered that only like quantities can be added. We cannot, for instance, add 1 yd., 2 ft., and 6 in. without first changing all the dimensions to the smallest or least of the dimensions we are using. In this case, the smallest dimension is 1 in. We therefore change 1 yd. to 36 in., 2 ft. to 24 in., and then add 6 in., making 66 in. in all.

In like manner, when adding fractions with different denominators, they must be changed so as to have the same or "common denominator." This is a number into which all the given denominators can be divided equally. Multiplying or dividing both parts of a fraction by the same number does not change the value of the fraction. Thus

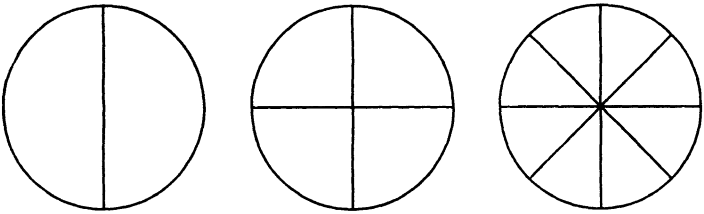


FIG. 111.—Dividing and subdividing a circle into fractional parts.

$$\frac{1}{2} = \frac{1 \times 4}{2 \times 4} = \frac{4}{8} \qquad \frac{13}{32} = \frac{13 \times 2}{32 \times 2} = \frac{26}{64}$$

Therefore, to add a number of fractional dimensions, we use this method:

$$\begin{array}{rcl} {}^{3}/_{64} & = & {}^{3}/_{64} \\ {}^{39}/_{64} & = & {}^{39}/_{64} \\ {}^{1}/_{2} & = & {}^{32}/_{64} \\ {}^{5}/_{8} & = & {}^{40}/_{64} \\ {}^{1}/_{32} & = & \underline{{}^{2}/_{64}} \\ & & {}^{116}/_{64} \text{ or } 1\,{}^{52}/_{64} \end{array}$$

However, we never see a fraction like $^{52}/_{64}$ on a blueprint, and, if several fractions are added together, the resulting fraction is always expressed with its least common denominator; in other words, unless the numerator is an odd number, the fraction is not in its simplest form. Therefore $^{52}/_{64}$ should be divided by 2, making it $^{26}/_{32}$; then this should again be divided by 2, leaving it as $^{13}/_{16}$, which is its simplest form.

In subtracting fractions, we use the same method as in adding, that is, we find a common denominator for all the fractions and subtract the numerators.

In the use of whole numbers and fractions the numerator of the fraction may be less than the numerator of the fraction being subtracted. In that event "borrow" 1 from the whole number and convert the 1 into a fraction. As an example:

$$\begin{array}{rcl} 2\tfrac{5}{16} & = & 1\tfrac{21}{16}\ (\tfrac{5}{16} + 1\tfrac{16}{16}) \\ -\tfrac{9}{16} & = & \underline{\quad\ \ \tfrac{9}{16}} \\ & & 1\tfrac{12}{16} \text{ or } 1\tfrac{3}{4} \end{array}$$

Decimals are added or subtracted in the same manner as whole numbers, except that the decimal points should form a straight vertical line:

$$\begin{array}{r@{.}l} 1 & 25 \\ 3 & \\ & 625 \\ & 016 \\ 3 & 11 \\ & 5 \\ \hline 8 & 501 \end{array}$$

In practice, it is less confusing and also good form to fill in all the zeros when writing down dimensions, some of which represent thousandths. The preceding figures would then be written

$$\begin{array}{r@{.}l} 1 & 250 \\ 3 & 000 \\ & 625 \\ & 016 \\ 3 & 110 \\ & 500 \\ \hline 8 & 501 \end{array}$$

and, when figuring in ten-thousandths, four decimal places should be shown for each dimension, as follows:

$$\begin{array}{r@{.}l} 1 & 5875 \\ & 2500 \\ 3 & 5000 \\ 2 & 7125 \\ \hline 8 & 0500 \end{array}$$

In multiplying decimals, the same form is used as for whole numbers, and the result is pointed off from the right according to the total decimal places appearing in the two figures being multiplied;

$$\begin{array}{rl}
3.7\,5 & \text{(2 decimal places)} \\
\underline{.2\,5} & \text{(2 decimal places)} \\
1\,8\,7\,5 & \\
\underline{7\,5\,0} & \\
.9\,3\,7\,5 & \text{(4 decimal places)}
\end{array}
\qquad
\begin{array}{rl}
1.0\,5\,9 & \text{(3 decimal places)} \\
\underline{5} & \\
5.2\,9\,5 & \text{(3 decimal places)}
\end{array}$$

When dividing decimals, there are two methods, *viz.*,

1. If you divide a decimal by a whole number, point off as many places in the quotient as there are in the dividend:

$$\begin{array}{rl}
 & \underline{.009\text{ (quotient)}} \\
5\text{ (divisor)} &).045\text{ (dividend)}
\end{array}$$

If necessary, use zeros to obtain a sufficient number of places in the quotient.

2. When dividing a decimal by a decimal, multiply both figures by a figure that will make the divisor a whole number; then proceed as in 1. This may be done by simply multiplying both figures by 10, 100, 1000, etc., according to the number of decimal places.

$$15 \div .25$$

Multiply both by 100; then you have

$$1{,}500 \div 25, \text{ or } 60$$

As another example

$$26.75 \div .055$$

Multiply by 1,000, which gives

$$26{,}750 \div 55, \text{ or } 486.36$$

Geometrical Forms.—There is no branch of mathematics which is of greater importance and practical value to an inspector than that which deals with angles and particularly with the right triangle, that is, a triangle that has one angle of 90 deg., or a right angle.

