Practical 2.1
BASIC ELECTRICAL MEASUREMENTS AND DATA PROCESSING

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1 Introduction

To measure electrical quantities one uses electrical measuring instruments. There are three main quantities that describe physical processes in electrical circuits: electric current (denoted by I), voltage or potential difference between two points in an electric circuit (V) and electrical resistance (R).

Current The electric current in a wire is the amount of charge passing through the cross-section area of the wire per unit time. In SI units the current is expressed in Amperes ($1A = 1C/1s$) or in the fractional units milliamperes ($10^{-3}A$) denoted by mA, microamperes ($10^{-6}A$) denoted by μA, etc. The electric current is measured by ammeters.

Voltage The potential difference (or voltage) between two points of the circuit is the work done to move a unit positive charge ($q = +1C$) between these two points in the field E. It is measured in Volts ($1V = 1J/1C$). The corresponding measuring instruments are called voltmeters.

Resistance The current and voltage are related by Ohm's law, $I = \frac{V}{R}$, where the electrical resistance R is a characteristic of the electrical circuit. It is defined as the ratio of the potential difference at the ends of a circuit to the current flowing through the circuit. The SI unit of the resistance is Ohm ($1\Omega = 1V/1A$). Instrument used to measure resistance is called ohmmeter.

The criteria for selecting an appropriate measuring device:

1. The instrument should be selected in accordance with the measured quantity (e.g. electric current, voltage, resistance, etc.). The type of the device is usually indicated by a letter (e.g. "A", "V", "Ω"), which can be found on the front panel.
2. The device type should correspond to the type of voltage or current (alternating or direct). This is indicated by the symbols $\sim$ and $-$, or by "AC" (alternating current) and "DC" (direct current), respectively.
3. You should select the measurement range according to the expected value of the measured quantity.
4. You should check that the instrument error satisfies the required accuracy of the measurement. In case of performing precise measurements, you need to consider the internal resistance of the device. Since the instrument becomes an additional element of the circuit, it affects the current in the circuit.
5. You must check that the measuring instrument is safe to use.

2 Experimental tasks

1. Measurement of basic electrical quantities by using different electrical measuring instruments.
2. Debugging electrical circuits with the help of electrical measuring instruments.
3. Estimation of measurement errors.

Equipment: digital multimeter, analogue measuring instrument, DC current source (rectifier), variable resistor, connecting wires.

3 Measurement and data processing

3.1 Part 1. Measurements with a digital multimeter

3.1.1 Task 1. Measurement of AC mains voltage

a. Examine the basic functions of the front panel, i.e. buttons, a selection knob and input jacks. Plug the test leads into the "COM"-jack and the "V/Ω"-jack in accordance with their colours.

Attention! For safety reason, it is strictly forbidden to touch the metal probes of the test leads. It is only allowed to handle the insulated parts of the probes.

Switch on the multimeter by pressing the yellow "POWER" button. Make sure that the display shows values of measured quantities in the form of large digits. Check the operation of the multimeter in different modes. In most modes, the display should show zeros. In the RESISTANCE mode, the multimeter displays "OL" (overload), which corresponds to infinity.

Note that there are not only basic units but also prefixed units such as M mega, k kilo, m milli, μ micro.

Switch off the multimeter by pressing the yellow "power" button. The multimeter turns off automatically after 5 minutes of inactivity to extend the battery life.

b. Prepare the multimeter for the appropriate measurement. As you might know, the mains voltage in this country is 220 V.

c. Turn on the device. The unit symbol "V" will be displayed in the upper right-hand corner. Since the measured voltage is alternating, the symbol "AC" will also appear on the display in the lower left-hand corner. If it does not show up, set the multimeter to measure AC voltage by pressing the "$\sim$" button.

d. Take a measurement. As follows from the definition of "voltage" (potential difference), the voltmeter should be connected to two different points in a circuit, i.e. in parallel with the circuit. That is why, to measure the mains voltage, you should plug the leads into different slots of the socket. Write down the value of voltage V_{meas} indicated on the display in your notebook.

e. Turn off the multimeter.

f. Estimate the absolute error.

You need to find the value of the measurement uncertainty in this case (i.e. measurement of the AC voltage in the "750 V" range) in the specifications and write it down in your notebook. They are given in the form $\pm(a\% + b)$, where $a\%$ is the error of the measured value given in % and b is the resolution. The value of b gives the smallest difference which may be resolved by the instrumentation usually in the rightmost digit position.

For example, the multimeter shows a value of AC voltage of $224V$ and the specifications tell us that the accuracy of measurement is $\pm(0.8\% + 3)$, and the least digital position corresponds to $1V$. Then:

$$\Delta V = \frac{0.8\% \times 224V}{100\%} + 3 \times 1V \approx 1.8V + 3V = 4.8V \approx 5V,$$

$$V = 224V \pm 5V.$$

g. Calculate a relative error $\varepsilon = \Delta V / V_{meas}$ and write down the value in your notebook. The final result should be represented in the following form: $V = V_{meas} \pm \Delta V$.

