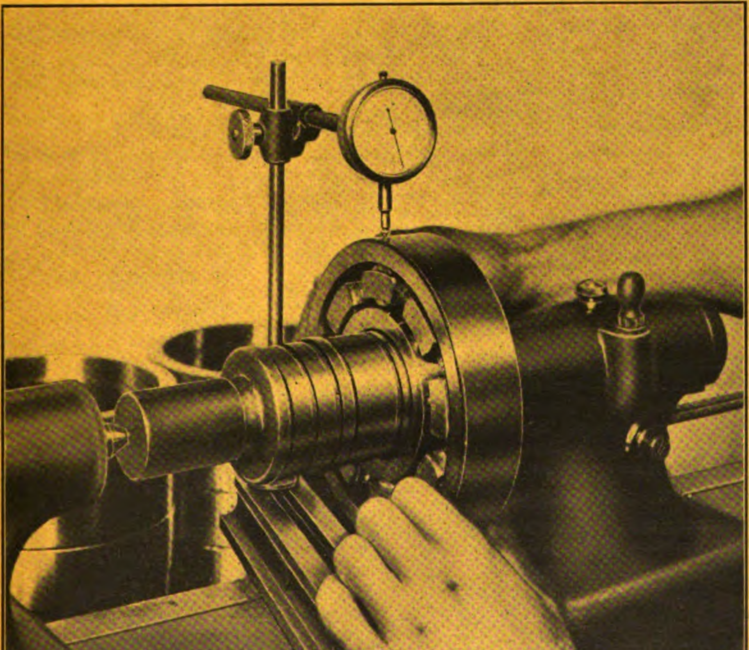
GAGING TOOLS AND METHODS

MEASURING INSTRUMENTS USED BY MACHINISTS AND TOOLMAKERS

BY FRANKLIN D. JONES



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NUMBER 130

GAGING TOOLS AND METHODS

By FRANKLIN D. JONES

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CHAPTER I

CLASSES AND STANDARDS OF MEASUREMENT

This treatise deals with the various forms and types of gages and measuring instruments used in machine shops and tool-rooms. Practically all of the measuring tools used by machinists and toolmakers may be divided into two general classes; *viz.*, the tools for measurements of length, and those for the measurement of tapers or angles. Length measurements, in turn, may be divided into *line* measurements and *end* measurements. The former are made by direct comparison with graduations on the measuring tool, and the latter by bringing the work into actual contact with the measuring surfaces of the instrument. Examples of line measurement are those made with a machinists' rule, whereas, end measurements are those made with a micrometer or similar tool. Angular measurements are also obtained either directly by means of degree graduations on an adjustable protractor, or by testing the work with a gage which conforms to the required angle.

In the two general classes of tools for length and angular measurements, there are many different types and designs. For instance, there is the adjustable type, which is graduated and is used for taking direct measurements in inches or degrees; then, there is another type which is fixed and cannot be used for determining various sizes or angles, but simply for gaging or testing one particular size. There are also tools for taking approximate measurements and others designed for very accurate or precise measurements. Ordinarily, both classes of measurements would be required in building a machine or tool, because some parts must be accurate, whereas others can vary in size to some extent, and, in such cases, any unnecessary refinement means an increase of time and cost. Measurements which, in machine and tool construction, belong in the approximate class, are those made by means of a rule or scale, or by working to lines which have been laid out on the work and represent finished surfaces. For precise measurements, there are vernier calipers, micrometers, fixed gages, and reference gages which represent subdivisions of the standard yard within very small limits.

Standards of Measurement

Evidently, if there is to be a uniform system of measurement, it is necessary to have a fixed standard. The yard is the commonly accepted standard of length in the United States, although it is not the legal standard. In 1866 Congress passed a law making legal the meter. In 1875 representatives of various countries signed a treaty providing for the establishment and maintenance, at the common expense of the contracting nations, of a scientific and permanent bureau of weights and measures, to be located in Paris. This bureau was empowered to construct and preserve the international standards and to distribute copies to the different countries.

The international meter adopted by this Bureau is the fundamental unit of length in the United States. The primary standard is deposited at the International Bureau of Weights and Measures near Paris, France. This is a platinum-iridium bar with three fine lines at each end; the distance between the middle lines of each end, when the bar is at a temperature of 0 degrees C., is one meter by definition Two copies of this bar are in the possession of the United States and are deposited at the Bureau of Standards, in Washington.

The United States yard is defined by the relation, 1 yard $= \frac{3600}{3937}$ meter. The legal equivalent of the meter for commercial purposes was fixed as 39.37 inches by law in July, 1866, and experience having shown that this value was exact within the error of observation, the United States office of standard weights and measures was, by executive order, in 1893, authorized to derive the yard from the meter by the use of this relation. No ultimate standard of reference for angular measurements is required, inasmuch as the degree can be originated by subdivision of the circle.

The Bureau of Standards employs various methods of making comparisons of bars which are submitted by manufacturers for test, the method depending upon the kind of bar, the accuracy desired, and the adaptability of the apparatus available to the bar or test piece. Thus, there are several classes of tests, such as Class *A*, for reference standards, Class *B*, for working standards, etc. The fee charged for this work depends, of course, upon the class and nature of the test. Metric length measures tested by the bureau are standardized at 20 degrees C., and standards in the customary units of yards, feet, and inches are made to be correct at 62 degrees F.

Value of a Standard of Measurement

The standard bars at Washington are the ultimate standard of reference for the manufacturers in this country. Working standards or duplicates have been made for the use of manufacturers of gages and measuring instruments. In 1893, the Brown & Sharpe Mfg. Co. decided to make a new standard to replace the one they had at that time. The following general description of how a copy of the government standard was made is taken from a paper by Mr. W. A. Viall, presented before the Providence Association of Mechanical Engineers, and shows the great accuracy necessary in connection with work of this kind.

First steel bars about 40 inches long and 1¼ inch square were planed, and then allowed to "season" for several months. At the ends of these bars two gold plugs were inserted with centers 36 inches apart, and a little beyond these, two other plugs 1 meter apart. This bar was placed in position upon a heavy bed so arranged that a tool carrier could pass over the bar. The tool carrier consisted of a light frame-work holding the marking tool. The point of this marking tool was curved and had an angle, so that if dropped, it made an impression in the form of an ellipse. A line made with this tool was short and that portion of the line was used which passed, apparently, through the straight line in the eye-glass of the microscope. In order to make these lines as definite as possible, the point was lapped to a bright surface. A microscope at the front of the tool carrier was set to coincide with the graduation on the standard bar from which the new bar was to be graduated. After obtaining this setting, the marking tool was dropped by turning a lever, thus making a line on the plugs that was so fine it was not visible to the naked eye. After making this first line the carriage and marker was moved along to coincide with the other line on the standard, and after the correction had been made by the use of a micrometer in the microscope, the marking tool was again dropped, giving a second line which was intended to mark the distance equivalent to one yard. This same operation was repeated in marking lines representing the meter. This work was done, of course, with the greatest care, and while it may appear very simple from the description, it required a great deal of time and patience.

The standard bar thus marked was taken to Washington and compared with the government standard Bronze No. 11 and also with Low Moor iron No. 57. In comparing these standards, a method was employed very similar to that used in marking. The bar, properly supported, was placed upon a box that rested upon rolls and on this same box was placed the government standard with which the Brown & Sharpe standard was to be compared. Both the government standard and the bar to be tested were placed in position under the microscope and by the micrometer screw of the microscope the variation between the two was measured. Three comparisons or tests were made on each end before determining the reading of the microscope, and after these comparisons the value of the B. & S. standard No. 2 was found to be 36.00061 inches for the yard, and 1.0000147 meter for the meter.

After completing this work, a second standard known as No. 3 was prepared, and comparison with the government standard showed the error to be 0.00002 inch for the yard, and 0.000005 meter for the meter. After establishing a yard in this manner, the next problem was that of obtaining an inch; this was done by subdividing the yard into two equal parts, and then further subdividing these two divisions into three, and the three into six, thus giving thirty-six subdivisions or inches.

CHAPTER II

CALIPERS AND MICROMETERS

Calipers are used principally for external and internal measurements not requiring great accuracy, and are made in a variety of designs. Sketch *A*, Fig. 1, shows outside calipers and indicates how they are used for testing the size of a cylindrical part. Inside calipers for testing the diameter of a hole are shown at *B*, and sketch *C* illustrates how the outside calipers are set by comparison with the inside pair or *vice versa*. For instance, if the shaft at *A* were being fitted to the hole *B*, the calipers would be set as follows: First the inside pair would be adjusted to just touch both sides of the hole, when held as shown. The outside calipers would then be set to just touch the ends of the inside calipers so that the outside pair, practically speaking, would represent the hole and could be used for testing the size of the shaft. Obviously, if a rather heavy pressure were required to force the outside calipers over the shaft, this would indicate that the diameter was too large. If the pressure were the same as between the two pairs of calipers, the shaft would fit tightly; whereas, if the calipers passed over easily and without perceptible pressure, a close sliding fit should be obtained.

Evidently, when testing sizes by means of calipers, the degree of accuracy attained depends largely upon the skill, judgment and experience of the one who sets and uses the calipers. Some machinists can work within very close limits, whereas others lack the delicate sense of touch that is necessary. In order to eliminate this personal factor, micrometers are extensively used in order to obtain direct measurements and secure different classes of fits by a definite allowance in thousandths of an inch, instead of by judging the allowance from the pressure or side play of the calipers. Fixed gages, which are accurately made to the sizes required, are also widely used, especially for testing duplicate parts in connection with interchangeable manufacture.

Most calipers are either the firm joint or the spring type; the former, which is shown in Fig. 1, simply has a friction joint between the two "legs," whereas the spring type (illustrated in Fig. 3) is provided with an adjusting screw and nut, and the two members are forced together against the tension of the curved spring at the upper or pivot end. These are merely constructional features and have nothing to do with the use of the calipers. Spring calipers are not made in large sizes like the friction-joint type.

Hermaphrodite and Shoulder Calipers

The caliper illustrated at *A*, Fig. 2, is half caliper and half divider. This form is often used for drawing a line parallel to a finished edge (as the illustration indicates) or for locating a central point on the end of a shaft by setting the caliper to the radius of the shaft, as near as can be judged, and then scribing arcs which, at the point of intersection, indicate the center.

The special form of caliper shown at *B* is useful either for testing the distance from the end of a shaft or rod to a shoulder, or the distance from one shoulder to another. This type of caliper is also convenient for testing the diameter when boring a cylindrical surface (such as the crown-brass of a locomotive driving box) which does not extend through a half circle, thus making it impossible to measure

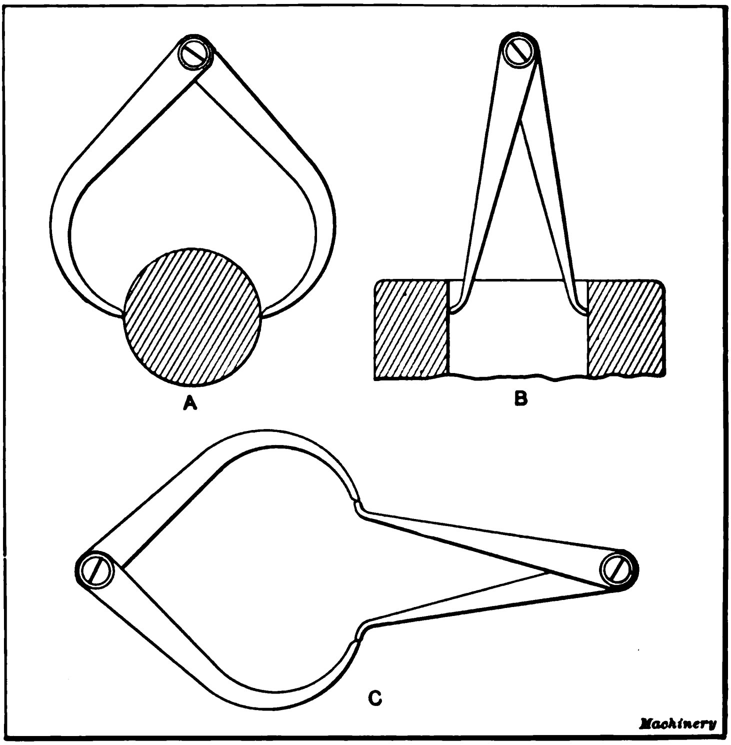

Fig. 1. Outside and Inside Calipers

the diameter of the cut directly. In the case of the driving box, the caliper points are set to the diameter of the journal and the size of the bore is tested by callipering from the point of the boring tool to the bored surface, when the box is turned around to locate the bearing brass away from the tool. Evidently, when the work is in this position, the distance from the cutting edge to the bored surface represents the diameter of the cut.

Thread Calipers

The spring type of calipers shown at *A* and *B*, Fig. 3, are used for measuring the diameters of threads. Caliper *A* is for testing the outside diameter. It has broad ends which span two or more threads so that the diameter across the tops of the threads can easily be obtained by first adjusting the calipers to just touch the threads and then measuring the distance beween the ends with a machinist's rule. Caliper *B* is for testing the diameter at the bottom or root of the thread. The ends are V-shaped so that the points will bear at the bottom of the thread groove. For accurate measurements a thread micrometer should be used. (See "Thread Micrometer.")

While the principal types of ordinary calipers have been referred to in the foregoing, other forms are often used. For some classes of work, combination calipers are very convenient. This type usually

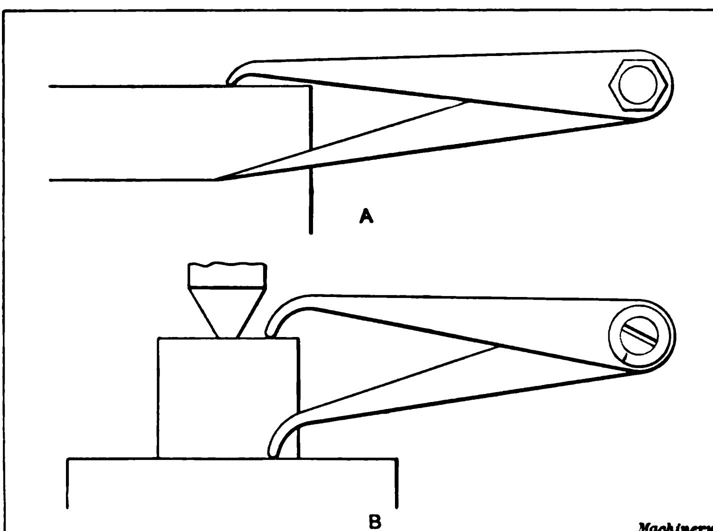

Fig. 2. (A) Hermaphrodite Calipers (B) Shoulder Calipers

combines dividers and outside and inside calipers in one tool. There are also many other special forms, many of which are made by machinists, for taking measurements under unusual conditions which make it impossible to use ordinary calipers.