But here, as in arithmetic, it is necessary to recall a few geometrical rules and constructions. First, the *angle* is the opening between two straight lines that meet (Fig. 112). A *triangle* consists of three straight sides and three angles. The sum of these three angles is 180 deg.; consequently, if we know the value of any two angles, we can find the value of the third angle.

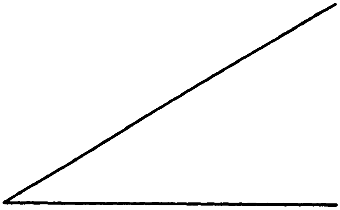


FIG. 112.—Angle.

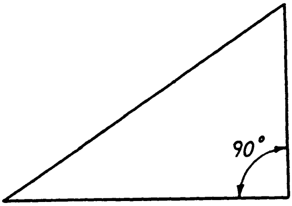


FIG. 113.—Right triangle.

A *right triangle* contains a right angle (Fig. 113). An *isosceles triangle* has *two* equal sides. A line drawn from the top or vertex of an isosceles triangle vertically to the base bisects the base and forms two equal right triangles (Fig. 114).

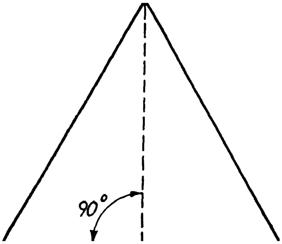


FIG. 114.—Isosceles triangle.

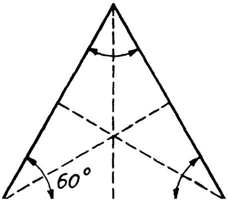


FIG. 115.—Equilateral triangle.

An *equilateral triangle* has three equal sides, which form three equal angles (60 deg.). This is also known as an *equiangular triangle.* A line drawn from any vertex of such a triangle through the center to the opposite side bisects that side and forms two equal right triangles (Fig. 115).

An *acute angle* contains less than 90 deg. When a circle is drawn in an acute angle so that the circle is tangent to (or touches) the sides of the angle, it is possible to bisect that angle by drawing a straight line from the vertex of the angle through the center of the circle (Fig. 116).

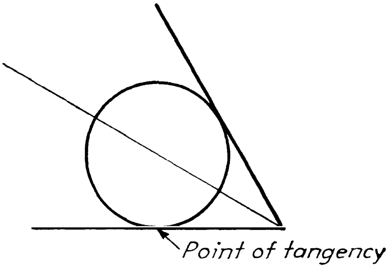


Fig. 116.—Acute angle with tangent circle.

Two straight lines are said to be parallel if they do not meet, however far extended (Fig. 117).

Fig. 117.—Parallel lines.

If two straight lines intersect, the opposite angles are equal (Fig. 118).

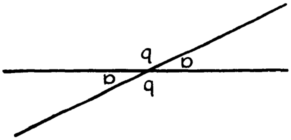


Fig. 118.—Intersecting lines.

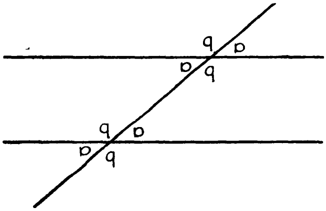


Fig. 119.—Diagonal line intersecting two parallel lines.

If two parallel lines are cut by a third line, the exterior-interior angles are equal (Fig. 119).

Two angles are equal when their sides are parallel right to right and left to left (Fig. 120).

These few "propositions," or proved statements, contain the basis of most inspection problems based on geometrical principles and should be kept prominently in mind in using indirect method of measurement.

INDIRECT MEASUREMENTS

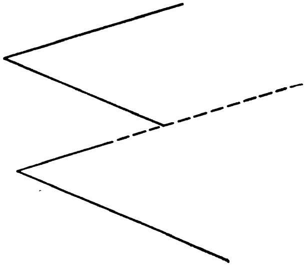


FIG. 120.—Two equal angles.

An inspector frequently has to check dimensions that, because of the form of the piece and the position of the surfaces, do not permit direct measurement with an instrument or tool. In such cases, it is necessary to use indirect measurements that are directly related to the dimension. This can be done very easily and accurately by using principles whereby, if two more of the related dimensions are known, the unknown dimension can be ascertained very readily. For instance, surveyors have for centuries been able to measure the height of inaccessible mountaintops, the width of streams, etc., without actually taking the direct measurement. In the same manner, an inspector can determine the accuracy of a dimension that is not directly measurable by checking other related dimensions and then by a simple formula determining whether the piece is correctly dimensioned in all other respects.

As a simple demonstration of the application of this principle, draw a straight horizontal line about 6 in. long; then draw a line of about the same length from one end of this line at an angle of, say 60 deg., or less. Along the latter line, mark a space exactly 1 in. from the intersection of the two lines; then mark distances of 2, 3½, and 4 in., respectively, from the intersection. Then from the base line draw vertical lines to each of these points. A diagram of this kind is shown in Fig. 121. It will be seen that four right-angled triangles have been constructed. With a ruler graduated in sixty-fourths, measure the length of each of these vertical lines. Note the length of lines 1, 2, 3, and 4 and that lines 2, 3, and 4 are, respectively, 2, 3½, and 4 times longer than line 1.

This shows that the length of line 2, for instance, is always in direct proportion to the length of the slanting line. This relationship is known as the *sine*. But, before going further, let us lay down a system of designating the various sides and angles of a right-angled triangle, in order to simplify the succeeding illustrations.

