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**ALMATY UNIVERSITY OF POWER ENGINEERING AND TECOMMUNICATION**

Power Plants,
Networks and
Systems Department

# ELECTROTECHNICAL MATERIALS SCIENCE

Methodological Guidelines for carrying out the laboratory works
for students of specialties 5B071800 – Power engineering,
5B081200 – Power supply of agriculture

Almaty 2015

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Basic information on electricity production process, main equipment of power plants and substations on discipline “Electrotechnical materials science” are contained in the presented work.

Il. 4, tables 3, references - 8

Reviewer: candidate of sciences in philology, V.S. Kozlov .

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**1 Laboratory work №1. Determination of the dielectric permittivity and the dielectric loss angle tangent of insulation materials**

1. Work objectives.
2. The laboratory installation and the electric circuit diagram.
3. Equipment list.
4. Experiment guidelines.

Work objectives

Determination of the main characteristics of insulation materials: a relative permittivity (ε) and a loss angle tangent (tg δ). Learning the electric circuit parameters measurements, using the device E7-22.

The laboratory installation and the electric circuit diagram

For the determination of the relative permittivity and the dielectric loss angle tangent of various insulation materials parameters of the sequential equivalent circuit of the capacitor (C and R) with a test material dielectric are measured. The electric circuit diagram for the capacitor parameters measurement is shown in Figure 1.1. The plate capacitor (block 2355), between the plates of which the test dielectric is placed, is connected to the tester E7-22 RLC (block 533). Power supply units 218 and 224.1 provide a source voltage of + 12V to E7-22.

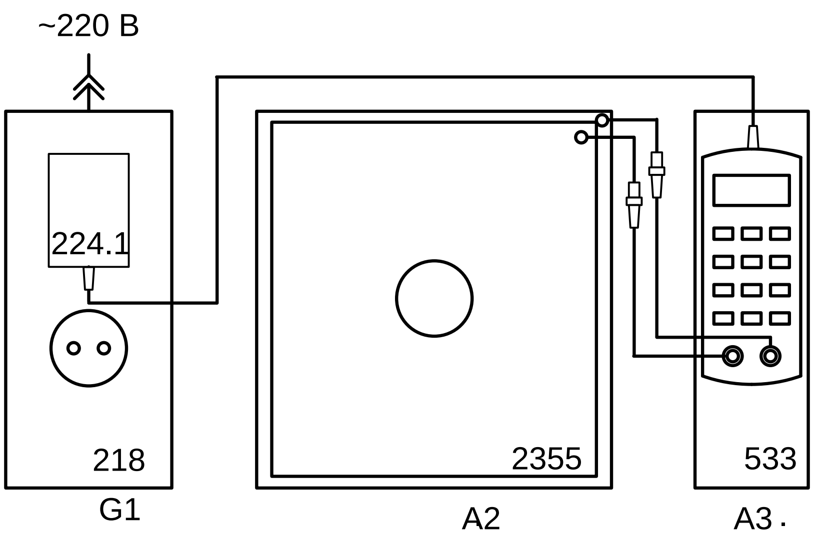



Figure 1.1 – The electric circuit diagram for the measurement of parameters of the capacitor with a test dielectric

A capacitance of the capacitor with the test dielectric is determined by formula:

$$C = \varepsilon\varepsilon_0 \frac{S}{d},$$

where $\varepsilon_0 \approx 8{,}854 \cdot 10^{-12} \frac{Ô}{ì}$ - an electric constant (a permittivity of free space);

$\varepsilon$ - the relative permittivity of the test dielectric;

$S$ - the area of the capacitor plates, [m$^2$]. In the experiment take into account the area of the upper plate of the capacitor.

The influence of the edge effect is neglected;

$d$ - the distance between the capacitor plates in meters, which is equal to the thickness of the test dielectric.

