GENERAL INSTRUCTIONS ON EXECUTION OF THE LABORATORY WORKS

Internal regulation

1. Laboratory works are carried out in accordance with the laboratory work schedule given to students at the beginning of every term.

2. Only students instructed on rules of safety measures are allowed to carry out the laboratory works.

3. Laboratory works are carried out by teams of 2-3 persons.

4. Each student must be ready to training by means of having a notebook containing all necessary schemes, calculations, explanations concerning fulfillment of the work as well as the tables to fill in with the investigation results. Untrained one is not allowed to carry out the laboratory work.

5. Before the work execution, the team chief gets the set of type elements and necessary electrical measurement instruments from a laboratory assistant; he responds in all possible damages and after the work execution he turns over the set to laboratory assistant.

6. There must be corresponding order and work environment during laboratory training. The group chief and student on duty respond for the order maintenance.

7. Strict follow-through safety instructions during the laboratory work execution is obligatory.

8. After completing the lab, each student has to obtain the teacher's signature in notebook testifying the correctness of measurements and permission to dismantle the circuit. In case of wrong results the student makes measurements once more trying to get positive results.

As for the report, the calculation results are performed in the table form, moreover, the calculation example is given for but one test from table. Formulae are noted initially with letters, further the data are substituted for the letters and finally the calculation result is performed with obligatory presentation of the dimension units. All the physical quantities' units are expressed in SI-form. Plots are drawn at the scale with presentation of the dimensions at the axes; experimental points being to be shown in form of little spots.

Special attention is to be paid to conclusions on work having been fulfilled; the test results obtained being to be compared with known theoretical correlations; causes of possible inaccuracy being to be mentioned.

Properly formalized report combined with rough copy one is performed by the next laboratory training.

9. Missed labs are carried out at extracurricular trainings in accordance with schedule.

Safety measures

All voltages one may deal with in the laboratories on electrical engineering are dangerous for human life. That's why there are the following safety measures which are to be strictly kept.

1. Electric circuits are to be assembled at switched off energy source only.

2. Assembled circuit need to be checked by teacher or laboratory assistant. Circuit may be switched on with their permission only.

3. At knife-switch closing, all apparatus (sources, rheostats, coils etc.) is to be in such position to guarantee the minimal current in the circuit.

4. All students are to be familiar with emergency shutdown system of the electric energy source.

5. In the laboratory, it is prohibited:

5.1. To switch on a circuit without warning of the team members. At switching it is necessary to say: "I'm switching".

5.2. To touch bare parts of installation being under voltage.

5.3. To produce reconnections in a circuit under voltage. Any reconnection is produced at disconnected knife-switch. After any reconnection the circuit is checked by teacher or laboratory assistant.

5.4. To jam the laboratory table with secondary things including excess connecting wires.
5.5. To leave the installation being under voltage without care.
5.6. To disassemble a circuit without prior condenser discharge.
5.7. To switch on a circuit if there is a vacant end of any connecting wire.
6. In emergency case at the working place (equipment damage, blowing of a fuse, etc.), student should immediately switch off electricity supply and report to a teacher.
7. In case of electric injury one should immediately switch off electricity supply at the working place and render the first aid to victim.

LEGEND ON THE INSTRUMENT SCALES

In accordance with State Standard 22261-82 any electric measuring instrument is supplied with following notation on its scale: designation and type of instrument; trade mark of the manufacturer, serial No and year of manufacture; as well as other notation pointing to the principal metrological characteristics, application conditions, etc.

Notation of the electric measuring instrument type consists of the letter code, it being followed by figures. The letter code characterizes the instrument system.

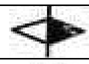
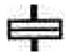
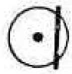
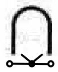
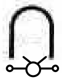
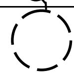
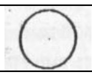
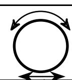
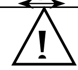
There are following letter codes; they being employed for the most types of the analog measuring instruments:

М – instruments of D'Arsonval measuring system (permanent-magnet system);
Э – electromagnetic instruments;
Д – instruments of electrodynamic system and ferrodynamic measuring system;
С – instruments of electrostatic system as well as cathode-ray oscilloscopes (oscillographs);
И – induction instruments;
Ц – rectifier (detector) instruments;
Ф – electromechanical instruments with electronic amplifiers;
Н – recording meters.

Principal legend mapped on the instrument scales in accordance with State Standard 23217-76 is presented in the following table.

Legend on the measuring instrument scales

Designation	Legend
1	2
1. Current kind	
Direct current	–
Alternating single-phase current	~
Three-phase current (general notation)	≋
2. Safety	
Testing voltage 500 V	☆
Testing voltage over 500 V (e.g. 2 kV)	☆ (2)
Instrument insulation is not to be tested	☆ (0)
3. Working position of instrument	
Instrument is applied at vertical position of scale	⊥
Instrument is applied at horizontal position of scale	⊓
Instrument is applied at the sloping position of scale (e.g. angularly 60°) with respect to horizontal plane	∠

Notation pointing to the instrument orientation in the external magnetic field	N
4. General legend	
Instrument of the permanent-magnet system with movable frame	
Logometer of the permanent-magnet system	
Instrument of the permanent-magnet system with movable magnet	
Electromagnetic instrument	
Logometer of the electromagnetic system	
Instrument of electrodynamic system	
Instrument of ferrodynamic measuring system	
Logometer of electrodynamic system	
Logometer of ferrodynamic measuring system	
Induction instrument	
Instrument of electrostatic system	
Permanent-magnet system instrument with rectifier	
Instrument of the permanent-magnet system with naked thermoelement	
Instrument of the permanent-magnet system with insulated thermoelement (thermoelectric device)	
Instrument of the permanent-magnet system with electronic transducer in the measuring circuit	
Electrostatic screen	
Magnetic screen	
Clamp to earth	
Corrector	
Main working conditions (reference to the instrument instruction)	
5. Accuracy rating	
Accuracy rating expressed in percentage terms of fiducial value of the quantity under measurement (at predominant additive inaccuracy)	1,5
Accuracy rating expressed in percentage terms of fiducial value which is determined by the scale length (for the instruments with sharply irregular scales)	1,5
Accuracy rating expressed in percentage terms of the quantity under measurement (at predominant multiplicative inaccuracy)	1,5
Accuracy rating expressed in percentage terms of the quantity under measurement (at commensurable additive and multiplicative inaccuracies)	0,5 / 0,2

Legend allows obtaining the principal characteristics of instruments. That’s why before the execution of each laboratory work one should look through the legend of all instruments involved in the laboratory work, it being placed into the instrument table in report.

Example to perform a report

ЭСиС-08ин-4	Report on laboratory work № I	Mohammed Awodi

Validation test of instruments

1. The purpose of work

Examination of technique to verify technical instruments and definition of their principal characteristics.

2. Installation and instruments

Table 1

List of the instruments involved

Name	T y p e	Serial No	System		Accuracy rating	Kind of current	Scale range	Division value	Working position	Test voltage, кВ
			Type	Symbol						
1. Ammeter	Э378	34101	ЭМ		1.5		1 -5 A	0.2 A/div		2

3. Work contents

3.1. Definition of the main inaccuracies.
3.2. Definition of the transition time of the readings.
3.3. Definition of the power consumption.
3.4. Definition of the instrument insulation resistance.

4. Testing schemes.
5. Measurement and calculation results.
6. Analysis of the results obtained and brief conclusions

Executed by	Checked by	Page	Pages	Signature
Mohammed Awodi	Михайлов В.Е.	1	3	

Laboratory work 1

CALIBRATION TEST OF TECHNICAL INSTRUMENTS

The purpose of work: examination of technique to verify technical instruments and definition of their principal characteristics.

Installation and instruments

Technical ammeter of the electromagnetic system of the accuracy rating 1.5 and standard ammeter of the electrodynamic system of the accuracy rating 0.2 as well as rheostats, step-down voltage transformer, stopwatch, megaohmmeter, millivoltmeter are employed at the work execution.

Work contents

1. Definition of the main inaccuracies.
2. Definition of the transition time of the readings.
3. Definition of the power consumption.
4. Definition of the instrument insulation resistance.

Explanatory notes to work

The measurement means are always to be ready for application, to guarantee unity and reliability of measurements. In application process of an electrical measuring instrument, its accuracy and reliability of the measurements are not kept (there are different causes). That's why in accordance with State Standard 8.002-71 all the measurement means are to be obligatory periodically calibrated. At calibration, the most important characteristics of the instruments (basic inaccuracies, transition time of the reading, insulation strength, self power consumption) are determined.

By the validation test results, the conclusion concerning the instrument suitability to the further application is realized.

Let's consider the principal characteristics of the electrical measuring instruments.

1. Basic inaccuracies and their definition.

In dependence on designation, the pointing measuring instruments are divided onto standard and working ones.

The results of a physical quantity measurement always differ from true quantity by definite value which is termed the measurement inaccuracy nevertheless they are executed thoroughly with perfect instruments.

Absolute error Δ of an instrument is difference between the instrument reading X_n and true value X of the measured quantity, i.e.

$$\Delta = X_n - X. \qquad (1.1)$$

Ratio error (relative error) δ of an instrument is the ratio of absolute error to true value of the measured quantity; it being usually expressed in percentage terms:

$$\delta = \frac{X_n - X}{X} 100\,\% = \frac{\Delta}{X} 100\,\% \qquad (1.2)$$

Reduced error γ is the ratio of absolute error Δ to true fiducial value X_H; it being expressed in percentage terms:

$$\delta = \frac{X_n - X}{X_H} 100\,\% = \frac{\Delta}{X_H} 100\,\% \qquad (1.3)$$

The fiducial value is a conditionally assumed value; in case of an instrument with unilateral scale, it being usually equal to full-scale deviation.

The measurement inaccuracy may not depend on the value of the measured quantity or may vary with its variation. Constant component of the measurement inaccuracy is termed additive inaccuracy, the variable component proportional to the measured quantity being called multiplicative inaccuracy.

Friction in supports as well as wear and tear of bearings and other causes result in variations in the instruments' reading.

Variation in the instruments' reading means the biggest possible difference in the instrument reading at one and the same value of the measured quantity. It is determined at soft approaching of pointer to the tested scale mark initially from the lower scale part and then from the higher scale part.

Inaccuracy value depends on the measurement conditions (temperature, pressure, air moisture, etc.).

Basic error is an inaccuracy at normal operating conditions for instrument.

Inaccuracies owing to deviations in conditions from normal ones are called additional inaccuracies. The highest inaccuracy which the instrument may be found to be valid at and to be allowed to application is called limit of allowable inaccuracy.

For majority of the electric measurement means used in static mode, the limit of allowable inaccuracy is rated. Questions connected with rationing of the allowable inaccuracies are considered in State Standard 8.401-80 "Accuracy ratings of the measuring means. General requirements". In accordance with Standard 8.401-80, the instruments are given with definite accuracy rating. It is the aggregate characteristic of an instrument which is set by limits of allowable basic and additional inaccuracies.