Points on Setting Calipers

The accuracy of caliper measurements is governed partly by the adjustment of the calipers and also by the skill or judgment of the workmen in transferring this size to the work. Outside calipers are commonly set to a given dimension in inches, by holding one end against the end of a scale and adjusting the other end until it coincides with the graduation line representing the required size. A more accurate and positive method is to use a standard plug or disk gage of the required diameter, if one is available.

When setting inside calipers with a scale, the end of the latter should be placed squarely against some true surface; then one end of the caliper is held against this same surface, thus aligning it with the end of the scale, while the other end is adjusted to the required measurement. To insure a square end against which to place a scale and caliper, some machinists hold the scale on the blade of the square with one end resting against the beam or stock.

Standard ring gages or an outside micrometer are preferable for setting inside calipers. A ring gage of the required diameter is not always available, but an outside micrometer is a common tool, and,

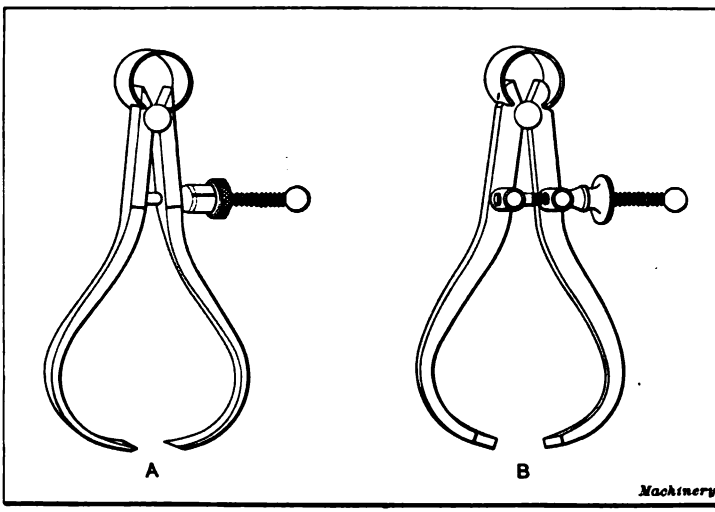

Fig. 8. Thread Calipers of Spring Type

being adjustable, affords an accurate method of setting inside calipers. The micrometer is first set to the size required; then the ends of the caliper are adjusted to just touch the parallel faces of the anvil and spindle of the micrometer. When an attempt is made to set inside calipers to a given measurement, by first setting outside calipers with a scale and then transferring the size to the inside calipers, obviously, several chances of error are introduced.

Side Play of Calipers

Judging a fit allowance by the amount of side play the calipers have in a hole, is a common method, although not very reliable, especially when considerable accuracy is necessary. To illustrate this method of fitting, suppose a pulley hub were being bored to fit a shaft. After setting the outside calipers to the size of the shaft, the inside calipers should be adjusted to the outside pair, so that the bearing or degree of contact is the same as between the outside calipers and the shaft.

The hole should then be bored to such a diameter that the inside calipers have a slight side play, in order to provide an easy sliding fit for the shaft.

The amount of this side play would depend upon the diameter and length of the hole and the accuracy required for the fit. For instance, a side play of only ⅛ inch might be sufficient for a small size hole, whereas, ½ inch or more might be necessary for a comparatively large hole, especially if quite long. The following rule may be used to determine the allowance for a given amount of side play, or, in other words, the difference between the diameter of the hole, and the

ALLOWANCES FOR DIFFERENT CLASSES OF FITS*

Diameter, Inches	Running Fits	Push Fits
Up to ½	−0.00075 to −0.0015	−0.00025 to −0.00075
½ to 1	−0.001 to −0.002	−0.0005 to −0.001
1 to 2	−0.0015 to −0.0025	−0.0005 to −0.0015
2 to 3	−0.0015 to −0.003	−0.0005 to −0.0015
3 to 4	−0.002 to −0.0035	−0.00075 to −0.002
4 to 5	−0.0025 to −0.004	−0.00075 to −0.002
5 to 6	−0.0025 to −0.0045	−0.00075 to −0.002
Diameter, Inches	**Driving Fits**	**Forced Fits**
Up to ½	+0.0004 to +0.0006	+0.0005 to +0.001
½ to 1	+0.0005 to +0.001	+0.001 to +0.003
1 to 2	+0.00075 to +0.002	+0.002 to +0.004
2 to 3	+0.0015 to +0.003	+0.003 to +0.006
3 to 4	+0.002 to +0.004	+0.005 to +0.008
4 to 5	+0.002 to +0.0045	+0.006 to +0.010
5 to 6	+0.003 to +0.005	+0.008 to +0.012

* These allowances are intended for average machine work. If the bearings are long the allowances for running fits may have to be increased.

dimensions to which the calipers are set or the length of a standard end-measuring rod.

Rule: Determine the amount of side play in sixteenths of an inch or the number of sixteenths; square this number and divide the result by twice the dimension to which the calipers are set, or by twice the length of the end-measuring rod. The quotient represents the allowance or difference in thousandths of an inch.

For example, suppose a standard end-measuring rod, 6 inches long, had a side play of ¼ inch in a bored hole. What is the difference between the length of the rod and the diameter of the hole?

In ¼ inch, there are 4 sixteenths; hence, the allowance or difference

$$= \frac{4 \times 4}{2 \times 6} = \frac{16}{12} = 1.3 \text{ thousandths or } 0.0013 \text{ inch.}$$

While this method does not give results which are absolutely accurate, the error is so small, especially when the amount of side play is small, that it can usually be disregarded. Judging an allowance for a fit in this way, however, is not to be recommended, and, in most shops, would be unnecessary, owing to the gages and micrometers for both external and internal measurements which are now in common use and give direct measurements.

A general idea of the allowances required for average machine work may be obtained from the table on page 10, which covers four different classes of fits and diameters varying from 0 to 6 inches.

The Vernier Caliper

The vernier is an auxiliary scale that is attached to vernier calipers, height gages, depth gages, protractors, etc., for obtaining the fractional parts of the subdivisions of the true scale of the instrument. When a scale is graduated in hundredths or even sixty-fourths of an inch, it is confusing to take measurements with it owing to the fineness of lines. If it were possible to graduate a scale to thousandths,

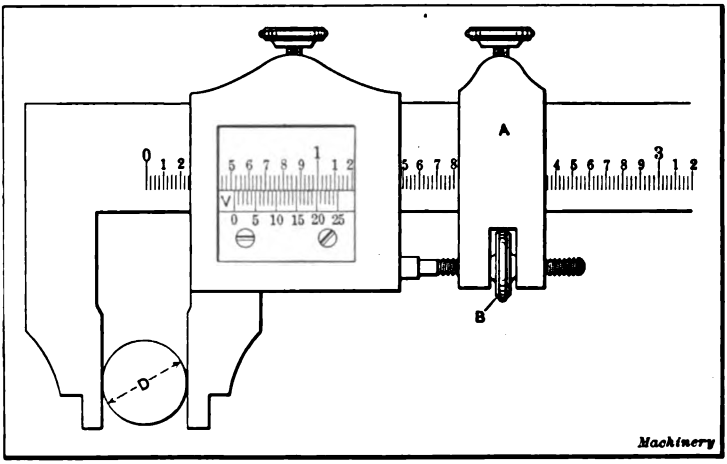

Fig. 4. Vernier Caliper

or with every inch subdivided into a thousand equal parts, such a scale would, of course, be useless, owing to the extreme fineness of the lines and the minute distances between them. Such fine divisions on a scale are not, however, necessary, for by means of the vernier scale, graduations which are comparatively large can be divided so that fine measurements may be taken.

For example, the true or regular scale of the vernier caliper shown in Fig. 4, is graduated in fortieths of an inch, but by means of the vernier scale *V*, which is attached to the sliding jaw of the instrument, measurements within one-thousandth of an inch can be taken. In other words, the vernier, in this case, makes it possible to divide each fortieth of an inch on the true scale into twenty-five parts. To measure the diameter *D* with a vernier caliper, adjust the sliding jaw until it is close to the work and then lock the slide *A* by the screw shown. With the nut *B*, which is used for making fine adjustments, move the jaw until it just touches the work. The distance that the vernier scale zero has moved to the right of the zero mark on the true scale (which equals diameter *D*) is then read directly in thousandths of an inch, by calling each tenth on the true scale that has been passed by the vernier zero, one hundred thousandths, and each fortieth twenty-five thousandths, and adding to this number as many thousandths as are indicated by the vernier. The vernier zero in the illustration is slightly beyond the five-tenths division; hence, the reading is 0.500 plus the number of thousandths indicated by that

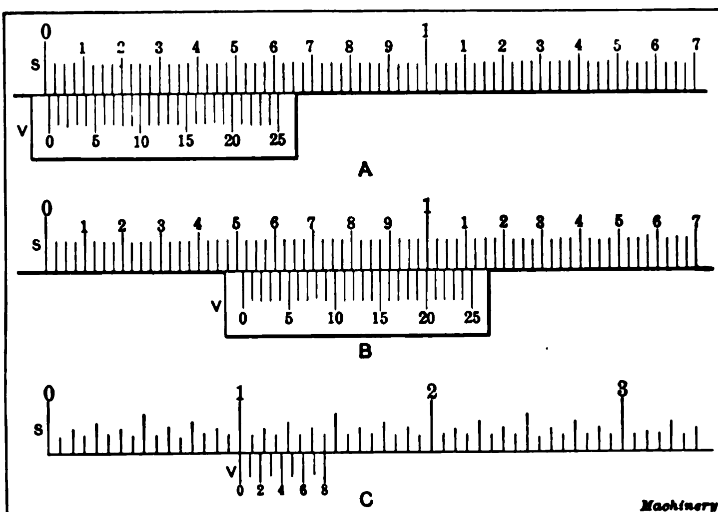

Fig. 5. Scales with Verniers set in Different Positions

line on the vernier that exactly coincides with one on the scale which, in this case, is line 15, making the reading 0.500 + 0.015 = 0.515 inch.

Principle of the Vernier Scale

By referring to the enlarged scales shown at *A* and *B*, Fig. 5, the principle of the vernier will be more apparent. When a vernier caliper reads to thousandths of an inch, each inch of the true scale *S* is divided into ten parts, and each tenth into four parts, so that the finest divisions are fortieths of an inch. The vernier scale *V* has twenty-five divisions, and its total length is equal to twenty-four divisions on the true scale, or 24/40 of an inch; therefore, each division on the vernier equals 1/25 of 24/40 or 24/1000 inch. Now, as 1/40 equals 25/1000, we see that the vernier divisions are 1/1000 inch shorter than those on the true scale. Therefore if the zero marks of both scales were exactly in line, the first two lines to the right would be 1/1000 inch apart; the next two 2/1000, etc. It is evident, then, that if the vernier were moved to the right until, say, the tenth line from the zero mark exactly coincides with one on the true scale, as shown at *A*, the movement would be equal to 0.010 inch, since this line was 0.010 inch to the left of the mark with which it now coincides, when the zero lines of both scales were together. Similarly, if the fifteenth line were exactly opposite a line on the true scale, the movement of the vernier would be equal to 0.015, etc.; so we see that the number of thousandths that the vernier zero has moved past a graduation on the true scale is determined simply by counting the number of spaces between the zero of the vernier, and that line on it which exactly coincides with one on the true scale. If the vernier were moved along to the position shown by the next sketch *B* (Fig. 5) the true scale would indicate directly that the reading was slightly over 0.500 inch, and the coincidence of the graduation line 15 on the vernier with a line on the true scale, would show the exact reading to be $0.500 + 0.015 = 0.515$ inch.

In Fig. 5 a true scale *S* is shown at *C* that is graduated into sixteenths of an inch, and the vernier *V* has eight divisions with a total length equal to seven divisions on the true scale, or 7/16 of an inch; therefore, each division on the vernier is 1/8 of 1/16, or 1/128 inch shorter than the divisions on the true scale; so we see that in this case the vernier enables readings to be taken within one hundred and twenty-eighths of an inch, instead of in thousandths as with the one previously described. The divisions then that may be obtained by a vernier depend altogether on the way the true and vernier scales are graduated.

In order to determine the fractional part of an inch that may be obtained by any vernier, multiply the denominator of the finest subdivision of an inch given on the true scale by the total number of divisions on the vernier. For example, if (as in Fig. 4) the true scale is divided into fortieths and the vernier into twenty-five parts, the vernier will read to thousandths ($40 \times 25 = 1000$). If there are sixteen divisions to the inch on the true scale and a total of eight on the vernier, the latter will enable readings within one hundred twenty-eighths of an inch to be taken ($16 \times 8 = 128$). It will be seen then that each subdivision on the true scale can be divided into as many parts as there are divisions on the vernier.

The following is a general rule for taking readings with a vernier: *Note the number of inches and whole divisions of an inch that the vernier zero has moved along the true scale, and then add to this number as many thousandths, or hundredths, or whatever fractional part of an inch the vernier reads to, as there are spaces between the vernier zero and that line on it which coincides with one on the true scale.*

The vernier caliper can be used for measuring the diameters of holes or for other inside measurements, as well as for external measurements, by using the outside surfaces of the jaws or measuring points. The width of the jaws should be added to the apparent reading as given by the scale and vernier, to obtain the correct inside dimensions. No such allowance is necessary when using the graduations on the opposite side of the beam of some vernier calipers, as two lines marked "in" and "out" indicate inside and outside maesurements.

Vernier Caliper with Metric Graduations

The application of the vernier to a caliper graduated on the metric system is illustrated in Fig. 6. In this case we have, instead of inches, centimeters which are subdivided into ten parts called millimeters. By the aid of the vernier, each millimeter is again divided into ten parts so that readings can be taken to within 1/10 of a millimeter or 1/100 of a centimeter (0.0039 of an inch). The reading with the caliper set as shown in the illustration is 2 55/100 centimeters, or, as commonly expressed, 25 5/10 millimeters. As shown more clearly by the enlarged detail view, the left-hand or zero mark of the vernier has

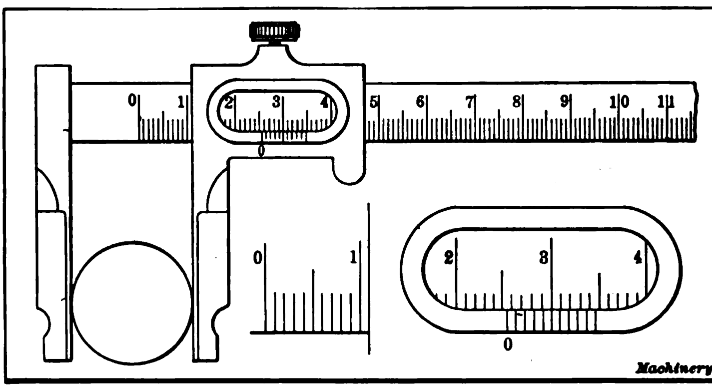

Fig. 6. Vernier Caliper Graduated on Metric System

passed the 2½ centimeter graduation, and the fifth line on the vernier coincides with one on the true scale; therefore, the reading is 25 millimeters plus 5/10 of a millimeter. This particular instrument has on the opposite side of the beam two series of inch graduations which, with the verniers, enable measurements within 1/100 and 1/128 of an inch to be taken. Therefore inches may be converted into metric measurement, and *vice versa*, by taking the reading first on one side of the beam and then on the other.

