Chapter Two

STRUCTURAL ELEMENTS OF ELECTROMETRIC EQUIPMENT

2-1. INSULATORS

a) Requirements and performance

Insulators are essential elements of the input circuits of any electrometric equipment. With their help, sections and elements of high-resistance circuits are isolated from low-resistance circuits or the housing. You can distinguish between input and mounting insulators. The input insulator of the device isolates its input from the case. Input insulators are most susceptible to pollution, dust, moisture. Mounting insulators are located inside the device case and are used to fasten the leads of high-resistance elements, such as resistors or circuit sections. Insulators are found in all special elements of electrometric equipment: dynamic capacitors, air capacitors, resistors, switches, relays.

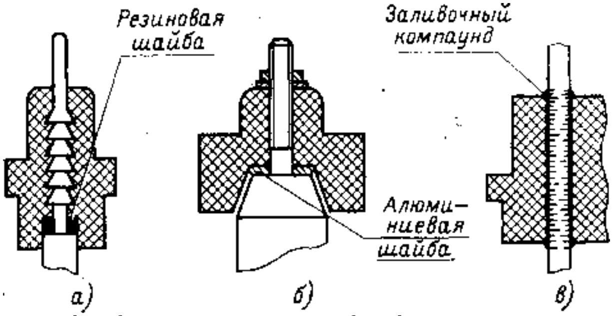
The requirements for the electrical characteristics of insulators are diverse and depend on the purpose of the insulator, the requirements for the equipment, and the conditions for its operation. The common ones are high resistance, low parasitic current and low dependence of these values on external conditions: temperature, humidity, etc. As a rule, they tend to have a low electrified insulator, i. the ability to form and store charges on the surface under the influence of random effects of friction, pressure, touch, etc. The greater the electrification, the greater the parasitic current can be expected.

In addition, the electrostatic fields of electrified insulators contribute to interference (see § 1-3).

Entrance insulators that provide a hermetic seal can be made from soft materials, such as fluoroplast-4 (Fig. 2-1, a). Conclusion in place

passing through the insulator is provided with a notch, and a rubber washer is used for sealing. Insulators made of viscous materials are also used in other cases when rigid fixation of the insulated material is not required.

section of the chain. Input insulators are also made of solid materials. The use of hard materials is especially important if structural parts are mounted on the insulator, such as relay contacts. An aluminum washer is used to seal the through contact through a rigid insulator (for example, made of amber) (Fig. 2-1, b). Strengthening the conductor or



Rice. 2-1. Examples of constructive execution of insulators.

a rod in a rigid insulator can also be obtained using a casting compound based on ED-5 resin (Fig. 2-1, c). This solution is most appropriate if there are several closely spaced leads through the insulator.

The properties of the compound can affect the resistance of the insulator and its parasitic current. With an excess

unreacted hardener (polyethylene polyamine) on the insulator around the conclusions, a little noticeable halo film appears [L.2-6]. The halo expands over time, and when it comes into contact with the halo of another contact or case, the resistance of the insulator drops to about 10^{12} ohms, and the parasitic current increases. *Good ones*

the results are given by a compound of the following composition (in mass parts): 10 parts of ED-5 resin, 2 parts

plasticizer DEG-1 and 9.6 parts of hardener L-20. For his

polymerization, the product is aged for 24 hours at room temperature, then 4 hours at 40 ° C, 4 hours at 80 ° C and

is cooled together with the thermostat to 25 °C.

б) materials

For the manufacture of insulators for electrometric instruments, sapphire, amber, quartz, fluoroplast, polystyrene, ceramics. The choice of material depends on constructive purpose of the insulator, requirements for metrological characteristics of the equipment, its operating conditions, technological considerations, cost [L. 2-5]. Let us give general estimates of such materials.

Synthetic sapphire is one of the best materials for electrometric insulators, it has high volume and surface resistances and generates low parasitic current. These properties are associated

[L. 2-15] with a clear sapphire crystal structure.

Its use due to the high cost and difficulty of processing is limited to the equipment

high sensitivity [L. 2-14]. Abroad, it is used in serial devices; in our country, the introduction of sapphire insulators into electrometric

hardware is just getting started.

Fused amber is somewhat inferior in its properties to sapphire, but has long been widely used, especially in laboratory development. To obtain high resistance and low parasitic current, the surface of an amber insulator must be processed according to the 11th or 12th accuracy class. The disadvantages of amber are fragility, which requires skills in processing, and a good ability to electrify by friction. Amber is suitable for making amber lacquer, which is now out of use.

