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Gage Section
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THE MEASUREMENT OF RADII ON PROFILE GAGES.

Profile or contour gages offer greater difficulties in inspection than other types of gages, since it is usually necessary to devise and employ special methods of measurement and arrangements of measuring apparatus to determine the various dimensions of such gages. There are, however, certain general methods of inspection which may be adapted to the measurement of numerous types of gages. There is presented herewith an explanation of the methods used by the Gage Section, Bureau of Standards, for the testing of curves on profile gages.

The complete inspection of an arc on a profile gage involves the determination of two elements: the radius of curvature and the location of the center of curvature with respect to certain gaging points. The methods of testing radii may be conveniently divided into two classes, those which are adapted to large radii and those which may be applied to small radii.

Method of Measuring Large Radii.

The first method to be described is one which may be applied with very little difficulty and may be used to test radii varying from two or three inches in length to the length of the largest surface plate available. It involves the use of a mechanical test indicator and Johansson or Hoke Precision Gages as means of measurement. The application of this method to the testing of a gage, and its check, for the profile of a shell is herein explained and illustrated in Fig. 1. The complete test of the arc on this gage involves the determination of the radius R and the dimensions A, B, C and D. The gage and measuring apparatus are set up on the surface plate and the dimensions are determined as follows:

a. Clamp two straight edges or parallel bars to a surface plate at 90° to each other in about the position shown in Fig. 1.

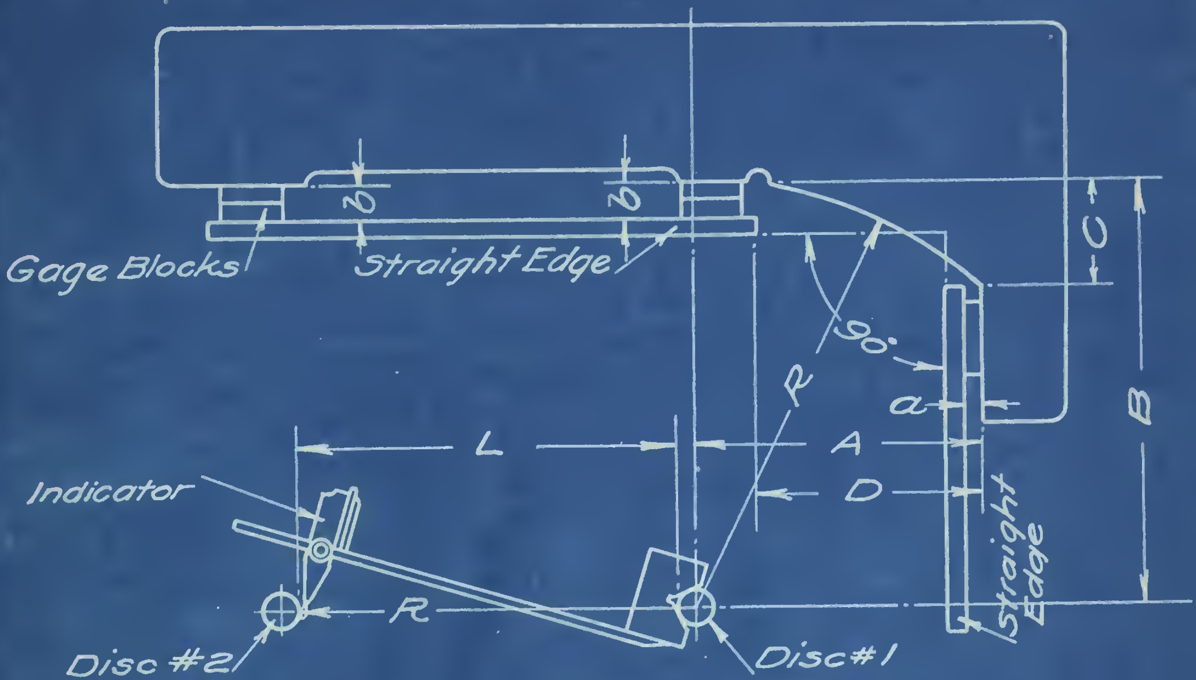
b. Clamp an accurately ground circular disc, No. 1, or toolmaker's button at convenient distances from each straight edge such that, by means of gage blocks a and b, the dimensions A and B may be varied.

c. Clamp a second disc, No. 2, for reference so that the distance from the center of No. 1 to the inside of No. 2, determined by means of gage blocks, will equal the correct nominal radius of the gage.

d. Clamp a rod on which is mounted a mechanical indicator such as the "Last Word" or "Deming" to a V-block as shown.

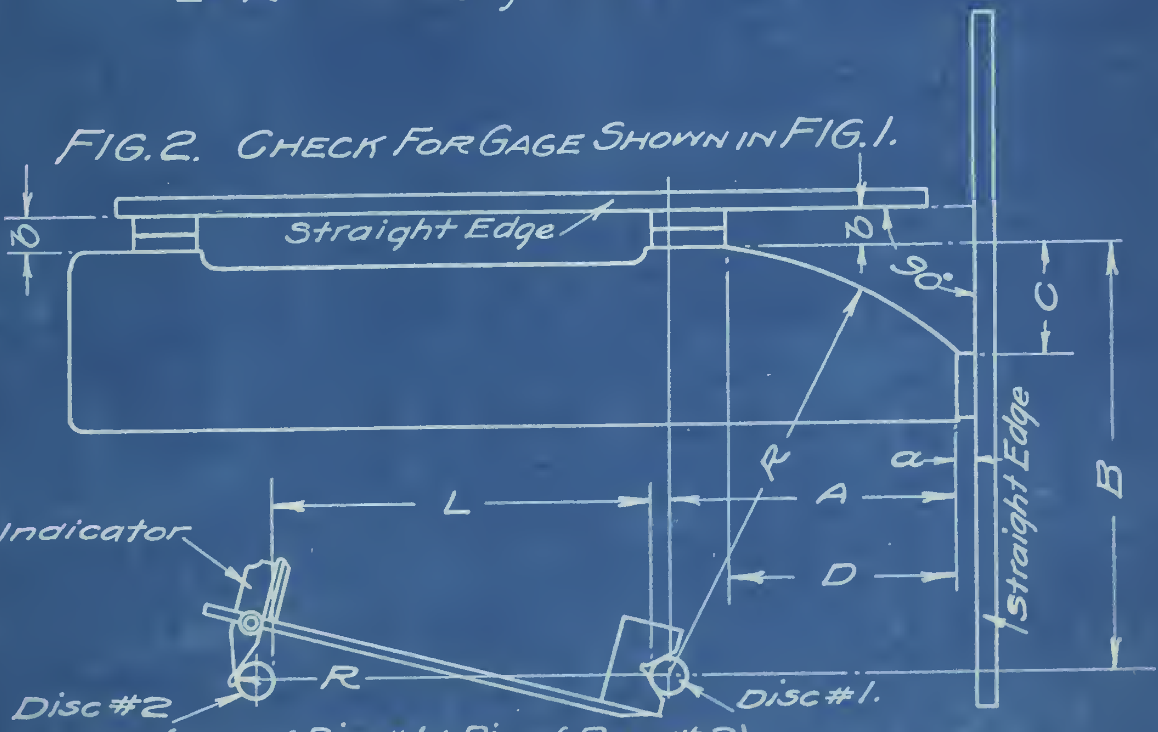
e. Place the gage in position so that the dimensions A and B are equal to the nominal dimensions and set the indicator to give any desired reading when swung against disc No. 2.