To begin with, in every right-angled triangle, one angle is 90 deg. This means that the sum of the other *two* angles is 90 deg., but the angle usually dealt with in simple problems is the one designated by *A*. Indicating the various sides of the triangle are three letters. In the conventional terminology of mathematics, these sides are known as *adjacent* (*b*), or the line that lies next to and forms one side of the angle *A*; the *opposite* (*a*), or the line that lies opposite the angle *A*; and the *hypotenuse* (*c*), which is the slanting line and always lies opposite the *right angle*.

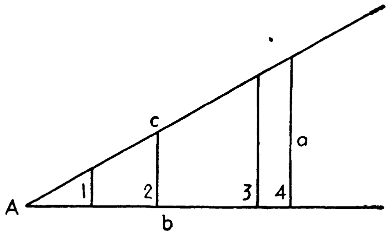


FIG. 121.

Now we return to the terms ordinarily used to denote relationships of the various sides and the angles. As has been shown, these relationships are *definite ratios* and are known as *functions*. For most inspection problems, we can confine our use of these functions to three, the *sine*, *cosine*, and *tangent*. The functions have been worked out in more or less detail depending on the degree of accuracy required. On referring to the table of the three functions shown in Fig. 122, it will be found that, if we measure the length of side *a* in Fig. 121 and find it to be $^{31}/_{64}$ this would have a decimal equivalent of .4844. If we find the decimal nearest this in the column of sines, it will be seen that this decimal represents an angle of 29 deg.

By reversing this process, we could first refer to the table if we knew the angle of any similar triangle, and we should then find a decimal representing the dimension of side *a*. This applies only when side *c* is 1 in., or unity. But, regardless of the length of side *c*, it will always have a definite ratio to side *a* regardless of the angular dimension *A*. These ratios are expressed in a few simple formulas which can easily be called to mind if the word SOHCAHTOA is memorized.

TABLE OF NATURAL TRIGONOMETRIC FUNCTIONS

Angle	Sine	Cosine	Tangent	Angle	Sine	Cosine	Tangent
1°	.0175	.9998	.0175	46°	.7193	.6947	1.0355
2°	.0349	.9994	.0349	47°	.7314	.6820	1.0724
3°	.0523	.9986	.0524	48°	.7431	.6691	1.1106
4°	.0698	.9976	.0699	49°	.7547	.6561	1.1504
5°	.0872	.9962	.0875	50°	.7660	.6428	1.1918
6°	.1045	.9945	.1051	51°	.7771	.6293	1.2349
7°	.1219	.9925	.1228	52°	.7880	.6157	1.2799
8°	.1392	.9903	.1405	53°	.7986	.6018	1.3270
9°	.1564	.9877	.1584	54°	.8090	.5878	1.3764
10°	.1736	.9848	.1763	55°	.8192	.5736	1.4281
11°	.1908	.9816	.1944	56°	.8290	.5592	1.4826
12°	.2079	.9781	.2126	57°	.8387	.5446	1.5399
13°	.2250	.9744	.2309	58°	.8480	.5299	1.6003
14°	.2419	.9703	.2493	59°	.8572	.5150	1.6643
15°	.2588	.9659	.2679	60°	.8660	.5000	1.7321
16°	.2756	.9613	.2867	61°	.8746	.4848	1.8040
17°	.2924	.9563	.3057	62°	.8829	.4695	1.8807
18°	.3090	.9511	.3249	63°	.8910	.4540	1.9626
19°	.3256	.9455	.3443	64°	.8988	.4384	2.0503
20°	.3420	.9397	.3640	65°	.9063	.4226	2.1445
21°	.3584	.9336	.3839	66°	.9135	.4067	2.2460
22°	.3746	.9272	.4040	67°	.9205	.3907	2.3559
23°	.3907	.9205	.4245	68°	.9272	.3746	2.4751
24°	.4067	.9135	.4452	69°	.9336	.3584	2.6051
25°	.4226	.9063	.4663	70°	.9397	.3420	2.7475
26°	.4383	.8988	.4877	71°	.9455	.3256	2.9042
27°	.4540	.8910	.5095	72°	.9511	.3090	3.0777
28°	.4695	.8829	.5317	73°	.9563	.2924	3.2709
29°	.4848	.8746	.5543	74°	.9613	.2756	3.4874
30°	.5000	.8660	.5774	75°	.9659	.2588	3.7321
31°	.5150	.8572	.6009	76°	.9703	.2419	4.0108
32°	.5299	.8480	.6249	77°	.9744	.2250	4.3315
33°	.5446	.8387	.6494	78°	.9781	.2079	4.7046
34°	.5592	.8290	.6745	79°	.9816	.1908	5.1446
35°	.5736	.8192	.7002	80°	.9848	.1736	5.6713
36°	.5878	.8090	.7265	81°	.9877	.1564	6.3138
37°	.6018	.7986	.7536	82°	.9903	.1392	7.1154
38°	.6157	.7880	.7813	83°	.9925	.1219	8.1443
39°	.6293	.7771	.8098	84°	.9945	.1045	9.5144
40°	.6428	.7660	.8391	85°	.9962	.0872	11.4301
41°	.6561	.7547	.8693	86°	.9976	.0698	14.3007
42°	.6691	.7431	.9004	87°	.9986	.0523	19.0811
43°	.6820	.7314	.9325	88°	.9994	.0349	28.6363
44°	.6947	.7193	.9657	89°	.9998	.0175	57.2900
45°	.7071	.7071	1.0000	90°	1.0000	.0000	

FIG. 122.—Functions of triangles.

