ETM-1 **(*english*)**

Ministry of Education and Science of Ukraine
Dnipro University of Technology

Department of Electrical Engineering

Kolb A.A.

COLLECTION OF METHODICAL MATERIALS
for laboratory work on discipline "Electrical Materials" (Section "Dielectric materials")

for students studying specialty 141 "Electrical Power Engineering, Electrical Engineering and Electromechanics"

Dnipro
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Methodical instructions are intended for laboratory work in the discipline of "Electrical Materials" (Section “Dielectric materials”) students majoring in 141 - Power Engineering, Electrical Engineering and Electromechanics.

LABORATORY TEST ETM - 1/1

STUDY OF PROPERTIES OF ELECTRICAL INSULATION MATERIALS

Aim of the training

Acquaintance with samples, study of properties and spheres of application of electroinsulating materials, the list of which will be offered by the lecture.

Work program

1. Get acquainted with the samples of electrical insulating materials, paying attention to their external features.
2. Study the properties and areas of application of electrical insulating materials.
3. The report execution.

The work procedure

Stage 1. Get acquainted with the samples of electrical insulating materials, paying attention to their external features

Get acquainted with the samples of electrical insulating materials, which are given in one of the columns of table. 1.1 (column number suggested by the teacher). Pay attention to the structure of samples of electrical insulating materials, their color, hardness, degree of transparency, surface structure and other features that can determine the names of materials and their origin.

Stage 2. Study the properties and areas of application of electrical insulating materials

The main properties, characteristics, areas of application and starting materials for the manufacture of samples of electrical insulating materials should be described in the form of table. 1.2, using the guidelines for this laboratory work and the recommended literature.

Stage 3. The report execution

The report on this laboratory work should contain:
1. Title and purpose of the work.
2. Completed table. 1.2.

Table 1.1

Електроізоляційні матеріали

1	2	3	4	5	6
Mikanite	Mica	Myco-tape	Glass tape	Glass	Collector micanite
Electro-cardboard	Polyvinyl chloride	Electrocardboard film	Polystyrene	Getinax	Polyethylene
Textolite	Rosin	Shellac	Rubber	Epoxy resin	Polyamide resin
Polyethylene	Fiberglass	Ftorolast-4	Mica	Cable paper	Rosin
Getinax	Bitumen	Capacitor paper	Rosin	Ftoroplast-4	Polyvinyl chloride
Lacquer fabric	Porcelain	Plastic compound from polyvinylchloride	Polytetra-fluoroethylene	Fiberglass	Textolite
Rubber	Polystyrene	Fiberglass	Plexiglass	Transformer motor oil	Electrical cardboard
Ftoroplast-4	Polymethyl methacrylate	Glass	Polyethylene	Mikanite	Bitumen
Cable paper	Polyethylene	Kapron	Foil	Electrocardboard film	Condensing paper
Asbestos	Asbestos cement	Getinax	Getinax	Kapron	Lacquer fabric
Viniplast	Getinax	Foil textolite	Lacquer fabric	Plexiglas	Porcelain
Bakelite	Paraffin	Epoxy	Textolite	Shellac	Bakelite

Table 1.2

EXAMPLE

The main properties of electrical insulating materials

Material	Characteristic external data, mechanical properties	Initial materials, method of production, structure, etc.	Basic electrical insulating properties				Other properties (chemical resistance, moisture resistance, radiation resistance)	Heat resistance class and allowable operating temperature	Field of application
			ε_r - relative dielectric constant	ρ_V - volumetric resistivity, Ohm·m	tgδ - the tangent of the dielectric loss angle	E_M - electrical strength, kV/mm			
Mikanite	Sheet material from mica plates, which are glued together and glued to a paper substrate. Firm. When bent, it stratifies into individual plates	Mica plates, resin. Obtained by gluing mica plates	-	10^{10}-10^{12}	0,05	15-60	When irradiated with neutrons, the electrical strength decreases by 60%	F, H, C 155 ^{O}C, 180 ^{O}C	Collector sleeves, insulation between collector plates of electric machines, groove insulation, gaskets between sections of windings of electric machines

Methodical guideline

To stages 1, 2 and 3

Electrical insulating materials according to their chemical structure are divided into organic (compounds of carbon with hydrogen, nitrogen, oxygen and some other elements) and inorganic. A separate group of materials - elemental, based on the structure of which, in addition to carbon, oxygen, nitrogen, includes atoms of silicon, magnesium, aluminum, titanium and other elements that are not characteristic of ordinary organic substances.

Many organic electrical insulating materials are flexible and elastic, they can be used to make fibers, films, products of various shapes. Unfortunately, they have relatively low heat resistance.

Inorganic electrical insulating materials are mostly not flexible and elastic. They have high heat resistance and are used in cases where it is necessary to ensure reliable operation of electrical insulation at high temperatures.

Test questions

1. Name the main properties of electrical insulating materials.
2. Justify the most important (from your point of view) property of electrical insulating materials.
3. How do you understand the concept of "electrical insulation"?
4. What is the difference between thermoplastic and thermosetting materials?
5. What synthetic polymers are most often used as electrical insulating materials?
6. Name the components of plastics. Which one is the main one?
7. List the main dielectric properties of polyethylene and polyvinyl chloride, give the scope of their application as electrical insulating materials and allowable operating temperatures for them.
8. Describe the organofluorine dielectric fluoroplastic -4.
9. How does radiation affect the properties of polyethylene, fluoroplastic-4?
10. Describe the method of production and scope of phenol-formaldehyde resins.
11. Describe the known electrical insulating laminated plastics, their properties and applications.
12. Name the most important natural resins, their properties and applications.
13. Name the features, properties and scope of mica (muscovite and phlogopite) as an electrical insulating material.
14. Name the main types of micanites, their composition, properties.
15. What is the practical significance of heat resistance of electrical insulating materials?
16. Give examples of the distribution of electrical insulating materials by individual classes of heat resistance.

17. How does increasing the temperature of the windings and their insulation affect the service life of electrical machines?

LABORATORY TEST ETM - 1/2

DETERMINATION OF VOLUME AND SURFACE SPECIFIC RESISTANCES OF SOLID DIELECTRICS

Aim of the training

To study technical means of measuring bulk and surface resistances of solid dielectrics.

Work program

1. Study of general information about the electrical conductivity of dielectrics.
2. Study of the principle of operation of technical means for measuring the volume and surface resistance of solid dielectrics.
3. Measurement of bulk resistance of dielectrics.
4. Measurement of surface resistance of dielectrics.
5. Processing of experimental data.
6. The report execution.

The work procedure

Stage 1. Study of general information about the electrical conductivity of dielectrics

Using the recommended literature and guidelines for this laboratory work, learn information about the electrical conductivity of solid dielectrics. Note that the electrical conductivity of solid dielectrics is quantitatively characterized by the specific volume γ_V and surface γ_S electrical conductivity or, most often, the specific volume ρ_V and surface ρ_S resistances

Stage 2. Study of the principle of operation of technical means for measuring the volume and surface resistance of solid dielectrics

Using the recommended literature and guidelines for this laboratory work, to study the principle of operation of the thermometer. Pay special attention to the connection circuits of the electrodes of the measuring instrument (Fig. 2.1, 2.2), which ensure the distribution of the dielectric current to its constituent parts and thus reduce the measurement error. Immediately before the start of the measurement it is necessary to read the instructions and procedure for working with the thermometer.

