OPTICAL MEASUREMENTS

A RATIO-MEASURING PHOTOMETER

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The use of the logometric method (i.e., the method of measuring ratios) in designing photoelectric measuring equipment makes it possible to avoid the greater part of the defects which are inherent in direct-reading photoelectric instruments and in instruments based on measuring or balancing the difference of the two fluxes being compared.

The strict application of the logometric principle presupposes the existence of a) a common source of light which determines the luminous flux of both the objects being compared (obviously excepting the case when the objects being compared consist of two light sources); b) a common transducer; c) a single-channel amplifier in the electronic measuring circuit, i.e., a strictly single-channel operation both in the optical and electronic circuits of the equipment.

The fulfillment of these conditions provides a complete elimination of the effect of possible instabilities of the parameters or conditions of operation of the light source, light-sensitive elements and electronic circuit components on the measurement results. The application of the logometric method thus makes it possible to develop instruments which provide considerable stability and good reproducibility of measurements.

The method discussed in this article can be used for constructing photometers which facilitate the solving of various spectroanalytical problems. The same electronic measuring device can be used in practice for the solution of all such problems. The pecularities of any particular optical measurement are taken into consideration when the corresponding opticomechanical device is being designed to serve as a transducer for the electronic circuit.

The two luminous fluxes which are to be measured are first modulated by means of some modulating device with two frequencies f_1 and f_2 which are not in a harmonic relation to each other (Fig. 1). After modulation both luminous fluxes are fed to the cathode of a photomultiplier (or photocell), thus producing at the photomultiplier output a complex electrical signal, which consists of the sum of two oscillatory processes approaching a sinusoidal shape. Providing the value of the measured luminous fluxes does not exceed the linear portion of the photomultiplier light characteristic, the relation of the amplitudes of these oscillations will be determined only by the ratio of the luminous fluxes and will be independent of the sensitivity, fatigue or supply voltage of the photomultipliers.

The electronic circuit amplifies the total signal linearly without changing the ratio of the amplitudes. The division of the signal into components, i.e., separation of the two sinusoidal signals, is made by means of a simple selective amplifier. The selective amplifier consists of an electron tube which has two circuits in its anode tuned to the modulation frequencies f_1 and f_2. The signal of frequency f_2 is fed from the amplifier straight to the measuring instrument. The signal of frequency f_1 is fed to the so-called subtracting stage. This stage is also fed with a reference blocking voltage from any stable source (for instance, a stabilivolt). The amplified difference of the voltages $U = U_{f1} - U_{stab}$ is used as a controlling voltage in the negative feedback. The object of the feedback is to keep constant the voltage of frequency f_1 at the output of the tuned amplifier by changing the gain of the amplifying circuit. Any increase in the amplitude of U_{f1} at the output of the tuned amplifier leads to a rise in the feedback voltage and automatically returns U_{f1} to its original value. A reduction in the value of U_{f1} leads to a decrease in the feedback, i.e., to a rise in the gain which again brings U_{f1} back to its original value. A change in the gain for the signal of frequency f_1 leads at the same time to a similar change in the gain for the signal of frequency f_2, since the circuit is the same for both frequencies.

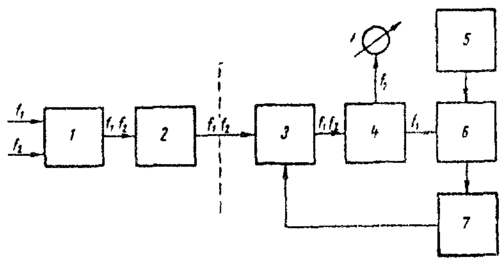

Fig. 1. Block schematic of the logometric photometer. 1) Photomultiplier; 2) preamplifier; 3) adjustable potential divider unit; 4) selective amplifier; 5) source of the reference voltage; 6) the subtracting stage; 7) feedback power amplifier.

If the value of the two compared luminous fluxes is determined by a single light source, and the law of the variation of these fluxes with changes in the source is the same, the ratio of the amplitudes of the electrical signals $K = U_{f2}/U_{f1}$ at the output of the selective amplifier is determined only by the individual properties of the two optical objects being compared. If, however, the source of the signal frequency f_2 consists of a stable object, the entire work of the circuit is reduced to the measurement of the ratio K which has as its denominator a constant quantity, i.e., to stabilizing the measuring conditions of signal U_{f2}. The indicating instrument which measures the value of U_{f2} in relative units, is, in fact, measuring the ratio K which has a constant denominator.

The accuracy of such a logometric device is determined by the stability of the reference voltage U_{stab} and the value of the feedback gain.

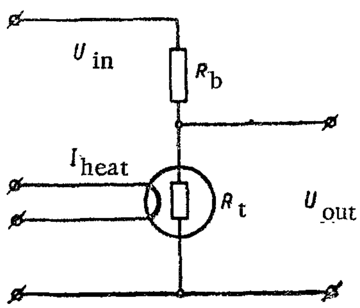

Fig. 2. Controlled potential divider

In the model of the instrument developed by us, a stabilivolt is used as a source of the U_{stab} voltage supply. The controlled elements of the electronic circuit consist of two potential dividers made up of two thermistors with indirect heating and ballast resistors (Fig. 2). A rise in the heating current I_{heat} leads to a decrease in the thermistor resistance and, hence, to a drop in U_{out} of the controlled divider. The simultaneous reaction of the feedback on the two controlled elements increases the efficiency of the control. The use of two controlling elements provides a sufficient accuracy in measuring the ratios when the absolute levels of input signals are changed by a factor of 15-20.

