

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE

Zaporizhzhya national technical university

METHODICAL GUIDES

For laboratory works on course

**“FUNDAMENTALS OF ELECTRICAL MEASUREMENT
AND METROLOGY”**

students towards the specialty
141 – Electric Power Engineering, Electrical Engineering and
Electromechanics
of all forms of learning

2016

Methodical guides for laboratory works on course "Fundamentals of electrical measurement and metrology" students towards the specialty 141 – Electric Power Engineering, Electrical Engineering and Electromechanics of all forms of learning. / Set. Ye.S. Nazarova, V.V. Kushch. – Zaporizhzhya: ZNTU, 2016. – 51 p.

Compilers:

Ye.S. Nazarova, docent c.t.n.
V.V. Kushch, docent c.t.n.

Reviewer: V.I. Bondarenko, docent c.t.n.

Responsible for the issue: V.I. Bondarenko, docent c.t.n.

Approved
chair meeting EPA
protocol number 7 on 10.03.2016 p.

Approved
chair meeting EMC ETF
protocol number 2 on 11.04.2016 p.

MAINTENANCE

Preface	4
Laboratory work №1	
Research of properties of electromechanical measuring devices	5
Laboratory work №2	
Expansion of measuring limits of ammeters and voltmeters by means of shunts and additional resistors.....	15
Laboratory work №3	
Measuring of power and electrical energy in three-phase circuits	22
Laboratory work №4	
Research of instrument current transformers	29
Laboratory work №5	
Investigation of induction energy meters	37
Laboratory work №6	
Measured resistance DC bridge	44
List of references	50

PREFACE

Methodical instructions contain descriptions of the six laboratory work on discipline “Fundamentals of electrical measurement and metrology” in accordance with the curriculum specialties Bachelor's Degree 141 – Electric Power Engineering, Electrical Engineering and Electromechanics and recommendations for their implementation.

Laboratory work containing brief theoretical information under the theme of work, objectives, recommendations for their implementation and test questions for better learning and verifying the student knowledge and skills.

For students of specialty 141 – Electric Power Engineering, Electrical Engineering and Electromechanics of all forms of learning.

Laboratory work №1

Research of properties of electromechanical measuring devices.

Aim of work: is to study structure and principle of action of measuring mechanisms of the different systems, investigate influence of frequency and form of periodic signal on the readings of devices.

Program of work.

Study of operation principle and construction of electromechanical measuring devices.

Research of influence of frequency of voltage that is measured, on the error of devices of the different systems.

Investigation of voltage curve influence on readings of devices of different systems.

Investigation of consumed power and internal resistance of devices of different systems

Treatment of results and arrangement of report.

Short theoretical information.

Electromechanical measuring device consists of measuring circuit, measuring mechanism and reading device. Measuring mechanism (MM) consists of immovable and movable systems. Generally immovable and movable parts of MM can contain current circuits, electrically charged bodies, permanent magnets etc.

Electrical energy of such system:

$$W_E = \frac{1}{2}LI + \frac{1}{2}CU^2 + M_{12}I_1I_2, \quad (1.1)$$

where L is total inductance of the circuits; M_{12} is mutual inductance of movable and immovable circuits; C is electrical capacity of charged bodies.

Magnetically-electrical measuring device is shown on the figure 1.1. it's immovable system is build up by a permanent magnet 1 with pole extensions 2 and core 3 from magnetically soft steel. Movable part is the frame 4 consists of copper wire wounded around aluminums frame. The frame is fixed with two half-axes 5, that are free to rotate around «kerns». The half-axes are rigidly joined with extensions of springs 6 made of beryl bronze, which are used to create counteracting moment. The arrow 7 is

joined to one of half-axes, and couple with scale 9 it creates the reading device. Counterbalances 8 increases moment of inertia of movable system and in couple with quitter of vibrations damp oscillations of movable system.

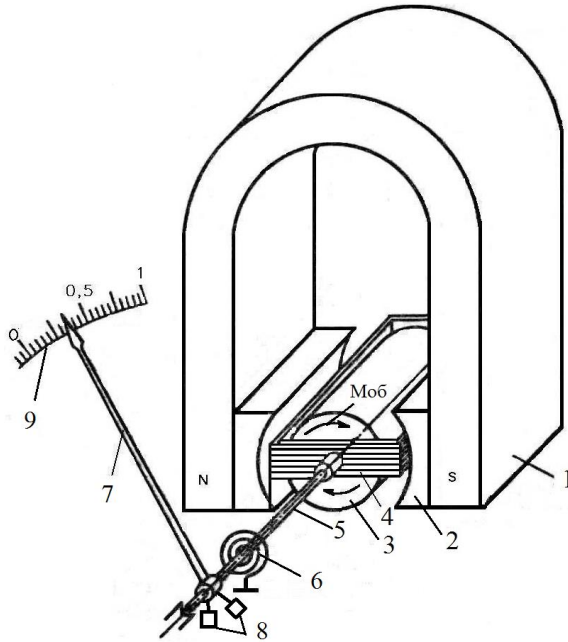


Figure1.1. – Magnetically-electrical mechanism.