To calculate the relative permittivity of the test dielectric the measured capacitance $C$, is compared with the calculated capacitance of the condenser $C_0$ with the same geometrical dimensions, but without a dielectric (the medium between the plates - the vacuum with permittivity $\varepsilon_0$). The magnitude of the calculated capacitance:

$$C_0 = \varepsilon_0 \frac{S}{d}.$$

The ratio of capacitances:

$$\frac{C}{C_0} = \frac{\varepsilon\varepsilon_0 S/d}{\varepsilon_0 S/d} = \varepsilon,$$

i.e. is equal to the relative dielectric permittivity of the test dielectric.

Dielectric loss angle tangent is determined for the capacitor sequential equivalent circuit consisting of an ideal capacitor with the capacitance $C$ and the connected in series with it resistance $R$. When measured at a frequency $\omega$

$$tg\delta = \frac{R}{1/\omega C},$$

i.e. dielectric loss tangent is equal to the ratio of the active ($R$) and the capacitive resistances ($1/\omega C$) of the circuit. Hence, it is possible to determine the resistance R of the capacitor sequential equivalent circuit:

$$R = \frac{tg\delta}{\omega C}.$$

Table 1.1 – The equipment list

| Designation | Name | Type | Parameters |
|---|---|---|---|
| G1 | One phase power source | 218 | ~ 220 V / 16 A |
| A3 | A meter of R-L-C | 533 | The measurement of R, L, C at a frequency of 120 Hz and 1 kHz |
| A2 | A condenser block | 2355 | Plates area 790 square sm |
| | A set of dielectrics samples | 600.20 | Dielectrics samples with the dimension of 285x297 mm |

Guidelines for the experiment

1. Make sure that the blocks «Network» switches used in the experiment are turned off.
2. Connect the power supply unit 224.1 to the «Meter R-L-C» (533) unit and to the outlet «220 V» of the single-phase power source G1 (unit 218) in accordance with the scheme 1.1.
3. Turn on the protection tripping device and the automatic circuit breaker in the single-phase power source G1.
4. Turn on the circuit breaker of the «Meter R-L-C» (533).
5. Select:

- a type of the measured parameter– a capacitance C (button «L/C/R»);
- an auxiliary measured parameter - tan delta D (button «Q/D/R»);
- an element equivalent circuit – sequential (button «PAR/SEQ», «SER» on the display);
- a frequency of the measurement – 120 Hz (button «FREQ»).

6. Insert a test dielectric sample between the plates of the capacitor and connect a capacitor to the meter RLC. The upper plate of the capacitor unit 2355 must be installed approximately in the middle of the bottom plate with a uniform offset from the edges around the perimeter of the plate.

7. Unauthorized and conductive objects should not be at a distance of at least 10 ... 15 cm from the capacitor unit 2355. Voltage supply from external sources to the device input and the capacitor unit plates is inadmissible!

8. Calculate the capacitance C and $tg\delta$ (D) of the capacitor 2355 with the dielectric.

9. Calculate the capacitance of the capacitor without dielectric $C_0 = \varepsilon_0 \frac{S}{d}$.

Area $S$ is indicated on the upper plate of the capacitor 2355, and the distance between the plates $d$ is equal to a dielectric thickness indicated in the test sample.

10. Calculate the relative dielectric permittivity of the test dielectric and the sequential equivalent circuit resistance

11. $$\varepsilon = \frac{\tilde{N}}{\tilde{N}_0}, \; R = \frac{tg\delta}{\omega C}.$$

12. Record the measurement results in Table 3.1.1 and repeat the measurements for other samples of dielectrics.

13. Turn off the unit power supply G1 (218).

Table 1.2 – Experimental data

| Sample | C, pF | *Tgδ* □□D□ | ε | R, Ohm |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |

**Control questions**

1 What characterizes ε и tgδ?
2 Which method is used in measurement of ε and tgδ of dielectrics?
3 What is the limit value of ε for technical dielectrics?
4 What are units of measurement for ε, tgδ, R.?
5 What curve expresses the dependence of ε = *f* (T) for polar dielectrics?
6 What is the maximum voltage for the measurement of ε and tgδ?
7 How can you calculate the dielectric permittivity?

# 2 Laboratory work № 2. Conductive materials

## 2.1 The determination of the temperature coefficient of the resistance

At the experiment performance are determined temperature coefficients of:

1) The semi-conductive resistor with a positive temperature coefficient. Resistors KT110, KTY81 or the same are used. Marking: “600.13-1; MF”.