Accuracy rating is symbolized in dependence on the relationship character between the instrument inaccuracies and value of the measured quantity.

The majority of indicating pointer and recorder instruments possess predominant additive component of inaccuracy; particularly, inaccuracy owing to friction and the reading error, it being constant all around the instrument scale, i.e. $\Delta = const$. Ratio error of such instruments increases while the measured quantity decreases. That's why the accuracy rating for such instruments is set by reduced error which is constant all around the scale and is expressed by single number.

A number meaning the accuracy rating defines the limit of allowable reduced basic error. For example, for the instrument of accuracy rating 0.2 the biggest value of the basic reduced error should not exceed 0.2%.

For measuring instruments with nonuniform scale (for instance, ohmmeter), the fiducial value X_n, which is used to calculate the reduced error, is set to be equal to the full scale length or to its part (in mm) corresponding to the measurement range. Accuracy rating of such instruments is symbolized by single number supplied with little angle below, for instance, 1.0.

There are the measuring means which measurement inaccuracy is proportional to the measured quantity, it being so-called multiplicative inaccuracy.

To symbolize the accuracy rating, in this case single number placed in circle is used, for instance, (1.0). Here, the accuracy rating sets the limit of allowable ratio basic error.

If both additive and multiplicative inaccuracies are comparable quantities (as it is true for digital instruments), the accuracy rating is given in form of two numbers separated by division sign, for instance, 1.0/0.5. At the same time, the limit of allowable ratio basic error is rated too, however it is calculated under the following formula:

$$\delta = \pm\left[c + d\left(\frac{X_H}{X} - 1\right)\right] \tag{1.4}$$

where: c - number over the fraction line; d – number below the fraction line in symbol of the accuracy rating.

Correspondence to the accuracy rating is verified through determination of the basic inaccuracies; it means at the normal application conditions. Basic inaccuracies are usually determined by comparative approach when the reading of the tested working instrument is compared with reading of much more precise standard instrument. Accuracy of the standard instrument has to exceed the accuracy of the tested one more than 3 times. In this case the accuracy of the standard instrument is of no importance and its reading is assumed to be true value of the measured quantity.

In DC case the instruments of the permanent-magnet system are used as standard instruments while in AC case the instruments of electro-dynamic system are used.

2. Transition time of the reading

Speed of response of the pointer indicator is characterized by the transition time of the reading; it being the time interval from moment of the measured quantity change up to moment when the instrument pointer is remote from the new steady state position not far than 1% of the scale length.

For absolute majority of analog devices the transition time of reading could not exceed 1 s with exception of thermo-electric and electrostatic instruments. They are allowed to have the transition time of reading up to 6 s.

3. Power consumption

Power consumption of the instrument is one of the most important feature, however it being not rated by standard.

As the electrical measuring instrument being connected to a circuit under voltage, it starts consuming definite power from the circuit. In most cases this power is negligible as for the electricity economy. However, at measurements in low-power circuits owing to this power consumption, the circuit mode may be changed, it resulting in the measurement inaccuracy increase.

To determine the power consumed by ammeter, a voltmeter is connected to its terminals, it being done at nominal current of ammeter. The voltmeter to measure the voltage drop across the ammeter terminals is to have quite little limit of effective range as well as high inner impedance. The most suitable for this purpose instruments are electronic, or digital, or rectifier voltmeters.

Consumed by ammeter power is found under the following formula

$$P = I_n^2 R_{np}$$

where R_{ins} - inner resistance of the tested instrument which is calculated under the readings of ammeter and voltmeter.

In accordance with State Standard 22261-82, the insulation resistance between the frame and electric DC circuits at nominal temperature and moisture conditions is to be higher than 40 MOhm at working voltages up to 1000 V.

Measurement of the insulation resistance is fulfilled by megaohmmeter with nominal voltage 500 V.

Order of the work fulfillment

1. Do examine instruments used in the laboratory work; write down their rating into the instrument table.
2. Assemble the scheme for testing.

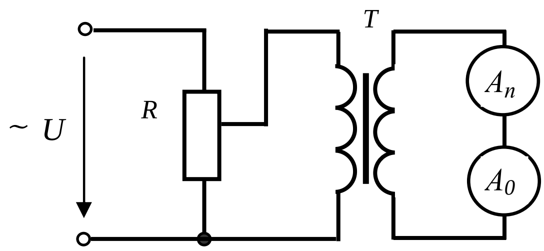


Fig.1.1 Scheme to test an ammeter

3. Supply the scheme for testing with voltage. Moving the slide contact of the rheostat, make the instrument pointer to travel from zero position up to maximal one and backwards; make sure the friction by pointer is absent.
4. Warm up the instrument with nominal current. After the circuit is switched off, check if the pointer is at the zero scale mark. If necessary, do set the pointer at the zero scale mark with the aid of corrector.
5. Do set the pointer of the tested instrument at all numerical scale marks one after another firstly at the current increase from zero to the biggest scale value and then at the same marks at the current decrease from the biggest value to zero. Pay attention if the pointer is approaching the numerical mark from but one side. Determine real value of the measured quantity at these marks by standard instrument.
6. Place the results of observations and the inaccuracy calculations into table 1.1. Calculate the reading variation γ_{var} and correction $-\Delta$ under the formulae:

$$\gamma_{вар} = \frac{I_{0\,возр} - I_{0\,убыв}}{I_H} 100\ \% \qquad\qquad -\Delta = I_0 - I_n$$

Table 1.1

Reading of the tested ammeter, A	Reading of the standard ammeter, A		Absolute inaccuracies, A		Relative inaccuracies, %		Reduced inaccuracy, %	Reading variation, %	Correction , A
I_n	$I_{0\ incr}$	$I_{0\ decr}$	Δ_{incr}	Δ_{decr}	δ_{incr}	δ_{decr}	γ	γ_{var}	$-\Delta$

At the calculation of the reduced inaccuracy and correction for each pair of the absolute inaccuracies, it is necessary to choose the biggest value.

7. Do determine the transition time of the tested instrument reading at the numerical mark in the centre of scale. Turn on simultaneously the scheme and a stop-watch, do turn off the stop-watch at the time moment when the oscillation amplitude of the pointer starts being less than 1% of the scale length. Repeat test three times. Place the results of observations and the calculations into table 1.2.

8. Measure the resistance of the tested instrument at the nominal current by method of ammeter-voltmeter. Place the results of observations and the calculations into table 1.2.

9. Measurement of the insulation resistance. Connect the clamp “line” of megaohmmeter with one of the terminals of the tested instrument; the clamp “earth” being connected with the instrument frame. Rotating the megaohmmeter generator handle uniformly with speed 90-120 rev/min, do make reading by scale. Write down the observation results into table 1.2

Table 1.2

Definition of the instrument characteristics

Decay time, s				Resistance and power consumption of the tested instrument				Resistance of insulation
t_1	t_2	t_3	t_{av}	I, A	U, V	R_{ins} , Ohm	P_{ins}, W	R_{ins} , $MOhm$

Contents of report

1. Scheme to verify the instrument.
2. Table of the measurement and calculation results.
3. Corrections plotted (do connection of experimental points with direct lines).
4. Analysis of the results obtained and conclusion if they meet the requirements of the State Standard.
5. Answers the self-control questions (in accordance with teacher’s instruction).

Self-control questions

1. What is purpose of the instrument periodical verification? Which characteristics are determined while verifying?
2. How are absolute, relative and reduced inaccuracies calculated?
3. Give the additive and multiplicative inaccuracy concept.
4. Perform the basic and auxilliary inaccuracy concept.
5. What is the accuracy rating of the measurement facilities? What ways exist to ascertain the accuracy rating of the electrical measuring instruments?
6. The accuracy rating of an instrument is 1.5. What does it mean?
7. How is the transition time of the reading determined?
8. How is the self power consumption of an instrument determined?
9. What is purpose to measure the instrument insulation resistance?
10. Give the definition of the reading variation.

Laboratory work 2

ANALYSIS OF THE DIRECT AND INDIRECT MEASUREMENT RESULTS

The purpose of work: study of the methods of analysis and performance of the single determination results by example of the rheostat resistance measurement.

Installation and instruments

While working, there are used: milliammeter, voltmeters Э505 (Э59), M2004, rheostat 100...800 Ohm, DC-source.

Work contents

1. Determine the rheostat resistance through the indirect measurements:
   - execute measurement by scheme an ammeter after a voltmeter;
   - execute measurement by scheme a voltmeter after an ammeter;
   - provide two variants of the voltage measurement for each mentioned case:
     by means of a voltmeter of the electromagnetic system with relatively small inner resistance;
     by means of a voltmeter of the permanent-magnet system with big inner resistance.
2. Determine both instrumental and methodical inaccuracies at the resistance measurement and do perform the results obtained for each case.
3. Analyze and compare the measurement results obtained in accordance with State Standard 8.011-72.

Explanatory notes to work

Any measurement result contains the inaccuracy. In electric measurements, one distinguishes both the instrumental inaccuracy which possesses the random character and the methodical inaccuracy which possesses the systematic character.

The instrumental inaccuracy is such inaccuracy which is inherent to the measurement facilities their-selves i.e. in that device or transducer by means of which the measurement is fulfilled. Causes of the instrumental inaccuracy may be imperfection of the measuring facility's characteristic, influence of environment upon this characteristic and so on.

Methodical inaccuracy is the result of the measurement method's imperfection:
- lack of correspondence between quantity and equivalent circuit used at the measurement;
- influence of the measuring facility upon the tested object and processes occurring in it.

For instance, voltage at the rectifier output is assumed to be constant and may be measured, for example, by magnetoelectric or electrodynamic voltmeter. However, if the measured voltage possesses the variable component (pulsations) then voltmeters give different readings because they react upon these pulsations in different manner.

Temporary connection of an ammeter (fig. 2.1) or a voltmeter (fig 2.2) at the direct measurements is the example of the instruments' influence upon the measured object. Value of current or voltage having been measured is less than true value.

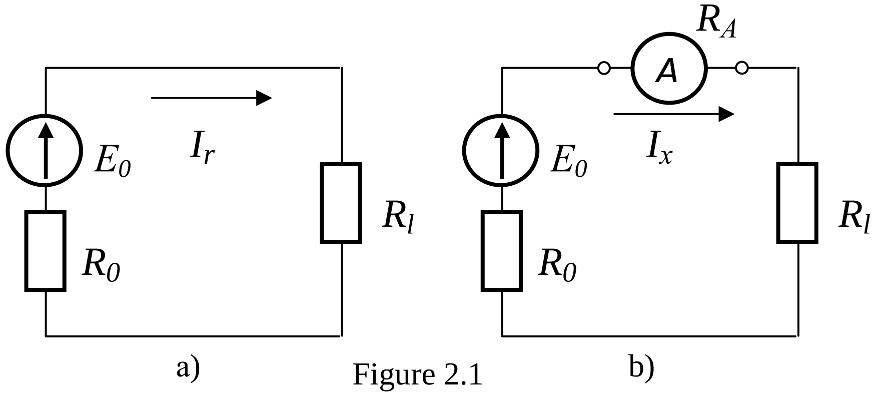


Figure 2.1

In order to measure the current flowing through load R_l, the ammeter is employed. Let's calculate the methodical inaccuracy at the temporary connection of ammeter.