Stage 3. Measurement of bulk resistance of dielectrics

Measure the volumetric resistance of solid dielectric samples in the following sequence:

- measure and record in table. 2.1 values of the diameter d of the measuring electrode B and the inner diameter D of the security electrode O;
- measure and record in table. 2.1 values of the thickness h of samples of solid dielectrics, which are proposed by the teacher for research;
- assemble the circuit according to Fig. 2.1;
- measure the volumetric resistance R_v of the samples, using the first or second scale of the device, and enter the results in table. 2.1.

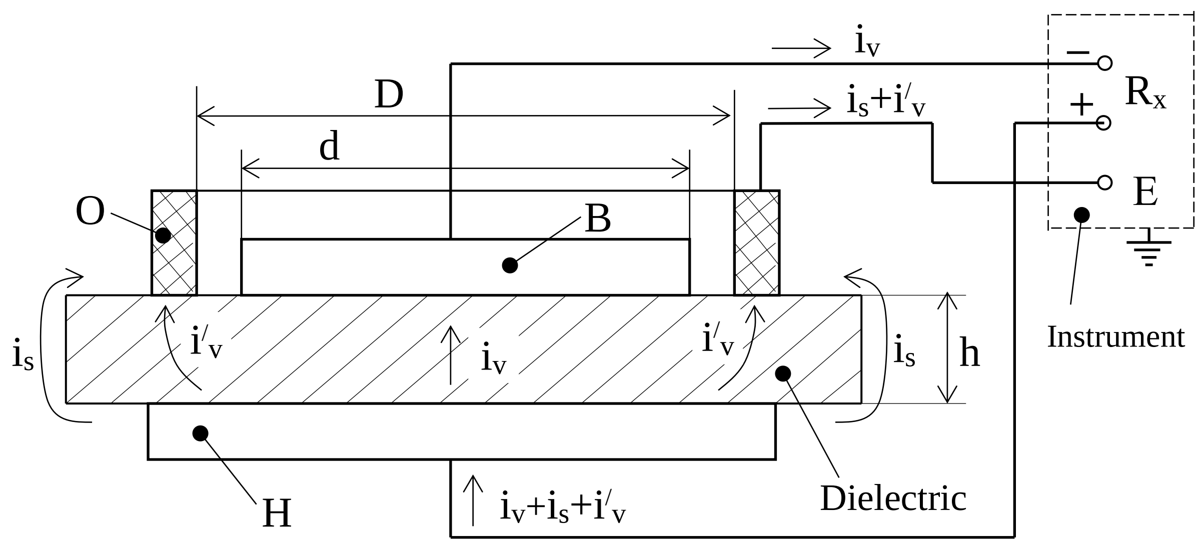

Fig. 2.1. Scheme of connection of electrodes for measurement bulk resistance of a solid dielectric

Table 2.1

Results of measurements and calculations

Dielectric	Measured					Calculated		
	d, m	D, m	h, m	R_v, Ohm	R_s, Ohm	ρ_v, Ohm ·m	ρ_s, Ohm	n, Ohm $^{-3}$

Stage 4. Measurement of surface resistance of dielectrics.

Measurement of surface resistances of samples of solid dielectrics should be performed in the following sequence:

- assemble the circuit according to Fig. 2.2;

- measure the surface resistance R_s of the samples, using the first or second scale of the device, and enter the results in table. 2.1.

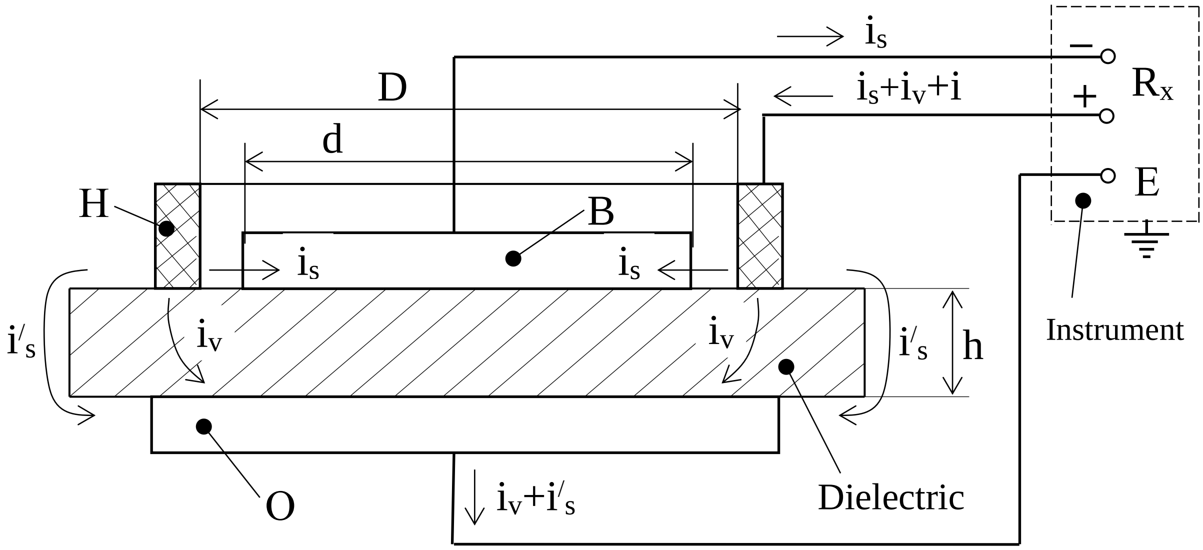

Fig. 2.2. Scheme of connection of electrodes for measurement surface resistance of a solid dielectric

Stage 5. Processing of experimental data

Process experimental data in the following sequence:

- calculate the specific volumetric resistance ρ_V of the samples of dielectrics according to formula (2.3) and the results of the calculations are entered in table.2.1;

- calculate the specific surface resistance ρ_S of the dielectric samples according to formula (2.4) and enter the results of the calculations in table 2.1;

- determine the concentration of free charges in the samples of dielectrics according to formula (2.5) and the results of calculations to enter in table.2.1;

- compare the concentrations of free charges in dielectrics and metals and draw a conclusion about the difference in their resistivities;

- on the basis of the obtained values of ρ_V and ρ_S to draw a conclusion about the quality of the studied dielectrics.

Stage 6. The report execution

The report on this laboratory work should contain:

1. Title and purpose of the work.
2. Schemes of fig. 2.1 and 2.2.
3. Completed table. 2.1.
4. Example of calculating the values of ρ_V, ρ_S, n.
5. Conclusions.

Methodical guideline

<u>To stage 1</u>

Virtually all electrical insulating materials (dielectrics) under the action of electric voltage pass some (usually very small) current, i.e. are not ideal due to the presence of some electrical conductivity. The electrical conductivity of solid dielectrics is explained by the presence of free electric charges in them, which is mainly caused by the movement of weakly fixed ions of random impurities and ions of the dielectric itself (especially at high temperatures). In some dielectrics, electrical conductivity can be caused by the presence of free electrons. In solid dielectrics, free charges are possible not only in their volumes, but also in a thin layer of moisture and various contaminants on their surface. Therefore, solid dielectrics distinguish between bulk and surface conductivity.