FIG. 1. GAGE FOR PROFILE OF SHELL.



L = R – Radius of Disc #1.

FIG. 2. CHECK FOR GAGE SHOWN IN FIG. 1.



L = R – (Rad. of Disc #1 + Dia. of Disc #2.)

f. Swing the indicator around disc No. 1 over the profile. If the radius of curvature is correct and the center of curvature is correctly located there will be no variation in the reading of the indicator from that obtained when the indicator is swung round against disc No. 2. In case there is a variation it is necessary to adjust the positions of the discs until none occurs.

The tolerance permitted in such a case should not be set on the individual dimensions A, B and R, but should be expressed in terms of the total deviation of the arc from the correct profile permissible at any point.

g. The only deviation from the above method in testing the male check shown in Fig. 2 is that the indicator is swung against the far side of disc No. 2 and the measurement R is accordingly made from the center of disc No. 1 to the far side of disc No. 2.

h. The dimensions C and D are determined by substituting the known values of A, B and R in the formulae:

$$D = A - \sqrt{R^2 - B^2}$$

$$C = B - \sqrt{R^2 - A^2}$$

In Fig. 3 is illustrated a similar case in which the curved surface bears a certain relation to another gaging surface and it is necessary to locate the center of curvature with respect to this surface. In this case the procedure is as follows:

a. Clamp a straight edge near the edge of the surface plate.

b. Clamp disc No. 1 at a convenient and known distance from the straight edge.

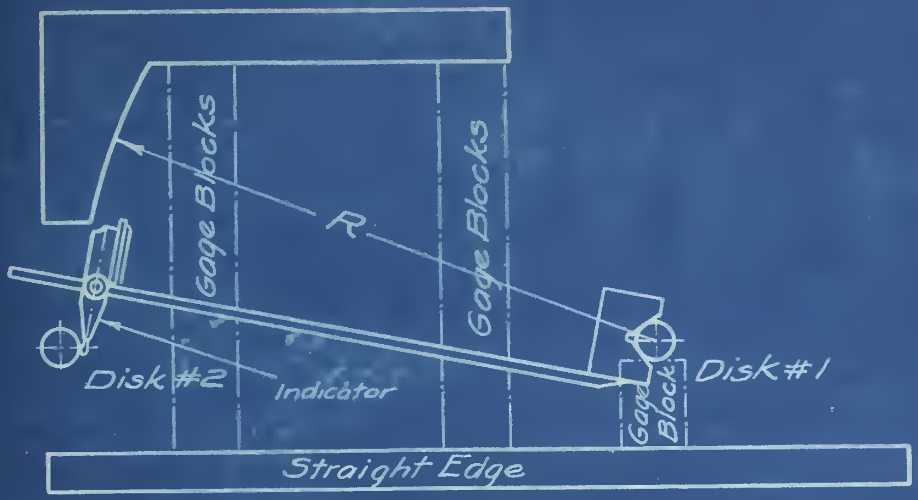
c. Clamp a reference disc No. 2 so that the distance from the center of No. 1 to the near side (for a concave arc) of No. 2 is equal to the nominal radius of the gage.

d. By means of gage blocks set the gage at a distance from the straight edge such that the distance from the center of disc No. 1 to the gaging surface with respect to which the center of curvature is located, is the correct nominal value.

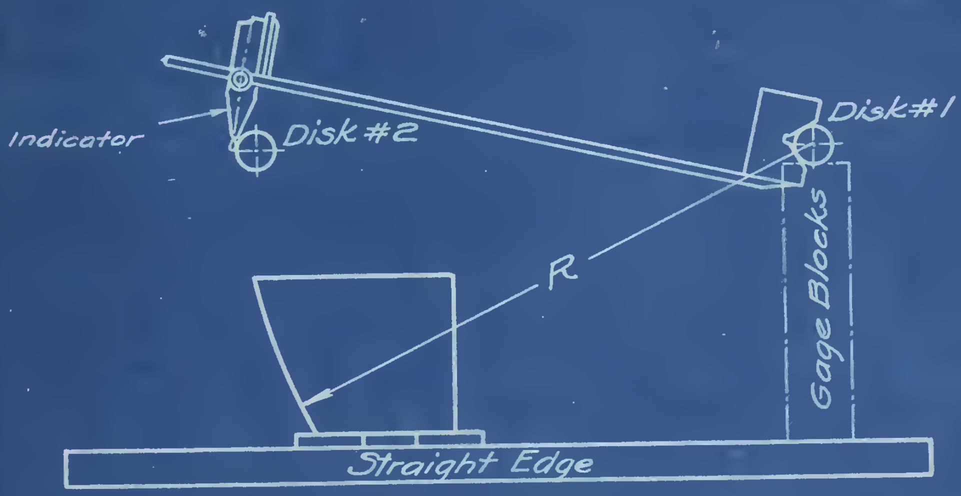
e. Clamp a rod, on which is mounted an indicator, to a V-block and set the indicator against disc No. 2 to give any desired reading.

f. Swing the indicator around disc No. 1 to read on the profile and move the gage parallel to the straight edge until the indicator registers the same as when against disc No. 2. Swing the indicator over the profile and adjust the positions of the gage and disc No. 2 until there is no variation. Dimensions are then determined as in the previous case.

FIG. 3.



GAGE



CHECK

Method of Measuring Extremely Large Radii.

Curves having radii of several feet, such as occur on gages for the profile of major caliber shells, can not be conveniently measured by the preceding method owing to the fact that a surface plate of sufficient length is not usually available. The method given below may be applied to an arc of any radius greater than a few inches provided that the length of the arc on the profile is great enough to permit its application. The radius is not measured directly but is computed from other measurements. For this reason results of the same degree of accuracy as those of the preceding method are not obtained; however, if the measurements are carefully taken, a fairly high degree of accuracy is attained.

