METHOD OF MUTUAL COMPENSATION FOR THE ERRORS OF ANGLE TRANSDUCERS

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Photoelectronic angle transducers are used widely in measuring equipment and control instruments. The main precision parameters of such a transducer are the error and reproducability of the measurements, which depend upon the error in manufacturing their functional elements: the code disks (graduation scales), the axis system, the photoelectronic sensing system (SS), and also upon the error in the relative positions of these elements. The error in manufacture can be reduced by improved production methods and by rational design. The error in the relative position of the transducer elements can be eliminated by adjustment.

The present article studies a method of increasing the accuracy of an angle transducer by experimentally determining the optimum ratio of its errors during the adjustment process.

The transducer errors caused by the relative position of its elements can be divided into two groups. The first group includes the errors of the SS itself. These relate to defocussing of the optical system, inclinations of the SS axis to the plane of the marks on the graduated scale, inclinations of the photocathode of the photocell to the optical axis of the system, and certain other circumstances. The second group includes errors that arise during the use of two or more SS, and appear as differences in angle between the two SS in relation to 180° and differences in the parameters of the signals from the SS.

By studying articles [1-3] and by analyzing the errors listed above, we are able to limit ourselves to investigating the parameters of the signals from the SS photocells: the ratio between the amplitudes of the signals (the maximum voltage at the output of the photocell U_{max}) and the ratio between the durations of the signals at the level U_m/U_{max} (where U_m is the measurement level) which is determined experimentally on the linear part of the rise time of the signal.

The angle transducer was investigated on the equipment shown in Fig. 1. The transducer consists of an optical scale 4 rotating in guides 2, two SS (SS_1 and SS_2) 5, arranged at 180°, and photocells 3. To check the readings of the transducer, we used a standard multiface prism 1, rigidly fixed to its axis. The readings of the transducers were registered on a V7-23 digital voltmeter 6 of class 0.04/0.02 accuracy. The position of the prism was fixed with the aid of an AK-0.25 autocollimator 7. The method of checking the accuracy of the transducer is considered in detail in [4].

The mean-square deviation of the measurements was determined by means of the accepted formula

$$\sigma=\frac{1}{3}\sqrt{\Delta_A^2+\Delta_B^2+\Delta_C^2}=0.31'',$$

where Δ_A is the maximum permissible measurement error of the autocollimator: $\Delta_A = 0.25 + \varphi/100 = 0.3''$; ($\varphi$ is the measured angle (not less than 5.0"). Δ_B is the maximum permissible error of the voltmeter, equal to $2\cdot 10^{-4}$ V, which corresponds in angular measure to 0.03"; $\Delta_C = \pm 3\sigma_C$ with a probability of P = 0.997; σ_C is the mean-square deviation of the measurements of prism angle (0.3").

The ratio of the amplitudes of the SS signals was set by a change in the supply voltage to one of the incandescent lamps. From the measurements we obtained, we plotted the relationship of the transducer errors Δ_E to the ratio of the signal amplitudes U_1/U_2, obtained from SS_1 and SS_2, respectively (Fig. 2a). This relationship is practically linear, the line intersecting the abscissa at the point $U_1/U_2 = 1.5$, after which it continues into the region of negative values of Δ_E. We can see from this that the ratio of amplitudes $U_1/U_2 = 1$ (i.e., $U_1 = U_2$) is not the best for such transducers, and that the region of low transducer error is found in the neighborhood of the point $U_1/U_2 = 1.5$.

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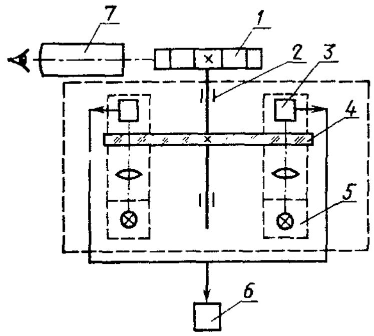

Fig. 1

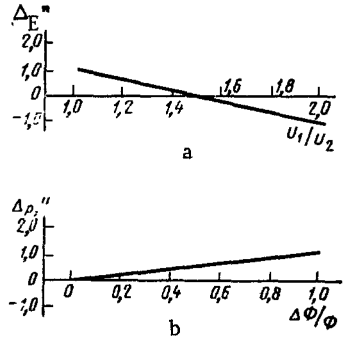

Fig. 2

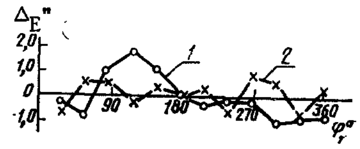

Fig. 3

However, [5] gives the following formula for finding the error in compensating for eccentricity when using bilateral readout:

$$\Delta\varphi = \frac{e \sin\gamma}{2R} \cdot \frac{\Delta\Phi}{\Phi}, \tag{1}$$

where e is the eccentricity of the scale; γ is the angle between the direction of eccentricity and the line of readout; R is the radius of the scale; $\Delta\Phi$ is the difference in light flux from the two SS.

Figure 2b gives the calculated relationship of $\Delta p = f(\Delta\Phi/\Phi)$. In this, the value $\Delta\Phi$ is taken as the difference in the light fluxes, proportional to $\Delta U = U_1 - U_2$. The resulting relationship is a straight line, which increases continuously with $\Delta\Phi$. Under these circumstances, the optimum value will be $\Delta\Phi/\Phi = 0, \Phi_1 = \Phi_2$. As we can see, the experimental line (Fig. 2a) differs from the calculated relationship (Fig. 2b), which can be explained by the influence of the errors introduced by inequalities in the durations of the signals.

For this reason, we determined the duration of the signals from SS_1 and SS_2 on the same installation. The measurements show that the durations of the signals differed by 20%. The reason for this is connected with errors in the SS themselves, which resulted in different rise times of the signal, leading in turn to transducer error.

The rise times of the signals from the SS can be equalized by varying the amplitude or duration of the signal from one of the SS. It was not possible to vary the duration of the signal to the extent necessary, due to errors inherent in the SS itself. We therefore increased the amplitude of signal U_1 to a value $U_1 = 1.5U_2$, which a study of the amplitude ratio of the signals had shown to be optimum. The results of our investigations of the errors in a photoelectric angle transducer having the parameters determined above are given in Fig. 3, in which curve 1 corresponds to $U_1/U_2 = 1$, while curve 2 corresponds to $U_1/U_2 = 1.5$. As we can see from this graph, the maximum transducer error has been reduced by a factor of 1.6 (to 1.0") by using the optimum ratio of amplitudes.

In this way, the ratio of the signal amplitudes of the SS can only be established after their durations have been measured. Formula (1) is valid in the special cases in which the durations of the signals from SS_1 and SS_2 are equal, or for the ideal system.

Our investigations have shown that for the case of real photoelectric angular displacement transducers of this type, assembly errors can be compensated by an appropriate variation in the parameters of the signals generated by the SS.

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