Real and measured current values (in schemes 2.1a and b) are determined under Ohm's law:

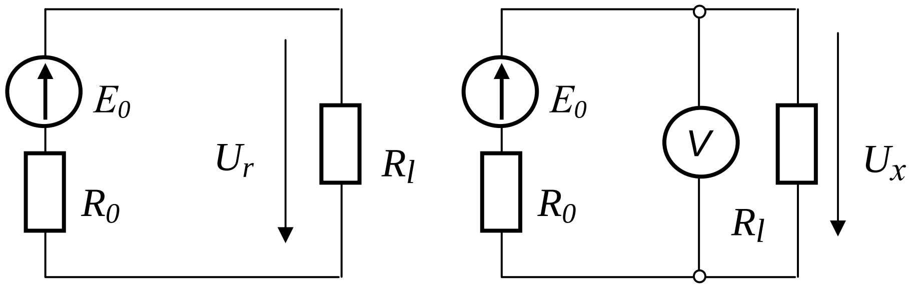
$$I_{\partial} = \frac{E_0}{R_0 + R_H} \qquad I_x = \frac{E_0}{R_0 + R_A + R_H}$$

Then absolute methodical inaccuracy is: $$\Delta_M = I_x - I_{\partial} = \frac{-E_0 R_A}{(R_0 + R_A + R_H)(R_0 + R_H)}$$

Relative methodical inaccuracy is: $$\delta_M = \frac{\Delta}{I_{\partial}} 100\% = -\frac{R_A}{R_0 + R_A + R_H} 100\%$$

If to assume $R_l >> R_0$ and $R_l >> R_A$ then $$\delta_{ì} = -\frac{R_A}{R_{í}} 100\ \%$$

In order to measure the voltage across the load R_l, a voltmeter is employed. Let's calculate the methodical inaccuracy at the temporary connection of voltmeter.



a) Figure 2.2 b)

Real and measured voltage values (in schemes 2.2a and b) are as follows:

$$U_{\partial} = \frac{E_0 R_H}{R_0 + R_H} \qquad U_x = \frac{E_0 R_H R_V}{R_0 R_H + R_0 R_V + R_H R_V}$$

Then absolute methodical inaccuracy is: $$\Delta_M = U_x - U_{\partial} = \frac{-E_0 R_H R_0}{(R_0 R_H + R_0 R_V + R_H R_V)(R_0 + R_H)}$$

Relative methodical inaccuracy is: $$\delta_M = \frac{\Delta}{U_{\partial}} 100\% = -\frac{R_0 R_H}{R_0 R_H + R_0 R_V + R_H R_V} 100\%$$

If to assume $R_V >> R_0$ and $R_l >> R_0$ then $$\delta_M = -\frac{R_0}{R_V}\ 100\%$$

There are two schemes being of use at measurement of the resistor's resistance by voltmeter-ammeter method: an ammeter after a voltmeter and a voltmeter after an ammeter (fig.2.3a and 2.3b respectively).

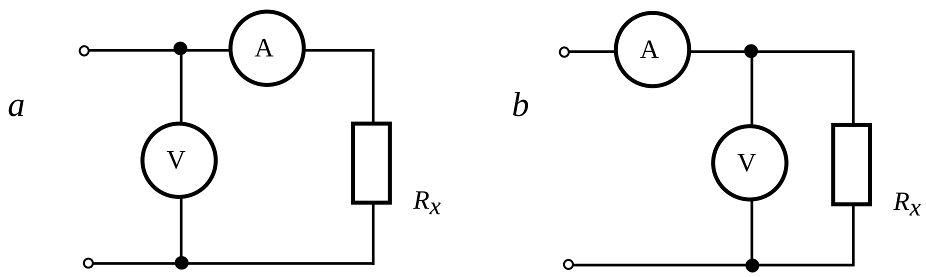


Fig. 2.3

While calculating the resistor resistance R_X under Ohm's law, the instrument influence is not taken into account for both schemes, it resulting in methodical inaccuracy appearance.

In scheme fig. 2.3*a*, the ammeter measures the current I_x of the resistor with resistance R_x and the voltmeter measures voltage $U_v = U_x + I_x R_a$. Here R_a – the ammeter resistance. Thus, the measured voltage is equal to sum of voltages across resistance U_x and across the ammeter terminals.

From here, in accordance with Ohm's law, the resistance measured (sum of resistances of resistor and ammeter) is as follows: $R_x^I = U_v / I_x = R_x + R_a$

However, real resistance is determined under formula:

$$R_x = R_x^I - R_a = R_x^I (1 - R_x^I / R_a)$$

Then absolute methodical inaccuracy is: $\Delta_м = R_x^I - R_x = R_a$

It is obvious that the measurement inaccuracy may be reduced by means of the ammeter resistance decrease.

Relative methodical inaccuracy: $\delta_м = -\frac{\Delta_м}{Rx}\ 100\,\% \approx -\frac{\Delta_м}{R_x^1}\ 100\,\%$

This scheme (at calculation under Ohm's law) is usually employed to measure relatively big resistances when $R_x >> R_a$.

In scheme fig. 2.3b, the voltmeter is connected directly to the resistor terminals and it measures voltage U_x across resistor. The ammeter measures sum of the resistor current and current in branch with voltmeter

$$I_A = I_X + I_V$$

Then total conductance is:

$$g_x^I = I_A / U_x = g_x + g_v = 1 / R_x + 1 / R_V,$$

where R_v – resistance of the voltmeter.

The resistor conductance may be found by subtraction of the voltmeter conductance from total conductance determined earlier:

$$g_x = g_x^I - g_V = g_x^I\,(1 - g_V / g_x^I), \quad R_x = R_x^I / (1 - R_x^I / R_V)$$

Then absolute methodical inaccuracy: $\Delta_м = R_x^1 - R_x = \frac{-(R_x^1)^2}{R_v - R_x^1}$

Relative methodical inaccuracy: $\delta_м = \frac{-R_x^1}{R_v} 100\%$

It is seen, we can improve the measurement accuracy by means of the voltmeter resistance increase.

This scheme (at calculation under Ohm's law) is usually employed to measure relatively little resistances when $R_x << R_v$.

Methodical inaccuracy has systematic character; that's why it has to be eliminated from the measurement results by means of the correction application:

$$R_x = R_x^I - \Delta_м$$

For scheme a) $R_x = R_x^I - \Delta_м = R_x^I - R_a$

For scheme b) $R_x = R_x^I - \Delta_м = R_x^I + (R_x^I)^2 / (R_V - R_x^I) = \frac{R_x^1 R_V}{R_V - R_x^1}$

The instrumental inaccuracy has the random character and depends on the instrument accuracy rating.

In case of the indirect measurement of a resistance, the instrumental inaccuracy is determined under formula:

$$\delta_И = \pm\sqrt{\delta_A^2 + \delta_V^2}$$

where δ_A and δ_V are relative errors of the ammeter and the voltmeter respectively.

While performing the measurement results, one should follow the rules:

1. The measurement result consists of the measured quantity and numerical accuracy figure (the measurement inaccuracy) characterizing the precision of measurements.

2. Numerical expressions of the measured quantity and numerical accuracy figure are to have the same order of the least number position.

3. Numerical accuracy figures are expressed in units of the measured quantity and are to contain not more than two significant digits.

Such presentation of the measurement results is based от the fact, that they determine only the bounds of interval within which the true value of the measured quantity occurs.

Order of the work fulfillment

1. Do choose the measuring instruments for indirect measurements of the rheostat resistance. While working, do make use of DC-source 25 V.
2. Assemble the scheme fig. 2.3a, do make use of magnetoelectric voltmeter and electromagnetic milliammeter. Take the instrument readings and tabulate them in tables 2.2 and 2.3.
3. Substitute the magnetoelectric voltmeter by electromagnetic one and do take reading. Place data into tables 2.2 and 2.3.
4. Assemble the scheme fig. 2.3b, do make use of magnetoelectric voltmeter and electromagnetic milliammeter. Take the instrument readings and tabulate them in tables 2.2 and 2.3.
5. Substitute the magnetoelectric voltmeter by electromagnetic one and do take reading. Place data into tables 2.2 and 2.3.
6. Note down the serial data of instruments and having fulfilled necessary calculations, do fill in table 2.4.

Table 2.2.

Parameters of the measuring instruments

Scheme	Type of voltmeter	Instrument resistance		Fiducial value		Accuracy rating		Division value		Absolute inaccuracy	
		R_v, *Ohm*	R_A, *Ohm*	U_N, *V*	I_N, *A*	K_v, *%*	K_A, *%*	C_v, *V/div*	C_A, *A/div*	Δ_v, *V*	Δ_A, *A*
a											
b											

Table 2.3.

Results of the direct measurements

Scheme	Type of voltmeter	Indication		Reading of instruments		Measurement results	
		α_v, div.	α_A, div.	U_v, *V*	I_A, *A*	$U \pm \lvert\Delta_v\rvert$, V	$I \pm \lvert\Delta_A\rvert$, *A*
a							
b							

Contents of report

1. Perform the schemes of investigation (fig.2.3).
2. Tables with the measurement and calculation results.
3. Table of the basic characteristics of instruments.
4. Conclusions on work.
5. Answers the self-control questions (in accordance with teacher’s instruction).

Table 2.4.
Calculation results of indirect measurements

Scheme	Type of voltmeter	R_x^I, *Ohm*	δ_M, *%*	Δ_M, *Ohm*	R_x, *Ohm*	$\delta_И$, *%*	$\Delta_И$, *Ohm*	Measurement results $R_x \pm \|\Delta_x\|$
a								
b								

Self-control questions

1. What measurements are termed direct ones?
2. What measurements are termed indirect ones?
3. What is the measurement inaccuracy?
4. Present the classification of the measurement inaccuracies.
5. Give definitions of the absolute, relative, systematic, random, additive multiplicative and instrumental inaccuracies of measurements.
6. What is the cause of the instrumental and methodical inaccuracies' appearance?
7. How are ratio and absolute errors of the electrical measuring instruments calculated with different notation of the accuracy rating?
8. What are the rules to express the measurement results?
9. Find out in table 2.4 the most precise measurement result and explain it.

