А. М. Илюкович

# ТЕХНИКА ЭЛЕКТРО-МЕТРИИ

**6П2.1.081 AND 48**
UDC 621.317.3.01

**Ilyukovich A. M.**

And 48 Equipment of the electrometry. M, "Energy", 1976.

400 pages about silt.

In the book methods and measuring instruments of small electric signals in high-resistance chains and resistance of such chains are considered at small levels of constants or slowly changing currents (up to 10 — $10^{-1617}$A). General information about the electrometric objects of measurement, about the electrometric equipment and its elements is supplied. The principles of creation and property of different types of electrometric amplifiers of tension are in detail stated. The questions connected with creation of electrometric measuring instruments of tension, charges, currents, resistance, parameters of capacitive objects on the infralow frequencies are analyzed. Methods and means of checking of the electrometric equipment are described, features of its operation are affected.

The book is intended for the electric equipment specialists who are engaged in creation and production of the electrometric equipment and also for the persons putting it into practice.

**"30306-054 "**
**1 051(01)-76** 258-75 **6P2.1.081**

© Energiya Publishing house, 1976.

## PREFACE

The increasing differentiation of certain areas is characteristic of development of modern science and technology. This trend extends also to the electric equipment within which rather recently there was one more new direction — the so-called electrometry.

Emergence of the concept "electrometer" belongs to the middle of the 18th century. Its emergence is connected with work of the academician G.V. Rikhman who created the first-ever device possessing all basic elements of the modern electrical measuring instrument. In it ■ the device and also in the systems of similar assignment which followed it for assessment of the studied electric phenomena forces of electrostatic attraction were used. In those days it was not clear yet that the electric phenomena are diverse and are characterized by the large number of the interconnected parameters therefore introduction of the concept "electrometer" was quite natural.

In the 19th century when electrical measuring instruments of other types were created (the galvanometer, the ampermeter, the voltmeter, the electric power meter, etc.), the concept "electrometer" was a little specified and by it began to designate highly sensitive devices of the cgs electrostatic system with very big input resistance, i.e. with very small input current.

By the end of the 19th century electrostatic electrometers reached high degree of perfection and were used as one of fixed assets of electric measurements in experimental physics. Maxwell, and then other authors, developed their detailed theory. By means of electrometers it was possible to measure not only small tension in high-resistance chains, but also small electric currents and charges of ionization chambers and other objects and also big resistance. The pilot studies executed with use of electrometers by Rutherford, Curie's spouses and other largest scientists formed the basis for fundamental opening in nuclear physics.'

In the thirties our century along with electrostatic electrometers amplifiers on electron tubes with the small grid current and big input resistance which received the name of vacuum tube electrometers began to use. At once after World War II

electrometers on the so-called vibrating-reed capacitor, and then electrometers on field transistors with the MOS and other elements appeared. In the last 20 — 30 years on the basis of different electrometers the large number of various devices with ample metrological, functional and operation capabilities is created; these devices usually integrate the concept "electrometric equipment".

During this time repeatedly scopes of the electrometric equipment for scientific research extended and there was its implementation in the industry, power, health care and so forth. The level of development of the modern electrometric equipment substantially defines progress of the number of the major directions of science and technology: technique of the physical experiment, equipment of dielectrics and high ohmic semiconductors, microelectronics, technology of ionizing radiation, mass-spectrometry, vakuummetriya, gas chromatography, low-frequency piezometry, electrochemistry, rn-metriya, biology (intracellular researches), researches of space radiations and many others.

Many organizations, in some cases specialized are engaged in the research, creation, production and use of the electrometric equipment. The quantity of types of the serial electrometric equipment in our country is calculated by tens and if to consider measuring instruments in which such equipment is used in the form of the built-in nodes, then hundreds. Annually the large number of works on electrometric methods and measuring instruments is published in the world.