The ends of the frame are connected to half-axes and through them with springs. Measuring value is direct current I which is penciled to the spring. As far as frame is located in magnetic field of the permanent magnet the couple of forces acts on it during current passing through the frame and it creates moment:

$$M_{o6} = BSNI \sin \alpha, \quad (1.2)$$

where B is induction of magnetic field; S is square of frame; N is number of turns; I is current flowing through the frame; α – is angle between vector of magnetic induction and perpendicular to the frame plane. Counteracting moment is directed towards the rotating moment which increases linearly with increase of rotating angle.

$$M_{np} = G\alpha, \quad (1.3)$$

where G is specific counteractive moment
When the equilibrium is set:

$$M_{o6} = M_{np} \quad (1.4)$$

motion of system will stop.

To make the rotating moment independent on frame rotation angle in the gap between poles of the magnet, core 3 is set. Magnetic induction vector B in the gap is directed along the radius of intersection of core and at any angle of frame angle between induction vector and perpendicular of frame plane equals 90 degrees. Then from (1.2) and (1.3) follows:

$$\alpha = \frac{1}{G} B S n I . \quad (1.5)$$

As far as movable system of the drive has inertia momentum, then by being moved and shifted by angle α it will oscillate around the equilibrium position for a while. For it being damped, in measuring equipment oscillation dampers are set (air, hydraulic and magnetically-inductive ones). At devices of magnetically-electric system magnetically-inductive dampers are used. At framework of the frame is a short-circuited conductor. When it is rotated inside magnetic field, EMF is set inside it and Eddy's currents occur. Interaction of Eddy's currents field and field set in gap creates braking moment which damps frame oscillations. The described above device for creation of counteracting moment and counting device are typical ones and are also used in devices of other systems: electrodynamical, electrostatical and electromagnetic. The rotating moment direction in mechanism of magnetically-electrical system depends on direction of current in a frame. That's why devices of magnetically-electrical system without counters are used only for direct current measurement.

By analyzing (1.5) it can be concluded that the error of magnetically-electrical device depends on specific counteracting momentum G stability and on magnetic induction's B stability. As well as spring elasticity, induction of magnet's field depends on temperature, then for magnetically-electrical device, temperature error is essential.

This error can be avoided or decreased by inclusion of temperature-compensating circuits into the measuring circle, that is series or parallel connection resistor and termoresistor.

Electromagnetic measurement mechanism (fig. 1.2) contains immovable coil 1 and movable plain or core 2 made of magnetically-soft

material, which is fixed with axis 3 or stretches. Axis is rotated at cores on toes 5. Spiral spring 4 is used for creation of counteracting moment. Arrow 6 and scale 7 form reading device. Piston 8 is joined to the terminal of arrow, that is the damper of movable system's oscillations.

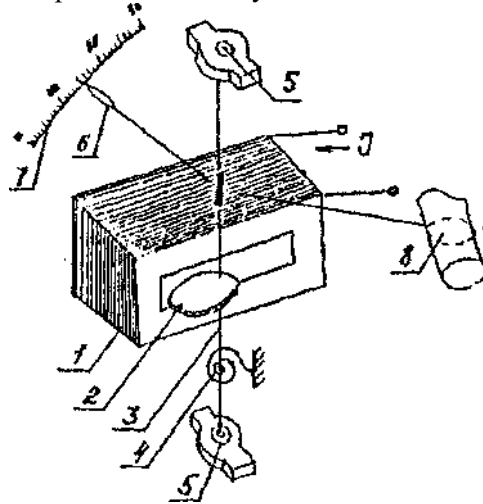


Figure 1.2 – Electromagnetic mechanism

When current flows through the coil, the core is being drawn inside it and torque acts on the axis:

$$M_{\text{ог}} = \frac{dW_e}{d\alpha} = \frac{d}{d\alpha} \left(\frac{1}{2} LI^2 \right) = \frac{1}{2} I^2 \frac{dL}{d\alpha}. \quad (1.6)$$

Moment $M_{\text{п}}$ counteracts it.

If these moments are equal, movable system stops:

$$\alpha = \frac{1}{2G} \frac{dL}{d\alpha} I^2. \quad (1.7)$$

This equation holds with direct current and rms value of alternating current. The device's scale is non-uniform, but in specific construction types $\frac{dL}{d\alpha} I \approx \text{const}$ and the non-linearity of a scale can be reduced from 20-25% to 0,5-0,2% which makes scale almost uniform.