Micrometers for External and Internal Measurements

Micrometer calipers are used for taking accurate measurements. A small size for external measurements is shown at *A*, Fig. 7. The part to be measured is placed against the anvil *a* and the adjustable spindle *b* is then screwed in until it bears lightly against the work, by turning the thimble or sleeve *c;* the size is then determined by referring to the micrometer graduations. Most micrometers are graduated to read to thousandths of an inch, although some have an auxiliary vernier scale which enables readings to within 0.0001 inch to be taken. (The method of reading a micrometer will be explained later.) This particular micrometer will measure all sizes varying from 0 to 1 inch. Some outside micrometers have a lock-nut which is used to clamp the spindle in order to convert the micrometer into a fixed gage. To use a micrometer in this way is generally considered poor practice. The proper method of taking a measurement is to close the contact points against the work with a light pressure and then determine the size by the graduations as previously explained.

Many micrometers have what is called a ratchet stop *d* at the end of the barrel or thimble. If this is used when adjusting the measuring point against the work, it will slip when the point bears lightly, and thus prevent excessive pressure. The advantage of securing a

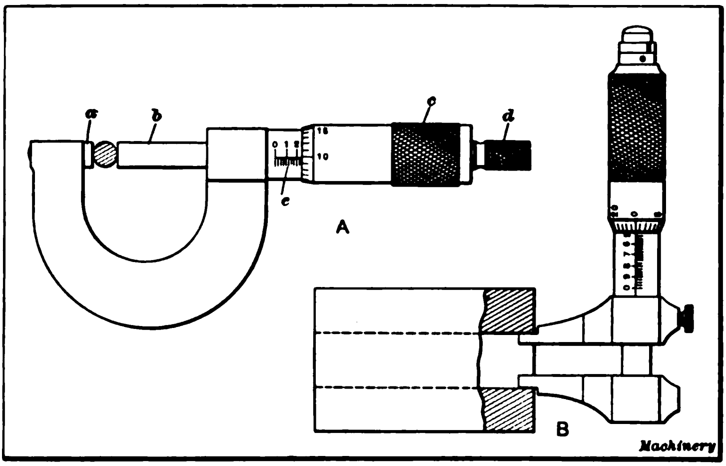

Fig. 7. Outside and Inside Micrometers

uniform contact or degree of pressure is that uniform readings are then obtained. Obviously, a difference in pressure will give a different reading and might result in a serious error. Inaccuracies from this cause might be negligible so far as one workman is concerned, but they become important where measurements are taken by many different workmen, because everyone does not have the same sense of touch.

A micrometer for measuring the diameters of holes or for taking other internal dimensions is shown at *B*, Fig. 7. The measuring surfaces are hardened and ground to a radius to secure accurate measurements and to avoid cramping when measuring the distances between parallel surfaces. The movable jaw has a clamp screw that is tightened when it is desired to retain the setting of the calipers.

Another form of inside micrometer is shown in Fig. 8. This particular size can be used for measurements varying from 2 to 12 inches. When testing the diameter of a comparatively small hole, when there is not sufficient room for the hand, an auxiliary handle *a* is screwed into the micrometer head as shown in the illustration. The micrometer screw has a movement of one-half inch and by inserting extension rods of different lengths in the head at *b*, any dimension up to 12 inches can be obtained. Two of these extension rods are shown to the right. They are provided with collars which serve to locate them accurately in the micrometer head.

An inside micrometer gage that is especially adapted for large internal measurements is shown at *A*, Fig. 9. This gage consists of a holder equipped with a micrometer screw with graduations reading to 0.001 inch, and into this holder is inserted an adjustable rod. This rod also has graduations in the form of a series of annular grooves of a form and depth that allow clamping fingers on the holder to spring into them, thus making it possible to shift the rod in or out to the required length. Gages of this type usually have a series

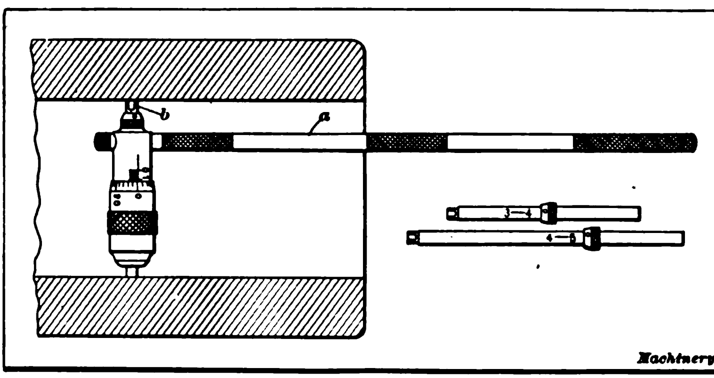

Fig. 8. Inside Micrometer equipped with Extension Rods

of rods so that a wide range of sizes can be measured. They are not only used for internal measurements but for setting calipers and for similar work.

A micrometer caliper for large external measurements is shown at *B*. The micrometer screw has an adjustment of one inch and is graduated to read to 0.001 inch. When measuring small sizes, the long anvil or spindle *s* is used, whereas, for larger sizes, one of the shorter spindles is inserted. The sides of the steel frame are covered with hard rubber to prevent inaccuracies in the measurements as the result of expansion from the heat of the hands. As will be noted, this micrometer has a ratchet stop to insure uniform pressure when measuring.

Thread Micrometers

For the accurate measurement of screws or threads, the special thread micrometer shown in Fig. 10 is often used. The fixed anvil is V-shaped so as to fit over the thread, while the movable point is cone-shaped so that it will enter the space between two threads. The contact points are on the sides of the thread, as they must be in order that the pitch diameter may be determined. The cone-shaped point of the measuring screw is slightly rounded so that it will not bear at the bottom of the thread. There is also sufficient clearance at the bottom of the V-shaped anvil to prevent it from bearing on the top of the thread. The movable point is adapted to measuring all pitches, but the fixed anvil is limited in its capacity. To cover the whole range of pitches, from the finest to the coarest, a number of fixed anvils are required.

To find the theoretical pitch diameter, which is measured by the micrometer, subtract the single depth of the thread from the standard outside diameter. The depth of a V-thread equals 0.866 ÷ number of

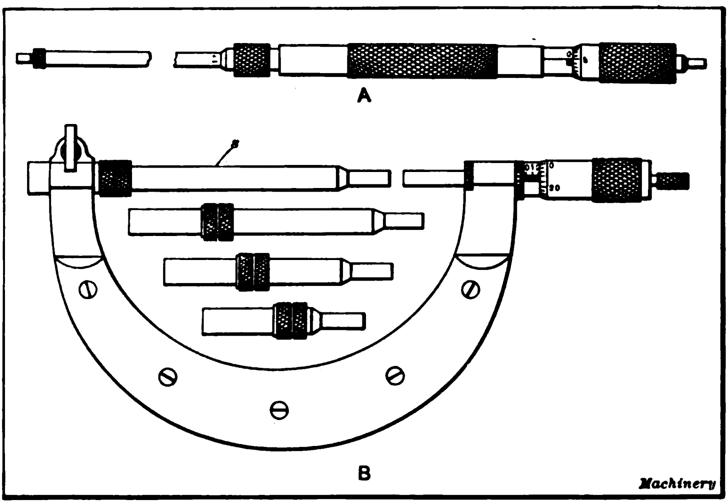

Fig. 9. (A) Inside Micrometer Gage for Large Holes (B) Large Outside Micrometer

threads per inch, and depth of U. S. standard thread equals 0.6495 ÷ number of threads per inch.

If standard plug gages are available, it is not necessary to actually measure the pitch diameter, but merely to compare it with the standard gage. In this case, a ball-point micrometer such as is shown in Fig. 11 may be employed. Two types of ball-point micrometers are ordinarily used. One is simply a regular micrometer with ball points made to slip over both measuring points, as shown by the detail sketch *B*. This makes a combination plain and ball-point micrometer, the ball points being easily removed. These ball points, however, may not fit solidly on their seats and are apt to cause errors in the measurements. The best method is to use a regular micrometer into which ball points have been fitted as shown at *A*. Care should be taken to have the ball point in the spindle run true. A hole is provided in the spindle so that the ball point can easily be driven out when a larger or smaller size of ball point is required.

How to Read a Micrometer

The pitch of the thread on the spindle *b* (Fig. 7) of an ordinary micrometer is 1/40 of an inch. Along the frame at *e* (see also detail sketch *A*, Fig. 12), there are graduations which are 1/40 inch apart; therefore, when thimble *c* and the measuring spindle are turned one complete revolution, they move in or out, a distance equal to one of

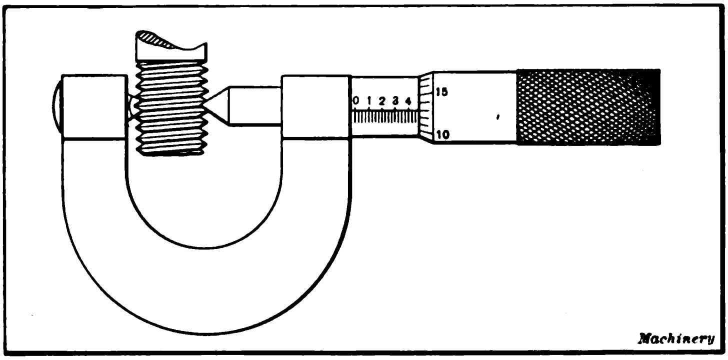

Fig. 10. Thread Micrometer

the graduations or 1/40 inch, which equals 25/1000 inch. It is evident then that if instead of turning the thimble one complete revolution, it is turned say 1/25 of a revolution, that the distance between the anvil and the end of the spindle will be increased or diminished 1/25 of 25/1000 of an inch, or one thousandth inch; therefore, the beveled edge of a micrometer spindle has twenty-five graduations, each of

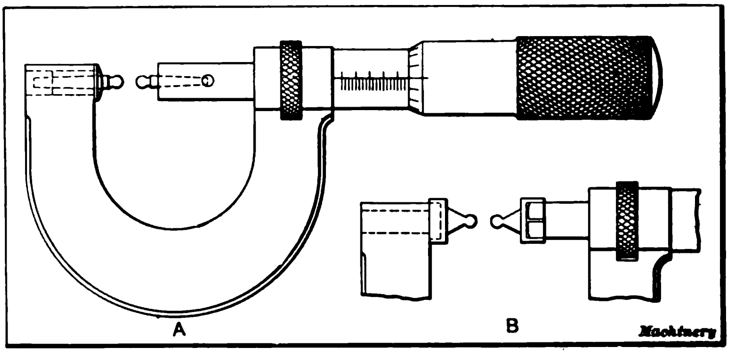

Fig. 11. Ball-point Thread Micrometer

which represents 0.001 inch. Following is a general rule for reading a micrometer:

Count the number of whole divisions that are visible on the scale of the frame, multiply this number by 25 (the number of thousandths of an inch that each division represents) and add to the product the number of that division on the thimble which coincides with the axial *zero line on the frame. The result will be the diameter expressed in thousandths of an inch.*

As the numbers 1, 2, 3, etc., opposite every fourth subdivision on the frame indicate hundreds of thousandths, the reading can easily be taken mentally. Suppose the thimble were screwed out so that graduation 2, and three additional subdivisions were visible (as shown at *A*, Fig. 12), and that graduation 10 on the thimble coincided with the axial line on the frame. The reading then would be 0.200 + 0.075 + 0.010, or 0.285 inch.

Some micrometers have a vernier scale *v* on the frame (see sketch *B*, Fig. 12) in addition to the regular graduations, so that measurements within 0.0001 inch can be taken. Micrometers of this type are read as follows:

First determine the number of thousandths, as with an ordinary micrometer, and then find a line on the vernier scale that exactly coincides with one on the thimble; the number of this line represents the number of ten-thousandths to be added to the number of thousandths obtained by the regular graduations.

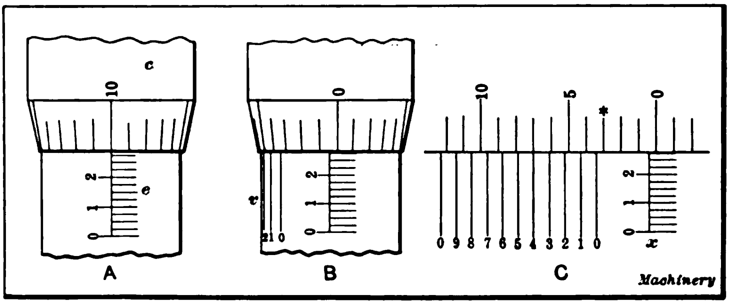

Fig. 12. Micrometer Graduations

The relation between the graduations of the vernier and those on the thimble is more clearly shown by diagram *C*. The vernier has ten divisions which occupy the same space as nine divisions on the thimble, and for convenience in reading are numbered as shown. The difference between the width of a vernier division and one on the thimble is equal to one-tenth of a space on the thimble. Therefore a movement of the thimble equal to this difference between the vernier and thimble graduations represents 0.0001 inch. When the thimble 0 coincides with the line *x* on the frame, the 0 of the vernier coincides with the third line to the left (marked with an asterisk). Now when the thimble 0 (or any other graduation line on the thimble) has passed line *x*, the number of ten-thousandths to add to the regular reading is equal to the number of that line on the vernier which exactly coincides with a line on the thimble. Thus the reading shown at *C* (Fig. 12) is 0.275 + 0.0004 = 0.2754 inch.

CHAPTER III

FIXED AND ADJUSTABLE GAGES

Strictly speaking, any tool or instrument used for taking measurements might properly be called a gage, but this term, as used by machinists and toolmakers, is generally understood to mean that class of tools which conform to a fixed dimension and are used for testing sizes but are not provided with graduated adjustable members for measuring various lengths or angles. There are exceptions, however, to this general classification.