The following is the method of procedure in the case of a male check for the profile of a shell:

a. Clamp two straight edges or parallel bars to a surface plate at 90° to each other as shown in Fig. 4A.

b. Clamp two accurately ground circular discs or toolmaker's buttons of equal radius r at a measured distance L apart. Each disc should be in contact with the curve of the profile and one straight edge as shown.

c. Clamp the gage in position, the curved portion bearing against the discs. By means of gage blocks set and determine the dimensions E, F, M and N.

d. Keeping the gage and discs clamped in position, remove the straight edges and clamp one of them in contact with the discs as shown in Fig. 4B. Determine by means of gage blocks the dimension T at the point midway between the discs.

e. From the dimensions thus obtained the values of R, A and B are computed. To determine the radius R it is necessary to compute the value of S, which is half the distance between the points at which the discs have contact with the gage, and the dimension h. To do this it is necessary to knownthe approximate value of R. In case the nominal value of R is not known it is necessary to substitute the value of $\frac{L}{2} + r$ for S in the following solution. From the value of R thus obtained the values of S and h are computed which in turn are used to compute the correct value of R. In any case it is evident that the values of S and h are approximations until the correct value of R is known and it is advisable to recheck using the final value of R obtained.

From the geometrical relations shown in Fig. 4B the values of S, h and R are derived as follows:

$$S = \frac{R(\frac{L}{2}+r)}{R+r}$$

$$Z = r + \frac{r}{R}\sqrt{R^2 - S^2}$$

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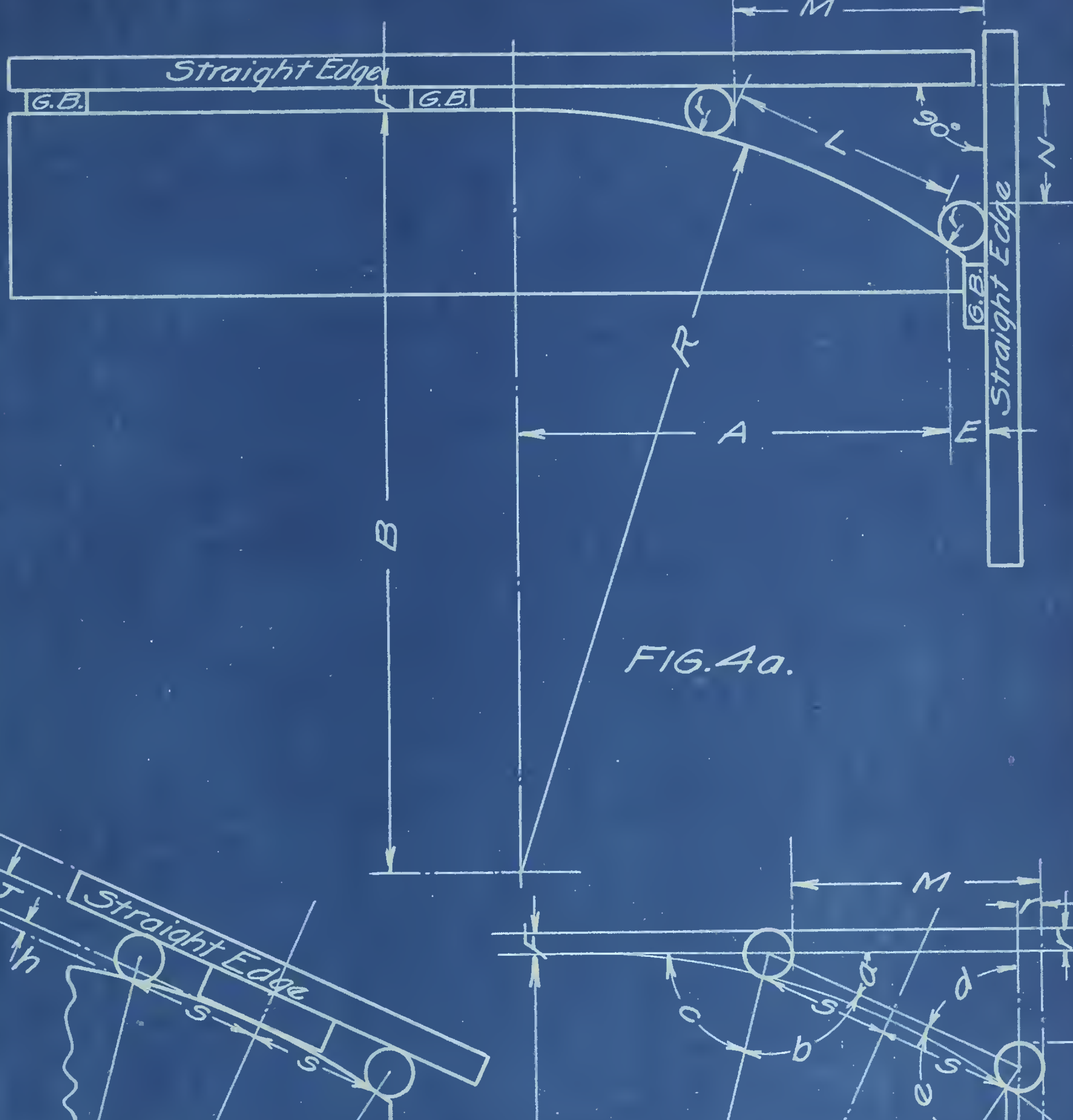


FIG. 4a.

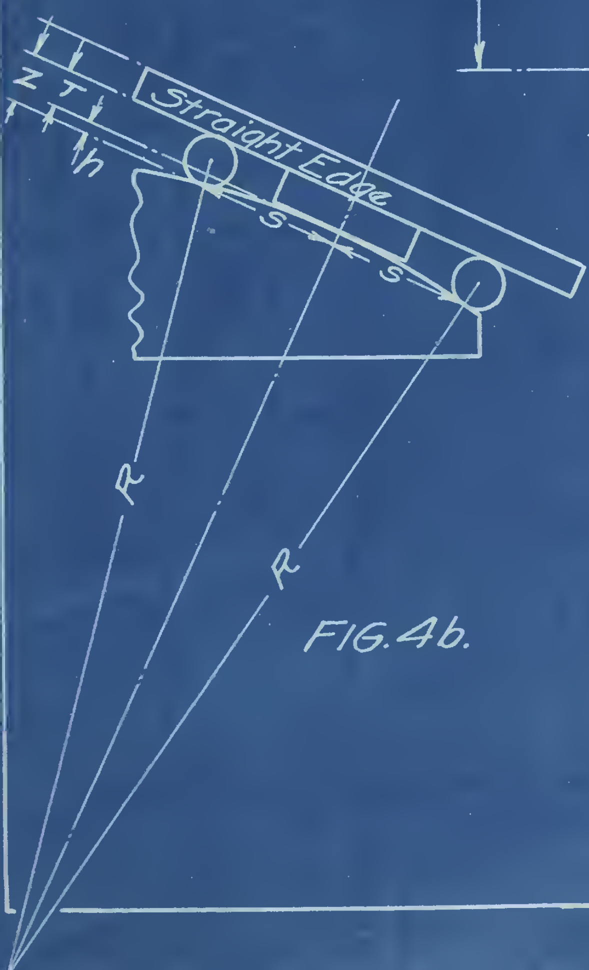


FIG. 4b.