To compare different dielectrics in terms of their conductivity, the specific volume γ_V and the specific surface γ_S of the electrical conductivity or the specific volume ρ_V and the specific surface r$\rho_S$of the support, which are inverse with respect to the respective specific conductivities, are used. From the course of physics it is known that the specific conductivity γ depends on the concentration of free charges n, their mobility u and the magnitude of the charge q:

$$\gamma = q \cdot n \cdot u \qquad (2.1)$$

The mobility of free electrons in their presence in the dielectric does not differ significantly from the mobility of electrons in metals (for copper $u = 3.5\times10^{-3}$ $m^2/V\times s$, $n = 10^{28}$ m^{-3}). Therefore, the low electrical conductivity of dielectrics can be explained only by a small concentration of free charges in them.

Surface conductivity is determined by the ability of the dielectric to adsorb moisture and dust on its surface, and therefore it depends on the state of the surface of the dielectric and the properties of the environment. The surface of nonpolar dielectrics is wetted and contaminated to a lesser extent than polar ones. Less moisture and pollutants are adsorbed on the smooth and smooth surface of the dielectric, and therefore the specific surface resistance ρ_S of such a dielectric is much higher than the specific surface resistance of the same material with a rough surface.

As the temperature of the dielectric increases, the mobility of its free charges increases (this applies primarily to ions) and their concentration due to the thermal dissociation of molecules. This causes an increase in electrical conductivity and a decrease in the value of ρ_V. The electrical conductivity of solid dielectrics also depends on the magnitude of the applied voltage. At high voltages, polar molecules are partially destroyed or electrons are pulled out of atoms, which leads to an increase in the concentration of free charges and an increase in the electrical conductivity of the dielectric. The electrical conductivity of solid dielectrics increases in the case of their humidification, if they have a hygroscopic structure.

The resistivity of polar solid dielectrics is usually lower than that of nonpolar ones. This is due to the complexity of purification of polar dielectrics and the ease of destruction of their molecules by electric field.

According to the values of the specific volume ρ_v and the specific surface resistance ρ_s of the dielectrics are conventionally divided into:

high quality – $\rho_V=10^{13}...10^{16}$ Ohm ·m, $\rho_S=10^{14}...10^{16}$ Ohm;
quality – $\rho_V=10^{9}...10^{12}$ Ohm ·m, $\rho_S=10^{10}...10^{13}$ Ohm;
satisfactory – $\rho_V=10^{6}...10^{8}$ Ohm ·m, $\rho_S=10^{8}...10^{9}$ Ohm.

To stage 2, 3 and 4

Measurements of dielectric resistances must be performed at constant voltage, because at alternating voltage there is an additional charge-discharge current caused by polarization. For this reason, the readings of the device are taken not earlier than 60 s after applying a constant voltage, because it takes some time to complete the polarization. In order to be able to separately measure the volumetric and surface resistance, three electrodes are used, which are called measuring electrode B, voltage electrode H and protective electrode O.

In the circuit of electrodes for measuring the volumetric resistance of a solid dielectric (Fig. 2.1), the current conductivity of the dielectric coming from the terminal (+) of the power supply through the voltage electrode H is branched. The first part iv, which passes through the measuring electrode B and is registered by the measuring device, depends only on the volumetric resistance R_v of the dielectric sample in its middle part, where the electric field is homogeneous. The second part of the current passes through the protective electrode O (ring) to the terminal E (screen) of the measuring device and therefore are not registered by this device. The second part of the leakage current has two components - the volumetric current i / v in the extreme regions of the sample, where the electric field is inhomogeneous, and the surface current is. Due to this scheme, the errors are insignificant, because the second part of the current (i_s + $i^/_v$) is diverted from the measuring electrode B. If you remove the protective electrode O from the sample, instead of volumetric conductivity current i_v, i.e. will show less resistance. Electrode O also provides a virtually uniform electric field in the sample between electrodes B and N.

In the circuit of electrodes for measuring the surface resistance of a solid dielectric (Fig. 2.2) the role of the protective electrode O is performed by the lower electrode - it diverts past the measuring circuit current of bulk conductivity iv and external surface current i'_s. The surface current is flowing through the annular gap between the electrodes B and H (ring), is measured by the device and determines the size of the surface resistance R_s.

Electronic megohmmeters, thermometers and DC bridges are used for direct measurement of dielectric resistance. The E6-13A thermometer, which is available in the laboratory, is designed to measure DC resistance in the range from 10 to 10^{14} Ohms. The main element of the device is a DC amplifier P with a high gain, in the forward or reverse circuit of which is included a measuring element with an electrical resistance R_x.

The set of the device includes the measuring chamber serving as the screen. During the measurement, the test specimen is placed inside the chamber, and the chamber itself is connected to the ground terminal of the instrument.

<u>To stage 5</u>

Specific volume resistance ρ_V (Ohm·m) is determined by the formula:

$$\rho_v = R_v \frac{S}{h} , \tag{2.4}$$

where R_V – volumetric resistance (measurement result, table 2.1);

$S = \pi \cdot d^2/4$ – the area of the contact surface of the measuring electrode B;

d – diameter of the measuring electrode (measurement result, table. 2.1);

h – the thickness of the dielectric sample (measurement result, table. 2.1).

Specific surface resistance ρ_S (Ohm) is determined by the formula:

$$\rho_s = R_s \frac{L}{g} , \tag{2.5}$$

where R_S – surface resistance (measurement result, table 2.1);

$L=\pi \cdot (D+d)/2$ – the effective perimeter of the measuring electrode B, from which the surface free charges flow;

D – the inner diameter of the voltage electrode H according to the scheme of Fig. 2.2 (measurement result, table 2.1);

$g=(D–d)/2$ – the distance between the measuring electrode B and the electrode voltage H, which is overcome by surface free charges.

The concentration of free charges in dielectric samples can be determined based on formula (2.1):

$$n = \frac{1}{\rho_v \cdot q \cdot u}, \qquad (2.6)$$

where ρ_V – specific volume resistance (result of calculations of tab. 2.1);

$q=1{,}602 \cdot 10^{-19}$ Cl is the charge of an ion or an electron;

u – average mobility of charges (since in dielectrics free charges are mainly ions, the calculations can take $u=10^{-9}$ м²/V·s).

Test questions

1. Why do dielectrics have non-zero electrical conductivity?
2. What types of electrical conductivity are possible in solid dielectrics?
3. What parameters characterize dielectrics in terms of their electrical conductivity?
4. On what factors depends the value of the resistivity of dielectrics?
5. What factors affect the value of surface resistance?
6. How to explain the difference in rv values of polar and nonpolar dielectrics?
7. At what voltage (constant or variable) it is necessary to measure the resistance of dielectrics and why?
8. Why when measuring the resistance of dielectrics need a system of three electrodes?
9. Draw a diagram of the connection of the electrodes to determine the resistivity and explain the purpose of each of its elements.
10. Draw a diagram of the connection of the electrodes to determine the specific surface resistance and explain the purpose of each of its elements.
11. Explain how the reading of the device changes when measuring the resistance of the dielectric, if you turn off the protective electrode.
12. Why the readings of the device when measuring the resistance of dielectrics should be recorded after some time after the voltage is applied to the electrodes?
13. Explain the principle of operation of the theraometer.

LABORATORY TEST ETM - 1/3

DETERMINATION OF ELECTRIC STRENGTH OF LIQUID DIELECTRICS

Aim of the training

To study the breakdown mechanism of a liquid dielectric and perform a standard test of transformer oil for breakdown by electric field.