2) The metallic film of resistors of type MF, C2-33H or similar. Marking: 600.19-1; MF”.

3) The carbon film of resistors of type CF, C2-14 or similar. Marking: “600.19-2; C”.

4) The semi-conductive resistor with a negative temperature coefficient. Resistors B57861S, B57891M or similar are used. Mark: “600.19-3; NTC”.

5) The copper wire (a copper resistance temperature detector of type дTC014-50M.B3.20/0,2. The nominal resistance at 0 ° C - 50 ohms) Marking: “600.19-4; Cu”.

6) Straight voltage p-n transition of the silicon diode at direct current. Diodes of types KD522, 1N4148 or similar are used. Marking: “600.19-5; diode Si”.

1. Work objectives
2. The laboratory installation and the electric circuit diagram
3. List of apparatus
4. Guidelines for the experiment

### Objectives of the work

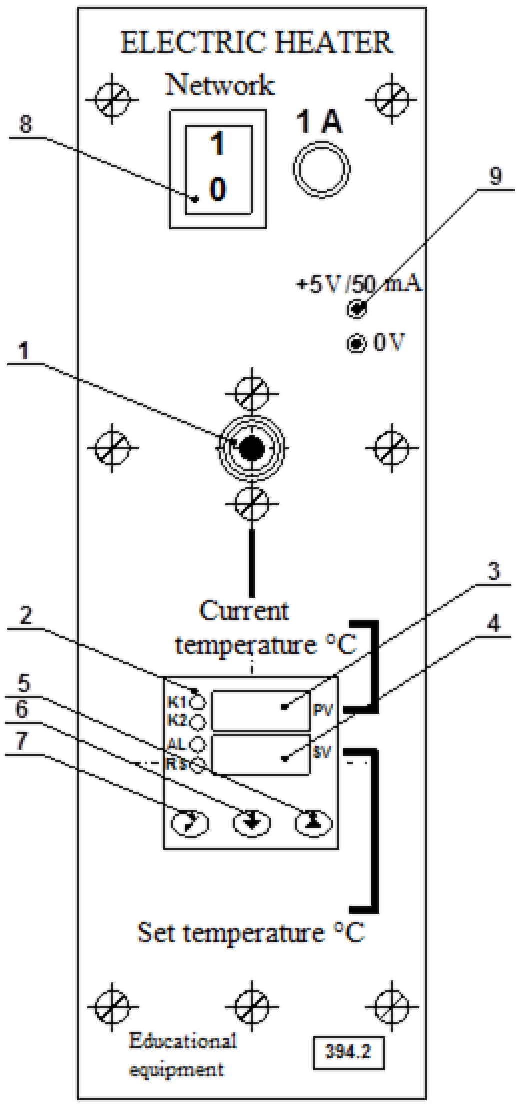
Determining the temperature coefficients of various conductor and semiconductor resistances and the direct voltage of the silicon diode p-n transition.

### The laboratory installation and the electric circuit diagram

In performing the work an electric heater (394.2) is used. A heater with the temperature regulator is embedded in a block. The test sample is inserted into the hole on the front of the heater, and its output resistance or voltage is measured using a multi-meter.

**Electric heating unit**

Electric heating unit is used to determine the temperature coefficient of the resistance of different materials. The unit allows you to set and automatically maintain the temperature of the heater. In the unit a low-power source + 5V is installed, which is used as an additional power supply source in some experiments.




1 – a hole of the electric heater; 2 –a temperature regulator; 3 –an indicator of the current value of the heater temperature (PV); 4 – an indicator of the given value of the heater temperature (SV); 5,6,7 – temperature control buttons; 8 – a power switch; 9 – power supply sockets of + 5V.

Figure 2.1 – The front panel of the electric heater (394.2)

To the left from the indicators 3 and 4 (Figure 2.1.), on the front panel of the temperature regulator, 4 light-emitting diodes (LEDs) are installed:

K1 – turned on at heating;

K2 – not used;

AL –an indicator of limit values exceedance (not used);

RS –an indicator of the automatic regulation mode. It should be turned on for the unit normal operation in the automatic regulation mode. At shutdown of the automatic regulation (see below) the device works only as an indicator of the heater temperature.