Thus, to replace the electrostatic electrometer which served kind service in the equipment fi-the zichesky experiment the new various equipment by means of which decide not so much laboratory, how many industrial tasks came. Within the electric equipment one more direction was allocated. Usually it is called the electrometry (there is also the textual interpretation of the term "electrometry" when by it designate all electric equipment in general; we will use this term only in its conditional value which origin was explained above). The modern electrometry is characterized by independent scopes and the electrometric ranges of the measured parameters. The physical processes defining metrological characteristics of electrometric measuring instruments are in many respects specific and are not characteristic of other directions of the electric equipment. Also the principles of creation of such measuring instruments and their elements are respectively specific. Methods and means for metrological support of unity and correctness of measurements in the electrometric range differ in the big originality. Service regulations of the electrometric equipment are also other than standard for other electrical measuring

instruments.

At the same time the experience accumulated in the field of the electrometry is not generalized yet that constrains its further development. By separate types of the electrometric equipment many interesting works, including the number of monographs are released. However the general consideration of all methods and means of electrometric measurements in their natural interrelation from uniform scientific and technical positions and with the identical depth of study of single questions is absent. This work is also devoted to the solution of this task.

Told above about the electrometry originality as the directions of the electric equipment, of course, does not mean that the electrometry develops outside the electric equipment in general. Many methods of measurement and the principles of creation of measuring instruments with success are in whole or in part borrowed. Development of the electric equipment created necessary base for modern raising of the electrometry. In this work, however, we will be interested first of all those questions which are specific to methods and means of the electrometry. At the same time * it is supposed that the reader is well familiar with bases of the electric equipment, especially with measurements on the direct current.

When writing the book the author to the same extent was guided by numerous publications on single questions of the electrometry and on more than ten years' experience of the laboratory of the electrometry of VNIIFTRI run by it. The staff of this laboratory V.M. Borzov, L.A. Vsevolozhsky, I.V. Dzyubenko, L.V. Kle-the mine, V.A. Kulikov, I.P. Mikhaylova, T.O. Petrova, A.E. Strelicheva, Yu.A. Tsygankov and others the author asks to accept deep appreciation as without their creative activity emergence of this work would be impossible. The author is grateful to numerous group of colleagues from other organizations for their continuous friendly aid in work on problems of the electrometry and the manuscript of this book. Made the reviewer doctor of sciences D.E. Polonnikov notes allowed to improve the manuscript of the book considerably.

As the first experience in the field of the generalized consideration of the electrometry the book is not deprived of shortcomings. All notes which readers will take the trouble to send to the address: Moscow, 113114, Shlyuzovaya Emb., 10, Energiya publishing house, will be with gratitude and are attentively studied.

*Chapter 1*

# GENERAL INFORMATION ABOUT ELECTROMETRIC METHODS AND MEASURING INSTRUMENTS AND ELECTROMETRIC MEASURING OBJECTS

## 1-1. GENERAL INFORMATION ABOUT ELECTROMETRIC METHODS AND MEASURING INSTRUMENTS

a) Distinctive properties

Most characteristic of the electrometric equipment distinguishing it from other types of means of the electric equipment is the specific nature of sources of own hindrances defining really achievable threshold of sensitivity. Stray currents of insulators, stray currents from the background radioactive radiation and radioactive impurity of materials, the electrostatic fields created by charges on insulators and contact potential difference, etc. concern them.

All these sources of own hindrances are shown only at small currents. Therefore, the most general sign of all types of electrometric measuring instruments is the small level of current in input metering circuits (about $10^{-17}$ — $10^{-10}$ A). This sign defines many features of the electrometric equipment.

First, small currents exceed currents of thermal noises and, therefore, can be found against the background of noise only in very high-resistance chains. Root mean square value of own current of thermal noises of the object with R resistance in frequency band $\Delta f$

equally:

$$\overline{i^2}_T = \frac{4KT\Delta f}{R},$$

where $K = 1{,}38 \cdot 10^{-23}$ J/K — Boltzmann constant; $T$ — absolute temperature (see § 1-3).

If, for example, at $\Delta f = 1$ Hz is required to be received at the room temperature ($T \approx 300$K) for some chain $\text{sqrt}(i^2_T) \leq 10^{-15}$A, is necessary that resistance of this chain of $R \geq 1{,}5\text{-}10^{10}$ Ohms. Thus, input circuits of the electrometric equipment of the vysokoomna.