Measuring instruments, such as the micrometer and vernier caliper, are indispensable because they can be used for determining actual

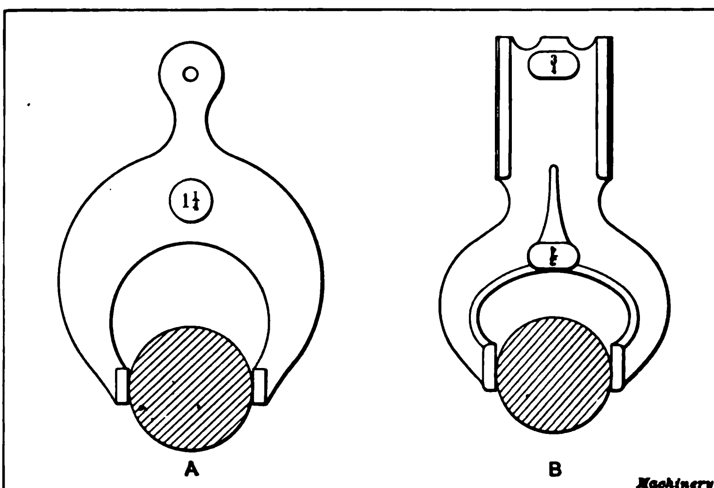

Fig. 13. (A) Snap Gage (B) Internal and External Gage

dimensions, and, being adjustable, cover quite a range of sizes. Any form of adjustable measuring tool, however, has certain disadvantages for such work as testing the sizes of duplicate parts, especially when such tests must be made repeatedly, and solid or fixed gages are commonly used. There is less chance of inaccuracy with a fixed gage and it is more convenient to use than a tool which must be adjusted, but owing to the necessity of having one gage for each variation in size, and because of the cost of a set covering a wide range of sizes, solid gages are used more particularly for testing large numbers of duplicate parts in connection with interchangeable manufacture.

Two different types of fixed gages are shown in Fig. 13. The form shown at *A* is commonly known as a "snap gage." The distance between the measuring surfaces is fixed and represents the size stamped upon the gage, within very close limits. This type of gage can be obtained in various sizes and is used for measuring duplicate parts in connection with general shop work. As a gage of this kind is repeatedly passed ovcr the work, it becomes worn, and, therefore, should be compared or tested occasionally with a standard reference plug or disk. In case of excessive wear, the gage can be closed in slightly smaller than the required size and then be reground or lapped to the original size, as shown by a reference gage.

Sketch *B* illustrates another form of snap or caliper gage. This is double-ended and is intended for both external and internal measurements, the width of the internal end being the same as the distance between the measuring surfaces of the external end.

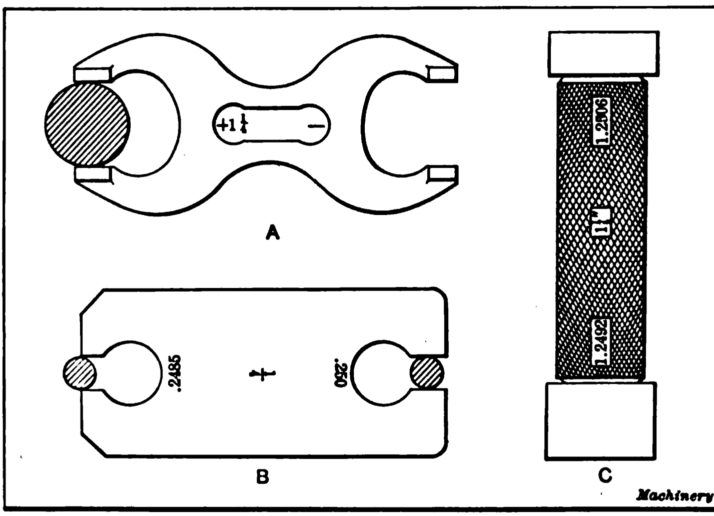

Fig. 14. External and Internal Limit Gages

Limit Gages

With the modern system of interchangeable manufacture, machine parts are made to a definite size within certain limits which are varied according to the accuracy required, which, in turn, depends upon the nature of the work. In order to insure having all parts of a given size or class, within the prescribed limit so that they can readily be assembled without extra and unnecessary fitting, what are known as "limit gages" are used. One form of limit gage for external measurement is shown at *A*, Fig. 14. It is double-ended and has a "go" end and a "not go" end; that is, when the work is reduced to the correct size, one end of the gage will pass over it but not the other end. When a single-ended snap gage *A*, Fig. 13, is used, the diameter of the work may be slightly less than it should be, but by having a gage for the minimum as well as for the maximum size, every part must come within the limits of the gage. This allowance or limit is made to conform to whatever amount experience has shown to be correct for the particular class of fit required.

Another external limit gage is shown at *B*, Fig. 14. Nominally this is a ¼ inch gage. The size of the "go" end is 0.250 inch and the size of the "not go" end is 0.2485 inch; hence the tolerance is 0.0015 inch. Therefore a part that is more than 0.0015 inch less than 0.250 inch will not pass the "not go" end of the gage.

An internal limit gage is shown at *C*. The nominal size of this particular gage is 1¼ inch. The diameter of the "go" end is 1.2492 inch, whereas the diameter of the "not go" end is 1.2506 inch; hence, in this case, the tolerance equals $1.2506 - 1.2492 = 0.0014$ inch. Incidentally, it is good practice to make all holes to standard sizes within

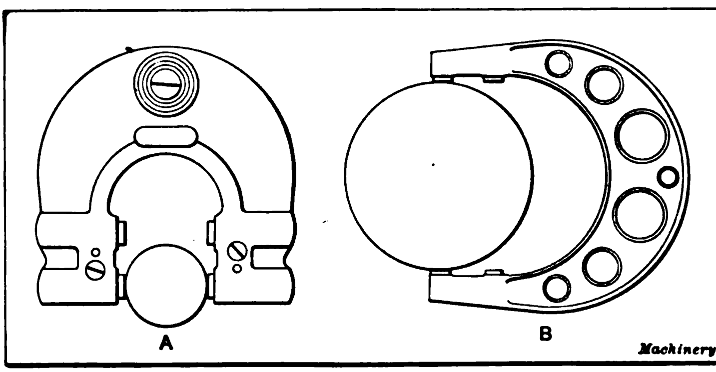

Fig. 15. (A) Adjustable Limit Gage; (B) Limit Gage with Fixed Points

whatever limits may be advisable, and vary the size of the cylindrical parts to secure either a forced fit, running fit, or whatever class of fit may be required.

It will be noted that the ends of these limit gages are of different shape so that the large and small sizes can readily be identified without referring to the dimension stamped on the gage ends. Limit gages are very generally used for the final inspection of machine parts, as well as for testing sizes during the machining process. They are superior to the micrometer for many classes of inspection work, because the adjustment and reading necessary with a micrometer often results in slight variations of measurement, especially when the readings are taken by different workmen.

Adjustable Limit Snap Gage

The snap gage shown at *A*, Fig. 15, differs from the ordinary single-ended type in two particulars: In the first place, it has two sets of measuring plugs and is a limit gage. The lower set forms the "go" end and the upper set the "not go" end. These plugs are also adjustable so that when the gage becomes inaccurate, as the result of wear, the plugs can easily be reset, a standard reference gage being used to determine the distance between them.

The plugs are plain cylinders of hardened steel and are lapped to a snug sliding fit in the hole of the gage body. The ends are square and bear against adjusting screws, the forward ends of which are also

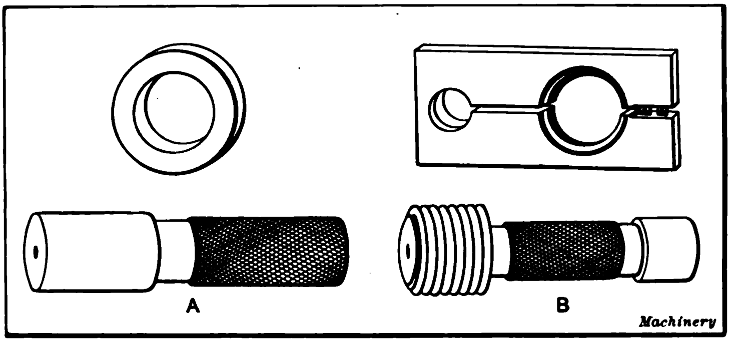

Fig. 16. (A) Plug and Ring Gages (B) Internal and External Thread Gages

lapped square. The clamping screws at the side not only clamp the plugs but tend to force them against the adjusting screws. The handle has an insulated grip.

Another snap gage of the limit type is shown at *B*. This gage has fixed points which can be renewed in case of wear.

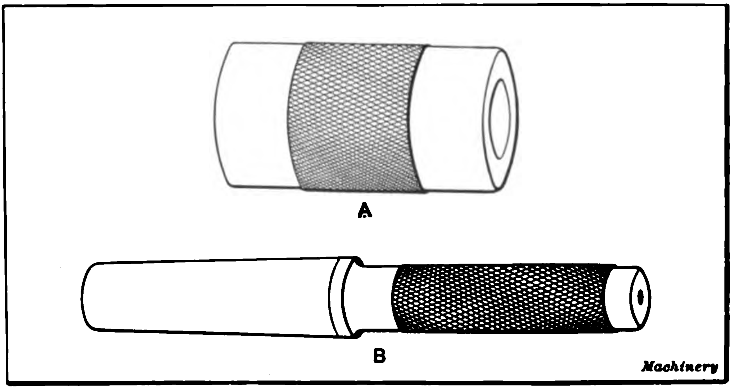

Fig. 17. Internal and External Taper Gages

Plug and Ring Gages

A standard external or ring gage and internal or plug gage is shown at *A*, Fig. 16. These gages are very accurately made and are used either as reference gages or for setting calipers, etc., or as working gages. One gage manufacturer makes solid gages of this type in diameters varying from 1/16 inch to 3 inches. For larger sizes, up to 6 inches in diameter, the plug gages are made hollow.

U. S. standard thread gages are shown at *B*, Fig. 16. These gages are intended as a practical working standard. The internal gage or plug is a standard to which the external templet is adjusted. The plain unthreaded end of the plug gage is ground and lapped to the exact diameter at the root or bottom of the thread.

Gages for testing the accuracy of tapers are shown in Fig. 17. The ring gage *A* is used for external tapers and the plug *B* for holes. The plug accurately fits the ring and when they are assembled, a line on the plug coincides with the end of the ring. This line is used for gaging the depth of holes which must conform to the standard size of the ring gage. When the plug gage is used as a working gage in the shop, the ring is usually kept as a reference gage. On the other

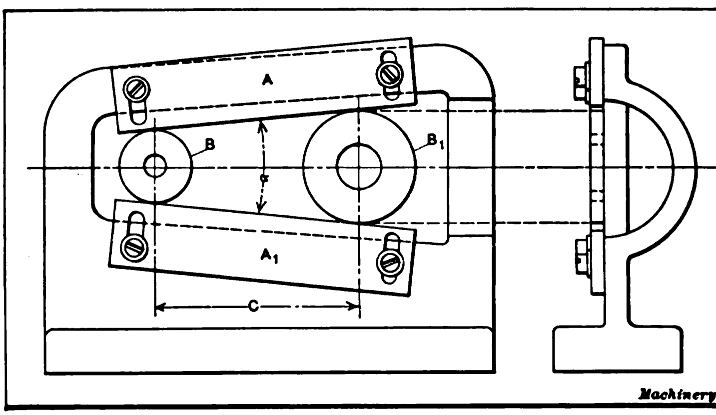

Fig. 18. Disk Gage for Originating or Accurately Measuring Tapers or Angles

hand, if a ring is used for testing external tapers, the plug is often preserved as the reference gage.

Gage for Originating and Accurately Measuring Tapers

When a certain taper or angle must be originated or accurately measured, the disk type of gage shown in Fig. 18 may be employed. The principle of the disk method of taper measurement is that if two disks of unequal diameters are placed either in contact or a certain distance apart, lines tangent to their peripheries will represent an angle or taper, the degree of which depends upon the diameters of the two disks and the distance between them. This gage consists of two adjustable straight-edges *A* and A_1, which are in contact with disks *B* and B_1. The angle a or the taper between the straight-edges depends, of course, upon the diameters of the disks and the center distance *C*, and as these three dimensions can be measured accurately, it is possible to set the gage to a given angle within very close limits. Moreover, if a record of the three dimensions is kept, the exact setting of the gage can easily be reproduced at any time. The following rules may be used for adjusting a gage of this type.

To Find Center Distance for a Given Angle.—When the straightedges must be set to a given angle a, to determine center distance C between disks of known diameter. *Rule:* Find the sine of half the angle a in a table of sines; divide the difference between the disk diameters by double this sine.

Example:—If an angle a of 20 degrees is required, and the disks are 1 and 3 inches in diameter, respectively, find the required center distance C.

$$\frac{20}{2} = 10 \text{ degrees; } \sin 10° = 0.17365;$$

$$\frac{3 - 1}{2 \times 0.17365} = 5.759 \text{ inches} = \text{center distance } C.$$

To Find Center Distance for a Given Taper.—When the taper, in inches per foot, is given, to determine center distance C. *Rule:* Divide the taper by 24 and find the angle corresponding to the quotient in a table of tangents; then find the sine corresponding to this angle and divide the difference between the disk diameters by twice the sine.

Example:—Gage is to be set to ¾ inch per foot, and disk diameters are 1.25 and 1.5 inch, respectively. Find the required center distance for the disks.

$\frac{0.75}{24} = 0.03125$. The angle whose tangent is 0.03125 equals 1 degree 47.4 minutes; $\sin 1° \; 47.4' = 0.03123$; $1.50 - 1.25 = 0.25$ inch;

$$\frac{0.25}{2 \times 0.03123} = 4.002 \text{ inches} = \text{center distance } C.$$

To Find Angle for Given Disk Dimensions.—When the diameters of the large and small disks and the center distance are given, to determine the angle a. *Rule:* Divide the difference between the disk diameters by twice the center distance; find the angle corresponding to the quotient, in a table of sines, and double the angle.

Example:—If the disk diameters are 1 and 1.5 inch respectively, and the center distance is 5 inches, find the included angle a.

$\frac{1.5 - 1}{2 \times 5} = 0.05$. The angle whose sine is 0.05 equals 2 degrees 52 minutes; then, 2 deg. 52 min. $\times$ 2 = 5 deg. 44 min. = angle a.

To Find the Taper per Foot.—When the diameters of the large and small disks and the center distance C are given, to determine the taper per foot (measured at right angles to a line through disk centers). *Rule:* Divide the difference between the disk diameters by twice the center distance; find the angle corresponding to the quotient, in a table of sines; then find the tangent corresponding to this angle, and multiply the tangent by 24.

Example:—If disk diameters are 1 and 1.5 inch, respectively, and center distance is 5 inches, find the taper per foot.