Escapon is processed at high

pressures and temperatures rubber. It is well processed, has low parasitic current and high resistance,

little affected by moisture and temperature and is especially suitable [L. 2-6] for equipment operating in severe climatic and mechanical

conditions.

Fused quartz is similar in insulation resistance to

sapphire, but its properties depend on the technology. Quartz has a high piezoelectric effect and is more hygroscopic

amber, but its ability to accumulate a charge is 10 times less than that of amber.

Fluoroplast-4 (Teflon) is widely used in equipment

medium sensitivity. He has a very high

resistance in a wide temperature range, water films do not form on its surface. insulating

the properties and parasitic current of PTFE do not depend much on humidity. It's handled well moreover, the cleanliness of processing according to the 6th -7th class is sufficient. Fluoroplast is chemically inert and does not change characteristics over time. Plasticity and fluidity of PTFE make it the most suitable for the manufacture of bushings. The disadvantage of fluoroplast is its good ability to form bulk and

surface charges under the influence of mechanical load or touch, the time for the absorption of charges is long. Therefore, it is not used in highly sensitive equipment.

Polystyrene is a good insulating material, but at high humidity forms water films on the surface. By treatment with dioxane, the surface resistance of polystyrene can be made independent of humidity [L. 2-16]. It is well processed, but often has internal defects. During operation, microscopic cracks can appear on polystyrene, which sharply reduce surface resistance. To reduce the tendency to cracking, it is recommended [L. 2-1] to anneal polystyrene parts with heating up to 85 °C and subsequent slow cooling down to 65 °C. Emulsion polystyrene has the least tendency to cracking, block polystyrene has the greatest. The surface of polystyrene after contamination is difficult to clean.

Fluoroplast-3 has almost the same large surface and volume resistance as polystyrene, it is well processed without defects, and its properties are close to fluoroplast-4.

Polyethylene has a very high volume resistance, is flexible and is most suitable for use in cables used with electrometric equipment.

Radioceramics has mechanical strength, low hygroscopicity, high volume resistance, high temperature resistance. To increase the surface resistance, it is treated with organosilicon varnishes, which, after drying, form a mechanically strong protective layer. Ceramic parts

with this treatment, they are easily cleaned of dust and dirt with a solvent or pure alcohol. The stray current of ceramics, especially at high humidity, is large, and it is not used in limiting equipment.

sensitivity.

Paraffin and ceresin were used to coat insulators

in order to increase surface resistance, but have a low softening point, low mechanical strength and are prone to contamination. They are rarely used at present.

Other materials are also used: glass-ceramic, steatite

ceramics with a moisture-proof layer of ceresin or polystyrene varnish, polystyrene paste; in electrostatic ebonite and sulfur were previously used in electrometers.

в) Resistance

Usually it is sufficient that the resistance of the insulator is not lower than 10^{12}-10^{13} ohms, sometimes 10^{15} and even

10^{16} Ohm. This is close to air resistance.

gaps; for air volume resistivity

equals 10^{19}-10^{20} Ohm * cm. The insulators have bulk and

surface leaks; the most significant are superficial. As the temperature rises, the values of volume and surface resistances decrease. Surface resistance, moreover, strongly depends on pollution, moisture formation, cracks on the surface. For most materials, it is the greater, the higher the surface finish class. A flat surface is less prone to dirt and moisture and is easier to clean.

For example, we present the technology of processing amber

cylindrical insulators for dynamic capacitors

DRC-4 [L. 2-6]. Side and end surfaces are polished

flannelette washer with paste 29 diluted with white spirit. Traces of machining and

scratches are removed by lightly pressing the insulator against the washer and systematically wetting it in white spirit with paste. After polishing, the insulators are washed in hydrolysis

alcohol with a soft brush until the paste is completely removed and

dried at 50-60 °C for 30 minutes. Fine polishing is done with a disk suede washer without paste. Lightly touching (no longer than 1 - 1.5 s) the washer with the insulator, eliminate the remaining

the smallest scratches. Then the insulator is washed with the highest purity alcohol using a soft brush, the alcohol drops are blown off with a blower and dried at 50 - 60 ° C for 1 hour. The treated insulators are stored in a desiccator.