Laboratory work 4

INVESTIGATION OF SINGLE-PHASE ACTIVE ENERGY METER

The purpose of work: study of the single-phase induction counter construction and execution of its calibration test .

Installation and instruments

While working, there are used: three-phase phase-shifting transformer, laboratory autotransformer, voltage transformer 127/36 V, ammeter, phasometer, wattmeter, tested single-phase induction counter of active energy and stop-watch.

Work contents

1. Determination of the relative inaccuracy of the active power measurement by wattmeter-stop-watch method.
2. Shunt running test of the induction counter.
3. Determination of a counter's threshold of sensitivity.

Explanatory notes to work

Single-element single-phase induction counter is employed to register (to indicate) the active energy in single-phase AC-circuits. Its crucial elements are as follows: parallel 1 and series 2 electromagnets, aluminum disk 3, permanent magnet 8 and counter mechanism combined with screw-gear 7 (fig. 4.1). The series electromagnet winding is made from relatively thick wire, it being connected in series with load. The parallel electromagnet winding possesses the great number of turns of thin wire, it being connected in parallel to load. Disk 3 with axis 4 is set in bearings 5, 6.

Alternating currents flowing through the electromagnets' windings create the alternating magnetic fluxes shifted each to other in space and in time. Magnetic fluxes penetrate the aluminum disk, they inducing EMF in it. Owing to EMF the eddy currents appear in the conducting disk. Interaction of the eddy currents and magnetic fluxes results in torque; disk starts rotating.

In order the rotation speed of disk n would be directly proportional to the load active power $P = C_r n$, the braking torque is produced in the counter with the aid of magnet 8.

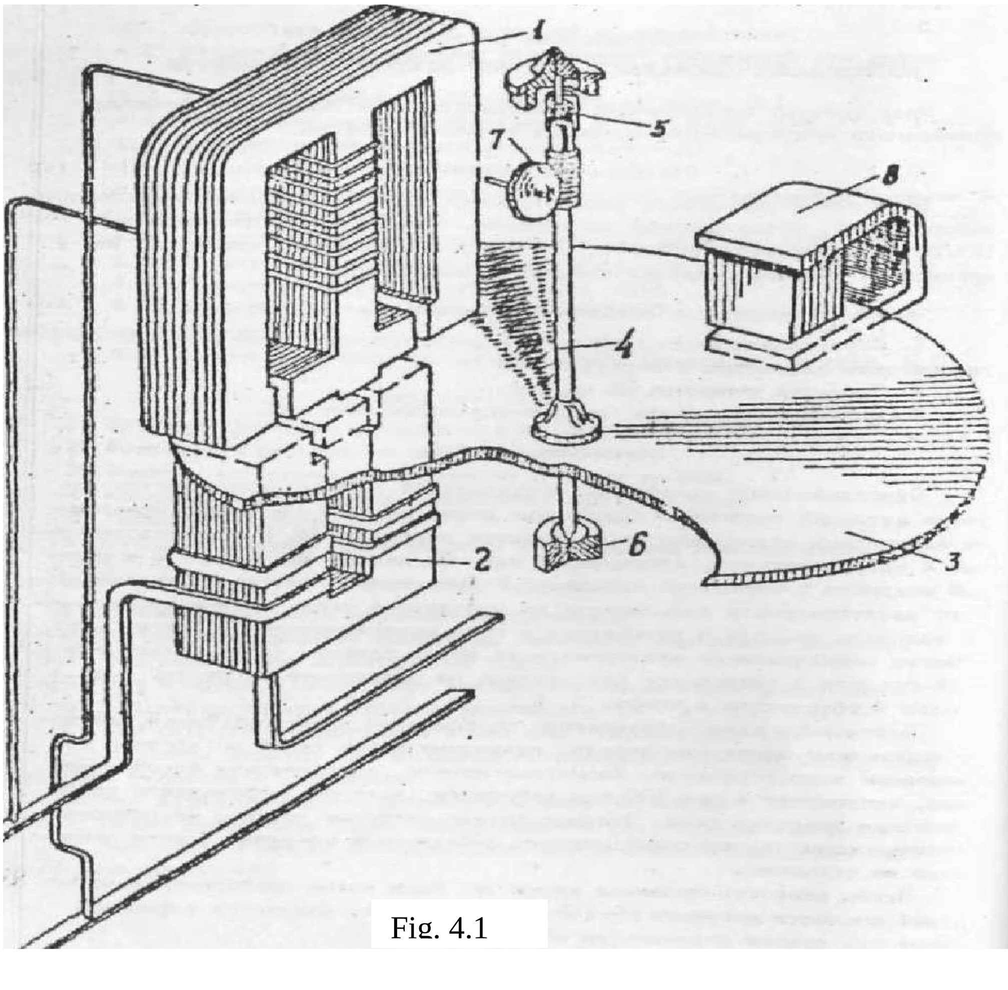


Fig. 4.1

Since power is $P= C_r n$, then active energy W_r consumed by load during time t is:

$$W_\partial = \int_0^t P dt = C_\partial \int_0^t n dt = C_\partial N \qquad (4.1)$$

it means the active energy is directly proportional to number of the disk revolutions N during time t.

Here $C_\partial = \frac{W_\partial}{N} = \frac{Pt}{N} = \frac{tUICos\phi}{N}$ - real constant of counter, it presenting the energy consumed by load per one full disk revolution.

Real constant C_r depends on the counter working condition and in general case is unknown. That's why the energy consumption is determined through the nominal constant C_n, which is the energy registered by the counter mechanism during one disk revolution:

$$W_x = C_н N \qquad (4.2)$$

Nominal constant C_n may be determined through the reciprocal quantity N_0, which is termed the gear-ratio and is indicated at the counter plate (number of revolutions corresponding to 1kW-hour of the registered energy):

$$C_н = \frac{1000 \quad 3600}{N_0} \qquad (4.3)$$

Quantities N_o, C_n depend on the counter mechanism construction and are constant. As a result of difference between C_n and C_∂, the energy measurement through the nominal constant is realized with inaccuracy. The counter ratio error is:

$$\delta_н = \frac{W_x - W_\partial}{W_\partial} 100\,\% = \frac{C_н - C_\partial}{C_\partial} 100\,\% \qquad (4.4)$$

The frictional torque in the counter mechanism and bearings has essential influence upon the accuracy of the counter reading at the low loads (at small current I). This frictional torque is directed towards the running one, that's why the energy registered by counter is less than real one. In order to reduce the counter inaccuracy from the frictional torque action in counters of all types, the additional running torque is produced. This is so-called compensating torque. While the counter running, compensating torque sometimes exceeds the frictional torque, the counter disk starts rotating even at zero current $I = 0$, i.e. when the consumer is not supplied with energy.

The shunt running is the counter disk rotation under the voltage action which occurs across the parallel circuit terminals at the absence of the current in the series circuit. The counter disk should not accomplish more than one full revolution at the absence of the current in the series circuit at any voltage being from 80% up to 110% of nominal one.

The counter's threshold of sensitivity S is minimum current value expressed in percentage terms of nominal current when the counter disk starts and keeps progressively rotating at the nominal voltage, $Cos\phi$ and current being lower than the values given in table 4.1.

$$S = \frac{I_{min}}{I_{ном}} \qquad (4.5)$$

Basic requirements produced by State Standard 6570-75 to single-phase counters are presented in table 4.1.

The electric energy counters are to be validate in accordance with State Standard 14767-69 which foresees the verification in one of the following ways:

1) the wattmeter-stop-watch method; here the real value of electric energy is determined

$$W_r = Pt, \qquad (4.6),$$

it being necessary to obtain the given number of the disk revolutions;

2) method of the standard counter; the reading of the tested counter is compared with reading of the standard counter.

In present work, a single-phase counter is tested by the wattmeter-stop-watch method.

Table 4.1

Basic requirements produced to the counters

Power factor $Cos\phi$	Current, % of nominal value	Limit of the allowable relative inaccuracy , %			
		For the accuracy ratings			
		0.5	1.0	2.0	2.5
1.0	From 5 to 10	1.0	2.0	2.5	-
	From 10 to 20	-	-	-	3.5
	From 20 to I_{max}	0.5	1.0	2.0	2.5
0.5 at ind. load	From 10 to 20	1.3	2.0	2.5	-
	From 20 to I_{max}	0.8	1.0	2.0	4.0
Threshold of sensitivity (% of I_{nom}) at U_{nom} , $Cos\phi$ and current		0.4	0.5	0.5	1.0

Order of the work fulfillment

1. Do examine instruments used in the laboratory work; write down their rating into the instrument table.

2. Assemble the scheme fig. 4.2; do pay attention upon the correctness of the connection to the generator terminals of the counter, wattmeter and phasometer.