3.1.2 Task 2. Measurement of DC voltage of a current source

a. Have a look at the front panel of the DC power supply. You can see a toggle switch, a power indicator, an output voltage switch, terminals with polarity marks for connection with elements of the external circuit.

b. Select the "20 V" range on the multimeter, this is the closest value to the maximum value of the voltage of the source (12 V). Turn on the device by pressing the "power" button. The multimeter should display "V"-mode. Set the multimeter to measure DC. In that case, "AC" indicator disappears.

c. Plug the power supply into the mains socket. Turn it on using a toggle switch on its front panel.

d. Touch the output terminals of the current source with test leads. Make sure that the black probe is connected to the "-" terminal, and the red one to the "+" terminal. If you connect them the other way about, you will see a "-" sign before the digits on the display.

e. Disconnect test leads from the terminals, turn the instruments off.

f. Calculate and write down the following data in your notebook: the value of the measured voltage V_{meas}, absolute ΔV and relative ε_V errors of the measurement (see Task 1). Your final result should be represented in the form of $V = V_{meas} \pm \Delta V$.

3.1.3 Task 3. Debugging an electrical circuit

One of the methods to identify electrical faults is to measure voltage at various parts of an electrical circuit and compare it with previously known values. However, this method is applicable only when there is a current in the circuit, which might be very dangerous. Therefore, electrical faults are mainly found by measuring resistance at different parts of the circuit in order to check conductors and other elements (lamps, wiring of devices, etc.).

If an ohmmeter is connected to an unbroken part of a circuit, it will display some resistance. If the resistance equals infinity ("OL"), it corrsponds to a break in this part of the circuit. By the way, this test can be made in a simpler manner by replacing an ohmmeter with a battery and a light bulb. In case of an unbroken circuit, the light bulb will glow. You can also connect a bell to the battery instead of the light bulb. Then, you will hear a sound if the circuit is not broken. Since you do not have to waste your time on looking at displays, this method really simplifies the test. What is more useful, this method can be performed with a multimeter.

a. Switch on the multimeter and set the diode test mode (there will appear a special indication in the upperright-hand corner of the display). Then, connect the leads to the open ends of the electrical wires. You will hear a sound indicating an unbroken circuit.

b. Ask an engineer for a device that has some faults in its circuit. Find these faults (e.g. break in a transformer coil, fault in a light bulb, a wire break, socket contact failure, etc.) using the multimeter. Record the obtained data in your notebook.

3.1.4 Task 4. Measurement of resistance

In contrast to current and potential difference, electrical resistance is a characteristic of elements of electrical circuits, but not processes that occur in the circuits. It is not necessary to connect a test element to an electrical circuit in order to measure resistance. If it is already a part of any circuit, it should be disconnected from it.

A variable resistor (or rheostat) is a cylinder made of an insulating material, with a wire wound round it. The rheostat has three terminals: two of them are fixed terminals connected to both ends of the resistive track and another terminal is connected to a sliding contact (wiper). The wiper moves from one end of the track to another that allows one to vary the resistance.

a. Write down the resistance of the rheostat.

b. Select the "Ω" -mode of the multimeter and choose the appropriate range for the rheostat resistance.

c. Switch on the multimeter. You will see indicators of the measurement unit (Ω, $k\Omega$, $M\Omega$) in the upperright-hand corner and "OL".

d. Make sure that the multimeter works properly. To check that, touch the probe leads together, the multimeter should show "0" (zero).

e. Move the wiper close to the middle position of the resistive track.

f. Measure the resistance R_{meas} between the wiper and one of the terminals.

g. Write down the following data in your notebook: the value of the measured resistance R_{meas}, the absolute ΔR and relative ε_R errors of the measurement (see Task 1). The final result should be represented in the form $R = R_{meas} \pm \Delta R$.

Do not change the position of the wiper because you will need it in the next task.

3.1.5 Task 5. Measurement of a current in an electrical circuit

To determine an expected current value I_{exp} in the electrical circuit, use Ohm's law.

a. Set the multimeter to measure DC current in the range close to the maximum expected value $I_{exp} + \Delta I_{exp}$.

b. Turn on the multimeter. You should check the current units in the upper right-hand corner. Connect the red probe of your multimeter to the "μAmA"-jack (it corresponds to "+" polarity).

c. Draw a circuit diagram using common symbols. It should consist of an ammeter, a current source and part of the rheostat between the wiper and one of its terminals connected in the series.

d. Assemble the circuit. The polarity of the measurement instrument must be correct. Connect an ammeter (or multimeter) in series with the electrical circuit in series. Always connect an ammeter with a power supply being switched off.

e. Turn on the power supply and measure the current. Write down the value of the current into your notebook.

f. Turn off the power supply and the multimeter.

g. Calculate the absolute ΔI and relative ε_I errors of the measurement. To find the absolute error of the current, use $\Delta I_{exp} = I_{exp} \times (\varepsilon_V + \varepsilon_R)$. Note: you obtained all the necessary data in Tasks 2 and 4.