Secondly, small currents can exceed currents of thermal noises only with not the really broad range of frequencies. Current of thermal noises grows in proportion to $\text{sqrt}(\Delta f)$ and at big $\Delta f$ can be considerable even at big resistance of the chain. Besides, if resistance R chains is high, then even the small shunting R tanks lead to significant band limiting on transmission of such chain. Thus, characteristics of the electrometric equipment are shown by that more than less its transmission band.

Let's notice that electrometric measuring instruments work only at constants and slowly changing signals. With this frequency range the majority of the specified sources of own hindrances works and features of the electrometric equipment are shown.

Everything told belongs both to electrometric measuring instruments and to subjects to measurements of electrometric range, the last high impedance also work at constants or slowly changing signals. Sources of own hindrances of such objects are defined by the small level of current in them and, as a result of it, their big resistance.

## b) Main types

Electrometric measuring instruments, as well as any other [L. 1-25], on the basis of their assignment are separated into measures, measuring transducers, measuring apparatuses and complex measuring devices. The last did not receive application in the electrometry therefore further consideration will be limited to the first three groups. We will also not be

to carry out clear split between measuring transducers and devices as in the electrometry most often the difference between them consists only available at devices of the built-in output indexes. First of all devices and converters will be considered, and measures will be considered separately in sections on checking of measuring instruments of different sizes.

On the basis of the measured or reproduced sizes electrometric measuring instruments are separated [L. 1-13—1-15] on measuring instruments of tension, currents, charges (parameters of signals), resistance and tanks (parameters of chains).

## в) Principles of creation

Let's consider the main features of measurements of each of parameters of signals and parameters of chains of electrometric range. Let's begin with measurement of tension. We will characterize the source of the signal by the internal resistance *of Ri* and the useful signal *of Ux,* and the measuring instrument — the input resistance of Rвх and level of own hindrances on tension *ep* and on in current (see § 4-2). Under own hindrances we will be ponies mother set of noise, drift and zero drifts (on tension and current respectively), i.e. the sum of the variables which are slowly changing and constant components. We will not consider the input capacitance of the measuring instrument as transitional or frequency properties of the measuring instrument do not interest us yet.

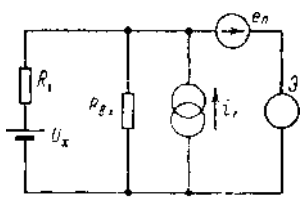


Fig. 1-1. Dual circuit of measurement of tension.

Dual circuit for measurement of tension, made taking into account told, it is given in fig. 1-1 where *E* — ideal (with infinitely big input resistance and not having own hindrances) the electrometric measuring instrument of tension.

Indications of electrometric measuring instrument E

$$U_э = U_x\left(1 - \frac{R_i}{R_i + R_{вх}}\right) + e_п + i_п\frac{R_i R_{вх}}{R_i + R_{вх}}.$$

Indispensable condition of correctness of measurements is At $R_i = 10^{12}...10^{13}$Ohms that can

to take place in practice, it is necessary that $R_{вх} \geq 10^{14} ... 10^{16}$Ohm. These values approach extremely possible, i.e. those which are provided when using as isolation of air intervals. At observance of the condition of the indication of the electrometric measuring instrument i.e. the relative error of measurements caused by own hindrances of the measuring instrument is equal $(e_п + i_n R_i)/U_x$ and for its decrease it is necessary to reduce *ei* and ip. Thus, the electrometric measuring instrument of tension has to have perhaps bigger input resistance and perhaps smaller own hindrances on tension and current.

To explain the principle of operation of electrometric measuring instruments of currents, it is reasonable to use concepts of the measuring instruments managed by current and the measuring instruments managed by tension. In the first case the measuring instrument reacts to availability and level of current of the pas the entrance. The characteristic example are devices of the magnetoelectric system. In the second case the measuring instrument reacts to availability and the voltage level on the entrance. Devices of the cgs electrostatic system can be the example. In the measuring instruments managed by current, the input circuit most often is provided by the winding through which the measured current is passed. Winding resistance for constructive and technology reasons does not exceed hundreds — thousands of ohms, and the level of thermal noises on current is big. Such devices are not suitable for measurement of small currents. In the measuring instruments managed by tension, input resistance can be very big (up to infinity), and thermal noises on current are very small.