Work program

1. Study of the breakdown mechanism of a liquid dielectric.
2. Familiarization with the current standards of electrical strength and technical means of testing for electrical breakdown of transformer oil.
3. Conducting a standard test for breakdown of transformer oil by electric field.
4. Processing of experimental data.
5. The report execution

The work procedure

Stage 1. Study of the breakdown mechanism of a liquid dielectric

Using the recommended literature and guidelines for this laboratory work, to study the breakdown mechanism of dielectrics on the example of transformer oil. Find out the electrical strength of E_m as a numerical characteristic of the dielectric to withstand electrical breakdown and maintain its electrical insulating properties. Pay attention to the mechanism of influence of impurities and temperature on the electrical strength of transformer oil.

Stage 2. Familiarization with the norms of electrical strength and technical means of testing for electrical breakdown of transformer oil

Using the literature and guidelines for laboratory work, get acquainted with the standards of electrical strength of transformer oil used in high-voltage oil-filled devices or transformers. Get acquainted with the principle of operation of the device AII-70, designed to determine the electrical strength of insulation (Fig. 3.1). Pay attention to the system of protective locking and alarm of the device.

Stage 3. Carrying out standard testing on breakdown of transformer oil

The standard breakdown test of transformer oil must be performed using the AII-70 apparatus in the following sequence:

- make sure that there is no voltage on the AII-70 device, enter the fenced part of the laboratory, put on rubber boots and gloves;

- check the grounding of the device, set the knob of the regulating autotransformer of the device to zero position (end position when it rotates counterclockwise), set the protection switch S2 to the “sensitive” position;

- pay attention to the fact that the brass electrodes were completely immersed in the transformer oil at a standard distance between them d = 2.5 mm;

- close the door of the chamber, stand on a rubber mat and with the participation of another participant to turn on the power outlet "grid", after which the green signal light L2 will light up;

- press the white "On" button (S1 in Fig.3.1) circuit breaker CB, as a result of which the primary winding of the high-voltage transformer T3 is supplied with voltage and the red signal lamp L3 begins to light;

- slow rotate of the autotransformer knob in the direction of the clockwise movement to increase the voltage to the breakdown of transformer oil, which is accompanied by automatic shutdown of the machine and extinguishing of the red signal lamp L3;

- determine the value of the breakdown voltage on the upper scale of the voltmeter of the device and enter the result in table 3.1;

- turn the knob of the regulating autotransformer to zero position and disconnect the device from the mains;

- open the door on the lid of the device and carefully mix the oil with a dry glass tube to remove from the discharge gap the decomposition products of oil in the event of a breakdown (while stirring to prevent air bubbles in the liquid);

- make six measurements of breakdown voltage with time intervals between breakdowns of 5 minutes (during this time the decomposition products of oil are removed from the space between the electrodes) and enter the measurement results in table 3.1.

Table 3.1

Results of measurements and calculations

Dielectric	Measured						Calculated		
	U_{br1}, kV	U_{br2}, kV	U_{br3}, kV	U_{br4}, kV	U_{br5}, kV	U_{br6}, kV	U_{br}, kV	Δ_m, %	E_s, kV/mm
Operational transformer oil									

Stage 4. Experimental data processing

Experimental data obtained as a result of a standard test for electrical breakdown of transformer oil should be processed in the following sequence:

- calculate the arithmetic mean value of the breakdown voltage U_{br}, kV:

$$U_{br} = \frac{1}{5}\sum_{i=2}^{6} U_{bri} , \qquad (3.1)$$

where U_{pri} is the breakdown voltage i - th breakdown, kV;

– calculate the maximum relative deviation of the breakdown voltage from its average value U_{br}:

$$\Delta_m = \frac{\delta_{\max}}{U_{br}} \cdot 100\% , \qquad (3.2)$$

where δ_{max} – the maximum absolute deviation of the breakdown voltage from its average value;

– if it turns out Δ_m>15%, then make 5 additional breakdowns of transformer oil and adjust the average value of the breakdown voltage U_{br} according to formula (3.1), based on 10 breakdowns (instead of 5 breakdowns);

– determine and enter in table 3.1 the value of electrical strength of transformer oil E_s, kV/mm:

$$E_s = \frac{U_{br}}{d} , \qquad (3.3)$$

where d is the standard distance between the electrodes (d=2,5mm);

– plot the breakdown voltage as a function of the experiment number and explain the reasons for the scatter of its values;

- make a conclusion about the suitability of the tested ("operational") oil on the basis of current standards of electrical strength (Table 3.2).

Stage 5. The report execution

The report on this laboratory work should contain:

1. Title and purpose of the work.
2. Schematic diagram of the device AII-70 (Fig. 3.1).
3. Completed table. 3.1.
4. Calculations of the values of U_{br}, Δ_m and E_s by formulas (3.1 ... 3.3).
5. Breakdown voltage graph with explanations.
6. Conclusion on the suitability of transformer oil.

Methodical guideline

To stage 1

Dielectric breakdown by an electric field is a process of sharp increase of electric current through a dielectric under the influence of electric field forces at high electric voltage, as a result of which the dielectric loses its electrical insulating properties. The ability of a dielectric to resist breakdown is characterized by the electrical strength Em - the average value of the electric voltage at which the breakdown of the dielectric. Liquid and gaseous dielectrics, in contrast to solid dielectrics, regain their electrical insulating properties after breakdown and voltage shutdown. Among liquid dielectrics, petroleum electrical insulating oil is widely used - transformer oil, which in addition to increasing the electrical strength of insulation helps to cool the windings and magnetic circuit of the transformer, as well as rapid quenching of the electric arc in oil circuit breakers.

The most important factor that affects the electrical strength of petroleum oils is the presence of impurities and especially water, which is in the oil in the emulsion state (in the form of extremely small droplets). The negative effect of moisture is enhanced by fibrous impurities, which intensively absorb water and become semiconductor. The breakdown of liquid dielectrics is explained by the fact that polar impurities (emulsion water, fibers, solid particles) are oriented in an electric field along its lines of force, forming elongated chains. Conduction current flows through such circuits, which causes intense local heating of the dielectric. At the same time, the resistance of the dielectric in such places decreases, the amount of current increases, which eventually leads to evaporation and boiling of the liquid (water or oil). Between the electrodes to which voltage is applied, a gas channel with lower electrical strength is formed, through which an electrical breakdown occurs. If the liquid dielectric is carefully cleaned of impurities, then in this case the breakdown occurs due to the following factors:

a) emission of electrons from the cathode surface;

b) shock ionization by free electrons of liquid molecules;

c) destruction of dielectric molecules by electric field;

d) the formation of gas bubbles due to the decomposition of hydrocarbon dielectric molecules under the action of a strong electric field.

It should be noted that the shock ionization of liquid molecules begins at a much higher electric field strength compared to gases, due to the higher density of the liquid and, consequently, the shorter free path of electrons. Therefore, the electrical strength of liquid dielectrics significantly exceeds the electrical strength of gases.

The electrical strength of liquid dielectrics increases with decreasing voltage time: the more impurities (especially water and fibers), the more noticeable this increase. This is explained by the fact that with decreasing time of stress ($t \leq 10^{-3}$ s) impurities do not have time to form extended chains, which usually begins to break.

The electrical strength of transformer oil increases with increasing temperature. This is due to the transition of water impurities from the emulsion state to the molecularly dissolved state (in the temperature range 60 ... 80° C, and when the oil is heated above 80° C it evaporates and water impurities and the formation of gas bubbles, which reduces E_s.

