In several industries it has become necessary to measure and control with high precision the distances between the centers of holes with small diameters (0.5-5 mm). To date this testing was normally made with universal microscopes. The precision in measuring the distances between axes depends substantially on the precision in evaluating the coordinates of the centers of holes, and this precision in turn depends mainly on the random errors due to the superposition of the hole and eyepiece axes. In universal microscopes this superposition is attained visually with the tester aiming at "inscribing" in the best manner one of the concentric circumferences of the microscope's radial head into the outline of the actual hole. It has been found that in a single measurement it is impossible to guarantee an error of less than 5-8 μm, which is approximately five times higher than the tolerated error \[1\]. A further rise in the precision of testing depends on the centering of holes in an objective manner. Moreover, an objective centering of holes would facilitate the tester's work, raise its efficiency, and provide the required prerequisites for producing completely automatic machines for evaluating the distances between centers.

In analyzing the various methods for an objective centering it is above all necessary to note that in engineering the concept of "center of a hole" is purely nominal, since the outline of a real hole is a complicated curve of an irregular shape. However, this outline approaches a circumference and, therefore, it is possible to approximate it to a circumference and to consider its center as that of the hole. According to GOST (All-Union State Standard) 10356-63 such an approximation consists of an inscribed circumference with the largest possible radius (the so-called "adjoining" circumference). The maximum distance from the actual hole profile to the adjoining circumference is known as noncircularity. It can be determined in the following manner (Fig. 1a). Let us draw, from center \(O\)' of the adjoining circumference with radius \(R_1\) a circumference which has the minimum radius \(R_2\) and encloses the entire actual outline of the hole. The width \(A_n = R_2 - R_1\) of the ring formed by the concentric circumferences then determines the noncircularity.

At present there are no devices for finding objectively the center of the hole defined by the standard. Any of the existing devices cite a certain "equipment" center of the hole and, therefore, they have an inherent error which is a function of noncircularity \(A_n\).

We shall classify the devices for an objective sighting by their method of determining the "equipment" center of the hole.

**Method of Extreme Points (Fig. 1b).** The outline of the actual hole is given in the system of rectangular coordinates \(XOY\). Let us draw tangents \(x', x''\) and \(y', y''\) parallel to the corresponding coordinate axes. The coordinates of the "equipment" center of the hole can then be determined as

\[
x_{o'} = \frac{x_1 + x_2}{2}, \quad y_{o'} = \frac{y_1 + y_2}{2}
\]

It can be easily shown that the maximum inherent error in this case amounts to \(\delta_m = \sqrt{2}A_n/2\), where \(A_n\) is the noncircularity of the particular hole.

**Method of Symmetrical Points (Fig. 1c).** Two straight lines of a fixed length \(AB = CD = d\) are given in plane \(XOY\) and set parallel to the corresponding coordinate axes with \(d\) being larger than the maximum hole diameter. Let us displace the outline of the actual hole with respect to these lines until equalities \(Aa = bB\) and \(Dd = cC\) are met, in other words until \(O'a = O'b\) and \(O'c = O'd\). We shall then consider that the position of the "equipment" center has been found. The maximum inherent error of this method also amounts to \(\sqrt{2}A_n/2\).
Method of Equal Areas (Fig. 1d). Let us use the straight lines $x'$ and $y'$, parallel to their corresponding coordinate axes, for dividing the area enclosed in the outline of the hole in such a manner that the areas which are on the opposite sides of these lines are equal to each other, i.e., that $S_1 + S_2 = S_3 + S_4$ and $S_1 + S_4 = S_2 + S_3$, in other words that $S_1 = S_3$ and $S_2 = S_4$. Let us then take intersection point $O$ of the straight lines as the "equipment" center of the hole. The resulting maximum inherent error is $\delta_{\text{in}} = \pi \Delta_2/4$. The application of the "extreme points" method entails the use of transforming optics. The sighting schematic then assumes the following form.

The image of the hole is transformed by means of cylindrical lenses into two mutually-perpendicular lines located in different planes. Each line is then superposed separately on its axial line. This is equivalent to superposing them over the center of the hole along coordinates $x$ and $y$.

As an example let us examine the device developed by the author of this article under the guidance of Professor S. F. Korndorf DSc (Fig. 2).

The device consists of a photoelectric intensity microscope which scans the luminous field occupied by the object and automatically registers the instant when the luminous fluxes on either side of the middle scanning line become equal to each other.

Component 1 with the tested hole is placed on stage 2 which can be displaced by means of micrometer screws in two mutually-perpendicular directions. The hole in the component serves as an opening for the luminous flux produced by lamp 3 and condenser 4. The luminous flux is transmitted to the semitransparent plate 5 located at an angle of $45^\circ$ to the axial line of the luminous beam. Part A of the luminous flux is reflected from the plate and transmitted through the optical system consisting of the spherical objective 6 and the cylindrical lens 7. Part B of the luminous flux falls on the semitransparent plate 8 which is also located at $45^\circ$ to the axial line, it is then reflected from the plate and transmitted through the spherical objective 9 and the cylindrical lens 10. The astigmatic images of the holes (lines) produced by the cylindrical lenses are projected by means of mirrors 11 and 12 onto the plane of the microscope's photodetectors. Since the cylindrical lenses are located at right angles with respect to each other, the lines thus produced are mutually perpendicular. Each of the photoelectric heads 13 and 14 comprise a polarized relay type RP-5 whose armature carries miniature photovaristors SP2-2. The photovaristors' signals are transmitted through preamplifiers 15 and 16 and phase detectors 17 and 18 to the recording pointer indicators 19 and 20. It is known that the instant of a photoelectric intensity microscope's sighting of a graduation corresponds to the zero reading of the pointer instrument. The entire device is adjusted by means of microscope 21 which is used for a visual setting of the hole center.