$\frac{1.5 - 1}{2 \times 5} = 0.05$. The angle whose sine is 0 05 equals 2 degrees 52 minutes; tan 2° 52′ = 0.05007; 0.05007 × 24 = 1.2017 inch taper per foot.

Reference Gages

Reference gages are intended for testing the accuracy of working gages such as are used in the shop and toolroom, and for setting other forms of measuring instruments. Reference gages are made in different forms varying from plain blocks or disks to special shapes designed for some particular class of work. The standard set of reference disks made by Brown & Sharpe contains 45 disks varying by sixteenths of an inch, from ¼ to 3 inches in diameter. Handles are provided so that these disks can be used in place of standard cylindrical gages, but they are generally used without the handles for setting calipers, testing measuring instruments and for reference purposes.

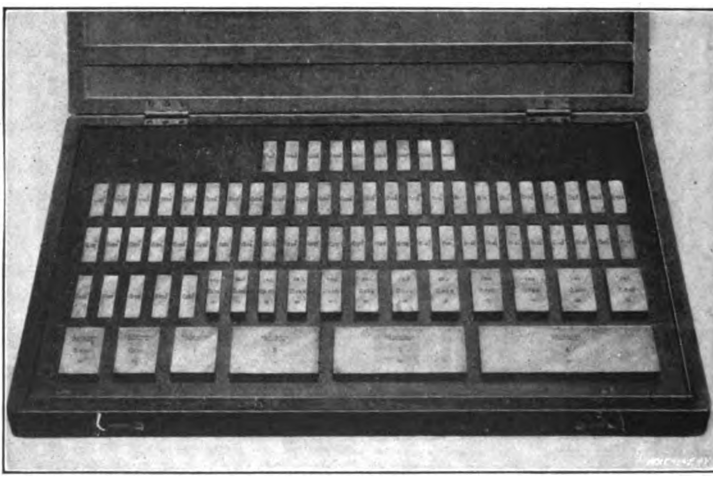

Fig. 19. Johansson Reference Gages

Plug and ring gages similar to the type illustrated at *A*, Fig. 16, are also used to some extent for reference purposes, as well as for working gages. In some shops it is the practice to use the plug as a working gage and the ring for testing it, or, in case the ring is required as a working gage, the plug is kept as a standard or reference gage, as previously mentioned.

End-measuring rods and blocks are often used for testing snap gages, etc. Ordinarily, the solid measuring rods are cylindrical in form and may be obtained in sets covering a considerable range of lengths. These rods are used for testing the parallelism and width of two finished surfaces, as well as for setting calipers and testing gages. The ends of some rods are made flat and parallel, whereas others have ends which are sections of spheres, the diameters of which equal the lengths of the rods. The spherical-ended form is very convenient for testing the diameters of rings, cylinders, etc. Some end-measuring rods are provided with an insulating handle in the center to prevent expansion from the heat of the hand.

Johansson Gages

The Johansson combination standard gages consist of a series of rectangular steel blocks which are finished on all sides with wonderful accuracy. The opposite sides of each block are parallel and the distance between them is equal to the dimension stamped upon the block, within a limit so small as to be inconceivable. The eighty-one blocks in what is known as Set No. 1 (see Fig. 19) are arranged in four series. The first series contains 9 blocks which vary in thickness from 0.1001 inch to 0.1009 inch, increasing by 0.0001 inch increments. The second series contains 49 blocks varying in thickness from 0.101 inch to 0.149 inch, increasing by 0.001 inch. In the third series there are 19 blocks varying in thickness from 0.050 inch to 0.950 inch, increasing by 0.050 inch. The last series of four blocks has 1, 2, 3 and

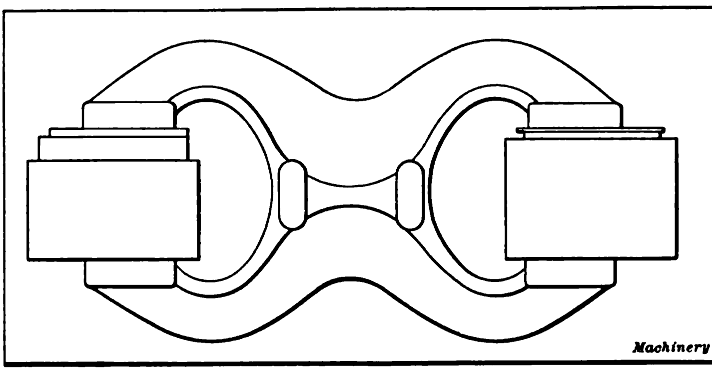

Fig. 20. Testing Size of Limit Gage with Johansson Gages

4 inch sizes, respectively. The gages for the English system of measurement are adjusted to their sizes at 66 degrees F.

The value of these gages lies in the fact that they are not only exceptionally accurate, but are so varied in size that, with the set referred to in the foregoing, a gage 10 inches long can be built and dimensions varying by 0.0001 inch be obtained. According to the makers, this one set will give at least 100,000 gage sizes, by using the various combinations of blocks which are possible. Any dimension up to 8 inches obtained by the systematic combination of these blocks is said to be exact within 0.00004 inch; hence, the error of any one block is exceedingly small.

How to use Johansson Gages

The combination of these Johansson gages to form any required dimension is simple but should be done systematically. Every block is marked with its size and in placing two blocks together they are slid over each other with a slight pressure. Any dust that might be on the surfaces should first be removed by using the finger. To illustrate how the gages are combined, suppose 3.4566 inches is the required size. First it is well to consider the ten-thousandths in the dimension; therefore, block 0.1006 (which is one of the first series previously mentioned) would be selected. The thousandths in the dimension are next taken care of by selecting block 0.106. The block

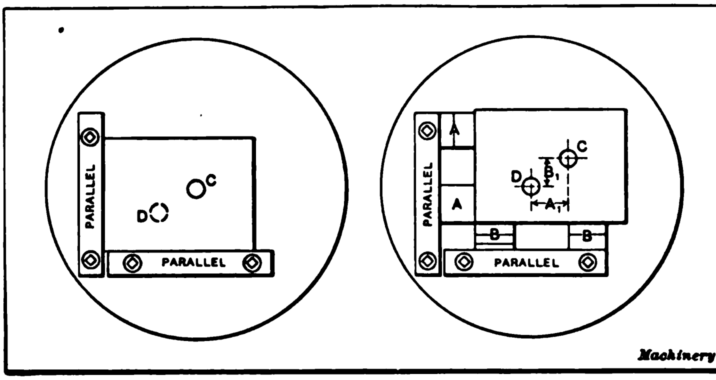

Fig. 21. Method of accurately setting Work on Faceplate with Johansson Gages

for the even number of inches, or the 3-inch size, is then added, which makes the dimension 3.2066 inches; therefore, the block needed to complete the dimension is 0.250. Thus, the entire set is made up as follows: 0.1006 + 0.106 + 3 + 0.250 = 3.4566 inches.

This same dimension could also be obtained by using an entirely different combination. In order to show how different combinations

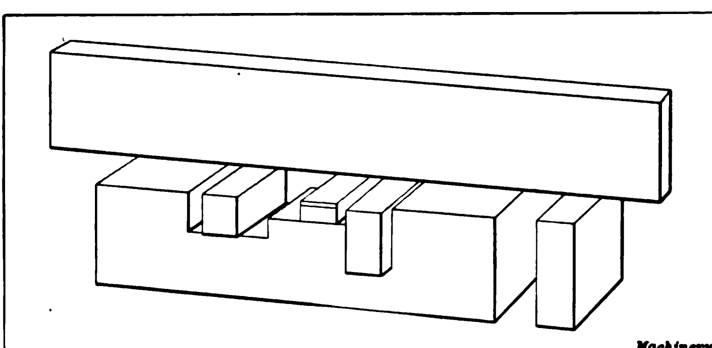

Fig. 22. Testing Location of Different Surfaces with Johansson Gages

can be used for obtaining the same size, suppose the dimension 0.600 inch is required. Gages of this size could be made up by using the following combination: 0.550 + 0.050; 0.450 + 0.150; 0.400 + 0.200; 0.350 + 0.250; 0.500 + 0.100, etc.

If a 1⅝-inch gage were required, the 1 inch, 0.500 inch and 0.125 inch blocks could be used. Thus: 1 + 0.500 + 0.125 = 1.625 or 1⅝ inch. If a size 0.002 inch larger or 1.627 inch were required, this could be obtained simply by substituting the 0.127 inch block for the 0.125 inch size. Other combinations could also be used for the size given in the preceding example. From the foregoing, it will be seen that a gage can be built up which will include the plus allowance for a forced fit, the minus allowance for a running fit, or any tolerance or limit which may be desired.

Application of Johansson Gages

Fig. 20 indicates how these gages can be used for testing snap gages and limit gages. When making a gage of the type illustrated, the size can be followed by variations of 0.0001 inch as the jaws are being lapped, and any tolerance or allowance for any class of fit can be obtained. An entirely different application is shown in Fig. 21. In this case the gages are used on a lathe faceplate in conjunction with two parallels for locating work so that two holes can be bored accurately with relation to each other. First hole *C* is bored with the work resting against the parallels as shown to the left; then gages *A* are inserted, thus moving the work over a distance A_1 after which gages *B* are placed beneath the plate to raise it a distance B_1, as shown to the right. In this way the plate is located for boring a second hole in accurate relation with the first hole.

These gages can also be used in conjunction with a surface plate and surface gage for accurately scribing lines on die faces, etc. Thus, instead of adjusting the pointer of the surface gage to different heights by the use of a scale, the pointer can remain in a fixed position and the work be accurately raised or lowered the required amount by placing it upon different combinations of gages. In this way lines can be laid out very accurately.

Fig. 22 shows still another application of these gages. In this example the depths of different plane surfaces and the total thickness of the piece are tested by using gages of the required sizes, in conjunction with a straightedge which is placed across the top of the work. These examples are simply given to illustrate a few of the many ways in which these gages may be used.

CHAPTER IV

MISCELLANEOUS MEASURING AND GAGING TOOLS

The variety of gages required in most machine shops and toolrooms is extensive, especially where many different classes of machines and tools are manufactured, and gages of special design are often necessary in addition to the standard measuring tools. Most of the commercial gages and measuring instruments are designed to test or measure the distance or angle between two points or surfaces, but when there are several surfaces, all of which must be accurate with relation to each other, a special form of gage is often designed. The construction and arrangement of such a gage depends, of course, upon the shape of the part to be tested and the location of the finished surfaces, and also upon the degree of accuracy required; therefore, in this treatise, special types designed exclusively for one class of work are not illustrated.

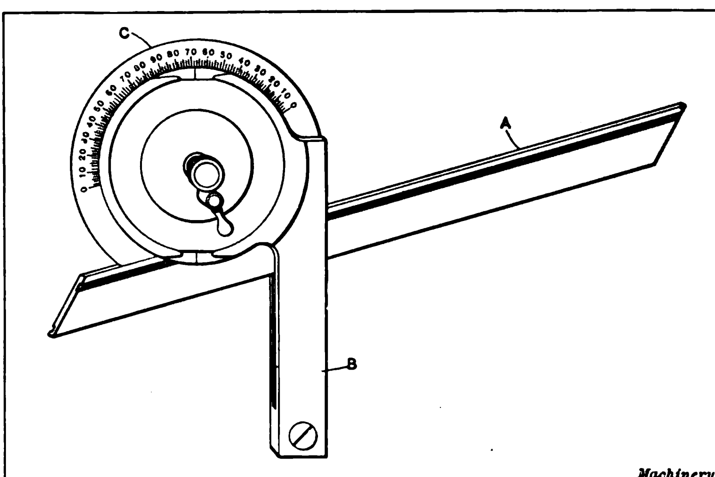

Fig. 23. Universal Bevel Protractor

Measuring Angles with a Protractor

The protractor is an instrument used for measuring angles. There are many different forms of protractors, but they all embody the same general principle. The type commonly used by machinists and toolmakers has a straightedge or blade which can be set at any angle with the base or stock, and the angle for any position is shown by degree graduations. This form is generally known as a bevel protractor. A design of bevel protractor that has been extensively used is shown in Fig. 23. The angular position between blade *A* and stock *B* can be varied as may be required, and disk *C*, which is graduated from 0 to 90 degrees in each direction, shows what the angle is for any position. The blade, which is clamped by an eccentric stud, can be adjusted in a lengthwise direction so that it can be used in any position. Fig. 24 illustrates some of the various ways in which this universal bevel protractor can be applied.

Reading a Protractor Vernier

The graduations on the protractors commonly used by machinists are ordinarily not finer than whole degrees, so that measurements of

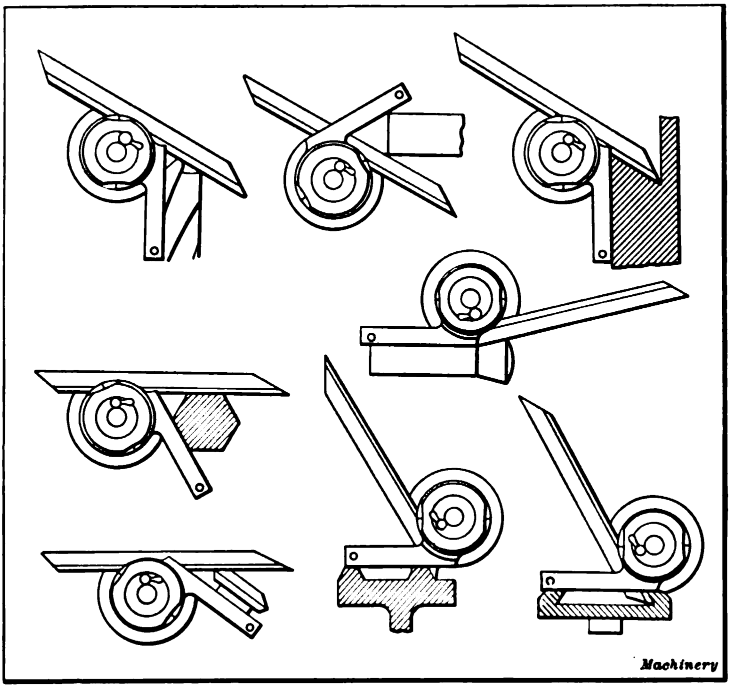

Fig. 24. Examples Indicating Application of Universal Bevel Protractor

fractional parts of a degree cannot be made with accuracy. By the addition of a vernier scale, subdivisions of a degree are easily read. The vernier scale of a universal bevel protractor is shown in Fig. 25. This particular vernier makes it possible to determine the angle to which the instrument is set, within five minutes (5′) or one-twelfth of a degree. It will be noted that there are practically two scales of twelve divisions each, on either side of the vernier zero mark. The left-hand scale is used when the vernier zero is moved to the left of the zero of the true scale, while the right-hand scale is used when the movement is to the right. The total length of each of these vernier scales is equal to twenty-three degrees on the true scale, and as there are twelve divisions, each division equals 1/12 of 23 or 1 11/12 degree. One degree equals 60 minutes (60′), and 11/12 degree equals 11/12 of 60 or 55 minutes; hence each division on the vernier expressed in minutes equals 60′ + 55′ = 115 minutes. Now as there are 120 minutes in 2 degrees, we see that each space on the vernier is 5 minutes