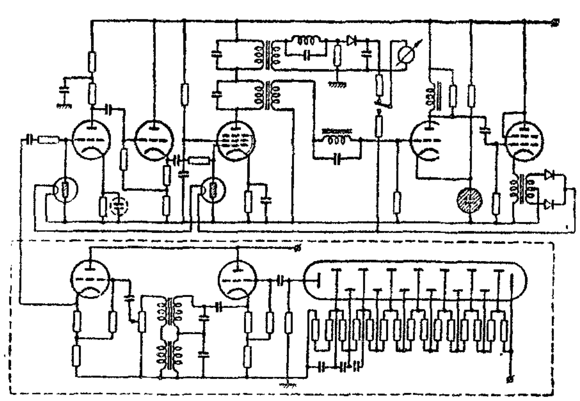

Fig. 3

Figure 3 shows the electronic circuit diagram of this device.

It has already been pointed out that, on the basis of the above method, photometers can be designed for the solution of various spectroanalytical problems (absorption, fluorescence measurements, flame photometry, etc). Their development is reduced to finding concrete transducers for various cases. The transducer must contain an illuminator and an optical system corresponding to the required method of analysis, a modulating device and a light-sensitive element with an output unit. In designing the transducers, the following fundamental requirements must be observed:

1. It is necessary to ensure a strictly defined position for the objects of testing, i.e., a complete reproducibility of the conditions of illumination of the objects and the photocathode by the light source.

2. The optical properties of the substance selected as the "standard" must bear the same relation to the variations in the source of light as the similar properties of the object under test. The substance used as a "standard" must be stable with time. Its temperature coefficient must correspond to that of the measured object.*

3. The modulating frequencies f_1 and f_2 must be stable with an accuracy of $\leq 1\%$.

4. Both luminous fluxes must be projected onto the same spot of the photocathode and produce a uniform illumination of the whole working surface. This requirement eliminates the effect of possible variations in the sensitivity of various portions of the photocathode on the value of the amplitude ratios of the electrical oscillations at the output of the photomultiplier; i.e., it provides a measurement of the ratio of the two luminous fluxes independent of the stability of the photocathode parameters with time.

As an example of the application of this logometric method, let us examine a logometric photometer FF-2 intended for luminescent analysis of semitransparent beads of NaF(U) for admixtures of uranium.

Instrument FF-2 consists of two separate units, a transducer and an electronic measuring unit.

The transducer contains an opticomechanical portion, a photomultiplier, a preamplifier and a connection to the electronic unit by means of two cables, one of which transmits the high voltage to the photomultiplier, and the other supplies the anode and heater voltages to the preamplifier, the voltage for the motor, and the ultraviolet source of light, and connects the output of the preamplifier, to the electronic unit. The optical circuit of the FF-2 photometer is shown in Fig. 4.

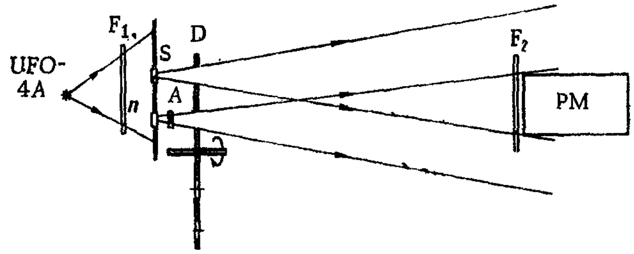

Fig. 4

The light from lamp UFO-4A passes through filter UFS-3 (F_1) which passes the ultraviolet radiations to the "standard" S and the analyzed bead n, making them luminescent. The standard consists of a glass ZhS-9 plate whose maximum luminescence coincides with that of the luminescent bead of NaF(U). The luminous fluxes of the "standard" and the bead are modulated by frequencies $f_1 = 1200$ cps and $f_2 =$ 2650 cps. The filter ZhZS-9 (F_2) admits the luminescent radiations to the cathode of the photomultiplier after they have been transmitted through disk modulator D which has two rows of holes. The photomultiplier is placed in such a position that its cathode is fully illuminated by both the fluxes under comparison. The instrument employs an optical method of switching the ranges. This "switch" consists of a holder carrying neutral light filters A (attenuator) of varying optical densities. The placing of a neutral filter in the path of radiation of the bead provides variations in the ratio U_{f_2}/U_{f_1} in steps of known integers. The control knob of the holder with indications of the range number is mounted on the side wall of the instrument. The ranges are switched by hand. Readings of U_{f_2}/U_{f_1} are read off a pointer instrument, mounted on the front panel of the electronic unit. The same instrument is used for checking the operation of the entire set. In a certain position of the special tumbler switch, it measures the value of the feedback, which determines the operating condition of the measuring device. The instrument is supplied directly from the ac mains.

Owing to the use of the selective amplifier, the instrument possesses a high sensitivity when measuring weak luminous fluxes. The instrument makes it possible to determine the content of uranium in a NaF(U) bead weighing 5 mg in the range of $5 \cdot 10^{-11}$ to $1 \cdot 10^{-6}$ g/bead. The error of measurements does not exceed 2-3% with mains variations of $\pm 10\%$ and ambient temperature changes in the range of + 10 - +40°C. After continuous operation for 8 hours, the instrument does not require recalibration or correction. The instrument calibration does not vary when tubes are changed. Ya. V. Puminov participated in the development and adjustment of some of the elements of the circuit.

* In applying the above method to spectral analysis, it is possible to use as a "standard" any line homologous to to the one being analyzed.