**Temperature setting of the electric heater**

1. Press one of the control buttons 5 or 6 of the temperature regulator 2 (Figure 2.1). The indicator of the given value of the heater temperature starts to flash on and off (SV, the green indicator 4).

2. For changing the given value of the temperature press repeatedly buttons 5 (decrease) or 6 (increase of temperature). Holding the button for some time turns on the mode of the value automatic accelerated change. The indicator continues to flash on and off in the process of temperature setting.

3. After setting of the required temperature value it is necessary to press once the button 7 (Figure 2.1). The indicator 4 flashing stops. The temperature is set.

At experiment performing it is recommended to begin from lower temperature values (higher than the room temperature for 5…$10^0$) and gradually to increase its value to $100^0$C, because cooling of the electric heater is much slower than heating.

**Switching on (shutdown) of the automatic regulation mode**

At turning on the power supply of the electric heater the automatic regulation mode is switched off. At experiment performing it is advisable to set the initial temperature value and after that to switch on the automatic regulation mode.

Switching the automatic regulation mode:

1) Press once the button 7 (Figure 2.1) of the temperature regulator. On the indicator 3 (red, PV) the inscription “r-S” is displayed. On the indicator 4 (green, SV) the current condition of the regulator “StoP” (STOP) or “rUn” (Work) is displayed.

2) For changing the regulator condition press any of buttons 5 or 6 – the indicator 4 starts to flash. A repeated pressure of the button 5 or 6 will switch the mode («StoP»↔«rUn»).

3) Pressure on the button 7 fixes the chosen value (the indicator 4 is not flashing). A repeated pressure of the button 7 returns the temperature regulator to the initial condition – the current and the given temperature values are displayed on the indicator. The Led RS signals about the regulator condition: switched on – the mode “rUn” (Work), switched off – “StoP” (STOP).

Operational modes of the temperature meter-regulator TP441 and the order of its program are described in details in literature: “The temperature meter-regulators TP440 и TP441Operation Manual”. ТАЛС.405111.040 РЭ. At experiment performing any changes of parameters of the temperature regulator except from above are not allowed.

**The electric circuit diagram**

The electric circuit diagram at determining the temperature coefficients of the resistance is shown in Figure 2.2.

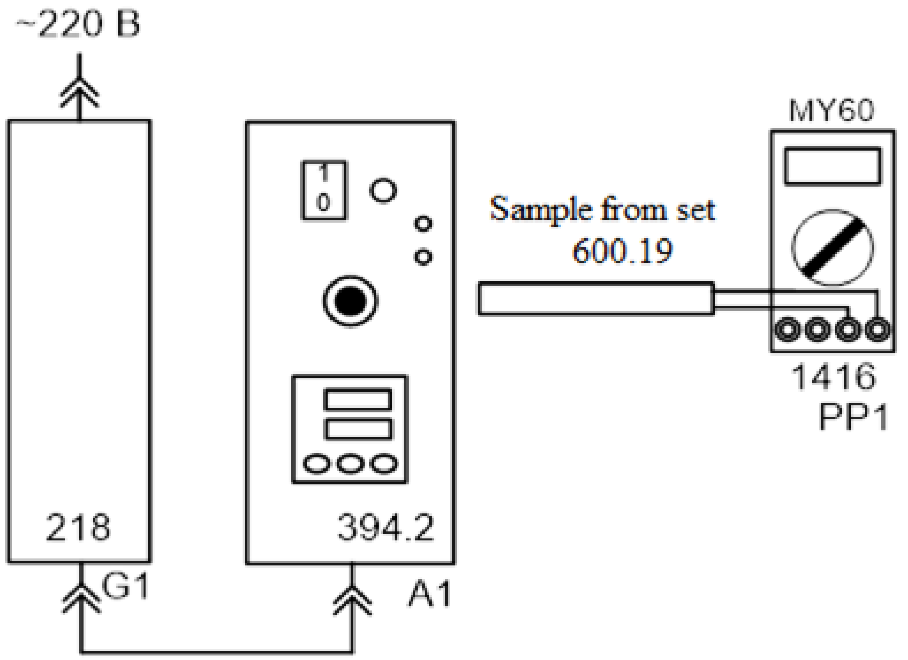



Figure 2.2 – The scheme for the determination of resistance temperature coefficients