3.2 Part 2. Measurements with an analogue instrument

Have a look at another instrument with a pointer indicator for measuring electrical quantities. This device is multifunctional and also multi-range. The type of any quantity and the range of measurement is determined by the terminals that are used to connect this device and positions of the selection knobs on the front panel. The scale of this instrument is marked in conventional units (scale units).

How do we use such an instrument? First, you should determine the measured value in scale units. Then, you need to define a scale division value, i.e. a coefficient used to convert the obtained value into proper units (amperes, volts, etc.). This coefficient is equal to the ratio of the measurement range to the maximum number of scale divisions. Finally, you need to multiply the value in scale units by this coefficient to get the correct measured quantity.

For example, you chose the range of 200 mA, and the maximum deviation of the pointer is 100 scale units. Thus, a scale division value is equal to 2 mA per unit. Let's assume that you measured some quantity and defined 62 scale units, then the correct value of current would be 124 mA.

An instrumental error of such measuring instruments is determined by so called the class of accuracy of an instrument. It is indicated on the scale as $\gamma = 0.05; 0.1; 0.2; 1.0; 1.5; 2.5; 4.0$. This number equals to the absolute instrument error of the selected range of measurements (expressed in %).

For example, the range of a measurement is $I_{max} = 200$ mA and the instrumental error is $\gamma = 0.5$. Then, you can find an absolute error as:

$$\Delta I = (\gamma/100\%) \times I_{max} = (0.5\%/100\%) \times 200mA = 1.0mA.$$

Suppose we have $I_{meas} = 40$ mA, then

$$\varepsilon_I = (\Delta I/I_{meas}) \times 100\% = (1.0mA/40mA) \times 100\% = 2.5\%.$$

However, if $I_{meas} = 160$ mA, then this error will be much smaller:

$$\varepsilon_I = (1.0mA/160mA) \times 100\% = 0.625\%.$$

This example demonstrates the importance of the proper choice of the measurement range. Choose the range as close as possible to I_{meas}.

3.2.1 Task 6. Measurement of a current with an analogue instrument

a. Make sure that your device is appropriate for DC measurements ("$\sim$" should be absent).

For DC measurements with a pointer indicator, it is important to keep the the proper polarity of connected devices. Otherwise, the pointer would be deflected in the opposite direction and the device will be damaged. Such symbols as "$-$", "$*$" or "common" indicate the terminal for a negative pole of the power supply.

b. Select the measurement range as close as possible to $I_{exp} + \Delta I_{exp}$. It is set by the selection knob.

c. Connect this device to your circuit. Turn on the power supply and write down the device output in scale units. Use the mirror under the scale to increase the accuracy of your measurements. If you are looking at the instrument correctly, you will not be able to see the image of the pointer in the mirror because the image will be directly behind the pointer.

d. Turn off the power supply.

e. Record the following data in your notebook: the measurement range of the device and the scale division value for this measurement range, the value of the measured current I_{meas} in mA, the class of accuracy, the absolute ΔI and relative ε_I errors of the measurement (see Task 1). Final result should be represented in the form $I = I_{meas} \pm \Delta I$.

f. Compare your results obtained with the digital and analogue measuring instruments taking into account the absolute errors of the measurements.

3.2.2 Task 7. Estimation of errors resulting from the connection of a measuring device into the electrical circuit.

If you connect an ammeter to the circuit, the current will decrease in comparison to its true value (without the connected device). It is due to the fact that any device has its own internal resistance. To determine the internal resistance of the ammeter, use the tables in the lower part of the devices scale.

a. Choose the values you need and record them in your notebook. Calculate R_{instr} in accordance with Ohm's law: $R_{instr} = V_{instr}/I_{max}$.

b. Calculate the uncertainty introduced by the connected device:

$$\varepsilon_{in} = R_{instr}/((R_{insrt} + R)) \times 100\%$$

where R is the measured resistance of the appropriate part of the rheostat.

4 Questions

1) What are the criteria for selecting a device for electrical measurements?

2) What is a class of accuracy of a device? Where is it specified?

3) What is the absolute instrumental error of a digital multimeter?

4) What is the instrumental error of an analogue device with a pointer indicator?

5) Why is it recommended to select the measurement range in such way that the measured quantity corresponds to the second half of the scale?

6) Describe the procedure to measure voltage, current, resistance.

7) Is it possible to measure current by a voltmeter? Is it possible to measure voltage by an ammeter?

8) How can one determine the internal resistance of a device?

9) Describe the following types of analogue instruments: permanent magnet moving coil (PMMC) instrument, moving iron instrument. Discuss advantages and disadvantages.