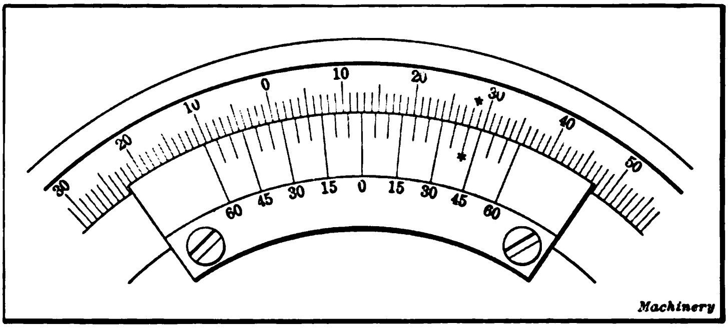

Fig. 25. Protractor Scale and Vernier

shorter than 2 degrees; therefore, when the zero marks on the true and vernier scales are exactly in line, the first graduation (either to the right or left) on the vernier is 5 minutes from the first degree graduation; the next two are 10 minutes apart; and the next two 15 minutes, etc. It is evident then that if the vernier is moved, say to the right, until the third line from zero is exactly in line with one

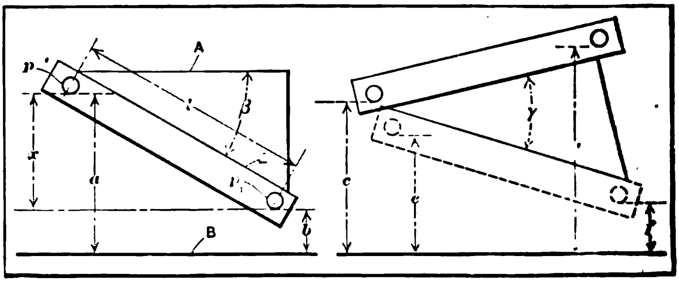

Fig. 26. Diagrams showing how Sine-bar is used for Measuring Angles

on the true scale, the movement will be equal to 15 minutes, as indicated by the number opposite this line on the vernier.

To read the protractor, first note the number of whole degrees passed by the vernier zero, and then count in the same direction the number of spaces between the vernier zero and that line which exactly coincides with one on the regular scale; this number of spaces multiplied by 5 will give the number of minutes to be added to the whole number of degrees. The reading of a protractor set as illustrated in Fig. 25 is 12 whole degrees plus 40 minutes. The vernier zero has passed the twelfth graduation and the eighth line on the vernier coincides with a line on the true scale; hence, 40 minutes is added to 12 degrees to get the correct reading.

Sine-bar for Measuring Angles

The sine-bar is used either for measuring angles accurately or for locating work to a given angle. It consists of an accurate straight-edge to which are attached two hardened and ground plugs p and p_1 (see Fig. 26). These plugs must be of the same diameter, and the

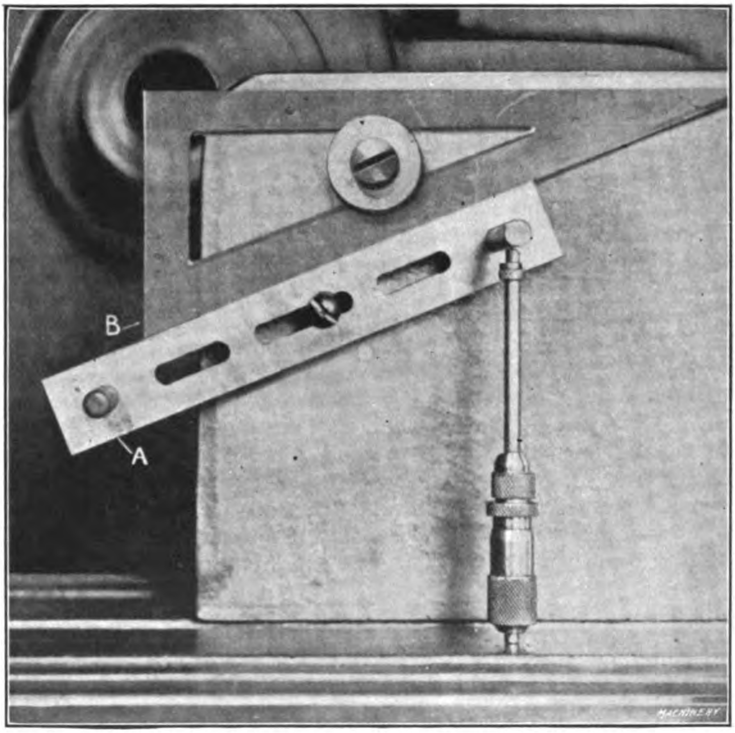

Fig. 27. Setting Sine-bar with Micrometer Gage

distance l between their centers should, preferably, be an even dimension, to facilitate calculations. The edges of the straightedge must be parallel with a line through the plug centers. The sine-bar is always used in conjunction with some true surface B from which measurements can be taken. Two methods of measuring an angle are illustrated. Referring to the left-hand sketch, the upper edge A of the part to be measured is set parallel with surface plate B. The heights a and b from the surface plate to the plugs p and p_1 are carefully measured either by using a micrometer gage or a vernier height gage. The difference between a and b is determined, and this difference, divided by the length l between the plugs of the sine-bar, equals the sine of the required angle β. The angle is then found by referring to a table of sines. For example, suppose length l is 10 inches, height a, 7.256 inches and height b, 2.14 inches; then the sine of the required angle equals $(7.256 - 2.14) \div 10 = 0.5116$, which is the sine of 30 degrees 46 minutes. A 10-inch sine-bar is convenient to use, as division can be performed mentally by simply moving the decimal one point to the left. Fig. 27 illustrates how the sine-bar A is used to determine the angle between the lower edge of triangle B and the machine table. A micrometer gage is used for measuring the vertical heights of the plugs.

The sketch to the right in Fig. 26 illustrates a method of measuring an angle without first setting one edge parallel to surface B, the angle of each edge being measured separately. Suppose the height d equals 8.75 inches and c equals 6.5 inches. Subtracting c from d: $8.75 - 6.5 = 2.25$. Next shift the sine-bar to the position shown by the dotted lines. Assuming that $e = 5$ inches and $f = 2.15$, then $e - f = 5 - 2.15 = 2.85$. Dividing 2.25 and 2.85 by 10 (or the center distance between the sine-bar plugs) we get 0.225 and 0.285 as the sines of the angles; 0.225 is the sine of 13 degrees 1 minute, and 0.285 is the sine of 16 degrees 34 minutes. The sum of these angles or $(13° 1') + (16° 34') = 29$ degrees 35 minutes or the required angle γ.

When the sine-bar is to be set to a given angle for locating some part with reference to it, it is first set approximately. The sine of the required angle is then found and this sine is multiplied by the distance l between the plug centers, to obtain the vertical distance x (see left-hand sketch Fig. 26) for that particular angle. The bar is then adjusted until the vertical distance x coincides with the dimension found. For example, if edge A is to be ground to an angle of 30 degrees 46 minutes from edge E, the sine-bar is clamped to the angle-plate at approximately this angle. The sine of 30 degrees 46 minutes, or 0.5116, is then multiplied by 10 to obtain the vertical distance x, and the bar is adjusted by the use of a vernier height gage until x equals $0.5116 \times 10 = 5.116$ inches.

Machinists' and Toolmakers' Squares

The squares used by machinists and toolmakers are such common tools that it seems unnecessary to illustrate them. There are two types of fixed tri-squares in common use. One type has a narrow blade of rectangular section and the beam or stock, as well as the edges of the blade, are hardened to prevent inaccuracy as the result of wear. The other type of square is intended for very accurate work. The blade is beveled on both edges so that practically a line contact with the work is obtained. (The advantage of the line contact as compared with a surface contact is explained in the paragraph on straightedges.) There is also the tool known as a "combination square" which is a type that is extensively used. It includes in addition to a square a protractor, a scale, and a center-head for locating the edge of the scale in line with the center of a shaft, etc.

Two methods of testing the accuracy of a tri-square are shown in Fig. 28. In order to make a reliable test, a 90-degree angle should be originated, unless a master square of known accuracy is available. A comparatively simple way of doing this accurately is to make a cylindrical plug similar to the one shown at *A*. The lower end of this plug is recessed to form a narrow edge which is beveled on the outside so that there will be no bearing in the corner where the blade joins the stock. This plug is ground on dead centers and lapped to form as perfect a cylinder as possible. The narrow edge at the end is then ground true so that it will be exactly at right angles to the cylindrical surface. By holding the square against the side and end of the plug, as the illustration indicates, and subjecting it to the light test, a very minute inaccuracy in the position of the square blade can be detected. The outside edge of the blade can be tested by placing the plug and square on an accurate surface plate, and bringing the blade edge into contact with the side of the plug.

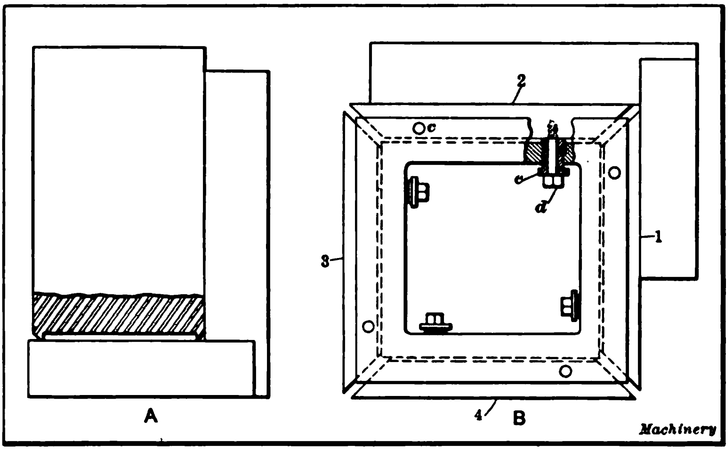

Fig. 28. Two Methods of Testing a Square

A more elaborate form of test block but one which gives very accurate results is shown at *B*, Fig. 28. This test block is formed of a square cast-iron frame which is grooved around the outside and contains four close-fitting adjustable strips which, in the illustration, are numbered from 1 to 4. The reliability of this test block depends largely upon the outer edges of these strips which must be accurately finished plane surfaces. The strips are held in place by close-fitting pins *c* near the ends, and by bolts *d*. The latter pass through clearance holes in set-screws *e* which are screwed through the frame and bear against the inner edges of the strips. By clamping one of these strips against the set-screws, it is locked in position after being properly adjusted.

The method of using this test block for determining the accuracy of a tri-square is as follows, assuming that the edges have not previously been adjusted: The square is first placed against two of the strips or straightedges of the test block. These strips are then adjusted until they exactly fit the square being tested. If the square were first applied to strips Nos. 1 and 2 (as shown in the illustration) strips 2 and 3 would next be set in the same manner, and then strips 3 and 4. After making these adjustments, if the square is applied to the strips Nos. 4 and 1, any error which might exist would be multiplied four times; whereas, if the square fitted these last sides perfectly, this would indicate that the angle between the square blade and stock was 90 degrees, within very close limits.

To illustrate how the error accumulates in going around the test block, suppose the angle between the blade of a square and its stock were 90 degrees 15 minutes. Evidently, then, sides 1 and 2 of the test block would also be set to this angle. Therefore, taking side No. 1 as a base, side No. 2 would be out 15 minutes. As side 2 is used in setting side 3, the error of the latter with reference to side 1 would be 30 minutes; similarly, side 4 would have an error of 45 minutes, and when the square was applied to sides 4 and 1 for the final test, the error would be four times the original amount, or 1 degree.

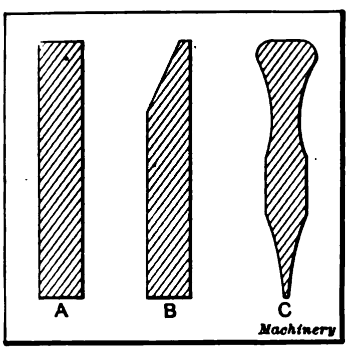

Fig. 29. Three Types of Straightedges

In order to originate a 90-degree angle, or, in other words, to set the test block to this angle, a sheet steel templet is used. This simply forms a temporary tri-square and is cut away so that there are two small projections along each test edge, in order that changes can be made by simply altering these small projections. This templet is first made as accurately as possible and it is then used in setting the test block. After adjusting the block, if comparison with the fourth and first sides shows an error, the templet is corrected and the test block again adjusted. This operation is repeated until the 90-degree angle is originated. The accuracy of a square can then be tested by comparison with any two sides of the test block and without making any adjustments.

Straightedges

Straightedges are used to test flat surfaces for determining whether or not they are true planes, and also for testing round parts for bends, or curvatures in a lengthwise direction. Perhaps the most common form of machinists' straightedge is of rectangular section, as shown at *A*, Fig. 29. In order to increase the sensitiveness of a straightedge for showing minute deviations or curvatures,, the testing edge is made narrower by beveling one side as shown at *B*, thus decreasing the width to about 1/16 inch. For work requiring extreme accuracy, the form of straightedge shown at *C* is commonly used. The testing edge is very narrow and is of semi-circular cross-section so that a line contact is obtained instead of a surface contact, as with the form having flat edges. This line contact shows any minute curvature which may exist and as the edge is curved the accuracy of the test will not be affected if the straightedge is not held exactly at right angles to the surface being tested. When using a straightedge having plane or flat surfaces, it should be held square with the work, because, if canted so that only one edge is in contact, any inaccuracy along this edge would appear as an inaccuracy in the surface being tested. When comparing a surface with a straightedge, there should be a good light on the side opposite the observer so that any irregularities or curvatures in the work can readily be detected.