Separating this word into its three syllables gives SOH-CAH-TOA. From this we make three formulas:

$$s = \frac{o}{h} \qquad c = \frac{a}{h} \qquad t = \frac{o}{a}$$

We "spell out" the first of these as follows;

$$\text{Sine of angle } A = \frac{\text{opposite side}}{\text{hypotenuse}}$$

the second

$$\text{Cosine of angle } A = \frac{\text{adjacent}}{\text{hypotenuse}}$$

and finally

$$\text{Tangent of angle } A = \frac{\text{opposite}}{\text{adjacent}}$$

The question now arises, "When do I use the sine, when the cosine, and when the tangent?" This of course depends upon what the known dimensions are and what unknown is being sought. For instance, $s = \frac{o}{h}$ would be used only when the angle and the opposite side, the angle and the hypotenuse, or the opposite side and hypotenuse are known, and the desired unknowns are, respectively, the hypotenuse, the opposite side, or the angle. To facilitate the use of these formulas, a series of diagrams are shown (Fig. 123). From these we now work out a practical application to an actual inspection problem.

Figure 124 is a drawing of a tapered shaft, in which the known dimensions are the diameter of the shaft and the distance from the point of the taper to the beginning of the taper. The unknown in this instance is the angle that the taper forms at the end of the shaft. Here should be interjected a rule that must be kept constantly in mind when solving problems involving right-angle triangles. To determine an unknown dimension or angle, a right-angle triangle must be found that *contains* the desired part and has sufficient other known parts to make it possible to determine the required angle or side. If no such triangle already exists, auxiliary lines must be drawn to form one.

Reverting to our problem, we notice that there is no right-angle triangle in the drawing that contains the sought-for angle.

It is therefore necessary to construct such a triangle. In this case, we draw the center line of the shaft through to the point of

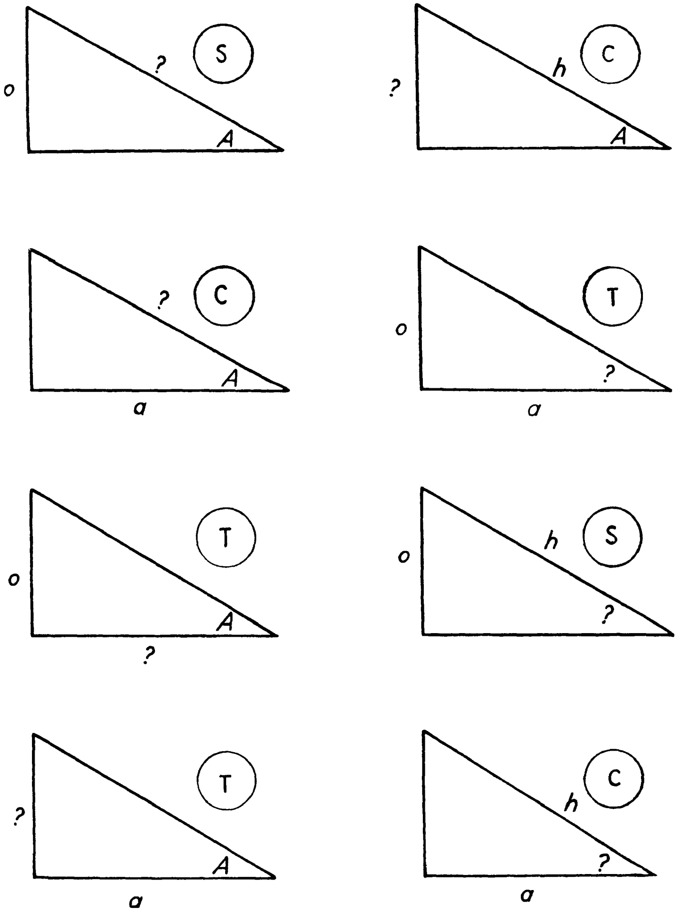


Fig. 123.—Diagrams showing when to use sine, cosine, and tangent (initial letter of function shown in circle).

the taper, which then forms the base of a right triangle, one of the angles of which is exactly one-half of the desired angle. This gives us a triangle with two known dimensions, a base of 1,270 and an opposite side of .6875. In other words, we have the adjacent and opposite sides, which in our simple code is $t = \frac{o}{a}$. We proceed to convert this formula into known figures, which gives us tangent $= \frac{.6875}{1.270}$, or .54134. Referring to our tables of functions, we find this decimal is between the tangent of 28° and that of 29°. A more detailed table would show it represents an angle of 28°26′. Since this angle is one-half the required angle, the whole angle is therefore 56°52′.

Before going further with the solution of right-angled triangles, it might be well to inform the reader that the past few pages represent a simple step-by-step exposition of a subject that, when named in advance, often raises a mental barrier in the mind of students who have never had the opportunity of studying it or who have a recollection of many tedious hours mastering the theory and complicated formulas of *trigonometry*, for that is the mathematical term applied to the study of the measurement of triangles. The purpose, however, has been to reduce what to some people seems a formidable task to a very easy and simple form. With what has already been outlined, many inspection problems involving right-angled triangles can be worked out without difficulty by using the simplified method outlined here.

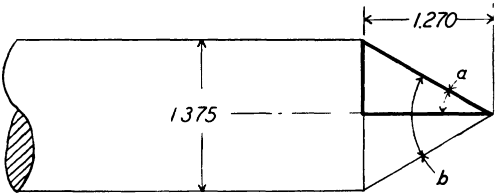


Fig. 124.—Tapered shaft.

There are hundreds of inspection problems in which trigonometry is useful and indeed necessary. It is suggested that the learner acquire a suitable textbook of shop mathematics, such as "Simplified Industrial Mathematics" by Wolfe, Mueller and Mullikin (McGraw-Hill), where scores of problems are outlined and the method of solution is shown for many.

CHAPTER XX

DEFINITIONS OF TERMS GENERALLY ASSOCIATED WITH MECHANICAL INSPECTION

The following terms are frequently encountered in inspection, and the definitions are specific rather than general. Many of the definitions are restricted to the meaning of the term from an inspector's viewpoint, and a full explanation of the term as applied to general machine-shop practice is not given. Many terms that are fully explained in the general text are not included.