г) **Influence of humidity**

Surface resistance is highly dependent on humidity. There is even an opinion [L. 2-5] that it is entirely determined by the thickness and composition of the water or oil film on the surface of the insulator. On wetted surfaces, a layer of moisture forms when exposed to air in a few minutes. Moisture affects the resistance of contaminated surfaces (Figure 2-2); especially dangerous is the appearance of traces of soluble salts in the surface layers of moisture [L. 2-5]. At relative humidity 90 – 100% surface resistance of teflon, styroflex, polyethylene and others materials is reduced by several orders of magnitude and reaches up to 10^{7}-10^{12} Ohm [L. 2-16]. At a humidity of 80% or less, the surface resistance of most plastics is quite sufficient for electrometric insulators.

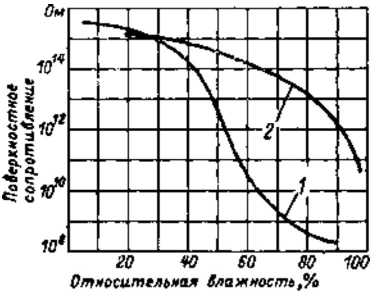


Рис. 2-2. Зависимость удельного поверхностного сопротивления плавленого кварца от влажности. *1 — до* очистки; 2 —после очистки.

To reduce the impact moisture insulators made of glass, ceramics, etc. are coated with water-repellent varnishes [L. 2-16]. Ceramics coated with varnishes FG-9 and SB-1s, after an hour and a half exposure to water and a subsequent two-hour exposure, has resistance

at the level of 10^{15} ohms. The surfaces of insulating plastics are water-repellent in themselves. In heavy-duty electrometric equipment, the input electrometric unit is completely sealed, in conventional equipment - partial,

protecting input circuits from dust, dirt and to some extent from moisture. Fluctuations in temperature may cause moisture to enter the semi-sealed unit. To avoid this, blocks are built in [L. 2-7] capsules with a desiccant, such as calcium chloride. It is periodically replaced with fresh. In equipment operated outdoors and in any weather, they resort to heating the input insulators [L. 2-8, 2-16].

д) **Effect of ionizing radiation**

Electrometric current meters used with ionization chambers sometimes operate under radiation exposure. The values of volume and surface resistances of insulators under the influence of radioactive radiation decrease, after which

the original resistance values are not fully restored. The degree of these influences depends on

Table 2-1

Permissible exposures for materials

Material	dose of gamma radiation, J / m^3	Neutron flux, 1/ cm^2
Glass..	$3 \cdot 10^{-4}$	10^{18}
Quartz..	10-3 –	10^{19}
Polyethylene....................................	10-2	10^{19}
Teflon	10-7 _	$5*10^{18}$

insulator material and type of duration and intensity of radiation [L. 2-9]. Irradiation doses that do not cause irreversible changes in the properties of materials (Table 2-1) are significantly different for different materials

[L. 2-12].

2-2. SWITCHING ELEMENTS

a) General information

Switching elements for input circuits

electrometric equipment can be divided into two groups: range switches for multifunctional or multi-limit instruments and keys (relays) for disconnecting the device from the object, closing the feedback circuit, etc. The requirements for the design of range switches depend on the input electrometric elements used (lamp, MOS -transistor, dynamic capacitor, etc.), the number of measurement ranges, etc., and they are usually developed based on a certain type or group of devices. Design and functionality requirements

relays are less diverse, and greater unification is acceptable.

To the electrical characteristics of switching insulators

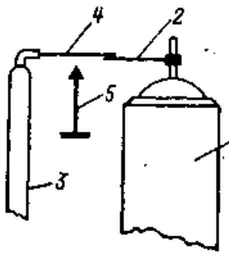


Рис. 2-3. Пример электрометрического ключа без дополнительных

elements (resistance, parasitic current, electrification) are subject to the usual requirements for electrometric equipment (see § 2-1). When designing switching elements, the following principle must be followed, if possible: the best insulation is no insulation. An example of a structural diagram of a key without insulators is shown in fig. 2-3. At the electrical terminal input element *1* reinforced spring contact *2*. At the output of high-resistance resistor *3* the second spring contact is strengthened *4*. Normally closed contacts *2 and 4 are* opened by a grounded pusher 5, which bends contact *4* and grounds it. The pusher is controlled manually or by an electromagnet.

When moving contacts touch or rub against insulators, parasitic charges arise on them, and thus parasitic currents. To avoid this, some parts of the insulators are covered with a conductive film, paint or aquadag [L. 2-5]. Mechanical forces on insulators during switching can also cause parasitic charges. Therefore, high contact pressures should be avoided.