Height and Depth Gages

The vernier height gage, shown at *A*, Fig. 30, is used for locating jig buttons, measuring the vertical distance from one plane surface

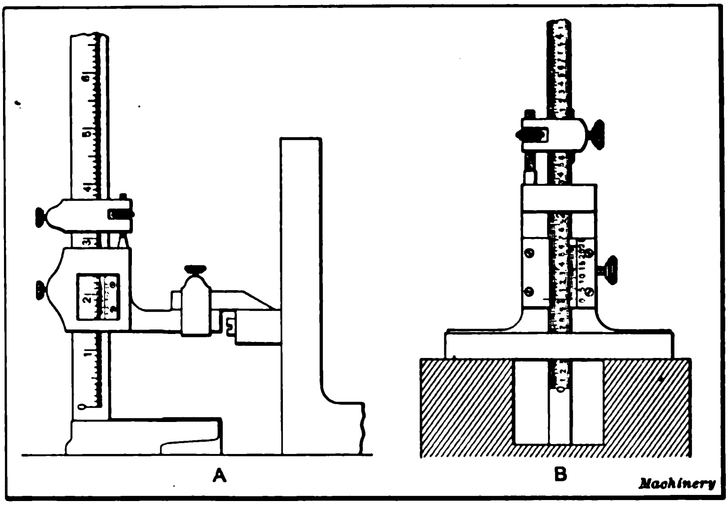

Fig. 30. (A) Vernier Height Gage. (B) Vernier Depth Gage

to another, etc. It is similar to a vernier caliper, except that there is a rather heavy base which allows the gage to stand upright. The movable jaw of this particular make of gage has a projection which extends beyond the base and is convenient for testing the height of a button attached to a jig plate (as the illustration indicates) and for similar work. The end of this extension is beveled to a sharp edge for scribing lines. The gage is graduated to read to thousandths, by means of a vernier scale on the sliding jaw. There are graduations on both sides, giving readings on one side for outside measurements and on the other side for inside measurements. This particular gage can be used for heights up to 8 inches.

Illustration *B*, Fig. 30, shows a depth gage for measuring the depths of holes, recesses in dies, etc. The vertical blade or scale is graduated and by means of a vernier gives readings to thousandths of an inch. Height and depth gages are also made on the micrometer principle; that is, instead of having a scale and vernier, the adjustments are effected by a micrometer screw, graduated to read to thousandths.

The Surface Gage

The surface gage is used extensively for scribing lines that represent finished surfaces, and also for testing the parallelism between a surface and the table of a machine, such as the planer or shaper. A common form of surface gage is shown in Fig. 31. It has rather a heavy base on which is mounted a rod carrying a pointer or scriber *S*. The latter can be adjusted in or out and it can also be moved to any position along the rod. After the scriber or pointer has been set to about the right height, it can be set accurately to the position desired by turning screw *A*, which gives a fine adjustment. There are two pins *B* in the base which can be pushed down when it is necessary to keep the gage in line with a finished edge or the side of a T-slot in the planer table.

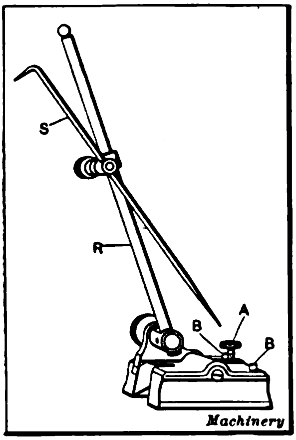

Fig. 31. Surface Gage

When using the gage to set a surface parallel with the table of a planer or other surface, scriber *S* is first set to just touch the work at some point. The gage is then placed in different positions in order to compare the height at various places. The surface gage is also

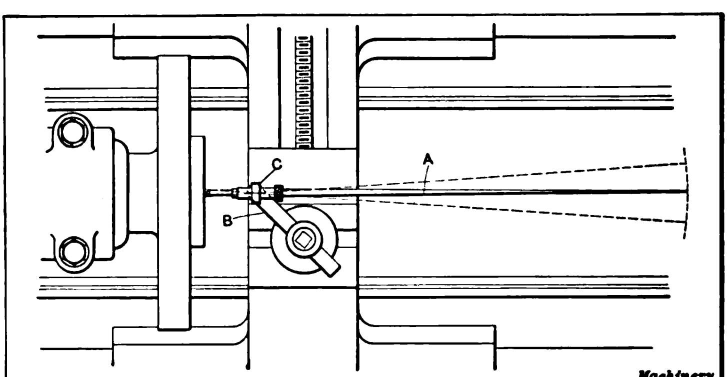

Fig. 32. Plan View Illustrating use of Center Indicator

extensively used for scribing parallel lines when laying out the work, scriber *S* being reversed to locate the straight or sharp end in front. This pointer is also useful for setting lines representing finished surfaces, prior to the planing operation.

Center Indicator

The center indicator is used to set any point or punch mark in line with the axis of a lathe spindle preparatory to boring a hole. The plan view, Fig. 32, shows how the indicator is used. It has a pointer *A*, the end of which is conical and enters the punch mark to be centered. This pointer is held by shank *B* which is fastened in the toolpost of the lathe. The joint *C*, by means of which the pointer is held to the shank, is universal; that is, it allows the pointer to move in any direction. When the part being tested is rotated by running the lathe, if the center punch mark is not in line with the axis of the lathe spindle, obviously, the outer end of pointer *A* will vibrate, and as the joint *C* is quite close to the inner end, a very slight error in

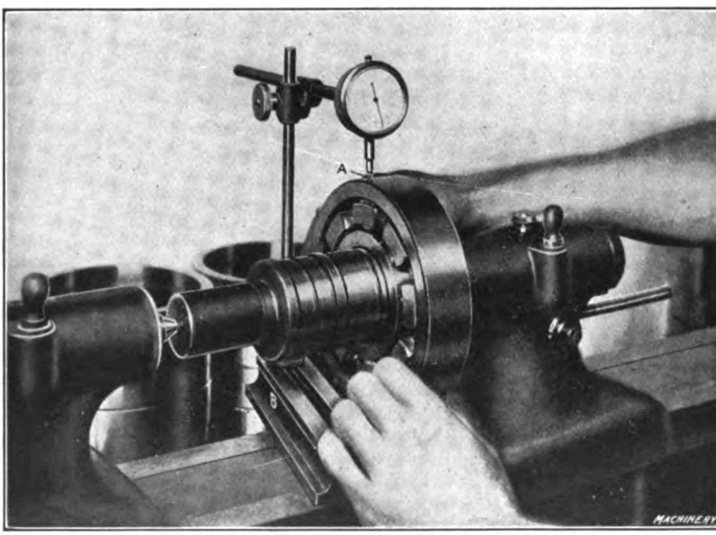

Fig. 33. Testing Concentricity of Roller Bearing, with Dial Test Indicator

the location of the center punch mark will cause a perceptible movement of the outer end, as indicated by the dotted lines. Obviously, when the work has been adjusted until the pointer remains practically stationary, the punch mark is in line with the axis of the lathe spindle. When two holes are being bored to a given center-to-center distance, by first laying out the centers and then indicating them true in this way, the accuracy depends largely upon the location of the center punch marks.

Test Indicators

The test indicator is extensively used in connection with the repair or erection of machinery, for detecting any lack of parallelism between surfaces, in inspection departments, and for testing the accuracy of rotating parts (such as spindles or arbors) in connection with general machine shop work. Fig. 33 shows how a dial indicator is used to test the concentricity of the outer race of a roller bearing. The assembled bearing is mounted upon an accurately running arbor, held between centers, and the contact point *A* of the indicator bears against the surface of the outer race. As the latter revolves, the slightest deviation or eccentricity is shown by vibrations of the dial hand, which is so connected with the contact point that any motion of the latter is magnified a number of times. The graduations on the dial face indicate thousandths of an inch, and the dial is adjustable so that it can be turned to locate the zero mark directly under the

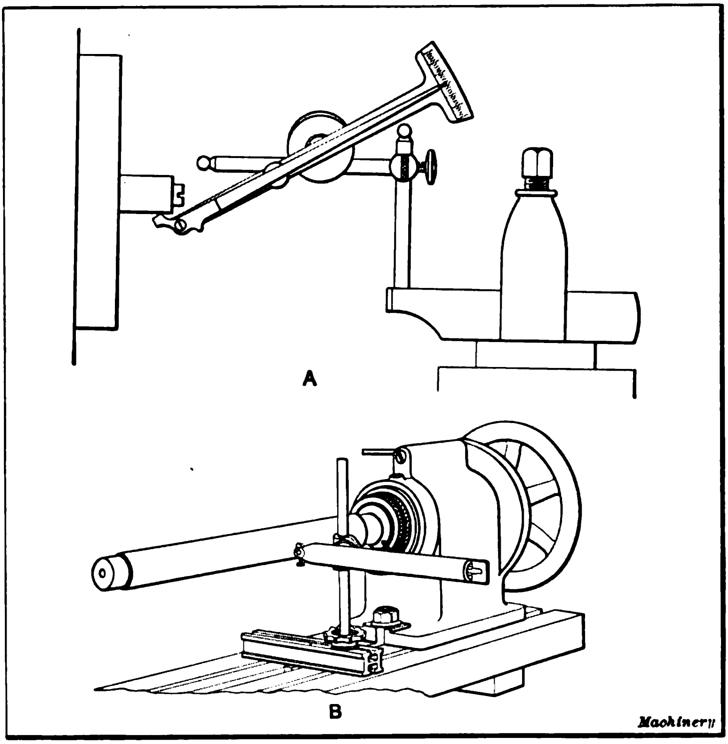

Fig. 34. Examples Illustrating use of Test Indicators

hand, after the contact point has been adjusted against the work. The graduations then give a direct reading in thousandths for any deviation from the central or zero position. The contact point is removable to permit inserting different forms.

In this particular case, the indicator is supported by a vertical rod attached to a base *B*, which forms part of the instrument. It is often used independently of the base, as when held in the toolpost of a lathe for testing the accuracy or concentricity of a cylindrical surface. The dial indicator is also used for many other purposes. For instance, it is often attached to a surface gage, in place of the pointer or scriber, for testing the parallelism of a surface, especially when it is desirable to know the exact amount of inaccuracy. This form of indicator is also useful for testing the parallelism between the cross-rail and table of a planer. To make a test of this kind the indicator is held in the toolpost and the slide is lowered until the contact point bears against the table. The dial is then turned until the zero mark coincides with the indicating hand, and, when the gage is traversed across the table by moving the toolhead along the cross-rail, any inaccuracy is shown by the movement of the hand away from the zero position. Of course, it is not necessary to adjust the dial to the zero position, but this is advisable as the reading can then be taken direct from the dial graduations. This form of indicator is often used on milling machines or shapers for setting the jaws of a vise or the side of an angle-plate exactly parallel to the line of feeding movement, and for many other similar purposes.

Two other forms of test indicators are shown in Fig. 34. This type is also used in connection with the erection or inspection of machinery for detecting inaccuracies, such as the lack of parallelism between two surfaces or the amount a cylindrical part runs out of true. Diagram *A* illustrates how a jig button is set true with the lathe spindle. The point of the indicator is set against the button and, as the latter revolves, any inaccuracy is shown by the vibrations of the pointer. Any movement of the contact point is multiplied several times by the pointer, and graduations at the end of the latter indicate thousandths of an inch.

Diagram *B* illustrates how another test indicator of different form is used for determining the accuracy of a spindle in relation to a T-slot in the bed. A true arbor is inserted in the spindle and the contact point of the indicator bears against it. Any inaccuracy is shown on a greatly increased scale by the pointer, the end of which may be seen at the right end of the indicator body.

While these two indicators differ in construction they operate on the same principle and are used for the same class of work. There are also many other forms or designs of this same general type.

Special Indicating Gages

The dial indicator is used in combination with many different gaging devices, for testing the accuracy of finished parts. Fig. 35 shows a gaging fixture which is used for testing the inside diameters of the inner races of ball bearings. The race to be tested is placed over a stud at the left end of the gage, as shown in the illustration. This stud has a two-point bearing and the gaging arm forms the third point. A multiplying lever extends to the other end of the fixture and the end of this lever bears against the plunger of a dial gage, which shows any variation in the diameter. Errors above or below the standard size are multiplied ten times so that the gage, which normally reads to thousandths, gives a direct reading to 0.0001 inch. By adjusting the dial so that the hand points to zero, when the gage is set to the standard size, the amount of variation either above or below this standard dimension is easily determined. Thus it will be seen that gages of this type are "comparators" that show variations from a standard size but are not used for taking measurements.

Another form of dial gage for testing the outside diameters of

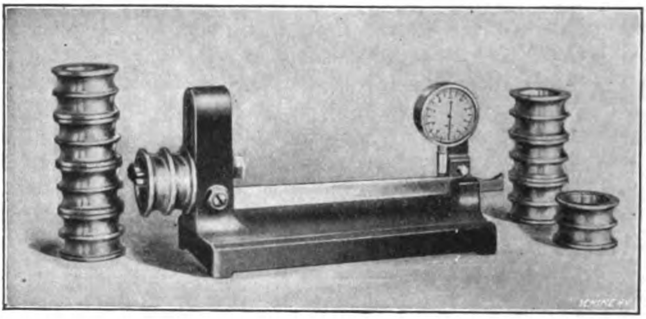

Fig. 35. Internal Gaging Fixture for Ball Bearing Races

finished ball bearings is shown in Fig. 36. This gage consists of a multiplying lever, one end of which comes into contact with the work while the other end bears against the plunger of the dial gage. The test is made by simply rolling the bearing on the true base of

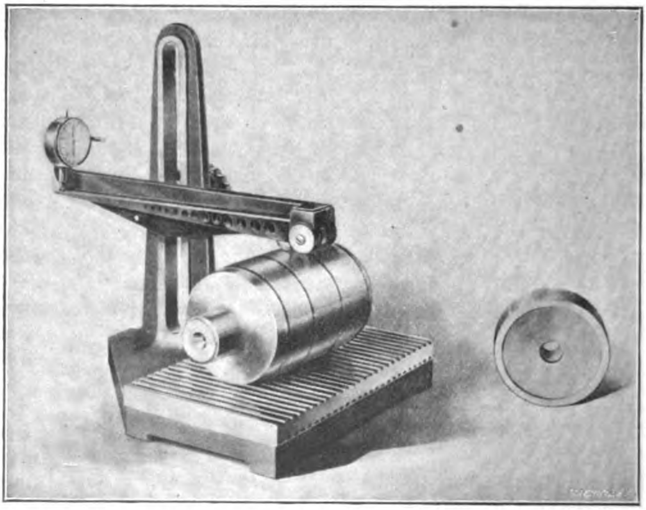

Fig. 36. Gage for Testing Outside Diameters of Ball Bearings

the fixture and under the end of the multiplying lever. Obviously, any variation from the standard size to which the gage is set, is indicated by the dial. The arm which carries the multiplying lever can be adjusted vertically in the slotted supporting bracket in order to set the gage for testing different sized bearings. The exact adjustment of the gage is obtained by comparing it with a master disk, such as the one shown to the right of the illustration. This disk is also used for checking the gage at intervals, to insure accurate readings.