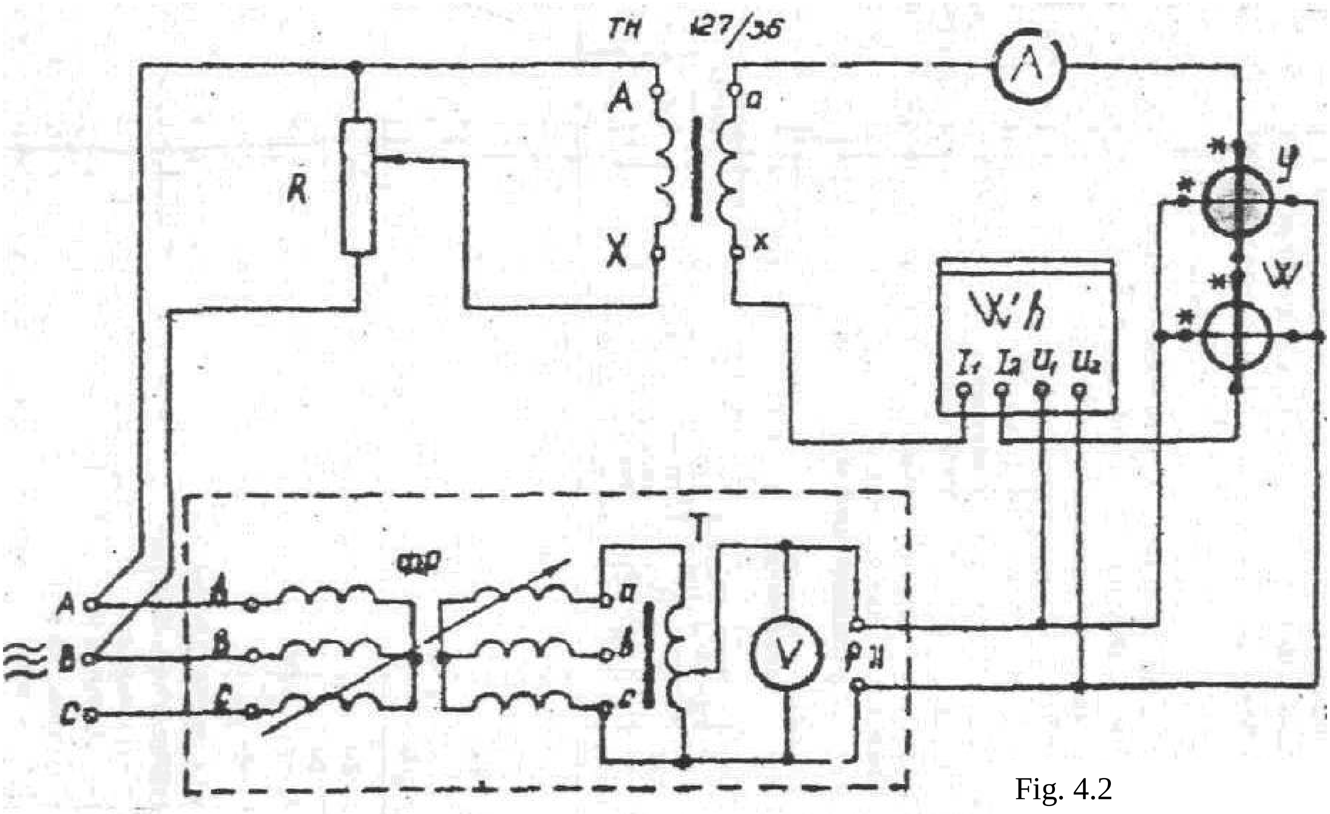


Fig. 4.2

3. Do set $Cos\phi=1.0$ (by phasometer) with the aid of the phase-shifting transformer at $U=U_{nom}$ and $I=I_{nom}$. Do keep $U=U_{nom}$ and $Cos\phi=1.0$ and set the current $I = 10, 20, 50, 75, 100$ % of I_{nom}. For each load current value, do measure the power P with the aid of the standard wattmeter and time t (by stop-watch) which is necessary for the counter disk to produce the number of turns N given in table 4.2.

4. Do keep $U=U_{nom}$ and $Cos\phi=0.5$ and set the current $I = 20, 50, 75, 100$ % of I_{nom}. For each load current value, do measure the power P with the aid of the standard wattmeter and time t (by stop-watch) which is necessary for the counter disk to produce the number of turns N given in table 4.2.

5. For each measurement, do calculate and place in table 4.2 the following:

- active energy W_x measured with the aid of the counter (under formula 4.2);
- real active energy W_r (under formula 4.6);
- ratio error of measurement δ (under formula 4.4).

6. Perform the shunt running test. Set $U=1.1U_{nom}$ and $I=I_{nom}$. Disconnect the load circuit and do determine number of the counter disk revolutions during 1 min.

7. Determine the threshold of sensitivity. Set $U=U_{nom}$, $I=I_{nom}$ and $Cos\phi=1.0$. Do reduce the load current down to 0. Additionally into the load circuit do connect a milliammeter (with limit of effective range *200 мА*). Increase gradually the circuit current and try to get the continuous disk rotation. Determine the threshold of S under formula 4.5.

Table 4.2

The measurement and calculation results

$Cos\phi$	I, % of I_{nom}	I, A	Measured				Calculated		
			P, div	P, W	N, rev	t, s	W_x, W·s	W_r, W·s	δ, %
1,0	10				2				
	20				4				
	50				10				
	75				15				
	100				20				
0,5	20				2				
	50				5				
	75				8				
	100				10				

Contents of report

1. Scheme to validate a single-phase counter.
2. Tables of the measurement and calculation results.
3. Results of the shunt running test.
4. Results of the determination of the counter’s threshold of sensitivity.
5. Conclusions.

Self-control questions

1. Owing to interaction of which magnetic fluxes does the running torque of a counter appear?
2. Explain the means to create the breaking torque of a counter?
3. What is the shunt running of a counter?
4. What conditions is the counter shunt running test realized at?
5. What is a counter’s threshold of sensitivity?

7. What methods are employed to verify the counters with respect to the correspondence to the accuracy rating?

8. How is the counter nominal constant C_n determined by the counter rating?

Laboratory work 5

ACTIVE POWER MEASUREMENT

The purpose of work: examination of the active power measurement schemes in three-phase circuits, connection of wattmeters through the measuring transformers.

Installation and instruments

While working, there are used: electrodynamic wattmeters, measuring current transformer, rheostat , laboratory workbench with three-phase active load.

Work contents

1. Do measure the active power of a three-phase balanced and unbalanced load by scheme of single wattmeter.
2. Do measure the active power of a three-phase balanced and unbalanced load by scheme of two wattmeters.
3. Do measure the load power by a wattmeter connected through the measuring current transformer.

Explanatory notes to work

Active power measurement in three-phase circuits is necessary for registration of the electric energy consumed by plants.

In dependence on the connection scheme and the load character, the active power in three-phase circuits is measured by scheme of single, two or three wattmeters.

Scheme of single wattmeter is employed but at full circuit symmetry; it means at the equality of the active powers of different phases to each other: $P_A = P_B = P_C = P_{ph}$. One wattmeter is so connected to measure the active power of a phase and then the three-phase circuit active power is:

$$P = 3\,P_{ph} \tag{5.1}$$

It is prohibited to measure the active power of the unbalanced three-phase circuit by scheme of single wattmeter because it results in hard error.

Scheme of three wattmeters is employed at the unbalanced four-wire three-phase circuits (Y-connection with neutral). Wattmeters are so connected to measure active powers of separate phases. This time, the active power is:

$$P = P_A + P_B + P_C \tag{5.2}$$

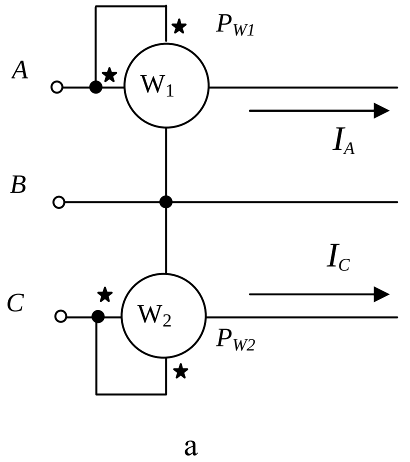
Scheme of two wattmeters is crucial one at the active power measurement in three-phase three-wire circuits independently on the load character. Possibility of such measurement is based upon fact that sum of currents of different phases in three-phase three-wire circuit is equal to zero. Indeed, $i_A + i_B + i_C = 0$. Then instantaneous power is:

$$p = p_A + p_B + p_C = u_A\, i_A + u_B\, i_B + u_C\, i_C = u_A\, i_A + u_B\,(-i_A - i_C) + u_C\, i_C = u_{AB}\, i_A + u_{CB}\, i_C\,.$$

Let's pass from instantaneous power value to the average one; we obtain:

$$P = P_A + P_B + P_C = U_{AB}\, I_A \,Cos\,(30^\circ + \phi_A) + U_{CB}\, I_C.\, Cos\,(30^\circ - \phi_C) = P_1 + P_2 \tag{5.3}$$

Here $P_1 = U_{AB}\, I_A\, Cos\,(30^\circ + \phi_A)$ и $P_2 = U_{CB}\, I_C.\, Cos\,(30^\circ - \phi_C)$ – readings of the 1st and 2nd wattmeters, respectively, of scheme fig. 5.1a. It is seen from the phasor diagram shown for this connection scheme in fig. 5.1b.



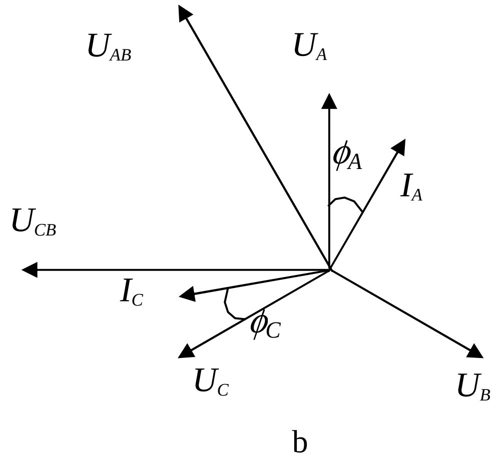


Fig.5.1

Expressing $i_A = (-i_B - i_C)$ or $i_C = (-i_B - i_A)$ it is possible to obtain two more equations identical to equation 5.3. Thus, there are three connection schemes in the two-wattmeter method, in each scheme the series current coils of wattmeters being connected in two any line conductors while the beginnings (generator clamps) of the parallel potential coils of wattmeters being joined with the same line conductors and their ends – to free line conductor. At angles $\phi > |60^o|$, the reading of one of wattmeters is negative (downscale reading). To obtain the upscale reading it is necessary to reconnect the terminals of the parallel coil of this wattmeter (for that the laboratory wattmeter possesses special voltage switch), its reading being taken with sign "minus".

In order to obtain the three-phase circuit power, the wattmeters' readings are added algebraically

$$P = P_1 + P_2 \qquad (5.4)$$

In practice, in order to measure the three-phase circuit active power, three-phase wattmeters are employed. Two-element three-phase wattmeters are used in three-wire circuits and they are connected in accordance with two-wattmeter method, while three-element wattmeters work in four-wire circuits under three-wattmeter scheme.

In order to expand the measurement range, the wattmeters are connected through the measuring current and voltage transformers. However, it is necessary to make sure the currents in the wattmeter coils have right (correct) direction.

The measurement inaccuracy consists of the methodical and instrumental ones.

Ratio instrumental error for the single-wattmeter scheme is as follows:

$$\delta_{И1} = \sqrt{3\delta_W^2} = \sqrt{3}\delta_W \qquad (5.5)$$

while that for the two-wattmeter scheme is

$$\delta_{И2} = \sqrt{\delta_{W1}^2 + \delta_{W1}^2} \qquad (5.6)$$

where δ_W , δ_{W1} , δ_{W2} - the wattmeters' inaccuracy, they being determined through the instrument accuracy rating.

At the wattmeter connection through the measuring transformers, the instrument error of the power measurement is found taking into account the errors given by the current and voltage transformers (δ_{TT} and δ_{TV}):

$$\delta_И = \sqrt{\delta_W^2 + \delta_{TT}^2 + \delta_{TH}^2} \qquad (5.7)$$

Then absolute instrumental inaccuracy is:

$$\Delta_И = \frac{\delta_И P_H}{100\ \%} \qquad (5.8)$$

Methodical inaccuracy of the three-phase load power measurement is explained by power self-consumption of wattmeters as well as the connection scheme of instruments.

There are two possible variants to connect the wattmeter coils, both of them being shown in fig. 5.2.