Sometimes a small open-loop capacitance is required

electrometric contact. This is achieved by selecting the dimensions of the contacts and the springs carrying them, or by using the principles of equipotential shielding (Figure 2-4). Contacts *1* and *2* separated from each other by a grounded metal screen *3*. Closing jumper *4* reinforced with spring *5* on insulator *6*. When contacts open *1* and *2* jumper is grounded. The capacitance between the contacts is zero, and the effect of the capacitances of each of the contacts relative to grounded parts can be done in a small way

rational choice of circuit potentials. In some cases, it is possible to reduce the influence of the contact capacitance by purely circuit measures.

When the electrometric contacts are opened, parasitic charges are generated on them. The reasons for the generation are contact electrification, contact movement in the electric field of insulators, contact potential difference between the contact and the surrounding

metal parts. For the RES-10 relay, the generated charge is 10^{-13} C or more [L. 2-6]. It charges the input capacitance of the device and is perceived as an interference decreasing exponentially with a constant

input circuit time. The voltage generated by the generated charge

can cause insulators to polarize and stray current to increase. Charge generation is not allowed if the measurement process is to start immediately after switching. Note that during switching, phenomena can occur that give the same effect as charge generation at the contacts, but have a different nature, for example magnetic pickups
an electrometric lamp from the excitation coil of the switching relay when it is de-energized.

To reduce the generated charge, the contacts are made of the same material, preferably gold. Their cleanliness and surface condition should be carefully monitored. The movement of the moving contact during switching should be kept to a minimum. To contact

the potential difference between the contacts did not create a large charge on them, the capacitance between the contacts should

be small. Contacts must be shielded from insulator fields, and the shields must be connected to a moving contact, reducing the potential difference between them to zero.

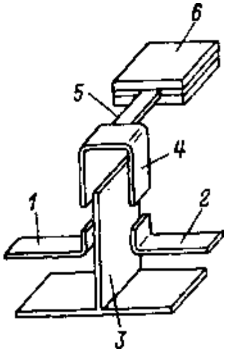


Рис. 2-4. Пример электрометрического контакта с нулевой емкостью.

Elastic deformation of the contacts during closing leads to their rebound (bounce). Bounce is inherent in all relays and switches, the bounce time is a few milliseconds. In some types of electrometric equipment, this is unacceptable. To eliminate contact bounce, it is necessary to take special measures, for example, to reduce the contact angle at contact so that the kinetic energy of the movable contact is completely spent on work friction between contacts. It is possible to feed the excitation winding of the relay with a slowly increasing voltage, which will ensure smooth contact movement.

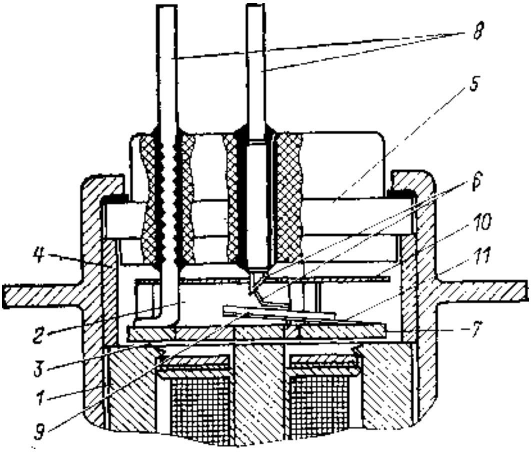
Unfavorable influences can be caused by thermo-emf.

on contacts. To reduce them, the contacts are made from the same material.

Serial switching elements of electronic devices usually do not meet the listed special requirements. Sometimes they can be used in electrometric equipment of low sensitivity, but only after a preliminary examination. Some types of serial magnetically controlled contacts have good characteristics from the point of view of electrometry [L. 2-11]. If it is not possible to do without a serial multi-position limit switch, then, in addition, a single-position electrometric contact is used, which short-circuits the switch at the moments of switching [L. 2-5].

б) Execution examples

Electrometric relay RV-3 [L. 2-6] is made in a housing designed for through-hole mounting (on the wall of a sealed electrometric unit). The main elements of the relay are (Fig. 2-5) solenoid *1* and contact group *2.* They are separated by an air gap <3, which is ensured by the distance ring *4,* sandwiched between the amber insulator of contact group *5* and an electromagnet. Two break contacts *6* relays located

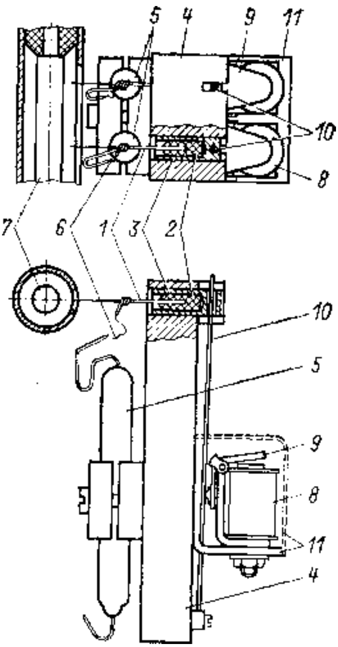


Rice. 2-5. The design of the relay RV-3.