Allowance. An intentional difference in dimension between two parts that are designed to fit together. The amount of the allowance depends on the class of fit required, for instance, *loose fit*, as a pin in a drilled hole; *running fit*, a shaft in a reamed hole; *close fit*, a ground pin in a reamed hole; *shrink fit*, where parts must be assembled by heating one member and cooling the other. For example, with a hardened steel sleeve on a brass shaft, the sleeve at normal temperature would be of smaller diameter than the shaft, and the parts could not be assembled, because of the "interference" of the shaft diameter. By heating the sleeve and cooling the shaft in dry ice, the parts would go together, and, as the sleeve cooled, it would "shrink" on the shaft. The allowance between parts that are to be shrink-fitted is known as a *negative allowance.*

Alloy. A metal made up of an intimate mixture of two or more metals that have been melted together. Common alloys are brass, bronze, stainless steel, etc.

Alloy steel. A mixture of steel with some other metal such as nickel, chromium, vanadium, etc. The physical properties of steel are considerably affected by the addition of small quantities of other metals. Nickel will make steel suitable for armor plate, nickel and chromium added to steel make it resistant to stain or corrosion, etc.

Angle plate. A cast-iron piece with two or more finished surfaces at right angles to each other, used on a surface plate as a support in setting up and laying out mechanical parts for checking or machining.

Arbor. A tool or shaft for holding bored or reamed parts while testing for eccentricity. The term is often used to designate a mandrel.

Backlash. The play between mating gear teeth, or lost motion between moving parts.

Basic dimension. The nominal size of a part from which variations are permitted.

Bearing. The support for a revolving part such as a shaft. It may have a smooth surface or balls or rollers to reduce friction.

Bell mouth. A hole that is enlarged slightly at one or both ends instead of being exactly cylindrical through its length.

Bevel. A cut extending over the entire length or width of a piece, at an angle to the other surfaces or to the axis of the piece. When the bevel is cut at 45 deg., it is often known as a miter.

Bevel gear. Gears cut on conical surfaces to transmit motion through shafts at an angle to each other.

Blind hole. A hole that does not go entirely through a part but is closed at its inner end.

Blocks. Precision or gage blocks used to check or lay out precise dimensions. "Jo" blocks are measuring blocks made by Johannssen; "Hoke" blocks, designed by Major Hoke, are made by Pratt & Whitney. Both types serve similar purposes.

Brinell hardness. The hardness of metals determined by the impression of a hardened steel ball of specific diameter, pressed into the metal with a known pressure. The harder the metal the smaller the impression. The diameter of the impression when measured provides a definite number known as the *Brinell number.*

Broach. A metal-cutting tool with a series of teeth, which increase in size from one end of the tool to the other. When pushed or pulled through a hole or over the work, the teeth cut the piece to the required form. The action is in effect that of a series of chisels.

Brown and Sharpe taper. A standard taper used for shanks on end mills and reamers. The taper is ½ in. per foot except for No. 10, which is 0.5161 per foot.

Buffing. A polishing process to secure a very fine surface on metals.

Burnishing. A method of securing smooth metal surfaces by application of highly polished tools or steel balls which compress the outer layer of metal.

Bushing. A tube or shell supported by other material, often used as guides for tools passing through holes, or as bearings for shafts.

Calibration. An accurate comparison of a measuring instrument with a standard.

Cam. A machine part that, by means of grooves or surfaces, imparts an irregular or intermittent motion to a member that rests against the surface or within the groove of the cam.

Carbon steel. A tool steel that has no metallic alloys. Steel itself is an alloy of iron and carbon.

Carburizing. Heat-treatment of steel by contact with carbonaceous material, in such a manner that the steel absorbs the carbon on and near the surface.

Casehardening. A carburizing process which hardens the outer layer of the steel.

Casting. A metallic part which has been produced by means of running molten metal into a mold or die. Castings made in a sand mold are sand castings; castings made in a metal mold or die are known as *die castings.*

Chattering. A vibration of cutting tool which causes ridges or nicks on the machined part. The vibration is usually caused by springing of the tool or work.

Clearance. Space provided between two parts to permit easy assembly or operation. *Example:* A $^{31}/_{32}$ bolt in a 1-in. hole. The clearance is the total difference in diameter between the two or $^{1}/_{32}$ in.

Comparator. An instrument that indicates variations from the standard size of a part. In practice, the instrument is first "set up" at zero with a known standard such as a plug gage or a combination of precision blocks. If the part conforms to the size of the standard, the instrument shows a zero reading; any variation is indicated by a plus or minus movement of the indicating hand.

Die casting. A casting made in a metal mold into which molten metal is forced under pressure. Metals used for die casting are usually zinc or aluminum alloys. Die-cast pieces can be produced to very close dimensions and consequently save many machining operations.

Dowel pins. Dowel pins are used to retain adjacent parts in a fixed relative position or to preserve alignment of such parts.

Draft. A slight taper in a pattern for a metal casting, to permit easy withdrawal of the pattern from the sand without injury to the mold.

Drill press. Any machine that presses or forces a revolving drill through metal.

Drill rod. A polished or unpolished tool-steel rod. The rod comes in the standard drill sizes and is reasonably accurate in diameter.

Fin. A thin edge or mark on a casting, caused by the parting line of a mold or die.

Fixture. A device for holding parts while they are being machined. The terms *jig* and *fixture* are generally used as though they referred to the same thing. Properly a jig is a tool that not only holds the part but has guides for the tools used in machining such as drills or reamers. A fixture merely holds the work in position for machining without having any method of guiding the tools.