Fig.5.2

In scheme fig. 5.2a, the wattmeter parallel coil is supplied with voltage equal to the sum of the voltage drops across the load impedance and own current coil. Accordingly, the wattmeter reading in this case: $P_W = I(U_l + U_{ser}) = P_l + P_{ser}$ is overestimated by the power value P_{ser} consumed by own series coil. Methodical inaccuracy in this scheme is:

$$\delta_{MW} = \frac{P_{посл}}{P_H} 100\ \% = \frac{R_{посл}}{R_H} 100\ \% \qquad (5.9)$$

In scheme fig. 5.2b, current flowing through the series coil of instrument is equal to sum of the load current and current of the own parallel coil. This time, the instrument reading includes the load power as well as power consumed by parallel coil of wattmeter: $P_W = U(I_l + I_{par}) = P_l + P_{par}$, and methodical inaccuracy of this scheme being:

$$\delta_{MW} = \frac{P_{парал}}{P_H} 100\ \% = \frac{R_H}{R_{парал}} 100\ \% \tag{5.10}$$

Scheme fig. 5.2b is applied to measure the power of load with impedance of no importance; however, scheme fig. 5.2a is by far the most common.

Methodical inaccuracy under consideration appears at the wattmeter connection in both single-phase and three-phase circuits. Furthermore, while measuring the three-phase load power, the methodical inaccuracy caused by the wattmeter connection scheme can appear. In two-wattmeter scheme used in three-wire circuit (without neutral) and in three-wattmeter scheme used in four-wire circuit, such error is absent. While measuring the three-phase load power by single wattmeter (or by two wattmeters in four-wire circuit), even at the negligible circuit non-symmetry there are high errors. Methodical inaccuracy of the single-wattmeter scheme in comparison with true two-wattmeter scheme in case of three-wire circuit is as follows:

$$\delta_{M\,cx} = \frac{P_{H\,1} - P_{H\,2}}{P_{H\,1}} 100\ \% \tag{5.11}$$

where P_{l1} and P_{l2} - load powers determined by single-wattmeter and two-wattmeter methods, respectively.

Summary methodical inaccuracy of the three-phase load power measurement is determined under the following expression:

$$\delta_M = \sqrt{\sum_{i=1}^{n} \delta^2_{M\,Wi} + \delta^2_{M\,cx}} \tag{5.12}$$

Methodical inaccuracy being systematical has to be excluded from the result with the aid of the instrument correction:

$$-\Delta_M = -\frac{\delta_M P_H}{100\ \%} \tag{5.13}$$

The measurement result of the three-phase load power is:

$$P_l = P_l^I \pm \Delta_{И},\quad \text{where:}\quad P_l^I = P_{l\,изм} - \Delta_M \tag{5.14}$$

In work of question, the measurements are executed at the laboratory workbench, its scheme being shown in fig. 5.3. At closed switch *K*, resistances R_{ph1}, R_{ph2}, R_{ph3} create the three-phase balanced Δ-connected load. In one of triangle phase there is a disconnection, here the series coil of wattmeter is placed, wattmeter measuring the phase power. At the opened switch *K*, the three-phase circuit starts being unbalanced one.

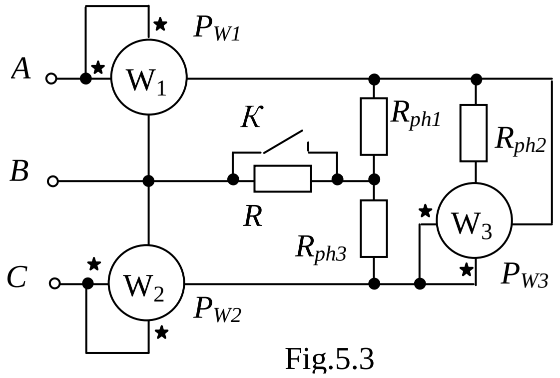


Fig.5.3

Order of the work fulfillment

1. Assemble the scheme fig. 5.1 to measure the active power by single and two wattmeters.

2. Take the instrument reading at balanced load (switch *К* is closed) and at unbalanced load (switch *К* is opened) and place the results into table 5.1.

Table 5.1

Three-phase load power measurement

Load	Wattmeter reading			Load power	
				Single-wattmeter scheme	Two-wattmeter scheme
	P_{W1}, W	P_{W2}, W	P_{W3}, W	P_{l1}, W	P_{l2}, W
Balanced one					
Unbalanced one					

3. Calculate instrumental inaccuracies and place the power measurement results into table 5.2.

Table 5.2

Inaccuracy calculation

Load	Instrumental inaccuracy of instruments			Instrumental inaccuracy of schemes				Power measurement result	
	W$_1$	W$_2$	W$_3$	1-wattmeter scheme		2-wattmeter scheme		1-wattmeter scheme	2-wattmeter scheme
	δ_{W1}, %	δ_{W2}, %	δ_{W3}, %	δ_1, %	Δ_1, w	δ_2, %	Δ_2, %	P_{1l}, W	P_{2l}, W
Balanced one									
Unbalanced one									

4. Do connect a wattmeter to measure the single-phase circuit power through the measuring current transformer (fig. 5.4). Determine the load power as well as inaccuracy of its measurement. The load power is determined under the wattmeter reading with account of the nominal transformer ratio of the current transformer:

$$P_{H\,изм} = P_W K_{IH} \qquad (5.15)$$

where $K_{IH} = \dfrac{I_{1H}}{I_{2H}}$ - nominal transformer ratio of the current transformer.

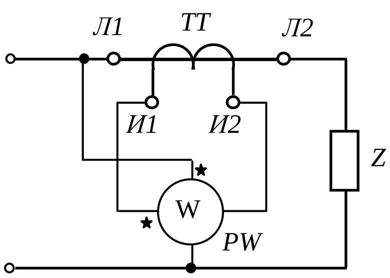


Fig.5.4

5. Place results into table 5.3.

Table 5.3

Measurement of the single-phase load power

Wattmeter reading	Transformer ratio	Load power	Measurement inaccuracy				Measurement result
P_W, W	K_{IH}	$P_{H\,изм}$, W	$\delta_{ИW}$, %	δ_{TT}, %	$\delta_И$, %	$\Delta_И$, %	P_H, W

Contents of report

1. Table of the instruments employed.
2. Schemes and tables with the measurement results.
3. Conclusions.
4. Answers the self-control questions (in accordance with teacher's instruction).

Self-control questions

1. What schemes to measure the three-phase load active power do you know?

2. In which cases is it possible to apply the single-wattmeter scheme? Perform the examples of such schemes. How is the load power determined by the instrument reading?

3. In which cases is it possible to apply the two-wattmeter scheme? Perform the examples of such schemes. How is the load power determined by the instrument reading?

4. In which cases and where is it possible to apply the three-wattmeter scheme? What is way (order) to connect the wattmeters in this scheme? How is the load power found?

5. Why in two-wattmeter scheme, at correct connection of instruments, may the reading of a wattmeter be negative? What is necessary to do in downscale reading case?

6. Why at the load active power measurement by two wattmeters, should one strictly follow the rule of connection of the coil generator clamps?

7. What does the instrumental inaccuracy of the three-phase load power measurement depend on? How is it determined?

8. What does the methodical inaccuracy of the three-phase load power measurement depend on? How is it determined?

9. What is the way to determine the measurement result?

10. What is purpose of the wattmeter connection through the measuring transformers? Give an example of the connection scheme. How is the load power determined in this case? Does the manner of connection of the measuring transformers have influence upon the measurement inaccuracy?

Laboratory work 6

SINGLE D-C BRIDGE

The purpose of work: examination of the bridge P333 construction and technique of the resistance measurement.

Installation and instruments

While working, there are used: bridge P333, set of resistances, multirange voltmeter.

Work contents

1. Do acquaint with the measuring bridge P333 construction and do look through the service instruction.
2. Do measure five resistances under dual clamp scheme and do determine the bridge's sensitivity.
3. Do measure two little resistances under the dual clamp scheme as well as under four-clamp scheme; determine error of the measurement of little resistances under two-clamp scheme.

Explanatory notes to work

Bridges are the comparison instruments; they being intended to measure the resistances or other quantities, which are expressed through them.

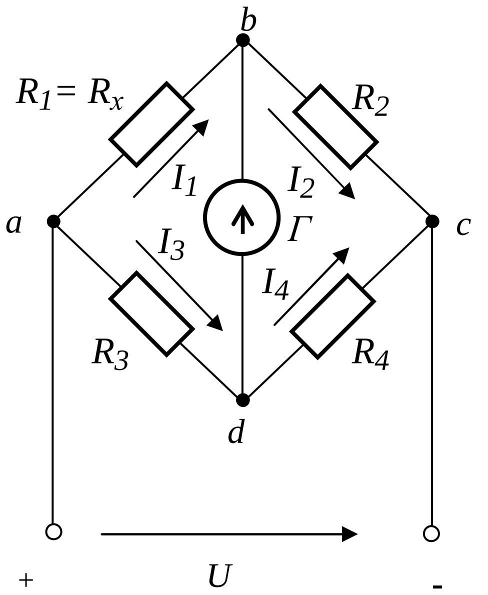


Fig.6.1

Such device is based on the measuring bridge scheme. The bridge schemes are commonly used at the electric measurements owing to high accuracy and sensetivity.

The bridge schemes are divided onto four-armed and multi-armed bridges; there are two- and four-clamp connection schemes for a resistance under measurement.

The simplest bridge scheme is shown in fig. 6.1; it being four-armed single D-C bridge. Points *a* , *b* , *c* and *d* are termed the bridge vertexes: branches *ab* , *bc* , *cd* and *ad* are the bridge arms; branch *ac* is the energy supply diagonal; branch *bd* is the measuring diagonal.

The bridge schemes possess an important property: at definite ratio of the arm resistances, there are neither current nor voltage in the measuring diagonal at any supply voltage. Such bridge state is termed the balanced state; ratio of the arm resistances of the balanced bridge being termed the bridge equilibrium condition. While the balanced bridge being employed, zero indicator is inserted in diagonal (galvanometer, microammeter, nanoammeter).

D-C bridge is balanced by changing of the bridge arm resistance. While the bridge being balanced the potentials of points *d* and *b* are equal to each other. Hence, the voltage drops across the first and third as well as across the second and fourth bridge arms are identical.

As the current through zero indicator is absent, it means the equalities $I_1 = I_2$ and $I_3 = I_4$.

Let's obtain the equilibrium condition for four-armed single bridge:

$$R_1 R_4 = R_2 R_3 \quad \text{or} \quad \frac{R_1}{R_2} = \frac{R_3}{R_4} \qquad (6.1)$$

Thus, for the balanced bridge, the products of opposite arm resistances are equal to each other.

If resistances of any three arms of the balanced bridge are known, then it is always possible to determine the fourth arm resistance from the equilibrium condition.

$$\text{Let it be } R_1 = R_x, \quad \text{then} \quad R_x = R_3 \frac{R_2}{R_4} \qquad (6.2)$$

As a rule, a measuring bridge is balanced by adjusting of the resistance R_3 .