All samples are connected to sockets «VΩ» and «COM» of the multi-meter MY60T (block 1416) and one of the limits of measurement of the resistance, corresponding to the resistance of the sample, is set. At connecting the silicon diode (a sample 600.19-5, the diode Si) it is necessary to follow polarity: an anode (the red wire) is connected to the socket "VΩ", and a cathode (the black or blue wire) to the socket "COM". For determining the forward voltage on the diode in millivolts the limit of measurement «⯈|» is used. In this case the constant direct current in the range of 1…1,5 mA flows through the diode. The accurate current value can be measured by the additional multi-meter, connected in series with the test diode.

A single-phase power supply source G1 is designed for the safe supply of the electric heating unit 394.2.

Table 2.1 – The list of the equipment

| Symbol | Name | Type | Parameters |
|---|---|---|---|
| G1 | A single-phase power supply source | 218 | ~ 220 B / 16 A |
| A1 | The electric heater | 394.2 | 30…100°C, source +5 V, |
| | Set of resistor samples | 600.19 | 6 samples |
| PP1 | A multi-meter | 1416 | MY60T |

## Experiment Guidelines

1. Check the power supply circuit of the electric heater units (394.2) and the power source G1 (218). Make sure that the circuit breakers "NETWORK" of these units are disconnected.
2. Connect the units according to the electric circuit diagram shown in Figure 2.1.
3. Select the temperature values at which you want to measure the resistance of samples. Due to the inertia of the heater it is advisable to choose a maximum of 5 ... 7 points in the temperature range up to 100 ° C. The initial value is the room temperature.
4. Turn on the protection tripping device and the automatic circuit breaker in the single-phase power supply source G1.
5. Turn on the circuit breaker "NETWORK" of the electric heater unit (394.2).
6. When power supply is turned on, the automatic mode of the electric heater temperature regulator is turned off. Set the desired temperature (see "The electric heater unit"). Turn on the automatic mode of the temperature regulator. The heater warming up starts (LEDs of indicators K1 and RS are switched on).
7. Measure the resistance of samples at the room temperature. To exclude the warming of samples of the hands you need to take the housing near the terminals.
8. After stabilizing the temperature of the heater near the set point, insert alternately each of the samples in the heater hole until it stops. Wait 2…3 minutes to stabilize the temperature and measure the resistance of the sample.
9. Set the next temperature value, wait for its stabilization and re-measure the resistance of samples. At sample's high temperature be careful: do not touch the working part of the sample extracted from the heater.
10. Based on measurements, construct the dependency graph of the sample resistance (or the voltage for the diode) of the temperature.

11. Upon measurement completion, turn off the power for all units.

12. On completion of testing, collect samples, having a linear relationship between the resistance and the temperature, and calculate their temperature coefficient of the resistance

$$\alpha = \frac{R(t_2) - R(t_1)}{R(t_1) \cdot t_2 - R(t_2) \cdot t_1}, \qquad (*)$$

where $R(t_2)$, $R(t_1)$ - the resistance of the sample, respectively, at a temperature $t_2$ and $t_1$.

$\alpha$ $\left[ \text{ãðàä}^{-1} \right]$ - a temperature coefficient of the sample resistance.

The resistance of the sample at an arbitrary temperature $t$ is calculated by the formula

$$R(t) = R(t_1) \cdot \frac{1 + \alpha \cdot t}{1 + \alpha \cdot t_1}. \qquad (*)$$

***Note***

At determining the resistance of only one sample the order of the experiment execution can be changed.

