CLASSIFICATION CONFIDENTIAL CONFIDENTIAL

CENTRAL INTELLIGENCE AGENCY
INFORMATION FROM
FOREIGN DOCUMENTS OR RADIO BROADCASTS

REPORT

CD NO.

50X1-HUM

COUNTRY USSR

SUBJECT Scientific - Electronics, electrical measurements

HOW PUBLISHED Monthly periodical

WHERE PUBLISHED Moscow

DATE PUBLISHED Nov 1949

LANGUAGE Russian

DATE OF INFORMATION 1949

DATE DIST. 8 May 1950

NO. OF PAGES 3

SUPPLEMENT TO REPORT NO.

SOURCE Zavodskaya Laboratoriya, Metallurgizdat, No 11, 1949.

AN ACCURATE VACUUM-TUBE ELECTROMETER

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It is often necessary in research practice to measure potentials in high ohmic circuits. An example of this is the measurement of corrosion potentials on grain boundaries, with the help of capillary electrodes. In this case, the resistance of the circuit amounts to tens of megohms and, therefore, a greater degree of accuracy is necessary than in ordinary instruments, i.e., of the order of 0.1-0.2 millivolt.

It is difficult to obtain such accuracy because of the considerable effect of electrostatic fields on the high ohmic grid circuit of an electrometer tube, and also due to possible fluctuations of plate current in this tube. The author, in conjunction with G. Ya. Lion, has designed a vacuum-tube electrometer of high accuracy which satisfies these requirements. The instrument is constructed on the basis of the USSR-produced four-electrode electrometer tube. The grid current of the control grid of this tube is not more than 10^{-14} amperes.

In making measurements, the positive voltage applied to the control grid is compensated by a voltage from a three-stage measuring voltage divider (potentiometer), consisting of two potentiometer-type units and a rheochord, connected in one of the filament leads. The total range of voltage measurements on the potentiometer is 1.1 volts. The first unit enables measurements to be made with an accuracy of 100 millivolts, the second with an accuracy of 10 millivolts. The rheochord has 100 divisions, each of which corresponds to 0.1 millivolt. The resistances of the potentiometer must be made with great accuracy. Calibration against a "Raps" standard potentiometer showed that the potentiometer described gives an error of not more than 0.05 millivolt.

To increase the range of measurement and to measure potentials, which might change their sign in the process of measurement, a reversible switch is included which enables a normal cell to be introduced into the potentiometer circuit in either polarity. One arm of the switch also serves as the negative terminal for the input voltage to the tube.

The difference between the measured voltage and the voltage on the potentiometer is applied to the control grid of the electrometer tube which is located in a special aluminum, hermetically sealed shield containing a vessel with a moisture absorbent. A push button is mounted on the upper cover of the shield which, when pressed, connects the control grid of the tube with the grid lead-out. The latter is carefully insulated from the grounded housing of the shield. This type of shield design serves simultaneously as an electrostatic shield and desiccator. Before installing the tube, the surface of the bulb is carefully wiped with alcohol, so as to prevent surface leakage.

In order to smooth out sharp potential impulses on the grid when switching, and in order to improve stability in the shield, a condenser is connected between the grid and the ground. The input lead to the grid of the tube consists of a flexible shielded conductor. The plate circuit of the tube, which has a high resistance with respect to ground, is also shielded. For stable operation of the instrument, it is important that the filament current and working current of the measuring potentiometer be maintained constant. Both these currents are regulated simultaneously by two rheostats and are checked against a second normal cell. The indicator is a galvanometer which is connected in the circuit of the normal cell when the double-pole double-throw switch is in the left position. In the given circuit the galvanometer used has a sensitivity of 5×10^{-9} amperes, with an internal resistance of over 1,000 ohms.

The initial negative bias on the control grid of the electrometer tube is obtained by the voltage drop created by the filament current through a cathode resistor. To regulate the bias, two identical and mechanically interconnected rheostats are used in the filament circuit. When these are turned together, the total resistance of the filament circuit and the measuring potentiometer does not change, and a new adjustment of the working current is not required. (In practice, a small adjustment is sometimes required.)

The electrometer tube is connected in the circuit as one arm of a bridge circuit formed by two fixed resistors, the plate load resistor of the tube, and the sections of two voltage dividers (potentiometers). Due to this arrangement, it is possible to balance the bridge with great accuracy. The balance point is determined by the galvanometer and the double-pole double-throw switch.

It should be pointed out that where the requirements for accuracy and stability of measurement are high, the quality of the contacts of the potentiometer units in both the bridge and filament circuits is of exceptional importance. Therefore, in building the instrument, special attention was paid to selecting high-quality potentiometer step-switches, and, in addition, the rheochord and rheostat contacts were specially designed.

The electrometer tube is operated as follows: before beginning measurements, negative bias is established by means of the rheostats. Then the working current of the filament and potentiometer are checked against the normal cell by means of the galvanometer. During this time, the push button should be pressed down and the control grid connected to ground, i.e., the established bias is applied to it. In this position, the bridge is balanced with the aid of the voltage dividers and the galvanometer, which at this time is connected in the diagonal of the bridge. To carry out the measurement, the push button of the shield-desiccator is pressed down. When this is done, the control grid of the tube is disconnected from the ground, and the positive voltage to be measured is applied to it. In this manner, the negative bias on the grid is decreased, the internal resistance of the tube also decreases, and the equilibrium of the bridge is upset, which can be observed by the deflection of the galvanometer. The position of the arms and the rheochord of the filament potentiometer are then altered until the galvanometer returns to the zero position. This indicates that the voltage being measured and the voltage on the potentiometer are equal. The voltage being measured can then be obtained from the position of the potentiometer arms and the rheochord reading.

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In the case of high ohmic electrodes (tens of megohms), a phenomenon may be observed whereby, despite the absence of a difference between the measured and balancing potentials, the galvanometer gives a deflection when the push button is pressed down. This deflection depends on the resistance of the electrodes, but is not more than 0.2-0.3 millivolt, and vanishes completely when the push button is released. Therefore, the measurement can be made by observing the deflection when the push button is up

The vacuum-tube electrometer described is located in a wooden box, shielded with sheet aluminum on the inside. The shield-desiccator, arms, rheochords, and rheostats are mounted on an inclined duralumin panel which is faced with getinax (laminated insulation). The galvanometer with a luminous scale is mounted in a cut-away portion of the panel.

The use of this instrument for measuring potentials of microinclusions under the microscope with the help of a thin capillary showed that it enables measurements of potential to be carried out reliably with electrodes of high resistance (30-50 megohms), giving an accuracy of $\pm$ 0.2 millivolt.

(Editor's note: Instruments for potentiometric measurements are necessary for accurate determination of hydrogen ion concentration, for potentiometric titration, for the study of corrosion processes, etc.

The assembly, testing, and calibration of such instruments in institutes and laboratories, even when detailed descriptions are provided, takes much time and demands a considerable amount of work. It would be much simpler and cheaper to centralize the manufacture of such instruments, whose use in scientific research and plant laboratories would facilitate considerably the solution of many current problems.

The Editor draws the attention of the Ministry of Machine and Instrument Building to the necessity of organizing series production of instruments for potentiometric measurements in 1950.)

[Exterior view of the apparatus available

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