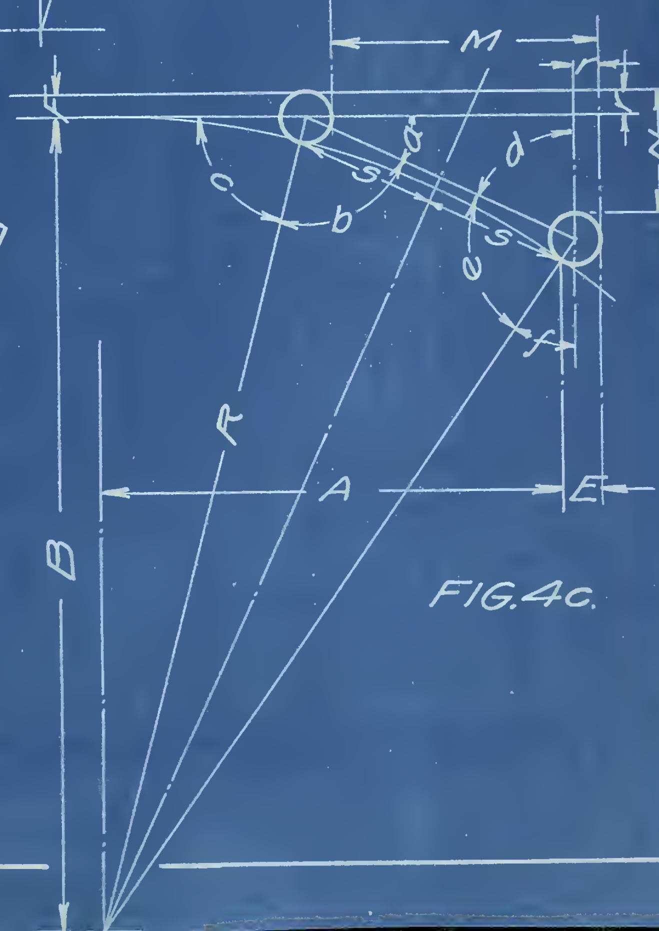


FIG. 4c.

$$h = Z - T$$

$$R = \frac{S^2 + h^2}{2h}$$

The solutions for A and B involve trigonometric functions, tables of which may be found in various handbooks. They are made, with reference to Fig. 4C, as follows:

$$\frac{N}{M} = \tan a$$

$$\frac{S}{R} = \cos b$$

$$c = 180° - (b+a)$$

$$B = (R+r) \sin c - (F-r)$$

$$\frac{M}{N} = \tan d$$

$$e = b$$

$$f = 180° - (d+e)$$

$$A = (R+r) \sin f - (E-r)$$

In a similar manner the radius and center of curvature of the curve on the female gage for the profile of a shell is determined:

a. Clamp two straight edges or parallel bars to a surface plate at 90° to each other as shown in Fig. 5A.

b. Clamp two accurately ground circular discs or toolmaker's buttons of equal radius r at a measured distance L apart, and each in contact with a straight edge and the curve of the profile.

c. Clamp the gage in position as shown. By mdans of gage blocks determine the dimensions E, F, M and N.

d. Keeping the gage and discs clamped in position, remove the straight edges and clamp one of them in contact with the discs as shown in Fig. 5B. By means of gage blocks and an accurately ground plug of known diameter determine the dimension T at the point midway between the discs.

e. From the dimensions thus obtained the values of R, A and B are computed as in the previous case. The values of S, h and R are derived from the geometric relations shown in Fig. 4B as follows:

