RAISING THE SENSITIVITY OF PHOTOGALVANOMETRIC COMPENSATED INSTRUMENTS

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Photogalvanometric compensated instruments (photocompensators) are highly stable, precise and rapid in operation, they consume a small energy from the measuring circuit, and they are adequately protected from external electromagnetic fields. However, the basic quality which accounts for their wide utilization in various fields of science and technology consists of their high sensitivity.

The theoretical threshold of sensitivity of photogalvanometric amplifiers is determined by the level of their input-resistance thermal noise and the random Brownian oscillations of the galvanometer coil, whose total energy amounts to

$$\overline{\epsilon} = \frac{1}{2} kT,$$

where $k$ is the Boltzmann constant, $T$ is the temperature of the medium in °K.

An evaluation based on the above formula for a galvanometer's theoretical threshold of sensitivity was first made in [1]. The fluctuation threshold of sensitivity for a photogalvanometric compensated amplifier can be determined from its transfer function. Taking into consideration that galvanometers of highly sensitive instruments usually operate in an overdamped condition, let us write their transfer function in the form

$$I(p) = \frac{S_u K_c}{T_0 \beta p + 1},$$

where $S_u$ is the voltage sensitivity of a photogalvanometric voltage compensator; $T_0$ and $\beta$ are the period of its natural oscillations and the degree of damping; $K$ is the conversion factor of the photoelectric transducer. These quantities are related to the parameters of the measuring mechanism and of the circuit by the expression [2].

$$S_u = \frac{\psi}{\Sigma r W}; \quad T_0 = 2\pi \sqrt{\frac{J}{W}}; \quad \beta = \frac{P}{2 \sqrt{J W}},$$

where $\psi$ is the measuring mechanism's flux linkage in Wb-turns; $I$ is the moment of inertia in kg·m² of the moving part; $P$ is the damping factor in N·m·sec/rad of the moving-coil torsion oscillations; $\Sigma r$ is the galvanometer circuit resistance in $\Omega$; $W$ is the specific opposing moment in N·m/rad.

In the absence of a galvanometer-shunting resistance we have

$$W = W + \frac{\psi K_c r f_b}{\Sigma r},$$

where $W_m$ is the specific mechanical opposing moment in N·m/rad of the measuring mechanism's taut suspensions; $f_b$ is the feedback resistance in $\Omega$. 753
The fluctuations' spectral density $S(\omega)$ of the output current in a photogalvanometric compensated voltage amplifier with a transfer function of (1) is related to the input-noise spectral density $S_n(\omega)$ by the expression

$$S(\omega) = S_n(\omega) \frac{S_n^2 K_C^2}{1 + \frac{T_0 \omega^2}{\pi^2 \omega^2}}.$$  \hspace{1cm} (2)

It is known from [8] that

$$S_n(\omega) = \frac{4\pi \Sigma r_i}{\pi},$$

where $\varepsilon = 2 \cdot 10^{-21}$ J is the fluctuations energy for one degree of freedom at 20°C.

The rms value of the input current fluctuations in a photogalvanometric voltage amplifier is

$$\bar{e} = \int_{0}^{\infty} 4\pi \Sigma r_i \frac{S_n^2 K_C^2 d\omega}{1 + \frac{T_0 \omega^2}{\pi^2 \omega^2}} = \frac{2\pi \Sigma r_i S_n^2 K_C^2}{T_0 \beta}.$$ \hspace{1cm} (3)

By referring the above expression to the input and assuming that for a single measurement the sensitivity limit is equal to the rms value of the emf fluctuations in the second circuit, we obtain

$$\bar{e}_r = S_n K C r_k \sqrt{\frac{2\pi \Sigma r_i}{T_0 \beta}}.$$ \hspace{1cm} (4)

The decay time of the photocompensator is $t_d = 1.2 BT_0$. Usually $W_m \ll W$ and, therefore, (4) can be reduced to the expression obtained by G. Ising for galvanometers,

$$\bar{e}_r = 1.12 \cdot 10^{-10} \sqrt{\frac{2 \pi r_i}{t_d}}.$$  

If we assume that $e_X$ is the instrument's absolute error and the measured voltage is $e_{in}$, the relative error will be

$$\frac{e_x}{e_{in}} \approx 10^{-10} \cdot \frac{1}{\sqrt{e_{in} \bar{e}_r \frac{t_d}{t_d}}} = 10^{-10} \cdot \frac{1}{\sqrt{e_{in} i_0 W_m}}.$$ \hspace{1cm} (5)

where $i_0 = e_{in} / \Sigma r$ is the switching-on current [2].

In a steady-state condition the consumption of a compensated instrument is determined by the current:

$$i = \frac{i_0 W_m}{W_m + W_0}.$$ 

Expression (5) demonstrates graphically the relationship discovered by G. Ising between the instrument's error, consumption and speed of operation. A more detailed analysis of this relationship is contained in [4].