Hence low magnetization power of the coil and absence of steel magnetic circuits, intrinsic magnetic field of electromagnetic measuring device is weak, that's why external magnetic fields influence it

considerably and they may cause error. To reduce this error, measurement device is placed inside a shield or is constructed in an astatic way.

Advantages of electromagnetic measurement devices are construction simplicity, high reliability and overload capability, ability to measure both ac and dc. Drawbacks – not very high sensitivity and relatively low accuracy. Widespread devices have accuracy class 1,5, special designs may reach accuracy class 0,2.

Electrodynamical and ferrodynamical measurement mechanisms and devices are schematically shown on fig. 1.3 (a and б).

Electrodynamical measurement mechanism contains immovable coil 1, which consists of two parts and movable coil 2, which is fixed on axis or by means of stretches in the middle of immovable one. Spiral springs are used to create the counteracting moment and to supply current to the movable coil. When current I_1 and I_2 flows through the coils, interacting magnetic fields are set around them and they create the torque

$$M_{o6} = \frac{dW_e}{d\alpha} = \frac{d}{d\alpha} \left(\frac{1}{2} L_1 I_1^2 + \frac{1}{2} L_2 I_2^2 + M_{12} I_1 I_2 \right). \quad (1.8)$$

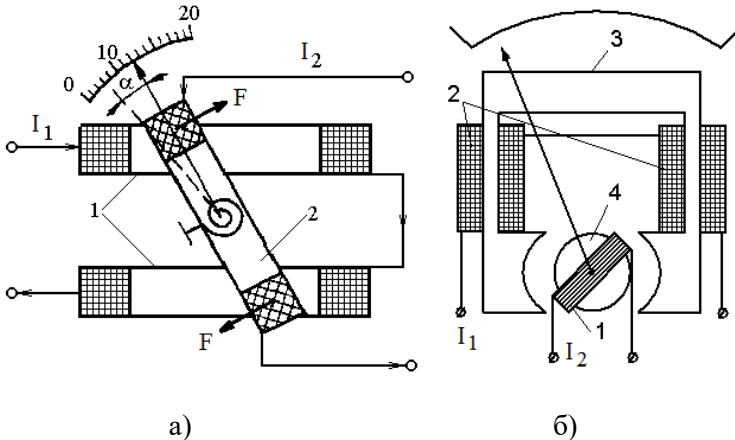


Figure 1.3 – Electrodynamic and ferrodynamic measurement mechanisms

For direct current:

$$M_{o6} = \frac{dM_{12}}{d\alpha} I_1 I_2. \quad (1.9)$$

For alternating current:

$$M_{\text{о6}} = \frac{dM_{12}}{d\alpha} I_1 I_2 \cos \Psi, \quad (1.10)$$

where I_1 and I_2 - rms current values; Ψ - angle between vectors I_1 та I_2 .

Counteracting moment, created by the springs,

$$M_{\text{np}} = G\alpha .$$

In general case:

$$\alpha = \frac{1}{G} \frac{dM_{12}}{d\alpha} I_1 I_2 \cos \Psi . \quad (1.11)$$

Immovable coil in electrodynamical devices in general case is wound with thicker wire, then the movable one, contains less turns and is connected to the measurement circuit in series; that's why it is called the current coil. Movable coil contains much greater number of turns which are wound by thin wire. In wattmeter's movable coil is connected in parallel with the source or load. That's why it is called the voltage coil.

The scheme of electro dynamical wattmeter is shown on fig. 1.4

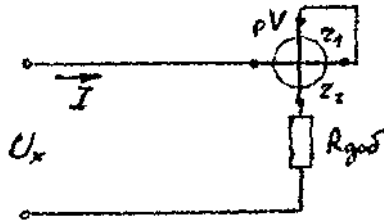


Figure 1.4 – The scheme of electro dynamical wattmeter.

For this scheme on a direct current

$$\alpha = \frac{1}{G} \frac{dM_{12}}{d\alpha} I^2 = \frac{1}{G} \frac{dM_{12}}{d\alpha} = \frac{U_x^2}{(R_{\text{до6}} + r_1 + r_2)^2}, \quad (1.12)$$

$$\text{if } \frac{dM_{12}}{d\alpha} I \approx \text{const}; \quad \alpha = AU_x; \quad \frac{1}{G(R_{\text{до6}} + r_1 + r_2)} = A .$$

Coils size and their mutual disposition are chosen with respect to equation:

$$\frac{dM_{12}}{d\alpha} I \approx \text{const}$$

Then, starting with 20-25 %, the scale of device is uniform.