During storage, transportation and operation of oil, the amount of moisture and impurities in it, as a rule, increases, which reduces the electrical strength. During the operation of the device, for example, a transformer filled with oil, under the action of electric field, elevated temperature and oxygen, the oil ages, ie it produces pollutants (acids, resins, etc.). Due to this, the oil gradually loses its initial electrical strength. Decreased electrical insulating properties of the oil can cause accidents in electrical installations. Therefore, to ensure the normal operation of the equipment periodically, as well as before pouring check the quality of the oil and, above all, its electrical strength.

To stage 2, 3 and 4

The value of electrical strength of transformer oil is not set by state standards, and this is no accident. The fact is that the electrical strength of the oil is a parameter that is too sensitive to moisture and dirt. Water or dust can easily get into the oil during transportation, storage, transfusion into insufficiently clean containers. Moistened oil will have a test electrical strength lower than pure, and if the Em values were set by state standards, such oil would have to be lacking. At the same time, moisturized oil can be easily dried. With proper drying and cleaning, the electrical strength of the oil is completely restored. Thus, E_{br} is not a defective indicator of the quality of transformer oil, but it must be carefully monitored.

According to the rules of technical operation of electrical equipment, the allowable values of electrical strength (Table 3.2) for two types of oil: a) "fresh" - pure and dry oil, prepared for pouring into a transformer or other device; b) "operational", which is in operation in an oil-filled apparatus.

Table 3.2

Norms of electrical strength of transformer oil

Nominal voltage of the device filled with oil, kV	Electrical strength of oil E_{br} (not less), MV / m	
	for "fresh"	For "operational"
Up to 15 inclusive	10	8
From 15 to 35 inclusive	12	10
From 60 to 220 inclusive	16	14
From 330 and above	20	18

To ensure a certain period of operation of the device without changing the oil in it, fresh oil according to table 3.2 are higher requirements.

The AII-70 device (Fig. 3.1) with the highest output voltage of 50 kV at alternating current (current value) and 70 kV - at direct current is used for oil testing. The device is equipped with a protective interlocking and alarm system and has a fence. The voltage from the mains through the blocking contacts BC and fuses F is applied to the regulating autotransformer T1, which serves to smoothly change the voltage, and to the transformer T2 - to heat the kenotron L1. The high voltage is switched on by pressing the button S1 of the circuit breaker CB, which has three windings, two of which are connected in series and connected to one phase, and the third is shunted by the protection switch S2. The open state of this switch corresponds to protection "sensitive" - the circuit breaker CB works at breakdown of a dielectric and disconnects from a network the high-voltage transformer T3. When switch S2 is closed, the protection is "rough". In this case, the circuit breaker CB remains on if the power on the high voltage side at 50 kV does not exceed 2 kVA. This mode should not last more than a minute. Measurement of the voltage applied to the dielectric is performed by a voltmeter kV on the low voltage side, which is graduated according to the voltage at the output of the transformer T3 (in kV).

Capacitors C1 are used to protect against overvoltage of the primary winding of the transformer T3. Resistor R1 protects transformer T3 and kenotron L from current overload in case of dielectric breakdown. The green light L2 signals the supply of voltage to the device, the red L3 - the inclusion of a high-voltage transformer.

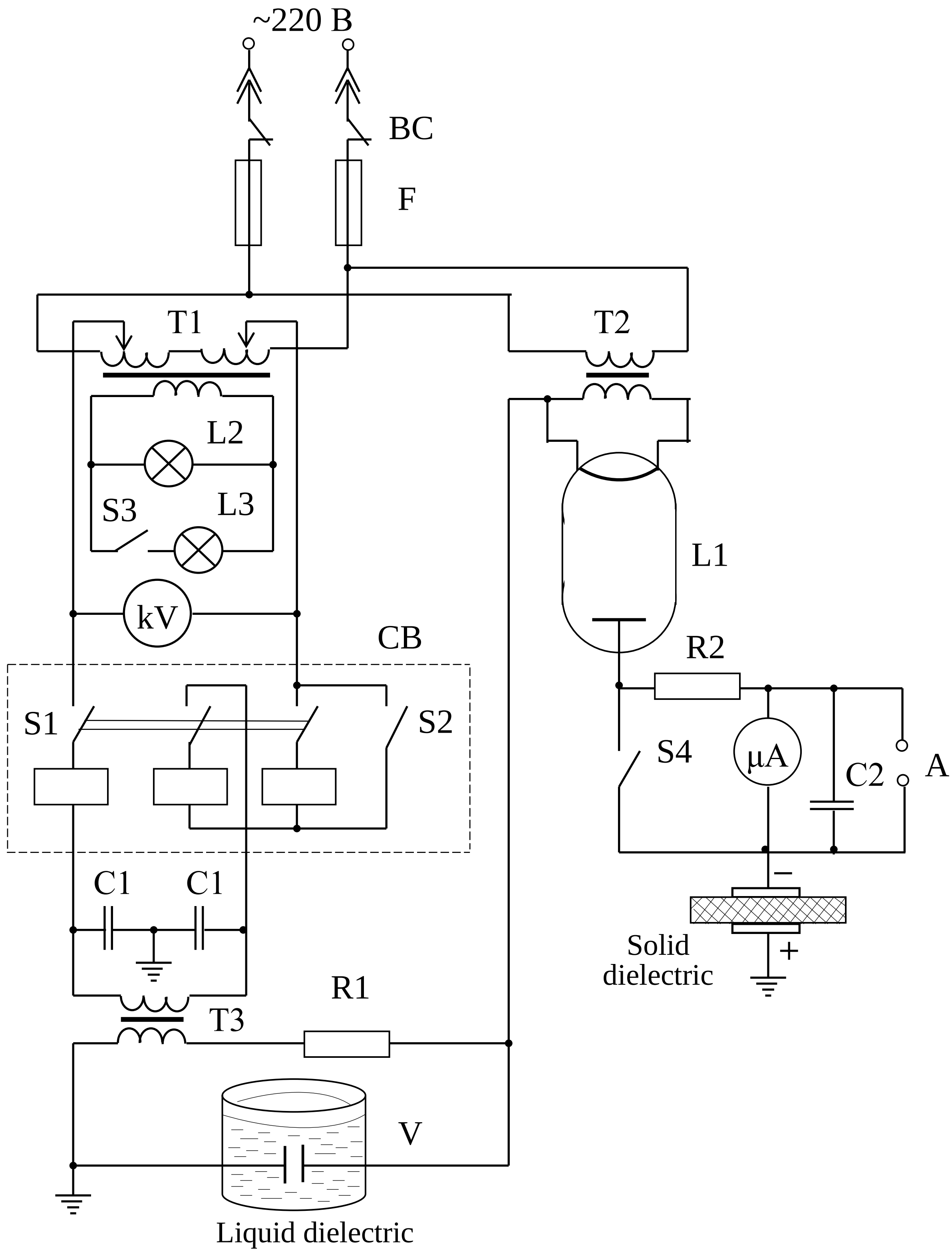

Fig. 3.1. Schematic diagram of the AII-70 device

The device has a vessel V with electrodes, which is filled with liquid dielectric. Access to the vessel - through the door on the lid of the control panel. Two electrodes are mounted in the vessel V - brass disks with a diameter of 25 mm with rounded ends. The standard distance between the electrodes is 2.5 mm, the oil level must be at least 15 mm higher than the end of the electrodes.

The conclusion on the quality of transformer oil as an insulating material and the suitability of its use in high-voltage devices and transformers can be made only after several breakdowns (at least six) and averaging experimental data, taking into account the random nature of breakdown, according to current rules of technical operation.