Flange. A rib or rim for strength, for guiding, or for attachment of a part to another part.

Form tools. Tools used on lathes and milling machines for forming curved or irregular shapes through the reproduction of the shape of the cutting edge.

Gib. A small flat piece in a sliding member to take up play or wear.

Heat-treatment. The heating and cooling of a metal to obtain certain desirable characteristics of the metal. Operations such as hardening, tempering, and annealing are classified under the term heat-treatment.

Jig (see Fixture). A production tool used in mass production of parts for interchangeable manufacture, in which a part is located and held while being machined by tools which have been guided into position by accurately located bushings. The part is "banked" on a previously machined surface so that the holes are in correct location not only to each other but to the general contour of the piece.

Knurling. A series of ridges on the surface of a cylindrical part, to provide a better hand grip or for ornamentation. There are two types of knurls—straight and diamond.

Lay-out. To prepare for future machining operations by scribing finish lines, holes, and other contours on a rough casting, or to check the casting for suitability for such operations.

Limits. The maximum and minimum dimensions of a mechanical part.

Lug. A projection from a casting which serves to support the casting during machining. Lugs are an integral part of the casting but are often removed on finishing so as not to interfere with the function of the part.

Mandrel. A slightly tapered cylindrical shaft with centered ends for supporting bored parts while checking for concentricity, etc.

Profiler. A milling machine adapted to milling of duplicate parts of an irregular contour.

Rib. A ridge, fin, or wing which serves to strengthen a part.

Rockwell hardness. A method of measuring hardness by determining the depth of penetration of a steel ball or a diamond into a test piece, under fixed conditions. The higher the number the harder the material.

Shim. A thin sheet of material, usually metal, to be applied between parts to provide an adjustment of fit. Shim stock is used in inspection as a "feeler" to determine dimensions of small gaps or apertures.

Spline. When a gear or other part must not only rotate with a shaft but be free to move lengthwise along the shaft, a key is fixed to the shaft or the hub to permit such motion. In most cases, however, multiple splines are used around the shaft to give added strength.

Straddle milling. In milling opposite sides of a part so that the surfaces will be parallel, two cutters are used on one arbor. This operation is known as straddle milling.

Tap. A tool to cut an internal thread.

Tolerance. A permissible variation from a basic dimension (see Chap. IV).

Web. The plate, or thin portion, sometimes perforated, connecting the rim and hub of some wheels, especially gears.

Woodruff key. A half-circular metal disk used as a key by inserting the circular portion into the keyway. Part of the key projects and enters a straight keyway in the mating part.

Worm. A short revolving screw, the threads of which mesh with the teeth of a worm gear.

APPENDIX

ATTAINMENT TEST

Following is a list of questions designed as an attainment test for those who have studied the contents of this handbook. The answers to most of the questions can be found in the text, but the others must be reasoned out by "common sense." As a matter of fact, mechanical inspection calls for extensive use of common sense, and, if from the beginning the inspector takes nothing for granted but carefully studies the reasons and principles that govern even the simplest problems, he will make much more rapid headway with the more difficult problems.

Detailed answers to each of the questions are found on pages 170 to 173.

1. A plug gage checks the diameter of a hole. What are two other defects of a hole which a plug gage will check?

2. What is the pitch of a micrometer screw?

3. Which of the following can be checked accurately with a steel scale graduated in 32nds of an inch:

$\frac{1}{16}$ $\frac{1}{2}$ 0.375
0.754 $\frac{7}{32}$ $1\frac{1}{64}$

4. Why is interchangeability necessary to mass production?

5. Name several causes of variations in machined dimensions.

6. Define tolerance.

7. What are limits?

8. Define allowance.

9. A tapered hole through a piece $1\frac{1}{2}$ in. thick measures 0.516 at the small end. If the taper is $\frac{1}{2}$ in. per foot, what is the larger diameter of the hole at the large end?

10. What is the included angle of the taper?

11. What number thread gage would you use to check these threaded holes:

0.216-24 0.099-56 0.190-32

12. A tolerance of 0.005 means which:
  (*a*) plus 0.005 and not minus.
  (*b*) plus 0.005 and minus 0.005.
  [✓ (*c*) 0.005 divided any way.]

13. A lot of 8 shafts measure:

0.999
1.000
1.001
0.996
0.998
0.997
1.002
1.004

The blueprint dimension is 1,000 ± 0.002
How many would you accept? How many would you reject?

14. How far may a no-go thread plug gage enter a tapped hole to permit acceptance?

15. What is unilateral tolerance?

16. In dimensioning the diameter of a shaft, would a plus or minus tolerance be shown? Why?

17. A dimension is given on a print as 2.150 +0.001 −0.003.
  a. What is the mean dimension?
  b. What is the low limit?
  c. What is the tolerance?

18. What are the two general classifications of measuring instruments?

19. How many threads per inch does the standard micrometer screw have?

20. How many thousandths of an inch are represented by one complete turn of the thimble?

21. What is the purpose of the scale on the barrel?

22. What is the purpose of the scale on the thimble?

23. What is the purpose of the ratchet?

24. Can the wall thickness of a cylinder be accurately checked with a standard micrometer?

25. Under what circumstances would you make use of the lock nut of a micrometer?

26. How may an out-of-round condition of external diameters be detected with a micrometer?

27. How may a tapered condition be determined?

28. What difference would be noticed, if any, in the measurement of a cold (40-deg.) 1-in.-diameter aluminum shaft, using a 0.0001 micrometer, as compared with the measurement of the same part at a temperature of 70 deg.? (Give actual reading to tenths.)

29. In order to determine the inside diameter of a cylinder most accurately, would you use an inside micrometer or a vernier caliper?