A great many special gages of the same general type as those shown in Figs. 35 and 36 are now used, especially in inspection departments. A common idea of a gage is that it should have gaging surfaces which are a duplicate or exact complement of the part to be tested. A thread plug gage, for instance, is often regarded as being properly a steel plug threaded and hardened, the thread shape conforming exactly to that of the standard thread. While manufacturers furnish gages of this type in response to common demands, it is well known that such a gage is not a properly designed testing instrument. It is true that the ordinary thread plug gage may answer the purpose for which it was designed and it is also true that it is hardly practicable to devise a low-priced gage in which the faults of the plug gage are eliminated. The plug gage satisfies the common demand for a standard form that can be referred to for all dimensions, angles and shapes. A gage, however, which is used to test, at the same time, all the dimensions of even a simple part, is likely to be inaccurate and unreliable. As a general principle, a cylindrical plug gage should never be required to measure more than on diameter, and a solid gage should not be made to verify the concentricity of more than two cylindrical surfaces simultaneously. Some gages cover so many surfaces that it is impossible to determine definitely where the inaccuracies are; moreover, a gage of this type may seem to fit perfectly when in reality there are errors which remain undetected. A thread gage which is in the form of a threaded hole may seem to fit a screw perfectly and yet the screw may be several thousandths of an inch under size. For instance, if there is an error in the lead of the thread this may cause a screw that is under size to fit into the gage without perceptible play.

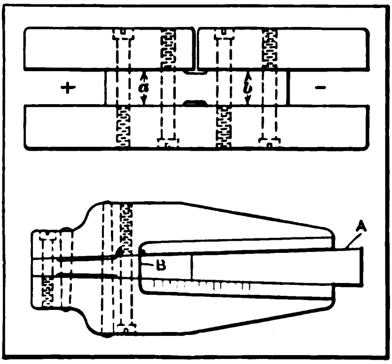

Fig. 37. Sectional Gages

The type of gage having movable parts connecting with graduated dials, so that plus or minus readings can be taken directly, has replaced many gages of the fixed type, especially for inspection work, because they give a direct comparative measurement within very small limits of accuracy. Such gages, however, are often quite expensive and, in many cases, simpler forms serve all practical requirements.

Sectional Gages

A sectional snap gage formed of four parts is shown in the upper part of Fig. 37. The measuring jaws, instead of being integral with the gage body, are attached to a central block by screws, as shown. The width *a* of one end of this central block equals the size of the "go" end of the gage; width *b* equals the size of the "not go" end. The gage jaws are made flat. The advantage of this design, as compared with a solid snap gage, is that when the accuracy is impaired as the result of wear the gage can be restored to its original accuracy by simply removing the gage jaws and truing them by grinding and lapping.

The same principle can also be applied to an angular taper gage, as shown by the lower view, Fig. 37. The gage jaws are attached to a central block *B* finished accurately to the required taper, and the size of the work *A* is tested by pushing it between the jaws and noting the position of the end relative to a standard graduation mark. When the gage becomes inaccurate, as the result of wear, the jaws are removed and trued. A master plug should be used, occasionally, for testing the accuracy of the gage. By having one jaw graduated, as shown, the amount of inaccuracy may also be gaged, by noting how far the end of the work comes short of or projects beyond the standard dimension mark.

Spirit Levels

Levels are frequently used by machinists especially when erecting engines or heavy machinery. The accuracy of a spirit level depends entirely upon the curvature of the glass tube. This tube is ground on the inside to a barrel shape, except in cheap levels which simply have a glass tube bent to the approximate curve. The bent tube type is not to be recommended except for work which does not require great accuracy. The tube is nearly filled with spirits of wine, ether or some similar fluid and is hermetically sealed at each end. The larger radius of curvature the glass has, the more sensitive will be the level. The air-space in a ground glass is much longer than in a bent one, being ordinarily from 1/4 to 1/3 the length of the tube. Modern levels are graduated to tenths and twentieths of an inch, except when they are divided according to the metric system. The angular value of a division may be determined roughly as follows: Support the level upon a piece of metal, the lower surface of which has been filed or cut away so that it bears on two points exactly 12 inches apart. Insert packing under one of the bearing points to bring the air space near the center. Note carefully where the air space is and then put a "feeler gage," say, 0.002 inch thick, under one of the bearing points; then if the air space moves, say, one-tenth inch, the angular value in seconds for one division of the level is found as follows: The distance from the bearing point to the feeler gage is 12 inches, which is the radius of a circle the circumference of which is 75.3984; hence 75.3984 inches is equivalent to 1,296,000 seconds angular measurement. Therefore, 0.002 inch equals 34.3 seconds and each one-tenth inch on the level also equals 34.3 seconds. The angular value of the graduations can, in this way, be determined.

A good level is a very sensitive instrument and should be carefully used. The leveling glass or "bubble" is generally fixed in a brass tube with plaster-of-paris. This method is satisfactory for all levels having an accuracy of about five seconds angular measurement to each one-tenth inch graduation. For finer levels, it is better to fix one end only with plaster-of-paris and the other end with cork, for if the glass is fixed rigidly at both ends with plaster-of-paris, there will be a strain on the level due to temperature changes, and as the expansion of glass and brass is different, a slight inaccuracy is liable to result. It is also advisable to have an extra glass tube surrounding the leveling tube for very accurate levels, in order to provide insulation from the heat of the hand. A level of one minute angular measurement to one-tenth inch graduation is the most serviceable for general use.

Measuring Machines

The measuring machine is an instrument of great precision that is used for originating standard lengths and for verifying the accuracy of reference gages. It might properly be defined as an instrument for obtaining accurate subdivisions of the standard Imperial yard, which is the basis of the English system of measurement. The Pratt & Whitney measuring machine is shown in Fig. 38. This machine has a heavy cast-iron bed upon which two heads are mounted. One of these heads, *A*, is normally fixed to the bed, whereas the other head, *B*, is adjustable along the accurately machined ways of the bed, for the measurement of various lengths. Each head has a spindle or measuring point and the part to be measured is supported between these spindles upon the rests *C*, which are of suitable shape at the top to center the work. Measurements up to 1 inch are obtained by means of a large graduated index wheel *D*, a scale and pointer at *H* being provided for approximate setting. For lengths greater than 1 inch, the sliding head is set by means of a standard bar *E* at the rear. (See Fig. 39.) The divisions or graduations, which are exactly 1 inch apart, are marked upon the surfaces of plugs set into this bar and are so fine that they are imperceptible to the naked eye. The sliding head is located for the inch positions by adjusting it with reference to these lines. In order to secure an adjustment which will exactly conform to the divisions on the standard bar, the sliding head is equipped with a powerful microscope *F* which is provided with a very fine line which is set with reference to the bar graduations. The screw of the sliding-head spindle, by means of which the adjustments for fractional parts of an inch are obtained, has twenty-five threads per inch, and the index wheel *D* has 400 graduations on a machine for English measurements; therefore, each graduation represents a 1/400 of 1/25 or 0.0001 inch, and the divisions can easily be subdivided into quarters or even less by estimation.

In order to insure a light contact or delicate and uniform pressure between the measuring points each time a measurement is taken, the machine is provided with a simple indicating device on the fixed head. This consists of two auxiliary jaws between which is held a

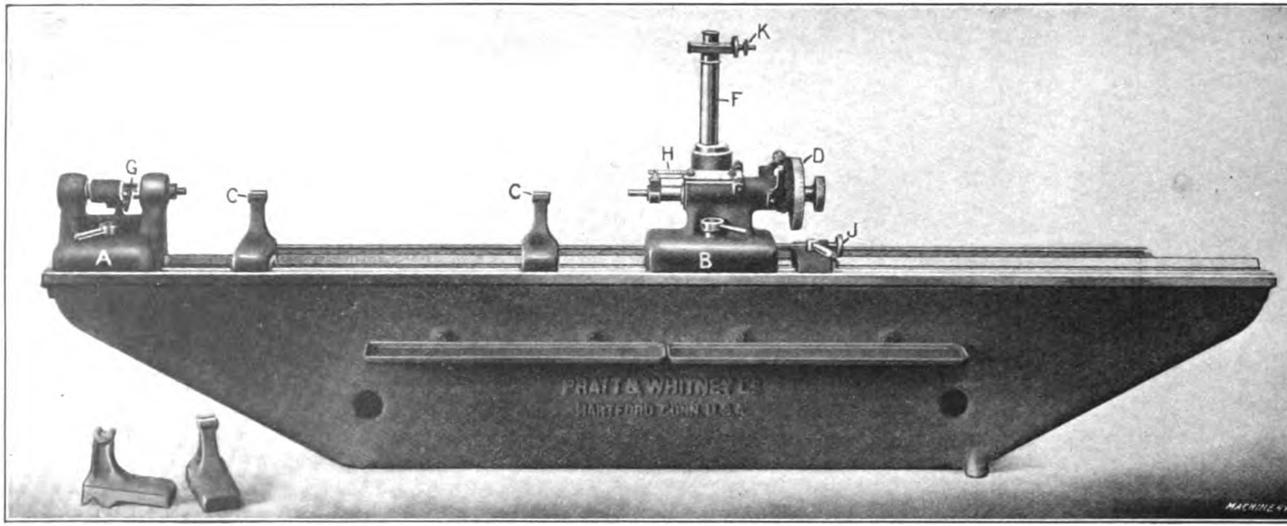

Fig. 38. Pratt & Whitney Standard Measuring Machine

small cylindrical plug *G*, by the pressure of a light helical spring, which operates the sliding spindle to which one of the jaws is attached. The tension of this spring is so adjusted that when the measuring points are not in contact the jaws will hold plug *G* in a horizontal position by friction. When the spindles are in perfect contact, either with each other or with the work, the tension on the spring is slightly reduced and plug *G* swings down to a vertical position, but any excess pressure will cause the plug to drop out of the jaws; hence, the contact for all measurements should be just enough to cause plug *G* to swing down to the vertical position.

To illustrate the application of this machine, suppose it were necessary to set it for testing the accuracy of a special end-measuring bar or gage 10.2508 inches long. First the machine should be set in the zero position with the measuring points in contact. In order to do this, adjust the screw of the linear scale at the top of the head to zero, and set the pointer of the index wheel *D* nearly to zero; then slide the head until the measuring faces are almost in contact, and then by means of screw *J*, at the right of the head, adjust one spindle against the other until the indicating plug *G* shows a tendency to move from its horizontal position. Next clamp the head firmly and adjust the index wheel until the plug *G* swings down to a vertical position. Then set the adjustable index pointer to zero, and the line in the eye-piece of the microscope so that it exactly coincides with the zero line of the graduated reference bar *E*, Fig. 39, at the rear. The adjustment of the line in the eye-piece is made by means of screw *K*. The machine is now set in the

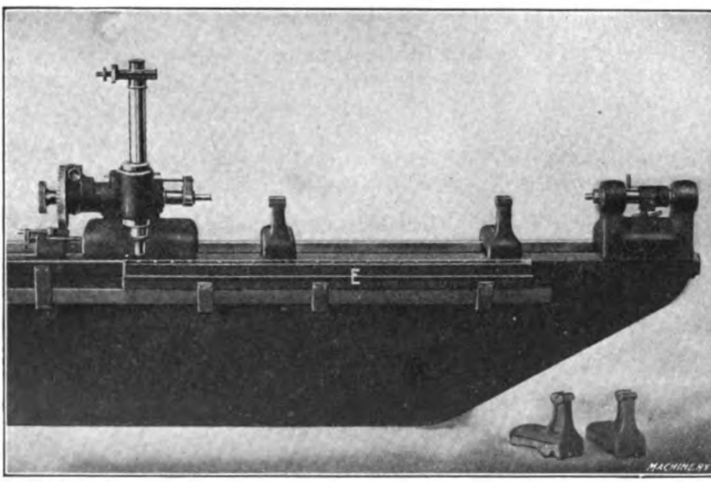

Fig. 39. Rear View of Pratt & Whitney Measuring Machine

zero position, and, when adjusting the head for the required measurement, care must be taken not to disturb the eye-piece of the microscope.

To measure from zero to one inch, the micrometer screw can be used direct, but for greater dimensions locate the sliding head so that the line in the eye-piece of the microscope coincides with the graduated plug from which the measurement is to be taken, the fine adjustment necessary being obtained by means of screw *J* at the right of the head. In this particular case, the head would be moved back along the bed until the line in the eye-piece of the microscope exactly coincided with the tenth graduation line. The distance between the measuring surfaces is now 10 inches. As the length required is 10.2508 inches, the screw would be turned back until the scale and index wheel of the adjustable spindle showed a movement of 0.2508 inch. As the pitch of the screw is 1/25 inch, each complete turn of the index wheel equals 0.040 inch; hence, for a movement of

0.2508 inch, the turns of the index would equal 0.2508 ÷ 0.040 = 6.27, or six full turns and 108 divisions.

To test the rod, the index wheel would be turned a little beyond the required distance and the rod placed between the measuring surfaces. After setting plug *G* in a horizontal position, the index wheel would be turned back to the 10.2508 position. If plug *G* dropped before this position was reached, it would indicate that the rod was too long, but if it remained in a horizontal position, it would show that the rod was under size. In either case, the exact amount of error could easily be measured. When measuring an end gage, especially if of considerable length, care should be taken to prevent any variation in the temperature of the gage. When it is desired to test one gage with another master gage, the machine is first set by adjusting the contact points with the master gage. The other gage is then placed between the jaws and its length compared by referring to the graduations on the machine.

The Pratt & Whitney machines graduated for English measurements are standard at 62 degrees F. It is not necessary, however, to use the machine at this initial temperature, because variations due to temperature changes will affect both the work and the machine practically the same, although when the machine is used for scientific research, the initial temperature should be adhered to.

Measuring Large Diameters

The accurate measurement of exceptionally large diameters is rather difficult because of the spring or deflection of the measuring instrument. The operation is often further complicated when using a gaging tool not provided with graduations giving a direct reading, owing to the difficulty of obtaining the exact length of a diameter, in feet and inches, after the gaging tool has been set. A fairly accurate method of determining the external diameter of a large circular part is to first measure the circumference with an accurately graduated steel tape and then divide the reading by 3.1416 to get the diameter. One advantage of measuring large work in this way is that the reading is magnified 3.1416 times, each inch of diameter being represented by this number of inches on the tape; hence, the diameter can be determined quite accurately provided a high-grade steel tape is used. A large internal diameter can also be measured by this method, when the outside and inside surfaces are finished concentric, by first measuring the circumference with a standard steel tape and then deducting from the diameter thus obtained twice the thickness of the wall between the inner and outer surfaces. The Pratt & Whitney car wheel circumference gages are made of flexible tempered steel ribbon, and are graduated to give, by circumference measurement, the standard diameters of car wheels varying from 24 to 42 inches. These gages are provided with adjustable handles for holding the ribbon or tape about the wheel.

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