1. Build the circuit.
2. Place the test sample in the hole of the heater.
3. Set the temperature to 100 ° C and turn on the automatic mode of the temperature regulator («rUn», the mode "WORK", the indicator RS is turned on). Wait for the set temperature and turn off the automatic mode of the regulator («StoP», the mode "STOP", the indicator RS is turned off).
4. As the temperature of the heater decreases, measure the resistance of the sample (or the voltage for the diode) at several temperature values in the range of 100 ... 30 ° C. The approximate time of sensor cooling is 15 ... 30 minutes.
5. Process received experiment results in accordance with the above recommendations.

## The Multi-meter

The multi-meter is designed to measure voltages, currents, resistances, temperatures, and also to check diodes and transistors. Its general form is shown in Figure 2.3. The detailed technical information about the multi-meter and operating rules are provided in the operating instructions of the manufacturer. Here we present only the basic information.

To turn on the multi-meter, press the button «ON / OFF», located to the left under the indicator.

At the top of the multi-meter the reading device, a digital data display, is located. The mechanical switch of work modes and limits of measurement of devices is located below. Under the switch the sockets for the conductor connection are located:

1) The socket "COM" is a common device connection socket in any measurements. When measuring the DC voltage or current the socket corresponds to the "-" (minus) of the device. When measuring the resistance a "-" (minus) from an internal power source is fed to the socket «COM». The polarity of internal sources should be considered, for example, when checking diodes.

2) The socket «VΩ» is used to connect to the device the second conductor at the limits of measurement of voltage and resistance. When measuring the DC voltage and current the socket corresponds to the "+" (plus) of the device. When measuring the resistance this socket is the "+" socket of the internal source.

3) The socket "A" of the multi-meter MY 60 is designed for connecting the current measuring circuit at all current measurement limits, except 10 A. The socket corresponds to the "+" (plus) of the device.

4) The socket "10 A" is designed for connecting the current measuring circuit at the limit of 10 A. The socket corresponds to the "+" (plus) of the device.

When measuring the DC voltage, device readings are positive if the voltage is directed from the socket «V» (i.e. "+") to the socket "COM" (i.e. "-"). Similarly, the current is positive if it flows through the device in the direction away from the socket "+" (i.e. «mA», «A" or "10A") to the socket "-" ("COM").

A pair of sockets TEMP is designed to connect the thermocouple, which is included in the package of the device or a special cable, and to connect these jacks or sockets with a thermocouple mounted inside the mini-block (about the mini-blocks see below).