Solid dielectrics are tested on direct (rectified) current. Current rectification is carried out using a kenotron L1 in a one-and-a-half-cycle scheme. If it is necessary to measure the dielectric current, then use a microammeter μA in the anode circuit of the kenotron. The microammeter is protected against overload by means of a shunt capacitor C2, resistor R2 and arrester A. The microammeter has several measuring limits.

Test questions

1. 1. How to use transformer oil and for what purpose?
2. 2. What property of the dielectric characterizes the electrical strength?
3. 3. How is the breakdown of technically pure liquid dielectrics?
4. 4. What is the mechanism of breakdown of purified liquids?
5. 5. Why decreases the electrical strength of oil in the presence of water and other impurities?
6. 6. Explain the dependence of the electrical strength of transformer oil on temperature and duration of voltage application.
7. 7. Why does the electrical strength of oil change during its operation?
8. 8. Explain the essence of the aging process of transformer oil.
9. 9. Why such an important characteristic of transformer oil as its electrical strength is not standardized?
10. 10. What types of oils differ in the normalization of electrical strength?
11. 11. Why, according to current regulations, the electrical strength of fresh oil should be higher than operating?
12. 12. Explain the purpose of all elements of the device "AII-70".
13. 13. How does the device record the breakdown moment of the dielectric?
14. 14. What safety measures are provided when working with the device "AII-70"?

LABORATORY TEST ETM - 1/4

INVESTIGATION OF DIELECTRICS POLEARIZATION

Aim of the training

Determine the main parameters of the process of polarization of dielectrics in an electric field - dielectric constant and the tangent of the angle of dielectric loss.

Work program

1. To study the mechanism of polarization of dielectrics in an electric field.
2. Get acquainted with the principle of operation and design of the AC bridge.
3. Experimentally determine the parameters of the polarization process of dielectrics.
4. Processing of experimental data.
5. The report execution.

The work procedure

Stage 1. Study of the mechanism of polarization of dielectrics in an electric field

Using the recommended literature and guidelines for this laboratory work, to study the mechanism and basic types of polarization of dielectrics. Find out the essence of the dielectric constant ε_r and the tangent of the dielectric loss angle tgδ as numerical characteristics (parameters) of the polarization process of dielectrics. Pay attention to how these parameters affect the process of energy accumulation and energy loss in the dielectric under the influence of the electric field. To get acquainted with equivalent schemes and vector diagrams of the capacitor with the investigated dielectric (Fig. 4.1).

Stage 2. Introduction to the principle of operation and design AC bridge

Using the recommended literature and guidelines for this laboratory work, study the principle of operation of the AC bridge (Fig. 4.2) and get acquainted with the method of determining the relative dielectric constant ε_r and the tangent of the dielectric loss angle tgd dielectrics. Pay special attention to the conditions and ways to achieve balance of the bridge. Find out the purpose of each of the elements of the bridge and the order of regulation to achieve balance of the bridge.

Stage 3. Experimental determination of parameters
the process of polarization of dielectrics

Measurement of the parameters of the process of polarization of dielectrics (capacitance of the capacitor C_x with the investigated dielectric and the tangent of the angle of dielectric loss tgd) to perform in the following sequence:

- form a capacitor with the dielectric under study, placing the dielectric between two flat electrodes (the surface of the dielectric sample should be smooth, smooth, without cracks and scratches and preferably round in shape according to the shape of the electrodes, and the ratio of sample diameter to thickness 10 should not be less than 10). ;
- measure the diameter of the electrodes d and, using a micrometer, the thickness h of the provided samples and the measurement results are entered in table. 4.1;
- measure the capacitance of a flat capacitor Cx with different dielectrics and the tangent of the dielectric loss angle tgd (the number of samples is specified by the teacher) and the measurement results are listed in table 4.1.

Table 4.1

The results of determining the parameters of the polarization process of dielectrics

Діелектрик	Measured				Calculated		
	C_x	tg δ	h	d	C_0	ε_r	P
	uF	–	m	m	uF	–	μW

Stage 4. Experimental data processing

Experimental data should be processed in the following sequence:

- calculate for all experiments the capacity C_0 of the vacuum capacitor, the distance between the plates of which is equal to the thickness of the dielectric, according to formula (4.2), and the results are recorded in table. 4.1;
- calculate the relative dielectric constant of the investigated dielectrics according to formula (4.1) and also enter the results in table. 4.1;
- calculate the formula (4.4) dielectric losses P (active power of the capacitor with dielectric) in the studied dielectrics for the conditions of their operation with voltage U = 1000 V and frequency f = 50 Hz and the results are recorded in table. 4.1;
- on the basis of the values of ε_r and tgδ to draw a conclusion about the mechanisms of polarization in each of the studied dielectrics and explain what physical processes cause power losses in them.

<u>Stage 5. The report execution</u>

The report on this laboratory work should contain:

1. Title and purpose of the work.
2. Schematic diagram of an AC bridge (Fig. 4.2).
3. Completed table. 4.1.
4. Examples of calculations of C_0, ε_r and P
6. Conclusions.

Methodical guideline

<u>To stage 1</u>

The process of dielectric polarization is a limited displacement of the bound charges of the dielectric or the orientation of dipole molecules under the influence of an electric field (due to the action of Coulomb forces). In particular, the polarization of the dielectric in the capacitor contributes to the additional accumulation of charges, ie increasing its capacitance C. The ability of the dielectric to polarize is characterized by relative dielectric constant ε_r, which can be determined by increasing the capacitance of the capacitor.

$$\varepsilon_r = \frac{C_x}{C_0}\ , \tag{4.1}$$

where ε_r - relative dielectric constant of the dielectric;

C_x - capacitor capacity with dielectric;

C_0 - the capacity of the vacuum capacitor (without dielectric), the dimensions of which coincide with the dimensions of the capacitor with the dielectric under study.

To determine the parameters of the process of polarization of dielectrics is more convenient and easier to use a flat capacitor, the capacity of C_0 which can be determined by the formula:

$$C_0 = \frac{\varepsilon_0 \cdot S}{h} \cdot 10^6 \text{, uF,} \tag{4.2}$$

where $S = \pi d^2/4$ – capacitor cover area, m^2;

h – the distance between the parallel covers of the capacitor (dielectric thickness), m;

$\varepsilon_0 = 8{,}85 \cdot 10^{-12}$ – absolute dielectric constant of vacuum, F/m.

The value of the dielectric constant of the material is used when choosing the dielectric for capacitors, when choosing the insulation of high-frequency communication cables or when calculating the electric field strength in dielectrics.

Polarization of dielectrics has several types. The main ones are:

Electron polarization is the elastic displacement of the orbits of electrons relative to the nuclei of atoms or the deformation of these orbits under the action of an electric field on the dielectric. It occurs in an extremely short time - about 10-15 seconds. Electronic polarization occurs in all types of dielectrics, regardless of the presence of other types of polarization. No energy loss is observed during the full period of field action. As the temperature ε_r increases with electron polarization, it decreases due to the thermal expansion of the dielectric and the decrease in the number of atoms or molecules per unit volume. For solid and liquid dielectrics εr with electronic polarization can be in the range of 1.8 ... 2.5.

