The stability and sensitivity of photoelectric recording devices (let us call them for the sake of brevity phototransducers) is raised by using them in differential circuits based on the comparison of two luminous fluxes.

A further development of this method consists in the recently produced scanning transducers which do not require an optical system to separate the compared luminous fluxes. Scanning phototransducers are widely used in systems requiring precise focusing on a graduation.

The principle of operation of a scanning phototransducer is shown in Fig. 1. The ray of light from lamp 1 illuminates graduated scale 3 through optical system 2. The image of a graduation is projected through optical system 4 and slit 5 onto phototransducer 6 which can consist of photocells, photomultipliers or photovaristors. The image of the graduation effects a relative oscillating scanning movement over the surface of the phototransducer. This movement is accomplished in various constructions by means of vibrating mirrors, slits or phototransducers. Two pulses are produced in the phototransducer circuit at twice the scanning frequency, since for each oscillation the graduation image passes twice over the phototransducer.

The two pulses have the same shape when the axis of scanning coincides with that of the graduation projection. These pulses have different shapes when the graduation projection axis is displaced with respect to the center of scanning. The lack of balance can be measured by comparing two adjacent pulses. The comparison is made in two ways.

In laboratory practice (in comparators of graduated measures or universal interference comparators for measuring graduated or block gauges) more complicated circuits are used with comparison of pulses by their duration [1, 2, 3].

In industry (in devices for precision focusing on graduations in coordinate-raster machines) circuits are used for comparing by means of areas, i.e., by the mean current value over half a period [4, 5].

Let us examine the second, more simple circuit.

Signals are fed from the phototransducer to an electronic measuring circuit which separates the adjacent pulses between two measuring channels and then provides the difference between the mean values of these channel currents.

The phototransducer current is proportional to the luminous flux

\[ i = \kappa S_{11} F, \]

where \( S_{11} \) is the illuminance; \( F \) is the area of the illuminated window; \( \kappa \) is the coefficient of proportionality.

For \( S_{11} = \text{const} \) and a constant length \( l \) of the slit, the luminous flux is proportional to the width \( h \) of the illuminated portion of the slit.

\[ i = \kappa S_{11} lh = \kappa h. \]

Thus, the phototransducer current is determined, within the linear range of its characteristic, by the law representing the variations in the width of the illuminated portion of the slit.

The shape of the luminous pulses (see Fig. 2) is thus determined by the relationship of the following variables in the plane of the phototransducer's sensitive layer: slit width \( a \), graduation image width \( b \), scanning amplitude \( A \), and the displacement \( Ax \) of the graduation image oscillation axis with respect to the slit axis (it is assumed that the
graduation is scanned with respect to a stationary slit.

The schematic of Fig. 2 illustrates the principle of operation of the device in the most general case when \( a \neq b \) and \( a \neq A \). The graduation oscillation axis is displaced by \( \Delta x \) with respect to the slit axis.

For a sinusoidal law of scanning \( x = A \cdot \sin(\omega t) \) and \( h \) also varies sinusoidally with the same amplitude from \( (a-b) \) to \( a \).

The shape of the current pulses is determined by oscillations in the direction coinciding with that of the displacement

\[
i(t) = \begin{cases} 
\kappa_1 (a-b) & \text{for } t=0-t_1 \\
\kappa_1 A \sin(\omega t) & \text{for } t=t_1-t_2 \\
\kappa_1 a & \text{for } t=\left[t_2-\left(\frac{T}{2}-t_2\right)\right] \\
\kappa_1 A \sin(\omega t) & \text{for } t=\left(\frac{T}{2}-t_2\right)-\left(\frac{T}{2}-t_1\right) \\
\kappa_1 (a-b) & \text{for } t=\left(\frac{T}{2}-t_1\right)-\frac{T}{2} 
\end{cases}
\]  

\[t_1 = \frac{\alpha_1}{\omega} = \frac{1}{\omega} \arcsin \frac{a-b-2(\Delta x)}{2A};\]

\[t_2 = \frac{\alpha_2}{\omega} = \frac{1}{\omega} \arcsin \frac{a+b-2(\Delta x)}{2A}.\]  

The shape of the second pulse is similar in nature and differs only in the value of its time intervals (see Fig. 2).

\[t_3 = \frac{\alpha_3}{\omega} = \frac{1}{\omega} \arcsin \frac{a-b+2(\Delta x)}{2A};\]

\[t_4 = \frac{\alpha_4}{\omega} = \frac{1}{\omega} \arcsin \frac{a+b+2(\Delta x)}{2A}.\]

The mean current value in each pulse is

\[I_m = \frac{2}{T} \int_0^T i dt = \frac{1}{\pi} \int_0^\pi \sin \alpha.\]

We thus obtain for the first pulse

\[I_{m1} = \frac{2\kappa_1}{\pi} \left[ A (\cos \alpha_1 - \cos \alpha_2) - (\alpha_2 - \alpha_1) c_1 + \left(\frac{\pi}{2} - \alpha_2\right) b \right],\]

\[c_1 = \frac{a-b}{2} - \Delta x.\]  

For the second pulse we have

\[I_{m2} = \frac{2\kappa_1}{\pi} \left[ A (\cos \alpha_3 - \cos \alpha_4) - (\alpha_4 - \alpha_3) c_2 + \left(\frac{\pi}{2} - \alpha_4\right) b \right],\]

\[c_2 = \frac{a-b}{2} + \Delta x.\]