The resistance ratio $\frac{R_2}{R_4}$ in equilibrium equation is called the scale factor, its value being chosen to be equal to 10^n, where n is integer positive or negative number (may be $n = 0$). In this case the third arm of the bridge R_3 is termed the equilibrium arm, correspondingly, the second R_2 and the fourth R_4 resistances are the ratio arms.

Measurement range of a bridge is chosen with the aid of the ratio arms.

Measurements by the balanced bridge are called null method of measurement.

The bridge measurement range is confined as from the top as from the bottom. It is confined from the top by the insulation resistance as well as by sensitivity of zero indicator, it being for usual bridges 10^6 - 10^8 Ohm. From the bottom, it is confined by influence of the lead-in resistances $R_П$- and resistance of transient contact $R_К$-, they producing the following error:

$$\delta = \frac{\sum (R_П + R_К)}{R_X} 100 \ \%$$

As the wire and contact resistances are of order 0.001 and 0.01 Ohm, then while measuring the resistance R_x of order 1 Ohm, these inaccuracies give annoying impairments.

The measurement field of the single bridge concerning little resistances may be expanded by application of four-clamp connection scheme of the resistance under measurement. In this case there are four clamps to connect R_x on the bridge board (fig. 6.2). Now the resistance of wire leading from R_x to clamp 3 is included into the arm resistance R_3, while the resistance of wire leading from R_x to clamp 4 is included into the arm resistance R_2. Resistances R_2 and R_3 are taken sufficiently great; so, it is possible to neglect by influence of resistance $\sum(R_П + R_К)$. Resistance of wires from clamp R_x to clamps 1 and 2 are included, respectively, in the bridge diagonal resistances. Four-clamp connection of the little resistances allows to measure resistances down to 10^{-4} Ohm. Thus, total measurement range of the single bridge is from 10^{-4} to 10^8 Ohm.

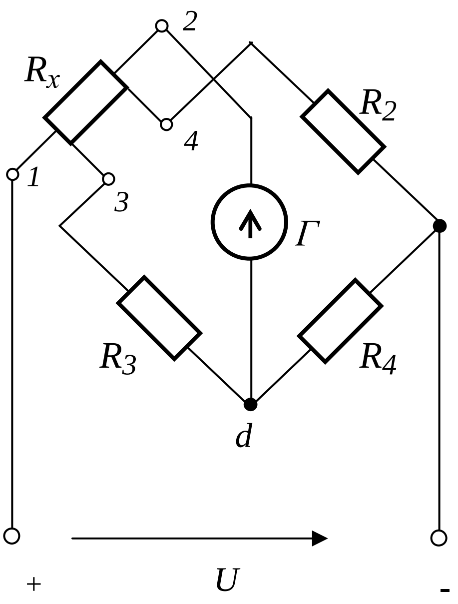


Рис.6.2

For more strict measurement of the little resistances, six-clamp (double) D-C bridges are applied.

In addition to single and double bridges, so-called universal bridges are involved, they working successfully under scheme both single and double bridge.

Important property of a bridge, which characterizes its service performance and operational functionality, is its ability to find out little changes in a quantity measured, it means its sensitivity. Thus, among the extremely sensitive null methods are measurements with the aid of the balanced bridges.

While an magnetoelectric galvanometer being employed to be zero indicator, absolute sensitivity of the D-C bridge is as follows:

$$S_M = \frac{\Delta\alpha}{\Delta R} \qquad (6.3)$$

where $\Delta\alpha$ - deflection of the movable part of the galvanometer;

ΔR - absolute change of the control arm resistance from its value at the balanced bridge.

In practice it is convenient to estimate the bridge sensitivity to relative change of resistance

$$S_M^I = \frac{\Delta\alpha}{\Delta R / R_3 \cdot 100} = \frac{\Delta\alpha}{\Delta R \cdot 100} R_3 \qquad (6.4)$$

The highest sensitivity of the single D-C bridge is reached under the following condition:

$$R_x = R_2 ,\ R_3 = R_4$$

The measurements by two-clamp and four-clamp schemes are realized with the aid of bridge P333. The bridge's characteristics are performed in table 6.1.

Order of the work fulfillment

1. Do examine the construction of the measuring bridge P333. Look at the tag on the internal side of the bridge cover; look through the scheme as well as brief service instruction of the instrument and determine its technical characteristics.

Table 6.1

Principal characteristics of bridge P333

Measured resistance	Accuracy rating	Suggested factors n	U , V	Connection scheme
$5\ 10^{-3}$ – 0,0999	5	0,0001	1,5	4-clamp
$1\ 10^{-1}$ – 0,9999	1,0			
1 - 9,999	0,5	0,001	1 – 1,5	
10 - 99,99		0,01	1,5 - 3	
100 - 999,9		0,1	3 - 10	2-clamp
1000 - 9999		1		
10^4 – 99999		10		
10^5 – 999999	5			

2. Do prepare the bridge to measure the resistances under 2-clamp connection scheme fig. 6.1; for that, it is necessary:

- disconnect clamps Б;
- throw the scheme switch into position "МВ";
- shunt the clamps 1 and 2;
- connect the resistance measured to clamps 2 and 3;
- set the switch of the arm ratio on corresponding factor n in accordance with table 6.1 depending on the probable value R_x;
- set the probable resistance on the four dials decade switch of the balancing arm.

3. Assemble the bridge scheme (fig. 6.3), its energy supply being realized from the external source. The bridge supply voltage is chosen in accordance with table 6.1 depending on the probable value of the resistance measured.

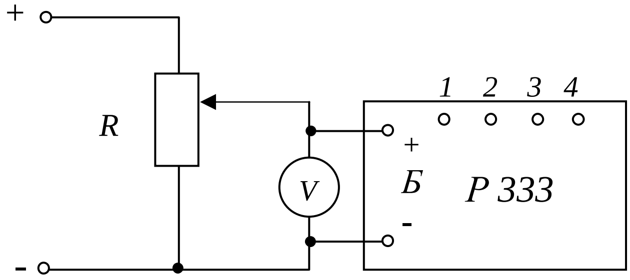


Fig. 6.3

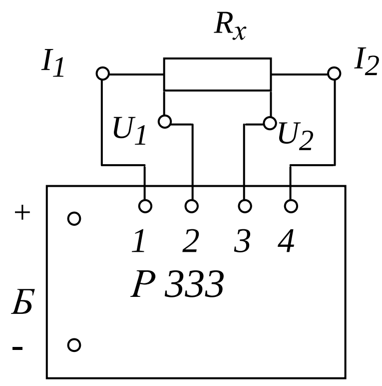


Fig. 6.4

4. Press button "вкл.Г". If at such pressing the energetic off-scale reading is observed, it is necessary to choose another factor n in order to obtain the pointer deflection not more than 0.2-0.4 divisions from zero mark. Then do fix the button "вкл. Г". Press button "грубо (rough)" and do balance the scheme, using the knobs of the dial switches until the galvanometer pointer is set in zero position.

Press button "точно (precisely)" and do balance bridge finally. Determine R_x by position of the dial switches, place the result into table 6.2.

5. Determine the bridge sensitivity. While all the buttons of the balanced bridge are pressed, do rotate the low dial switches and do reach the galvanometer pointer deflection by 5 divisions *($\Delta\alpha$=5)*. By the switches' position, do determine $R_{неур}$ (unbalanced resistance) place it into table 6.2. Let buttons be free.

Calculate $R_x = n\ R_{ур}$; $\Delta R_x = R_{ур} - R_{неур}$; S_M and S^I_M by formulae (6.3) and (6.4), respectively. The calculation results place into table 6.2.

6. Do perform all measurements and calculations similarly for two more resistances.

Table 6.2

Measurement of resistances under two-clamp scheme

Characteristic of resistances R_x, Ohm	n	$R_{ур}$, Ohm	$R_{неур}$, Ohm	R_x, Ohm	ΔR, Ohm	$\Delta\alpha$, div	S, div/Ohm	S^I, div/Ohm

7. Prepare the bridge to measure the resistances under four-clamp connection scheme (do not assemble the energy supply scheme of bridge), for that, it is necessary:

- disconnect the jumper (shunt) joining clamps 1 and 2;
- connect the resistance under measurement to clamps 1, 2, 3 and 4 with the aid of the four wires (in accordance with scheme fig.6.4).

8. The balancing process and calculation of the measurement results are realized in accordance with step 4. Do place results into table 6.3.

9. Calculate the conductivity by the measurement result R_x and given length L and diameter d of the wire-wound resistor:

$$\rho = R_X \frac{S}{L}, \quad \text{where } S \text{ is the wire cross-section.}$$

Tabulate results into table 6.3.

10. Measure the same little resistances under two-clamp scheme, the bridge being prepared in accordance with step 3; do connect clamps I_1 and I_2 of the resistances under measurement to the bridge clamps 2 and 3, respectively; fulfill the measurements.

Calculate the error of the little resistance measurement under two-clamp scheme, the value of resistance measured under four-clamp scheme being taken as true value:

$$\delta_2 = \frac{R_{X2} - R_{X4}}{R_{X4}} 100\%$$

Tabulate the measurement and calculation results into table 6.3.

Table 6.3

Measurement of the little resistances

Geometric sizes of resistors			n	Four-clamp scheme			Two-clamp scheme		
d, m	L, m	S, m^2		$R_{ур4}$, Ohm	R_{x4}, Ohm	ρ, Ohm·m	$R_{ур2}$, Ohm	R_{x2}, Ohm	δ_2, %

Contents of report

1. Four-armed D-C bridge.
2. Tables of the measurement and calculation results.
3. Conclusions.

Self-control questions

1. Equilibrium condition of D-C bridge.
2. What is practical way to reach the equilibrium condition of a bridge?
3. While measuring the resistances by single four-armed bridge, what is cause of the top value limitation?
4. While measuring the little resistances under two-clamp scheme, what is cause of the bottom value limitation?
5. Four-clamp measurement scheme expands the measurement range; what are the factors to guarantee this phenomenon?
6. What is absolute sensitivity of a bridge?
7. What is practical way to determine the bridge sensitivity?

Laboratory work 7

MEASUREMENT OF THE GROUNDING CONDUCTOR RESISTANCE

The purpose of work: examination of methods and technique of the grounding resistance measurement.

Installation and instruments

While working, there are used: device M-416, grounding model, ammeter, voltmeter, the current source.

Work contents

1. Do measure the grounding resistance by ammeter-voltmeter method.
2. Do measure the grounding resistance with the aid of the test prod.
3. Do measure the grounding resistance with the aid of the device.

Explanatory notes to work

The grounding is purposeful connection with earth of the metallic parts of an electric installation, which are not normally under voltage, by means of the grounding conductors.

Grounding electrodes are metallic bodies supplied with a current and buried underground, they being the constructive elements of the grounding. Electrical equipment is connected with the grounding electrodes by means of the grounding conductors.