Rice. 2-6. multi-position

electrometric needle

switch.



between insulator *6* and disk 7. Conclusions *8* contacts are fixed in the insulator. One of the contacts has a backing *9* from a ferromagnetic alloy, acting as an anchor. The disc 7 is made of ferromagnetic and diamagnetic materials in such a combination that the magnetic field of the electromagnet is concentrated at the location of the substrate *9,* as a result, a substrate with a contact
attracted to the disk. The output of the disc is the output of the movable
contact. Screen *10 is located above the moving contact.*

Relay contacts are made of Zl-15 gold alloy 0.11 mm thick in the form of triangular and rectangular frames; they are polished, and the quality of the working surfaces is carefully checked. The gap between the disk and the lower plane of the distance ring is set when the disk leads are filled with a compound. The pressure of the movable contact on the fixed contact is regulated by bending the spring *111.* The meeting angle of the contacts is significantly less than the direct one, and the gap between them is selected so that there is no chatter, after which the output of the fixed contact is filled with a compound.

The relay RV-3 has a generated charge of less than 10^{-15} C, the insulation resistance of the contacts relative to the case and between themselves is not less than 10^{14} Ohm. The relay actuation current is 20 - 30 mA, the current through the contacts is up to 1 mA. The capacitance between the contacts is about 2 pF. The RV-3 relay is designed to operate in the range from -50 to +60 °C, remains operational after exposure to an environment with a relative humidity of 98% at +40 °C and can operate under mechanical vibration conditions. On its basis, relays RV-4 with three contacts are also produced, two of which are normally closed, and RV-4A with three normally closed contacts.

In an electrometric multi-position switch (Fig. 2-6 shows a two-position switch) of the University of Tartu, contact needle *1* fixed in insulator *2* from polystyrene or PTFE. The insulator is placed in a metal sleeve, which is an electrostatic screen. The sleeve, together with the insulator and the needle, can move 2–3 mm along the groove guide in the upper part of the body *4* switch. Measuring resistor *5* connected to needle *1* flexible wire *6.* The resistor is connected with a needle to the input rod 7 of the electrometric amplifier when relay *8 is activated.* Anchor movement *9* relay *8* transferred to sleeve *3* through the rod spring *10.* When the relay is de-energized, needle *1* spring *10* moves away from the rod 7. The relay is placed in a magnetic shield *11.*

A switch can have any number of such elements. They can be located around the input rod, in a row on the same line or in groups of two or three elements on opposite sides of the rod.

2-3. CABLES FOR ELECTROMETRIC DEVICES

If a direct connection of the electrometric device with the object is impossible or undesirable, cables are used. Cables with polyethylene, polystyrene or fluoroplastic insulation have high resistance, for example, radio-frequency coaxial cables of the Republic of Kazakhstan according to GOST 11326-67. Their own interference is significant, especially if the cable is not fixed rigidly **and** is subjected to mechanical stress. In the best case, the parasitic current of the RF cable is 10^{-16}-10^{-15} A, in the worst - 10^{-13} - 10^{-12} A. The main causes of parasitic current in high-resistance cables are frictional electrification and the piezoelectric effect.

When high-resistance cables operate under mechanical stress, their own interference has

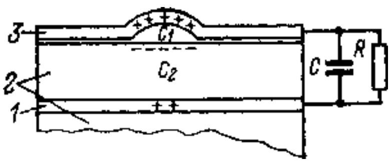


Рис. 2-7. К вопросу о возникновении низкочастотных шумов кабеля.

low-frequency component [L. 2-10,2-13]. The cable consists (Fig. 2-7) of a central metal core *1*, surrounding insulator *2* and outer metal braid *3*. The input of the electrometric instrument is connected to core *1* **and** braid *3* (in Fig. 2-7 it is represented by an RC chain). At

mechanical influences on the cable, the outer braid in some areas ceases to touch

with an insulating surface. When they are separated, charges of the opposite sign appear. The appearance of charges on the insulator induces charges on

central vein. Capacities of plots C_1 and C_2 are not equal, and the stresses arising on them are different. A voltage appears at the input of the electrometric meter, which changes from maximum to zero with a time constant T = *RC*. Local violations of the contacts of the metal braid with the external insulator occur continuously along the entire length of the cable, spectral the characteristics of the resulting noise are determined by the spectrum of mechanical effects.