$$S = \frac{R\left(\frac{L}{2} + r\right)}{R - r}$$

$$Z = r + \frac{r}{R}\sqrt{R^2 - S^2}$$

$$h = T - Z$$

$$R = \frac{S^2 + h^2}{2h}$$

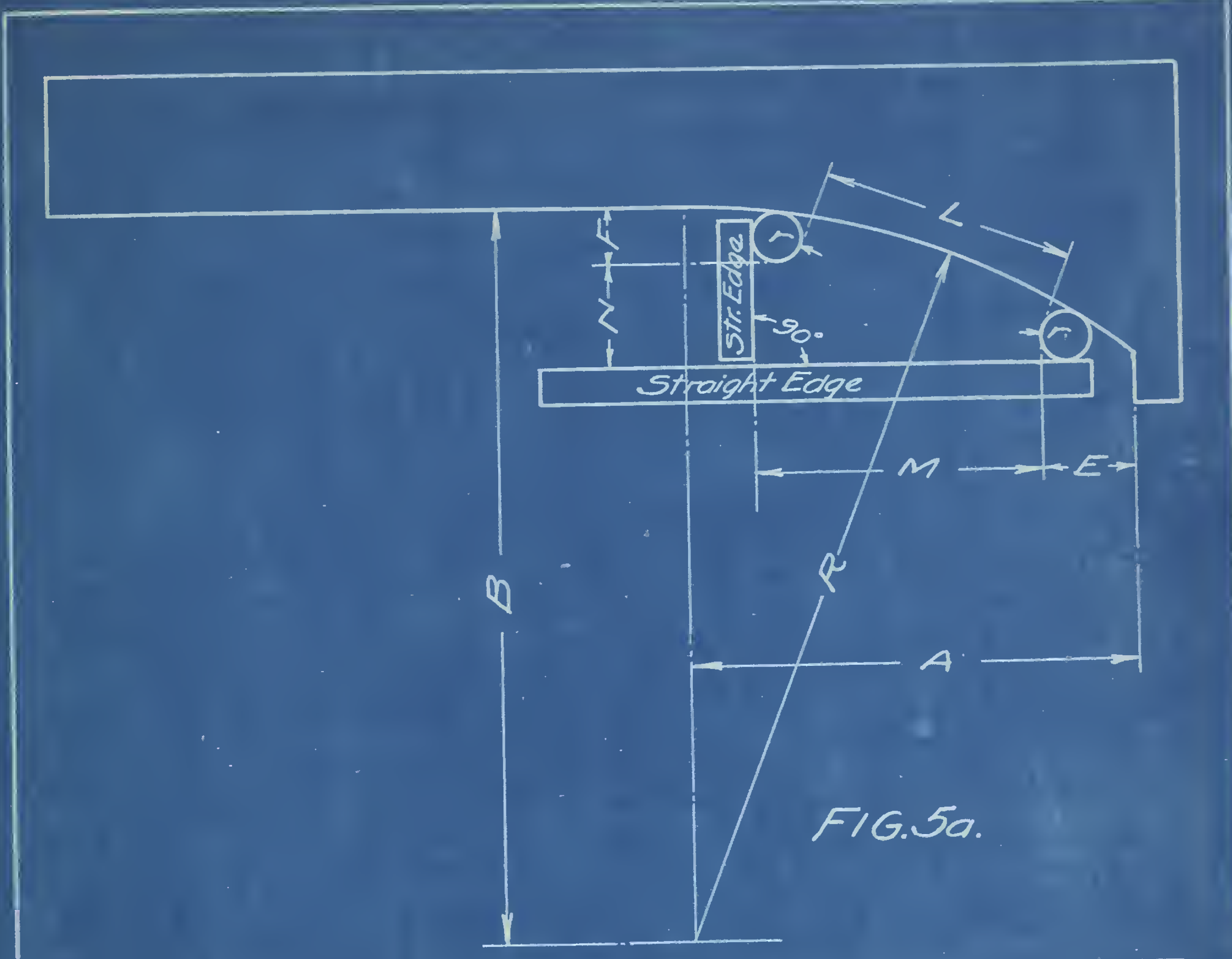


FIG. 5a.

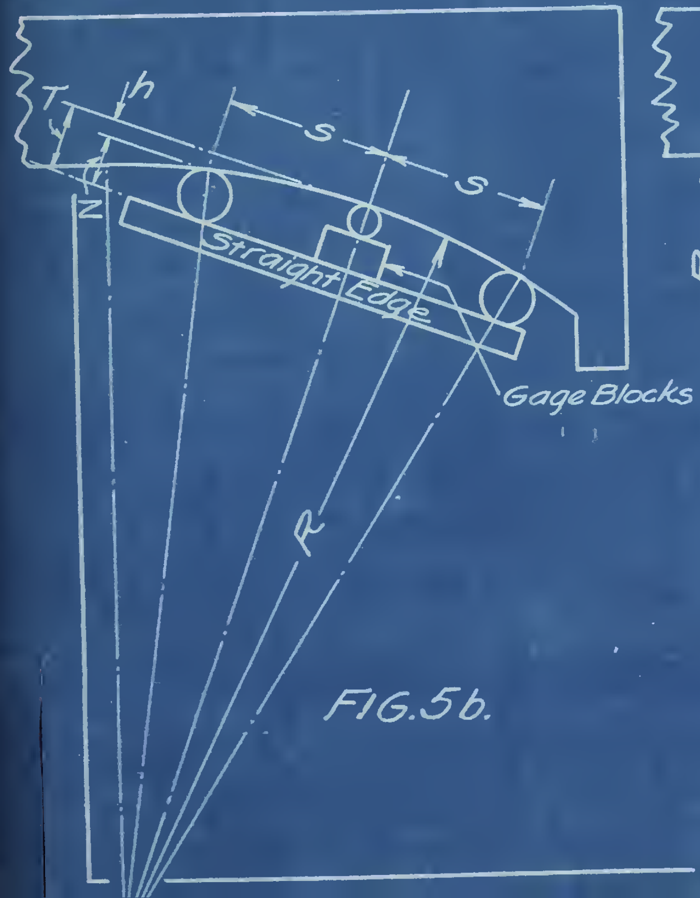


FIG. 5b.

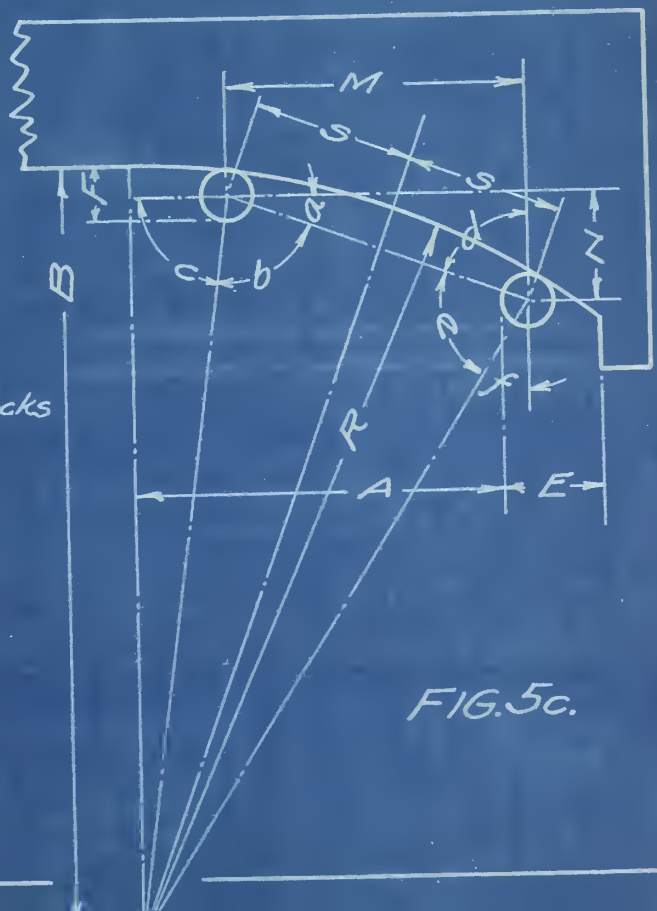


FIG. 5c.

The values of A and B are computed from the relations shown in Fig. 5C as follows:

$$\frac{N}{M} = \tan a$$

$$\frac{S}{R} = \cos b$$

$$c = 180° - (a+b)$$

$$B = (R-r) \sin c + (F-r)$$

$$\frac{M}{N} = \tan d$$

$$e = b$$

$$f = 180° - (d+e)$$

$$A = (R-r) \sin f + (E-r)$$

In Fig. 6 is shown a plate having three slots in which the buttons used in the above method may be clamped by means of screws. Two edges are ground and lapped at right angles to each other.

Methods of Measuring Small Radii.

The methods previously described are not adapted to the testing of arcs of small radii and it is therefore necessary to use other apparatus and methods in such cases. The methods applied depend upon the character of the gage and the accuracy required. Seven different methods of inspecting small radii are presented herewith.

1. A method commonly used for testing radii is that of matching the radius to be tested with an arc of correct nominal radius laid out on a sheet of blackened zinc. The zinc is blackened by coating with a solution of four ounces sulphate of copper, one pint of water, and ten drops of nitric acid. The arc is marked on the sheet by means of a pair of dividers. An accurate means for setting the dividers is provided by points placed on the bar and slide of a vernier caliper. This method can not be relied on to give an accuracy better than .002 inch and may, therefore, be used only when greater precision is not required.