Totality of the grounding electrode and grounding conductors is termed the grounding connection.

Resistance of the grounding connection during any season in accordance with State Standard 10.1.030-81 is to be not more than 0.5 -10 Ohm.

There are following peculiarities at the grounding electrode resistance measurement:

а) grounding electrodes perform a galvanic couple in the moist environment of soil;

б) as current flowing through the electrodes, the polarization occurs, it increasing the grounding resistance;

в) there are the stray currents in soil which are able to induce stray voltage in the grounding conductors;

г) stray voltages are not constant; so, being summarized they can distort the measurement results.

Measurement of the grounding resistance by ammeter-voltmeter method

In order to execute the measurements, it is necessary to have got three or more groundings.

Variation of the voltage drop across grounding electrodes R_1 and R_2 (fig. 7.1) is presented by curve ОАБО.

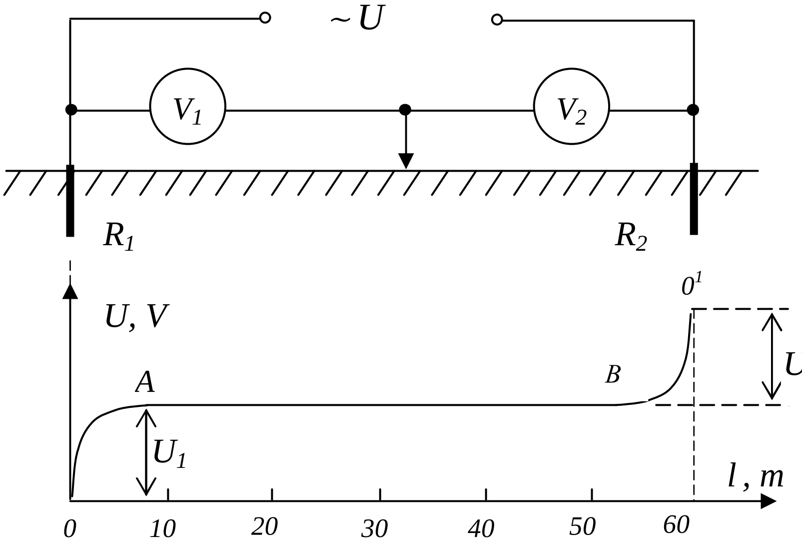


Fig.7.1

The biggest voltage drop and the current density are observed in the vicinity of electrodes, this area being of radius 10 m. As for area between R_1 and R_2, resistance of the soil layer is assumed to be equal to zero.

Thus, electrodes R_1 and R_2 are supplied with voltage $U_{12} = U_1 + U_2 = (R_1 + R_2)\cdot I_{12}$.

Consequently, measuring the current and voltage it is possible to determine resistance

$$R_{12} = \frac{U_{12}}{I_{12}} = R_1 + R_2$$

Executing in analogous way two more measurements, we obtain system of three equations with three unknown quantities, their right parts consisting of the measurement results:

$$R_1 + R_2 = \frac{U_{12}}{I_{12}} = R_{12}\ , \qquad R_1 + R_3 = \frac{U_{13}}{I_{13}} = R_{13}\ , \qquad R_2 + R_3 = \frac{U_{23}}{I_{23}} = R_{23} \qquad (7.1)$$

Solution of the equation system gives:

$$R_1 = \frac{R_{12} + R_{13} - R_{23}}{2} \qquad R_2 = \frac{R_{12} + R_{23} - R_{13}}{2} \qquad R_3 = \frac{R_{23} + R_{13} - R_{12}}{2} \qquad (7.2)$$

Measurement of the grounding resistance with the aid of the test prod

If a bridge for the grounding resistance measurement deals with but two grounding electrodes and they are remote by 50-70 m from each other, it is possible to measure voltages U_1 and U_2 (fig. 7.1) with the aid of the special test electrode-prod. A prod is a metallic rod which is plunged into soil by moderate depth at the area AB. Then voltmeter V_1 measures voltage U_1 , while voltmeter V_2 measures voltage U_2 . Consequently:

$$R_1 = \frac{U_1}{I_{12}} \qquad R_2 = \frac{U_2}{I_{12}}$$

Measurement of the grounding resistance with the aid of the device M-416

In device M-416, compensation method of the grounding resistance measurement is employed, it making use of auxiliary grounding electrode and test prod. Front panel of device (fig.7.2) contains:

"П" – knob to control the measurement range;

"Р" – slide-wire knob;

"К" – turn-on/off button of device;

four clamps to connect the measurement object;

slide-wire scale;

microammeter.

Device has four measurement bands: 0.1 – 10 Ohm; 0.5 – 50 Ohm; 2 – 200 Ohm; 10 – 1000 Ohm.

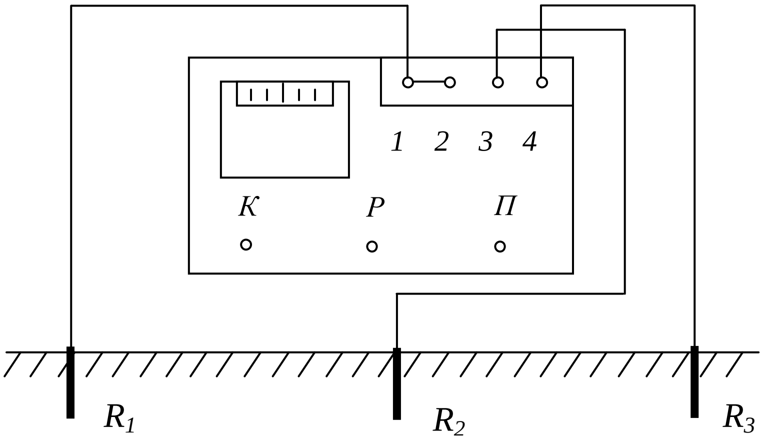


Fig.7.2

Order of the work fulfillment

1. Assemble scheme fig.7.3, do make use of the 1st and 2nd grounding electrodes, measure and write down into table 7.1 the instrument readings I_{12} , U_{12} . Perform the same measurements with usage of the 1st and 3rd electrodes; finally, do work with the 2nd and 3rd electrodes; measure and write down into table 7.1, respectively, I_{13} , U_{13} and I_{23} , U_{23} .

Calculate resistances R_{12} , R_{13} , R_{23} (under formulae 7.1) and resistances R_1 , R_2 , R_3 (under formulae 7.2). Tabulate results into table 7.1.

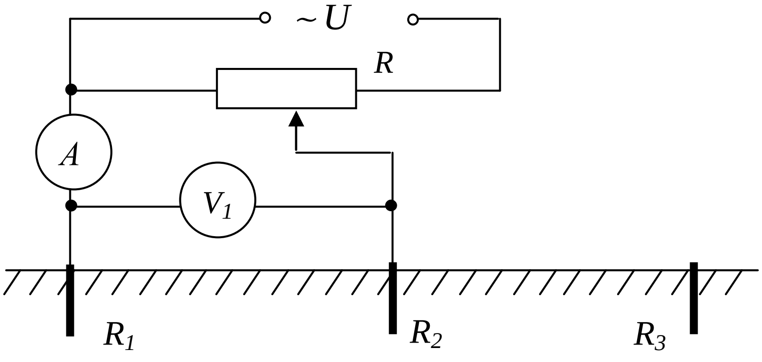


Fig.7.3

Table 7.1

Measurement of the grounding resistance by ammeter-voltmeter method

I_{12}, A	U_{12}, V	R_{12}, Ohm	I_{13}, A	U_{13}, V	R_{13}, Ohm	I_{23}, A	U_{23}, V	R_{23}, Ohm	R_1, Ohm	R_2, Ohm	R_3, Ohm

2. Assemble the scheme fig. 7.4; make use of the 3rd electrode as a test prod, measure and place in table 7.1 the instrument readings I_{12} , U_1 . Perform the same measurements with the 1st electrode as a test prod; do the same with the 2nd electrode; measure and write down into table 7.2, respectively, I_{23}, U_2 and I_{13} , U_2 .

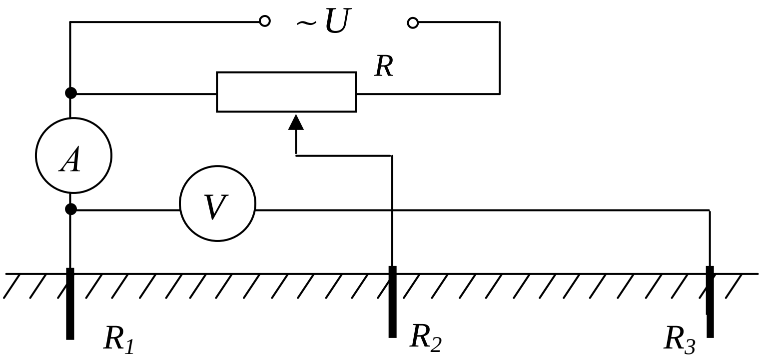


Fig.7.4

Calculate the resistances R_1 , R_2 , R_3 under formulae:

$$R_1 = \frac{U_1}{I_{12}} \qquad R_2 = \frac{U_2}{I_{23}} \qquad R_3 = \frac{U_3}{I_{13}}$$

Place the calculation results into table 7.2.

Table 7.2

Measurement of the grounding resistance with the aid of the test prod

I_{12}, A	U_1, V	R_1, Ohm	I_{23}, A	U_2, V	R_2, Ohm	I_{31}, A	U_3, V	R_3, Ohm

3. Connect the device M-416 to the grounding mockup to measure the resistance R_1 (in accordance with fig. 7.2). Place knob "П" in position "X1". Do short-term press on button "К". In case of in-scale reading, keeping the button "К" pushed, do set the equilibrium indicator pointer in zero position with aid of the slide-wire knob "Р". In case of off-scale reading, change the measurement range with the aid of the knob "П" (one after another "X5", "X20", "X100").

The measurement result for resistance R_1 is equal to product of the reading from the slide-wire scale times corresponding factor.

Connect the device to measure resistance R_2 ; finally, measure resistance R_3 .

Place the measurement results into table 7.3.

Table 7.3

Measurement of the grounding resistance with the aid of the device M-416

Measurement method	R_1, Ohm	R_2, Ohm	R_3, Ohm
Method of three measurements			
Single measurement method			
Measurement by device M-416			

Contents of report

1. Schemes to measure a resistance by ammeter-voltmeter method, with the aid of the test prod, with the aid of the device M-416.
2. Tables of measurements and calculations.
3. Conclusions.

Self-control questions

1. What is the voltage distribution between two electrodes at the current flowing?
2. How many tests are necessary to determine the grounding resistance by ammeter-voltmeter method? Why?
3. What is a test prod?
4. How many tests are necessary to determine the grounding resistance with the aid of the test prod?
5. Is it possible to measure the resistance of a single grounding electrode? If it is, which conditions are necessary?