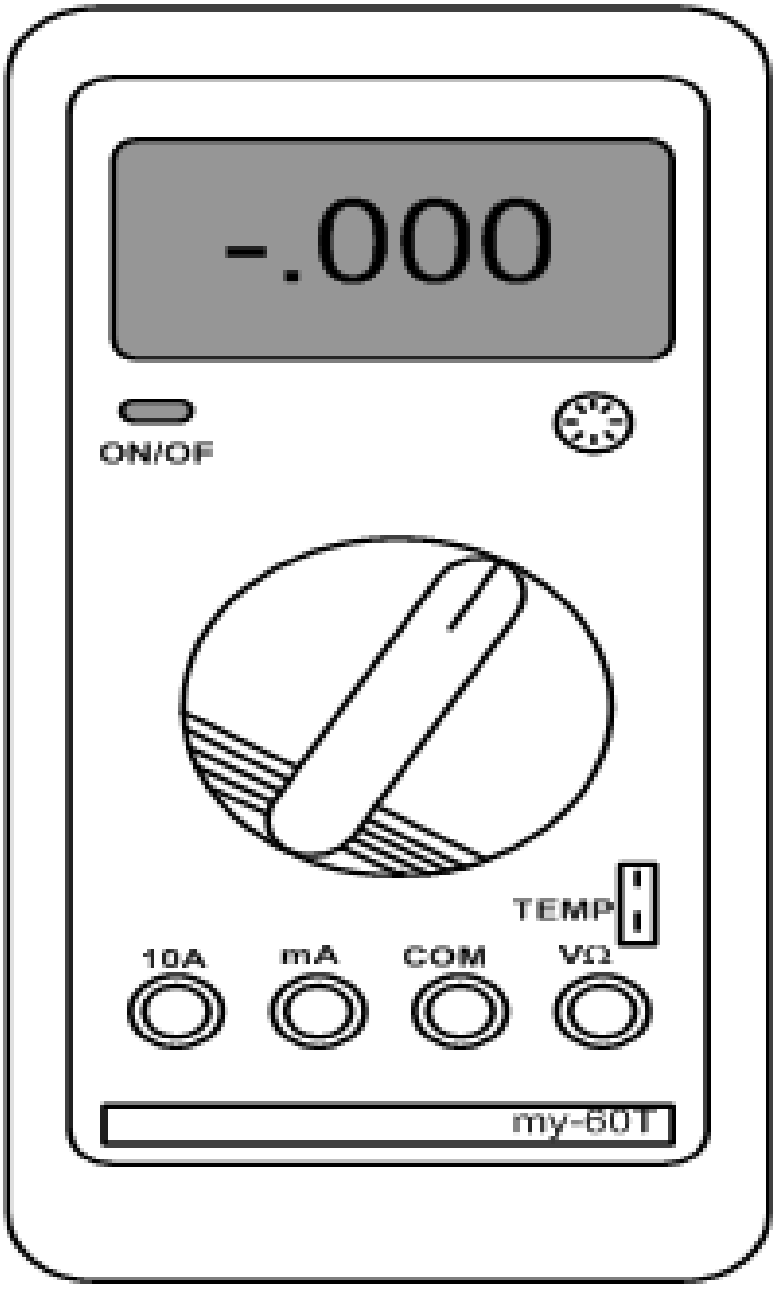



Figure 2.3 – General view of the multi-meter

The sequence of operation with a multi-meter:

1) Initially, the device is disconnected from the measured circuit.

2) Set the kind of the measured value and the desired measurement range by the switch. If the value of the measured voltage or current is not known in advance, you must set the most appropriate measurement limit value, which excludes the breakdown of the device when power is fed to the test circuit. Energizing the

inputs of multi-meters is possible only if their switches are set to position of the voltage or current measurement.

3) Connect the device to the de-energized test circuit. Turn on the power sources of the multi-meter and the test circuit and perform measurements.

4) The transition to the lower measuring limit of the measured value is allowed: a range-control switch is set to the neighboring with the original position.

It is unacceptable when switching the limit, even briefly, set the switch to the position corresponding to the other measured values.

5) To switch the device to another part of the test circuit, you must turn off the power supply of the circuit, change the connection of a multi-meter, set a limit of measurement, and re-energize the test circuit.

6) When measuring the parameters of electric circuit elements, diodes, resistors, capacitors, it is unacceptable to energize the device input from external sources (it is not allowed to measure the parameters of the elements in the circuit under the voltage). A capacitor before capacitance measuring must be discharged by shorting its terminals.

To ensure a reliable long-term operation of the multi-meter keep the following guidelines:

1) When the order of the measured value is unknown, set the measurement limits switch on the highest value.

2) It is unacceptable when switching the limit, even briefly, to set the switch to the position corresponding to the other measured values.

3) Before you turn the switch to change the type of work (not to change the measuring range!), disconnect the test leads from the circuit under test.

4) Do not measure the resistance in the circuit, to which the voltage is applied.

**Control questions**

1 What is the physical nature of the resistance?

2 What is the temperature coefficient of resistivity? How is it different from the temperature coefficient of resistance?

3 Why does the temperature increase the resistivity of metals increase and the resistivity of alloys decrease?

4 How do the dependency time curves of the resistivity for TKρ greater than 0, less than 0, and equal to 0 are like?

5 How are the $\rho$ and TK$\rho$ of the two metal alloy changed?

6 What is the physical nature of the thermal emf?

7 What are the properties of copper and aluminum?

8 What is superconductivity phenomenon? Hyperconductivity phenomenon?

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## Content

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Gulzhan Shayazdarovna Ospanova
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Compliers
Docent_________ G.S.Ospanova
Sen.teach._______B.K.Kurpenov

Specialist on standardization
____________N.K.Moldabekova
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GUEMC on MPE chairman
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