2. A method quite similar to the previous method is followed, in the case of a female arc, by placing the arc to be tested against the surface of a plug accurately ground to a diameter corresponding to the nominal radius of the arc and noting whether the curvature matches. By observing the contact with the aid of a magnifying glass any irregularities in the curvature can be detected. The test of male templates is somewhat more difficult but a test template may

FIG. 6. BUTTON PLATE TO TEST RADII.

be produced by reaming a hole, of the correct nominal radius, in a thin steel bar and splitting the bar. This method is unsatisfactory when the piece to be tested has any considerable thickness since in that case the contact can not be properly observed.

3. This Bureau has found the optical projection lantern very useful as a means for testing radii of .2 inch or less. A beam of parallel light is projected over the gage to be tested and the resulting shadow is magnified about seventy-five times and cast on a screen by means of a suitable lens arrangement. This shadow is matched against various arcs of known radius drawn on celluloid or other suitable material until one is found which matches the shadow exactly. The radius of this arc divided by the exact magnification of the shadow, gives the radius of the arc under test. A description of this lantern is available in Communication B510.

4. A simple method for measuring the radius of an arc on a male profile involves the apparatus shown in Fig. 7. A V-block is shown with a hole drilled through the bottom, through which is inserted the spindle of a depth micrometer. A reference standard consisting of a ground steel rod of any suitable radius, A, is provided. The test is made by determining the distance E, between the position which the reference standard takes in the V and the corresponding position of the arc to be tested, by means of the depth micrometer. When the angle of the V-block is exactly 90° the radius, R, of the arc to be tested is obtained by the formula:

$$R = A - 2.4142E$$

If the angle of the V-block is some value other than 90°, R is determined by the formula:

$$R = A\frac{1 - \cos M}{1 - \sin M} - E(\sec M + \tan M) \text{ in which}$$

$$M = 90° - \frac{1}{2} \text{ the angle of the V-block.}$$

The formula is derived, with reference to Fig. 7A, as follows:

$$(A + E)\cos M + a = A$$

$$a = R - R\cos M$$

$$(A + E)\cos M + R(1 - \cos M) = A$$

$$R = \frac{A - (A+E)\cos M}{1 - \cos M}$$

$$= \frac{A(1 - \cos M)}{1 - \cos M} - \frac{E\cos M}{1 - \cos M}$$

$$= A - \frac{E\cos M}{1 - \cos M}$$

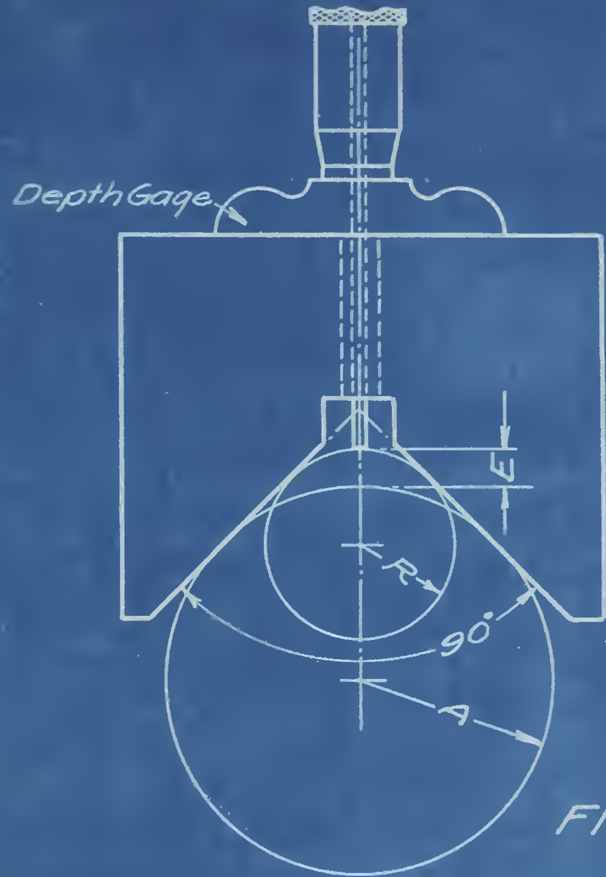


FIG. 7.

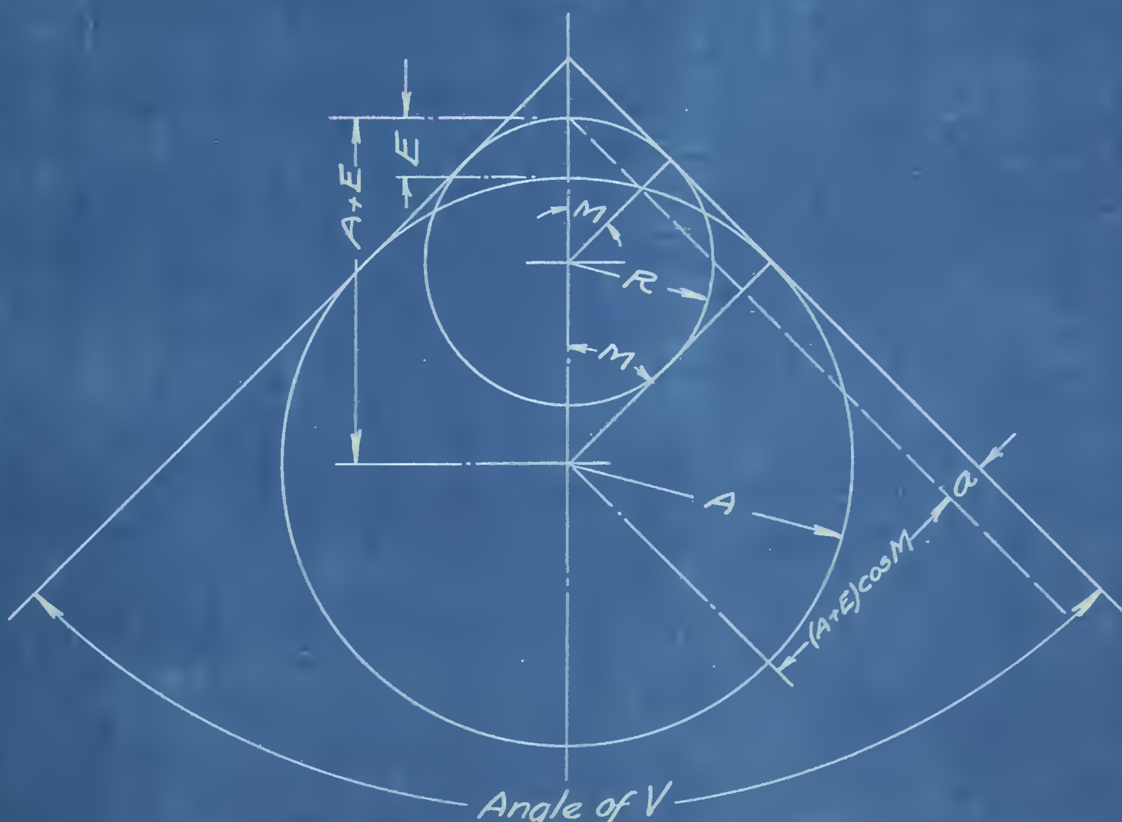


FIG. 7A.