In principle the measuring instruments managed by current too can be rather high-resistance (up to $10^9$—$10^{10}$Ohms) to be used in the electrometric range. For example, in amplifiers with the entrance cascade on bipolar transistors the pilot signal is current, nevertheless it is possible to receive big input resistance and to provide the high threshold of current sensitivity — up to $8\text{-}10^{-14}$A. In view of the high impedance of input circuits all specific features of the electrometric equipment remain and in this case.

However extremely possible threshold of current sensitivity manages to be provided only by means of the measuring instruments managed by tension therefore only they will be considered further so far.

At the same time for measurement of the small direct current it needs to be transformed to tension, and then to determine this tension by the electrometric measuring instrument. There are two types of converters of small currents in tension: the resistor with big (10 — 10 [89]Ohms and above) resistance *R* and the condenser capacity *With* with small leaks. Tension on the resistor is proportional to the measured current $I_x$, namely

$$U_R = I_x R;$$

tension on the condenser

$$\Delta U_c = I_x \Delta t / C,$$

where Δt — charge time, i.e. on the condenser is made transformation of current to the speed of voltage variation $(I_X = C\Delta U/\Delta t)$. Instead of the resistor sometimes use the high-resistance resistive element with logarithmic dependence between tension and current that is often useful. Different ways of transformation of small currents to tension do not exist (and cannot exist as there are no other elements of electric circuits with the resistance, rather big for the purposes of the electrometry, except the resistor and the condenser).

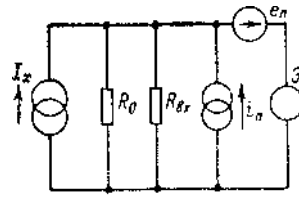

Fig. 1-2. Dual circuit of measurement of currents.

Let's consider requirements to the electrometric measuring instrument of tension at measurement of small currents by the resistor method. The dual circuit of measurement of currents is given in fig. 1-2 where *R0* — resistor measure resistance. Tension measured by the electrometer is equal:

$$U_э = (I_x + i_п)R_\Sigma + e_п,$$

where $R_\Sigma = R_{BX}R_0/(R_{BX}+R_0)$. The condition of the correct measurement is $R_{BX} >> R_0$. When using elektrometrical

amplifier (EMU) instead of the simplest electrometer the equivalent input resistance of the EMU due to the deep parallel negative feedback coupling (NFC) can be made very small, but it does not contradict the last statement. For the EMU the requirement of very big resistance will belong to the site between entrance and output potential clips. At observance of the condition the error is equal:

$$\frac{e_п}{I_x R_0} + \frac{i_п}{I_x}.$$

For its decrease it is necessary to increase resistor measure resistance (respectively and Rвх) and to reduce own hindrances on tension and on current, i.e. requirements to the electrometric measuring instrument the same tension, as in the previous case. It is easy to show that similar requirements turn out also at measurement of small currents with use of the condenser.

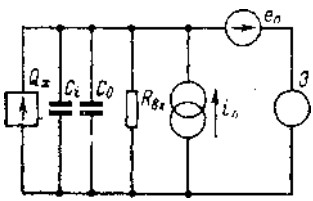

Fig. 1-3. Dual circuit of measurement of charges.

At measurement of the small slowly changing charges it is necessary too that current level in input circuits was small. Otherwise the speed of change of the measured charge due to availability of this current $\Delta Q_x/dt=I(t)$ will be considerable and it is possible to control the processes only fast-proceeding.' Low-impedance measuring instruments, for example the ballistic galvanometer, do not allow to measure small charges as thermal noises on current and consequently, and to the charge at them are big. At the most sensitive of ballistic galvanometers of M17/13 type the constant makes only $0{,}5*10^{-9}$ Kl-m//mm. For measurement of small harges they need to be transformed to tension, and then to determine this tension by the electrometric measuring instrument. For these purposes condensers with the big leakage resistance are used. *Uc* tension on the condenser is connected by the capacity of $C_0$ with the known expression *of* $U_c$ measured *by* $Q_x$ charge $U_c = Q_x/C_0$

At measurement of charges parallel to the capacity of the source of Ci which charge is measured, connected the-ism -