Ionic polarization is an elastic mutual displacement of dielectric ions under the influence of an electric field. It is characteristic of solids with an ionic structure and proceeds somewhat more slowly than the electronic one (due to the larger mass of ions) - in about 10^{-13} s. The electrical energy required to displace the ions is fully returned to the power supply after the voltage is removed, ie ionic polarization also occurs without loss of field energy in the dielectric. The magnitude of the polarization increases with increasing temperature as a result of a decrease in the elastic forces acting between the ions, as the distance between the ions during thermal expansion increases. In dielectrics with ionic polarization ε_r = 3 ... 15.

Dipole polarization is the rotation or orientation of dipole dielectric molecules by an electric field. It is characteristic of polar dielectrics and belongs to the slow types of polarization - the time of its realization is much longer compared to ionic - 10^{-2}...10^{-10}s. The rotation of dipole molecules under the action of an electric field requires overcoming the forces of internal "friction" in the substance, which is associated with the loss of electrical energy, which is dissipated in the dielectric in the form of heat. The dielectric constant of polar dielectrics ε_r can be in the range from 3 to 10 and significantly depends on their temperature and frequency of field change. In particular, at low temperatures, when the substance has a high viscosity, the orientation of the molecules is difficult, and therefore the polarization is weak. As the temperature increases, the viscosity decreases, the orientation of the molecules increases, due to which ε_r increases significantly. At even higher temperatures, due to the intensification of chaotic thermal oscillations of molecules, their field orientation decreases, so ε_r, passing through the maximum, decreases. When the frequency of the voltage applied to the dielectric increases to 10^2 ... 10^{10} Hz, the dipoles do not have time to orient in the direction of the field, which reduces ε_r.

Spontaneous polarization is present only in the group of solid ionic dielectrics (ferroelectrics) that have a domain structure (similar to ferromagnets). Within the macroscopic regions (domains), differently charged particles are mutually oriented in the absence of an external field, forming dipoles. The action of the external field contributes to the predominant orientation of the electric moments of the domains as dipoles in the direction of the field, which creates the effect of very strong polarization - ε_r can exceed 50000. The dielectric constant depends on the electric field strength and the dielectric temperature nonlinearly (with a maximum).

Energy dissipation in a dielectric is characterized by its power - dielectric losses that occur due to:

- through electrical conductivity (leakage current);
- orientation of dipole molecules in polar dielectrics and orientation of electric moments of domains in ferroelectrics;
- redistribution of charges in dielectrics caused by the heterogeneity of their structure;
- ionization of gas inclusions in a solid dielectric.

At alternating voltage all types of dielectric losses are possible, and at constant - only the first and last.

An electric field dielectric is essentially a capacitor with a dielectric in which there is a loss of energy. It can be represented by equivalent schemes: sequential (Fig. 4.1, a) or parallel (Fig. 4.1, b). The magnitude of the active resistance in the circuits is chosen so that its power is equal to the losses in the dielectric of the capacitor.

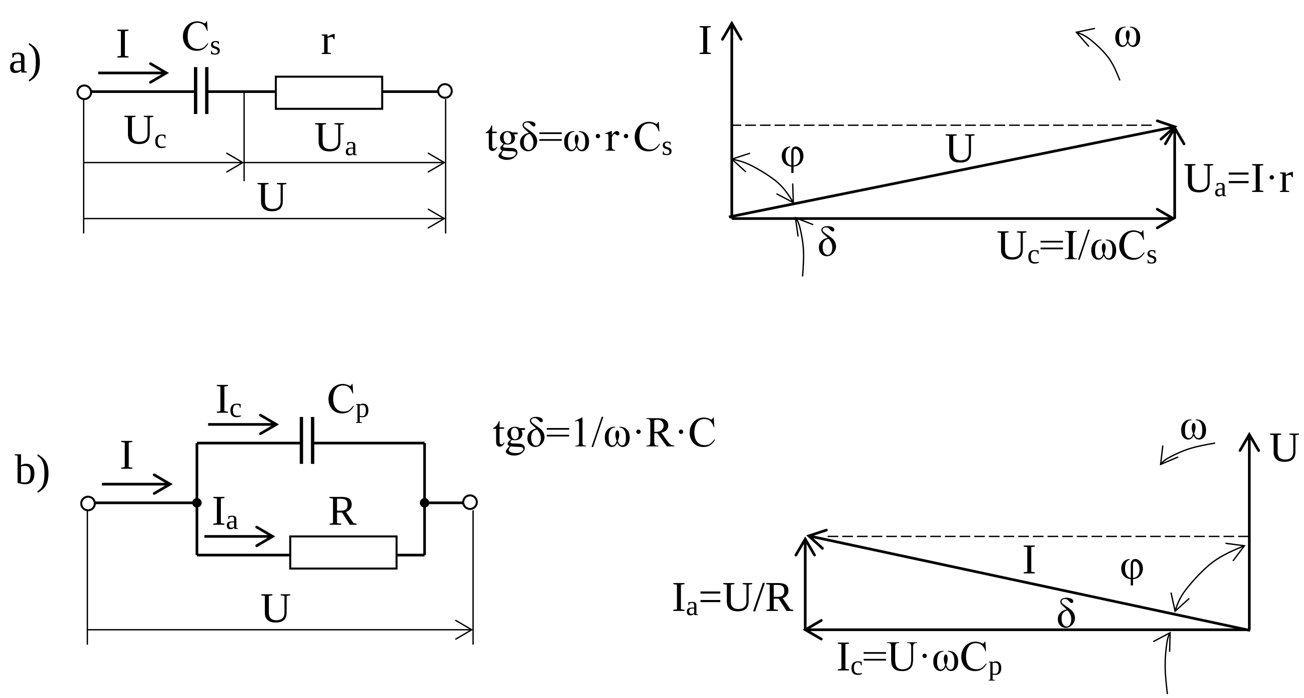

Fig. 4.1. Serial (a) and parallel (b) are equivalent circuits
and vector diagrams of the capacitor with dielectric, respectively

Due to dielectric losses, the alternating (sinusoidal) current in a real capacitor is ahead of the phase voltage by an angle φ less than 90°, ie φ = 90° - δ, where δ is the angle of dielectric loss. For the parallel scheme (Fig. 4.1, b):

$$tg\delta = \frac{I_a}{I_c} = \frac{1}{R \cdot \omega \cdot C}, \qquad (4.3)$$

where tgδ is the tangent of the dielectric loss angle;

I_a – active component of capacitor current, A;

I_c - reactive component of capacitor current, A;

ω = 2πf – angular frequency of voltage on the covers of the capacitor, 1/s;

f - voltage frequency on the capacitor covers, Hz;

R - the value of the active resistance of the equivalent capacitor circuit, Ohm;

C – capacitor capacity, F.

The active power of the capacitor (dielectric loss) taking into account (4.3) can be written as:

$$P = U \cdot I \cdot \cos\varphi = \frac{U^2}{R} = U^2 \cdot \omega \cdot C_x \cdot tg\delta \text{, μW}, \qquad (4.4)$$

where U is the voltage applied to the dielectric, V;

$R = \frac{1}{\omega C \cdot tg\delta}$ - from formula (4.3);

C_x – capacitance of the capacitor with dielectric, uF (table.4.1);

tgδ – the tangent of the angle of dielectric loss (table 4.1).

Nonpolar, homogeneous dielectrics (polyethylene, fluoroplastic-4) have t tgδ = $(2...5)\cdot 10^{-4}$. Materials with low tgd values are especially needed in high-frequency technology and at high voltages, so dielectrics with $tg\delta \le 5\cdot 10^{-4}$ are sometimes called high-frequency. The value of tgδ, like other parameters of dielectrics, does not remain constant. It depends on various external factors - temperature, voltage and its frequency, humidity and so on.