When the angle of the V is 90°, M = 45° and

$$R = A - 2.4142E$$

5. Small concave radii may be conveniently measured by means of two small cylinders or wires which are accurately ground to the same diameter. The two wires are inserted in the arc and the measurement B (Fig. 8) is taken. A single wire is then used and the measurement A is made. The radius r of the wires being known, the desired radius R is given by the formula,

$$R = \frac{(D + r)^2}{2D}$$

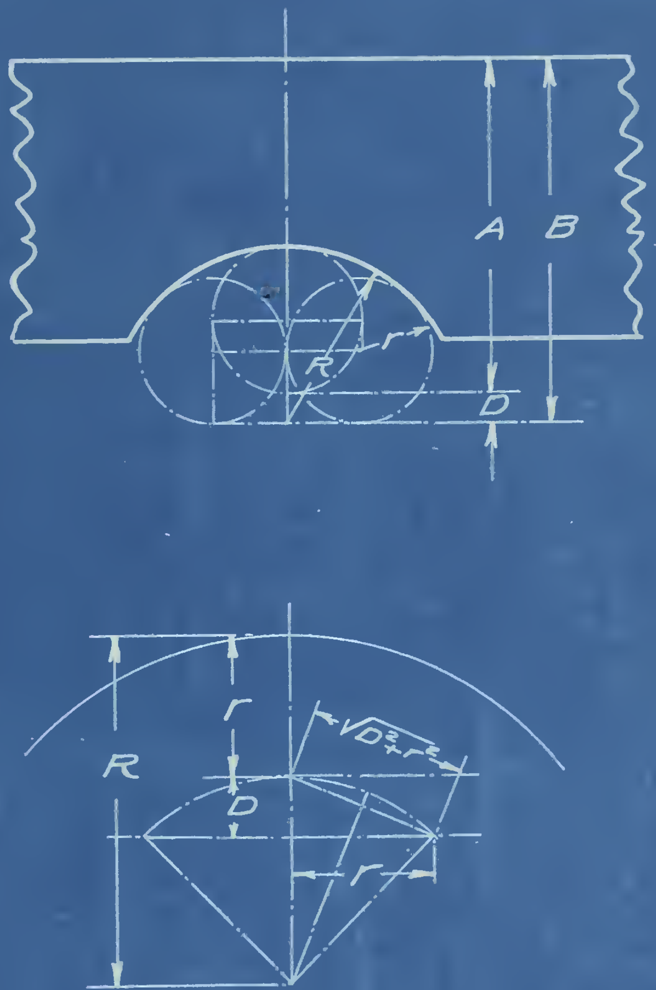
in which $D = B - A$

6. There is illustrated in Fig. 9 a fixture, designed by the Gage Section of this Bureau, which, with an indicator mounted on a height gage and gage blocks, provides a means for measuring the radius of a profile. The fixture consists of a face-plate mounted on an accurately ground cylinder which is supported by a V-block; the whole arrangement is set on a surface plate. The gage is first clamped to the face-plate with the arc to be tested as nearly concentric with the plate as can be judged by the eye. The gage is finally located by adjusting its position until there is no variation in the reading of the indicator when the point of the indicator is in contact with the arc and the face-plate is rotated. A gage block combination is set up which gives the same reading on the indicator and the difference between this dimension and the height of the center of rotation of the face-plate is the radius of the arc tested. Toolmaker's buttons may be clamped to the face-plate and used as locating points for determining the relation between the center of the arc and gaging points on the gage. This method involves the difficulty that the gage must be located by trial.

7. A method by which the indicator is rotated instead of the gage, as in the previous case, is carried out by means of a machine, the general design of which is illustrated in Fig. 10. A fixture of this kind, with the difference that a micrometer microscope instead of an indicator was used, has been built and used at one of the government arsenals. Such a machine is not only useful for measuring radii but, with a lateral motion of the fixture and a transverse motion of the indicator or microscope provided, it may be used to determine the dimensions relating various combinations of straight and curved sections on irregular profiles. An example of one of the applications to which it has been put is the measurement of the contour of rifle bullets (which must conform within close limits to a given size and shape).

The indicator A, is mounted on a cross-arm B, which is pivoted at each end to holders C. The fulcrum pins of the cross-arm are adjustable along the holders and are accurately located by means of gage blocks in any desired position. All pins have a semi-circular

FIG. 8.