30. If a vernier instrument is graduated in divisions of 0.050, how many vernier graduations would be necessary to read to 0.001?

31. How long would such a vernier scale be?

32. Explain in sequence the steps necessary to set a vernier instrument to 1.634.

33. If a learner in using a vernier caliper for outside measurements got consistently plus readings, what is the probable reason?

34. In reading a standard "tenth" micrometer, if a learner made frequent errors of 0.025, where would the trouble lie?

35. If the errors were +0.001 and the "tenths" usually correct, what is the reason? For instance, a wrong reading of 0.7528 for an actual dimension of 0.7518.

36. What is the accuracy of a vernier caliper in good condition?

37. What points should be checked to ascertain if a vernier caliper is in good condition?

38. How would you check the accuracy of a vernier depth gage?

39. How accurately can a measured angle be read with a vernier protractor?

40. In checking the squareness of a block 6 in. high with a solid square, a small gap is found between the blade of the square and the top of the block. How would you measure the width of this gap?

41. If the measured width of the gap is 0.017, how much out of square is the block in angular measurement?

42. The base of a casting rests on a surface plate. There are 5 holes to be checked for vertical location from the base by taking readings over the tops of plug gages in the holes. Which of the holes are off location and how much? A zero base reading has been made.

	Plug diameter	Readings	Blueprint dimensions
a	0.750	4.365	3.950 ± 0.005
b	0.368	7.264	7.284 ± 0.002
c	0.480	8.421	8.180 ± 0.002
d	1.000	2.100	1.600 ± 0.005
e	1.200	6.300	5.695 ± 0.005

43. If a blueprint dimension is given as 1.740 +0.000 and −0.002, what is the basic size?

44. If a dimension is shown as 0.432 +0.0005 −0.001, what is the tolerance?

45. A reamed hole is dimensioned 1.250 +0.002 and −0.000. The shaft to run in this hole is dimensioned 1.248 +0.000 and −0.002. What is the allowance?

46. What term describes the difference in size between the go end of a plug gage and the no-go end?

47. In case a plug gage seized in a reamed hole, how would you remove it?

48. Is it good practice to clamp a plug gage to a plate or a V block to allow the use of both hands in handling the parts? Why or why not?

49. Is the thread on a bolt known as an external or internal thread?

50. What is the standard term for the outside diameter of a screw thread?

51. To what limits of accuracy can you measure with an outside caliper and a steel scale?

52. In what other way could you check the radius of a fillet if a fillet gage were not available?

53. What is the purpose of the notch or groove in a thread plug gage?

54. Draw a sketch of a thread showing the pitch diameter.

55. What two features of a thread are checked with the go thread plug gage?

56. What feature does the no-go gage check?

57. The pitch of a thread is expressed in what unit?

58. The lead of a single thread bears what relation to the pitch?

59. Name four classes of thread fit by number and type.

60. Why is the no-go thread gage truncated?

61. What do the following markings on thread gages mean:

No. 1-64NC-1LH 1″-18NS-2

62. What is the purpose of the small inner dial found on some dial instruments?

63. Why is it considered better practice to have the indicator pointer start from the 9 o'clock position rather than from zero?

64. Why is the dial on an indicator rotatable?

65. Explain in detail how a gear blank is checked for concentricity with a dial indicator, naming the instruments used.

66. If the ball lever of an indicator is not approximately parallel to the surface, would the pointer show a greater or smaller reading than the true condition, if a variation of, say 0.005, existed?

67. Draw a simple diagram illustrating the reason for your answer.

68. How can a direct measurement be taken with a height gage?

69. Do you prefer using a true zero setting of a height gage, or an arbitrary zero setting?

70. Is it desirable to use an indicator in connection with a height gage in preference to the height gage alone? Why?

71. Which is more accurate, a combination square or a solid square? Why?

72. In checking concentricity of a shaft in V blocks, can a proper test be made if the two end diameters are different? How?

73. What precautions are necessary in using clamps on finished surfaces?

74. After using a height gage, would you leave it standing on your bench or surface plate, lay it down, or dispose of it otherwise?

75. How small an error can be detected in using cellophane feelers?

76. What is the effect of using a square when both the piece and the square are "out" in the same direction? Is there any way to check for such a condition?

77. What method would you use to check the depth of a Woodruff keyway?

78. Why is a depth gage not suitable for this purpose?

79. Draw a sketch showing how the dimension from the center line of a Woodruff keyway to the end of a shaft may be measured.

80. In setting up a large or heavy piece on a surface plate, why should you use three jacks instead of a larger number?

ANSWERS TO ATTAINMENT TEST QUESTIONS

1. Out-of-round condition and taper.

2. $\frac{1}{40}$-in. Pitch is always expressed as a fraction

$$\frac{1}{\text{number of threads per inch}}.$$

3. $\frac{1}{16}$, $\frac{1}{2}$, and $\frac{7}{32}$. It is not good practice to try to measure dimensions like $\frac{11}{64}$ with a scale divided in 32nds. As regards 0.375, this is $\frac{3}{8}$ in. (which could be checked with such a rule), but, when a dimension is expressed in decimals it is a precision dimension. Precision dimensions must be checked with a precision instrument. Fractional dimensions must be checked with nonprecision tools. In other words, do not use a micrometer to measure a $\frac{3}{8}$-in. dimension or try to check a 0.375 dimension with a scale or caliper.

4. To permit quick and accurate fitting together of parts in assembly.

5. See page 35.

6. See page 36.

7. See page 36.

8. See page 36.

9. 0.5785.

10. 2°23′10″.

11. 0.216-24 is No. 12.
0.099-56 is No. 3.
0.190-32 is No. 10.

