The main advantage of the "magic eye" consists in the minimum measuring effort it required. Taking into account the requirement of our industry for small hole gauges, and the fact that the "magic eye" may find wide application in many other instruments for linear and angle measurements, the Chelyabinsk gauges plant has developed and produced an experimental model of a "magic eye" attachment for a universal microscope.

Its schematic is shown in Fig. 1. Its "magic eye" consists of tube 6E6. When the probe touches the measured hole the shadow in the tube spreads, thus indicating a contact. The component with the hole under test is placed on the microscope stage. The probe is inserted to a certain depth into the hole, the position of the diameter plane (Fig. 2) is found and the diameter of the hole \( d = L + d_p \) is determined, where \( L \) is the difference in the readings of the microscope scale, \( d_p \) is the diameter of the probe.

The diameter plane \( DD' \) can be found by two methods. The first method consists in finding the maximum value of dimensions \( DD' \) by repeated displacements of the microscope stage in longitudinal and transverse directions. Tests have shown that by means of this method it is possible to find the measuring line \( DD' \) with an error not less than 0.06 - 0.1 mm which, as will be shown later, provides a considerable error in measurements.

The second so-called chord method consists in measuring dimension \( p'q' \) by means of the "magic eye." The position of the measuring line \( DD' \) will correspond to \( \frac{1}{2}p'q' \).

The error in such a setting by means of a universal microscope does not exceed \( 1 \mu \), which, according to calculations has virtually no effect on the accuracy of measurements.

Let us now examine various errors in measuring small holes [1]. When the measuring line \( DD' \) is displaced by \( QB = c \) the probes will touch the hole at points \( A \) and \( A' \) instead of points \( D \) and \( D' \), thus producing an error of

\[
\Delta_c = d - d_c.
\]

Since \( d = L + d_p \) and \( d_c = L_c + d_p \), the error can be determined approximately from the formula

\[
\Delta_c = \frac{c}{r (1-k)}, \quad \text{where} \ k = \frac{r_P}{r}.
\]

This formula provides a calculation exceeding 2%, which is quite satisfactory for computations of referred measurement errors. The above formula shows that this error depends not only on displacement \( c \) of the measurement line, but also on the probe diameter \( d_p \), and that it increases with a large diameter.

The results obtained in measuring rings with diameters of \( d = 1, 3, 5, 7, 10 \) and \( 20 \) mm by means of probes with diameters of \( d_p = 0.5, 2, 3.87 \) and \( 4.04 \) mm for different values of \( k \) agreed well with calculations within the accuracy range of the universal microscope.
The measurement error due to the slope angle $\alpha$ of the measurement line (Fig. 3) or the lack of perpendicularity in the bottom face of the measured hole can be represented as

$$\Delta_a = L_a - L$$

and calculated from the formula

$$\Delta_a = r (1-k) \alpha^2.$$ 

From a comparison of Figs. 2 and 3 and the formulas for determining $\Delta_c$ and $\Delta_{\alpha}$ we can see that $\Delta_c$ always has a "minus" and $\Delta_{\alpha}$ a "plus" sign, thus making it possible to select an optimum size for the probe by finding the value of $k$ for $\Delta_{\alpha} = \Delta_c$.

By solving equation

$$r (1-k) \alpha^2 - \frac{c^3}{r (1-k)} = 0,$$

we find

$$k_0 = 1 - \frac{c}{ra}.$$ 

The roots of this equation are real for $k > 0$.

Fig. 4 shows a nomogram for selecting an optimum size of a probe for measuring a hole having a diameter of $d = 1$ mm. The optimum value $k_0$ is at point A of the intersection of curves $\Delta_c$ and $\Delta_{\alpha}$. In the absence of a probe with a value of $k_0$ it is necessary to use one having a value of $k_1 < k_0$, since a probe with $k_2 > k_0$ would be in the area of the right of point A with a progressively rising measurement error. It will be seen from the drawing that the shaded area to the left of point A represents a total measurement error which has a positive sign and varies but little—providing $\Delta_{\alpha} > \Delta_c$.

The accuracy in establishing the instant of contacting is important in "magic eye" measurements on the universal microscope. The instant of contacting, when a reading was taken on the microscope scale in all the above tests, was assumed to take place when the "magic eye" blinked continuously, thus indicating a "zero effort" electrical contact.

In order to determine the accuracy in establishing the contacting instant on the universal microscope, several operators made repeated contacting tests of the probe with one side of the hole, and obtained readings on the microscope. No dispersion in the readings could be observed. It is interesting to note that when a contact is established between the probe and measured hole with a continuous flickering of the tube, and then the microscope frame is pressed with an effort not exceeding 0.2 - 0.3 kg-wt, a lighting or extinguishing of the tube is observed, i.e., the established contact is disrupted. As soon as the load is removed the system returns to its initial position with a flickering tube. This fact shows, on the one hand, the existence of an elastic deformation in the system even for small loads, and on the other, the great sensitivity of the "magic eye."

Several operators measured more than 200 different holes for the same purpose of determining the accuracy in establishing contact by means of different probes (the value of $k$ in all the cases did not exceed 0.1 - 0.2). The dispersion in the readings did not exceed fractions of a micron as measured on a spiral microscope. In our opinion this dispersion in readings is due to the subjective error of each operator in judging the coincidence of microscope graduations.

The probe should be approached to the side of the measured hole first roughly, by displacing the microscope stage up to a distance of 0.05 - 0.1 mm, and then accurately, by slow rotation of the microscrew until the tube begins to flicker.

The accuracy in determining the instant of contacting was checked by means of a contact interferometer PIU-2 of the "Kalibr" plant calibrated in 0.00005 mm. The probe was approached to a block gauge by means of a differential screw made from the head of a micrometer hole gauge with a measuring rod displacement of 1 µ for one division on the thimble. The end of the screw operated an arresting lever with an arms ratio of $\sim 3:1$. 