$$R = \frac{(D+r)^2}{2D}$$

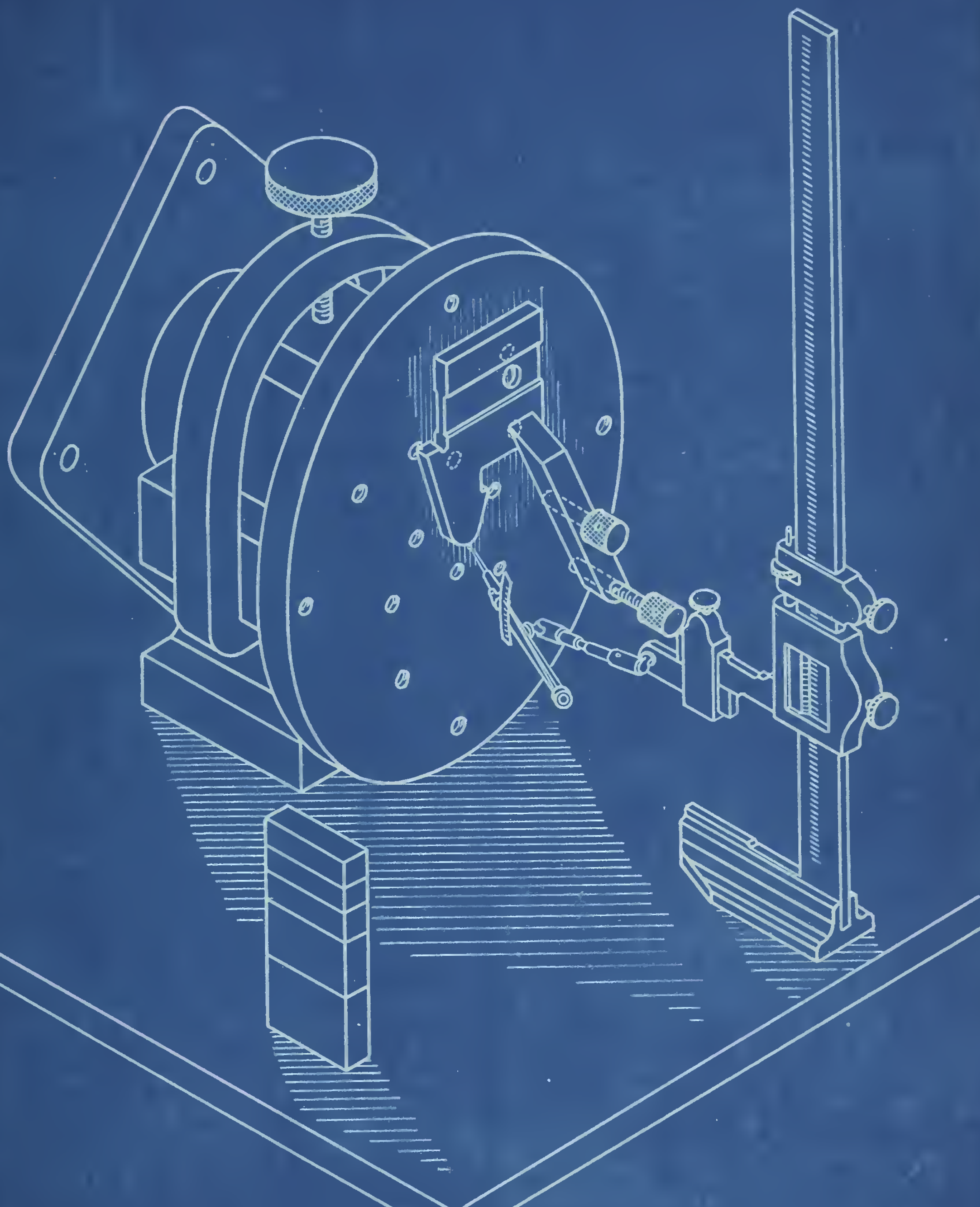
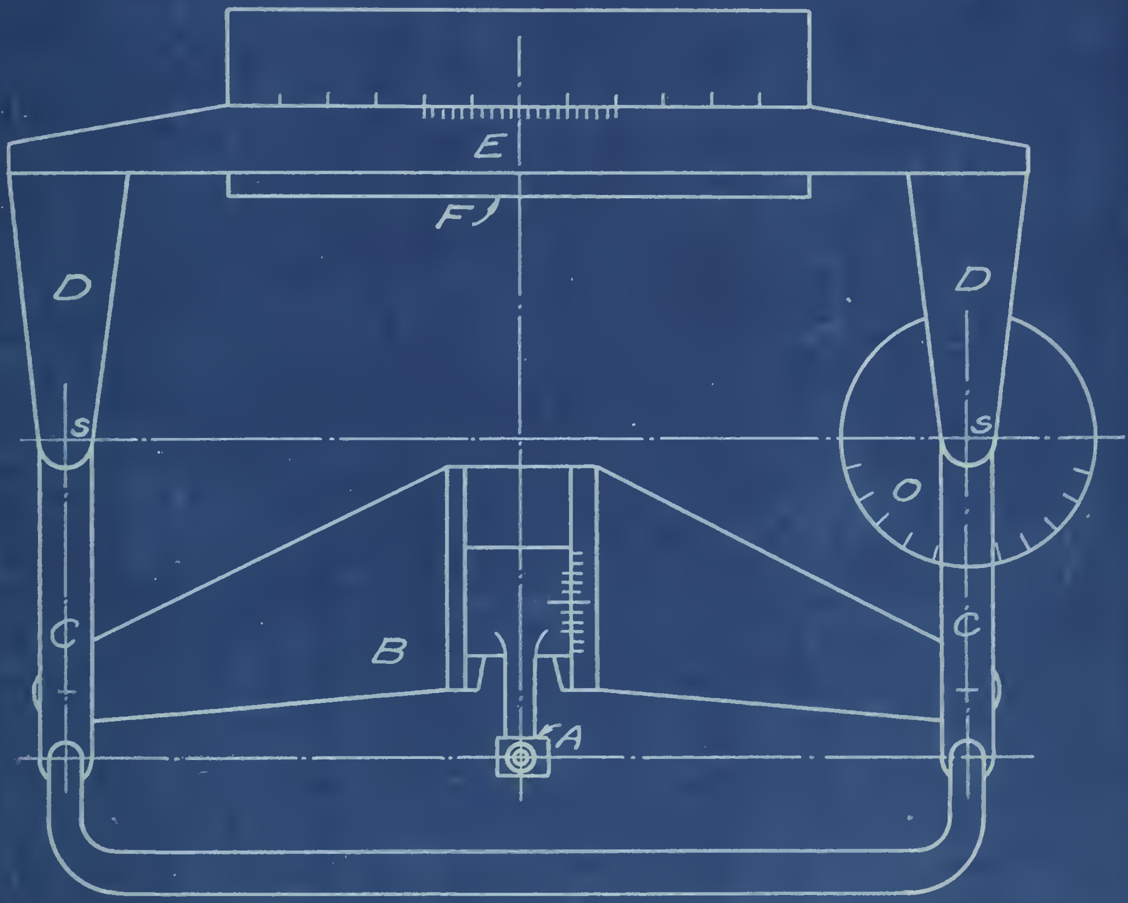


FIG. 9.

FIG. 10.



section inside the holder, thus permitting the fulcrum of the holder and that of the cross-arm to be made concentric if desired; accordingly a radius from zero up to the length of the holder may be measured. For example, if .020 inch blocks are inserted in each holder a radius of this dimension can be accurately measured. The gage-block holders are pivoted to brackets D attached to slide E, on which means is provided for clamping and measuring the lateral adjustment, and the outer ends of the holders are connected by tie-rods. The indicator, or microscope, is carried on a slide which can be adjusted at right-angles to the straight edge F, and motion along this slide may be measured by means of gage blocks or a micrometer. The circular movement of the indicator and its carriage is indicated on the graduated circle O. These adjustments and means of measurement permit the accurate determination of the movements of the indicator parallel or perpendicular to the straight edge F or along a circular path.

The work to be inspected is placed on the surface plate which forms the base of the instrument and may be located with reference to the straight edge F. When measuring the radius of an arc the pivots of the cross-arm B are set in the line of the fixed pivots S. The point of the indicator is then set in line with the center of the arc, this center being located by adjusting the indicator laterally and transversely with reference to locating points on the work and nominal dimensions of the gage. The cross-arm pivots are then adjusted to the required radius by inserting gage blocks in the holders C. When these adjustments are completed there is no variation in the reading of the indicator as it is swung over the arc when the radius is correct and the center of curvature is properly located.

A complete description of this machine is given in the June 1918 number of "Machinery". Other machines, have been designed to work in a similar manner and if accurately built usually give good results. Their construction is, however, rather expensive and since equally good results can, in most cases, be obtained by other methods, they are being used only where there is a considerable amount of profile work inspected.

BUREAU OF STANDARDS.