12. 0.005 divided any way.

13. Accept 5.
Reject 2.
Rework 1.

14. It may enter the tapped hole for the full length of the gage, provided the gage fits snugly.

15. A tolerance on one side only of a basic dimension. *Examples:*

$$1.000^{+0.002}_{-0.000} \qquad 1.000^{+0.000}_{-0.002}$$

16. A shaft should have a minus tolerance to assure a clear fit with the mating part, which should have a plus tolerance.

17. *a*. 2.149.
b. 2.147.
c. 0.004.

18. Precision and nonprecision.

19. 40.

20. 25.

21. To permit readings to be made in steps of 0.025.

22. To permit readings to be made in thousandths.

23. To assure a uniform measuring pressure, or to traverse quickly from one position of the spindle to another.

24. No; anvil of micrometer would not make proper contact with inside wall.

25. To set a planer gage or for some similar purpose; never use the micrometer as a snap gage.

26. By taking two or three measurements around the circumference.

27. By checking the diameter at several points along the shaft.

28. The "coefficient of expansion" of various metals may be found in various handbooks. This coefficient gives the expansion or contraction per inch for each degree of temperature change. In this case, the temperature increases 30 deg. The coefficient of aluminum is 0.00001234. Therefore the change will be 30 × 0.00001234, or approximately 0.00037, a measurable difference with a standard "tenths" micrometer.

29. An inside micrometer may be read to an accuracy of about 0.0005. A vernier caliper reads to ±0.001. Therefore the inside micrometer is preferable.

30. 50 graduations.

31. 2.450 in. (50 × the width of each vernier graduation 0.049).

32. *a.* Move the slide so that the 0 on the vernier is between the 1- and 2-in. marks on the main scale.
b. Move slide slowly so that it rests between the *small* figures 6 and 7 on the main scale.
c. Clamp the right-hand section of the slide.
d. With the adjusting nut bring the vernier 0 so that it rests on the first main scale subdivision between 6 and 7.
e. Move vernier slowly to the right until the 9th *vernier* graduation lines up with a main scale division.

33. Caliper not "square" with the surfaces being measured. Measuring contact too loose.

34. Incorrectly counting the subdivisions on the barrel scale. It should be remembered that these subdivisions are not entirely visible under the edge of the thimble until the thimble has been turned about 10 graduations past the zero.

35. Counting a thimble graduation betore it is on or below the index line on the barrel.

36. ±0.001.

37. Close the jaws of the vernier caliper and hold to the light. If any light shows between the measuring surfaces of the jaws the faces may be out of parallel or worn. While jaws are closed, check the zero point on main scale and vernier scale to see if they coincide.

38. Place the base on a surface plate or parallel, leaving the blade loose. See that the blade makes contact with the surface plate or parallel, tighten clamping screw, and check zero points.

39. ±5′.

40. With a thickness gage, known also as a feeler gage.

41. 10′ (approximately).

42. *a* is 0.040 high.
b is 0.204 low.
Others are correctly located.

43. 1.740. **44.** 0.0015.

45. 0.002. **46.** Tolerance.

47. By placing a wooden or soft metal rod in the *opposite* end of the hole and tapping it lightly with a mallet.

48. No. The important "feel" of the gage is lost. Difficult to center a gage when doing this.

49. External. **50.** Major diameter. **51.** ±1/64 in.

52. By a plug gage or steel rod of same radius. By cutting a small piece of cardboard or shim stock to the proper radius and using this as a gage.

53. To remove dirt and chips in gaging.

54. See page 86.

55. Major diameter, pitch diameter.

56. Pitch diameter.

57. As a fraction $\left(\frac{1}{\text{number of threads per inch}}\right)$.

58. Equal.

59. *a*. Loose.
b. Free.
c. Medium.
d. Close.

60. To clear the major and minor diameters so as to limit contact of gage to sides of thread.

61. No. 1: 0.073 major diameter.
64: 64 threads per inch.
N.C.: National Coarse series.
1: loose fit.
LH: left hand.

1″: 1 in. major diameter.
18: 18 threads per inch.
NS: National Special Series
2: free fit.

62. To count revolutions of large hand.

63. So that minus variations would be indicated. If the pointer were on zero while at rest it would record only plus variations.

64. To permit close adjustment of the zero point when "setting up" for a dimension.

65. Instruments: Bench center or V blocks, mandrel or plug gage, surface gage, indicator. For procedure, see pages 120.

66. A greater reading. **67.** See page 97.

68. By "setting up" the height gage on a block or parallel so that all the readings are "true" readings. Detailed procedures are outlined on pages 99, and 100.

69. Most inspectors favor arbitrary settings.

70. Yes. Because, with an indicator, any effect of "touch" or "feel" is absent. With a scriber, some "feel" is always present.

71. A solid square, which is fixed and not adjustable. Any adjustable instrument of this type has a greater tendency toward inaccuracy than a solid one.

72. Yes, provided any possibility of end motion is eliminated.

73. To place a heavy paper or cardboard between the clamp and the finished surface.

74. It should be placed in its case when not in use. If left standing, it might be knocked over. If laid down, it might be damaged by something dropping or resting on it.

75. 0.001.

76. The piece appears to be square. If the piece or the square is reversed, any error would immediately show up as twice the real error.

77. See page 124.

78. The square end of the depth gage will "bridge" the bottom of the keyway and give an untrue reading.

79. Insert a disk of equal or slightly greater radius than the keyway. Place shaft in vertical position. "Indicate" top end of shaft and top edge of disk. Subtract radius of disk from latter and then subtract result from reading of top of shaft.

80. Three jacks make it easy to level and also eliminate the effect of any "rock" due to uneven base of the casting.

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