The way to reduce low-frequency noise follows from the mechanism of their occurrence. The outer surface of the cable insulator is covered with a conductive material,

for example, graphite, and charges do not arise on it, since there is constant contact between the braid and the surface insulator. Low frequency noise

Table 2-2

Characteristics of anti-vibration cables

T AND II	Purpose	Outer - diameter , mm	noises	Capacitance , pF/m	Resistance , Ohm/m
AVK-1	For temperatures from - 40 to + 60 °C and humidity up to 98%	5.0	0.1 pC at 3-5 Hz and amplitude 45 m	—	—
AVK-2 AVK-3	Resistant to mineral oil and salt water	3.7	30 μV at 40 - 60 and 500 Hz and 10 *g*	110 80	10^{11} after 48 hours in water
AVK-6	For operation in the frequency range from 5 to 2500 Hz at 20 °C	2.2	30 μV at 40-60 Hz and 10 *g*	130	$3*10^{12}$
AVKE-1	Same as AVK-1, but shielded	5.5	0.1 pC at 3 - 5 Hz and 45 mm amplitude	—	—
AVKT-1 AVKT-2	heat resistant	2.5 3.5	100 μV at 40-60 Hz and *10g*	110 80	—
AVKT-3 AVKT-4 AVKT-5	Heat resistant with PTFE insulation	2.0 2.0 3.5	50 μV at 40-60 Hz and 10 *g*	110 130 130	$5*10^{12}$ under normal conditions and $5*10^{11}$ at 200C

are drastically reduced, the parasitic currents of anti-vibration cables are also less than those of conventional cables. Characteristics of some anti-vibration cables are given in table. 2-2.

Noise properties of anti-vibration cables are usually set by the charge q_w cylinder *3*, it contains the sensor with which the cable is supposed to be used. The cable is tensioned with a spring *4*, attached to cylinder *3*. Cylinder clamped between plates *5* and *6*, one of which is connected to the vibration test bench and performs reciprocating movements in the direction indicated by the arrows.

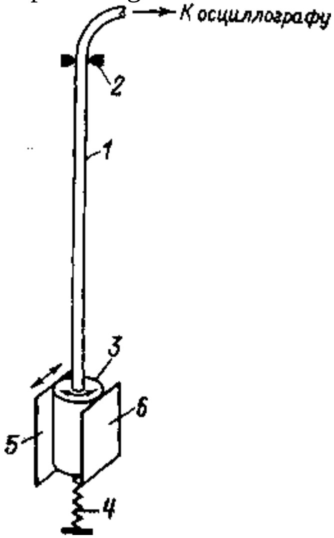


Рис. 2-8. Схема аппарата для испытания кабелей.

or voltage $u_ш$, to determine which one end of the cable is connected through the EMU to the oscilloscope, the other is left open. The cable section is fixed in the clamps of the vibro-device and ish is determined by the oscilloscope, and then qsh is calculated from the known capacitance of the sample. More objective methods for determining the noise properties of cables are also possible [2-10]. The best reproducibility is given by the method of periodic twisting of a prestressed cable (Fig. 2-8). The cable segment 1 is clamped in the tripod 2 with its upper end and connected to a noise voltage meter, such as an oscilloscope. An equivalent capacitance is fixed at the lower end of the cable

The amplitude and frequency of movements can be adjusted. Cylinder *3* and the lower end of the cable perform torsional vibrations through a certain angle a. To improve the reproducibility of results, the upper end of the cable is pre-twisted up to 360°. Noise properties are estimated by the coefficient $u_w C_\sum / a$, where *and* $_w$ *is* the noise voltage; a is the angle of periodic twisting of the cable;

$C\Sigma$ _ - the sum of the capacitances of the cable and the attached. This coefficient for each type of cable remains constant when changing the cable length, twist angle and connected capacitance.

A set of low-noise cable connections is sometimes attached to electrometric equipment. Applied Physics (USA) Cagy 401 electrometers are equipped with three types of cable connections recommended for measuring currents up to 10^{-13}, 10^{-14} and 10^{-15} A , respectively.