<u>To stage 2</u>

Measurements of the capacitance of the capacitor between the covers of which the investigated dielectric is placed (to find εr) and the tangent of the dielectric loss angle tgd at frequencies above 400 Hz are performed using AC bridges. The laboratory uses a bridge type R-577 (Fig. 4.2).

In the left upper arm of the first bridge, a capacitor Cx with a dielectric is connected. The right upper arm II and the right lower arm IV consist of several control resistors R_2 and R_3. The lower left arm IV includes a capacitor C_4 and a control resistor R_4, which is graduated in tgd values.

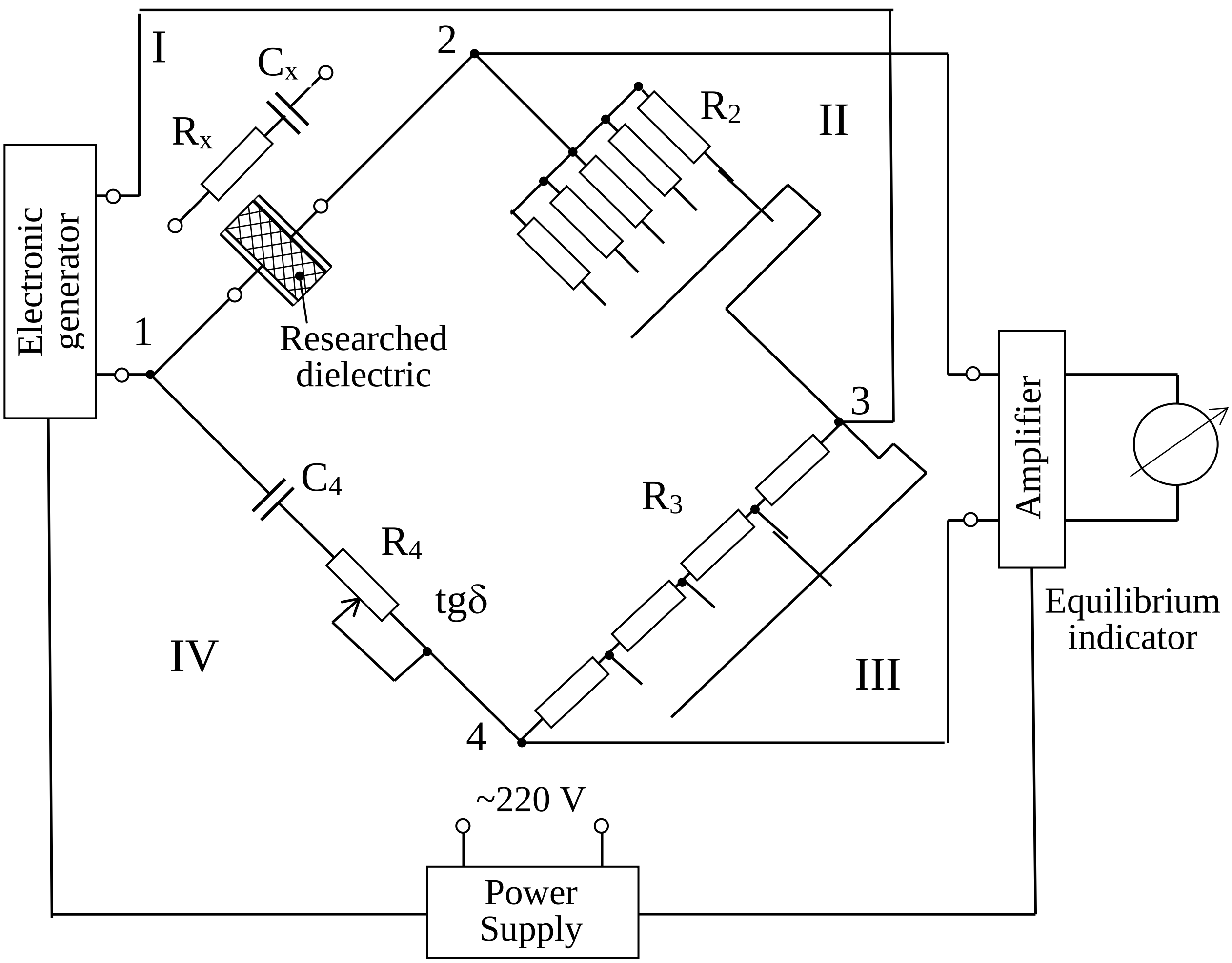

Fig. 4.2. Schematic diagram of an AC bridge

Equilibrium of the bridge is achieved by adjusting the resistors in the absence of voltage between points 2 and 4 (Fig. 4.2.) At the maximum possible value of the gain of the amplifier. The condition of equilibrium of the bridge is the equality of products of full (complex) resistances of opposite shoulders of the bridge:

$$Z_1 \cdot Z_3 = Z_2 \cdot Z_4 \tag{4.5}$$

$$\left(R_x + j\cdot\omega\cdot C_x\right)\cdot R_3 = \left(R_4 + \frac{1}{j\cdot\omega\cdot C_4}\right)\cdot R_2 \qquad (4.6)$$

Comparing the real and imaginary parts of the products of equation (4.6), we obtain two equilibrium conditions of the bridge:

$$C_x = C_4\frac{R_3}{R_2}, \qquad\qquad R_x = R_4\frac{R_2}{R_3} \qquad (4.7)$$

Multiplying equations (4.7) and multiplying them by w, we obtain:

$$\omega\cdot R_4\cdot C_4 = \omega\cdot R_x\cdot C_x = tg\delta, \qquad (4.8)$$

as follows from the formula in Fig.4.1, a.

The measuring bridge (points 1 and 3, Fig. 4.2) is powered by an internal electronic generator with an operating frequency of 1000 Hz. In the measuring diagonal (points 2 and 4, fig. 4.2) through the amplifier of alternating current the balance indicator is included.

Test questions

1. What property of dielectrics characterizes their dielectric constant?
2. Why is the capacitance of the capacitor (compared to vacuum or air) when placing the dielectric between its covers?
3. Name the main types of polarization and their features.
4. How does the dielectric constant of nonpolar dielectrics depend on the temperature and frequency of the applied voltage and why?
5. Describe the dependence of the dielectric constant of polar dielectrics on the temperature and frequency of the applied voltage.
6. Describe the method of determining the dielectric constant.
7. What property characterizes the tangent of the angle of dielectric loss?
8. At what voltage will the losses in the dielectric be greater - at constant or variable - and why?
9. Why are the values of tgδ polar and nonpolar dielectrics?
10. Explain the dependences of ε_r and tgδ of polar dielectrics on temperature.
11. Explain the dependences of ε_r and tgδ of nonpolar dielectrics on temperature.
12. Write formulas for calculating power losses in dielectrics.
13. Explain the principle of operation and equilibrium conditions of the AC bridge.
14. Explain the practical use of the values of ε_r and tgδ.

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CONTENTS

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МАТЕРІАЛИ МЕТОДИЧНОГО ЗАБЕЗПЕЧЕННЯ
лабораторних робіт з дисциплін “Електротехнічні матеріали”
(Розділ “Діелектричні матеріали”)
для студентів спеціальності
141–Електроенергетика, електротехніка та електромеханіка
(на англ. мові)

Редакційно-видавничий комплекс