Electro dynamical devices are widely used as wattmeter's. Wattmeter's scheme is shown on figure 1.5.

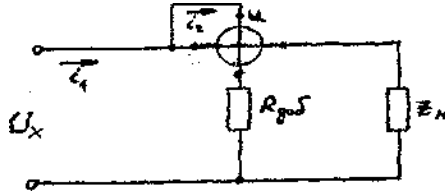


Figure 1.5 – Wattmeter's scheme

For this scheme:

$$i_1 = i_M; i_2 = \frac{U_x}{R_{доб} + r_2} \approx \frac{U_x}{R_{доб}}.$$

$$\alpha = \frac{1}{GR_{доб}} \frac{dM_{12}}{d\alpha} i_M U_x \quad (1.13)$$

For alternating current:

$$I_1 = I_M, I_2 = \frac{U_x}{Z_2},$$

$$\alpha = \frac{1}{GZ_2} \frac{dM_{12}}{d\alpha} I_M U_M \cos \varphi = \frac{1}{GZ_2} \frac{dM_{12}}{d\alpha} P. \quad (1.14)$$

Advantages of electrodynamical devices: high accuracy, ability to operate as ampermeters, voltmeters, wattmeters and phase meters (wide functional abilities) with direct or alternating current, properties' stability with respect to time; disadvantages: lower sensitivity compared to magnetoelectrical system's devices, high inner energy consumption, constructional complicity.

The peculiarity of ferrodynamical devise's system is that immovable coil is placed at magnetic system, movable – in the gap between poles of magnetic system and yoke of magnetically soft steel. For ferrodynamical devises the following ratios holds (1.8)-(1.14), and the scheme on figure 1.4 and 1.5. Because of the fact, that device contains magnetic system, which

magnetic properties depend on temperature and are unsteady in time, ferrodynamical devices have lower accuracy class.

Electrostatic measurement device (fig. 1.6) consists of two pairs of immovable electrodes 1 and movable electrode 2, fixed on axis or stretch. Electrostatic devices are used as voltmeters.

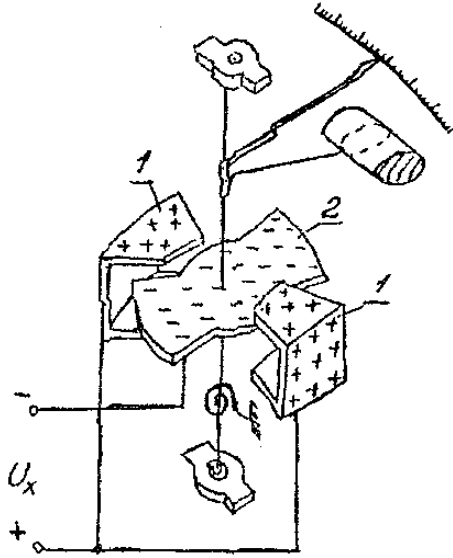


Figure 1.6 – Electrostatic mechanism

When voltage U_x is supplied to the device, electrical field is set between the electrodes, electrodes are charged and because of charges interaction torque is set, which tries to rotate the system.

$$\alpha = \frac{1}{2G} \frac{dC}{d\alpha} U_x^2, \quad (1.15)$$

where C – capacity of the capacitor, formed by electrodes; G – specific counteracting moment.

Scale of the device is non-uniform, but with the help of selection of electrodes' shape, dimensions and mutual disposition it is possible to provide scope $\frac{dC}{d\alpha} U_x = \text{const}$ between 20 and 100% of scale.

Electrostatic mechanisms' sensitivity is low, to increase it, movable parts are fixed on stretches or suspenders, optical reading device is used, mechanism's capacity is increased etc. Internal electric field of electrostatic device is small, that's why its readings are influenced by external electric fields. To protect the mechanism from these fields, shielding is used. Shield is joined with one electrode and grounded.

Temperature, frequency of applied voltage, voltage curve shape and external magnetic field practically don't influence electrostatic device's readings.

Inner energy consummation at alternating current is small, at direct is equal to zero. Mentioned above properties of electrostatic voltmeters cause their usage in wide frequency range at low-power circuits of high voltage less than hundreds of kilovolts.

The task.

Make a short synopsis of theoretical material laboratory work, which contains the structure, principle and basic equations of transformation electromechanical measuring instruments of different systems.

Contents of the report of the laboratory work.

The contents of the laboratory work should include the topic, the aim of laboratory work, short theoretical information, conclusions of laboratory work.

Control questions.

1.1 Construction and operation principle of the magnetoelectric measurement mechanism.

1.2 Perform static characteristic equation of the magnetoelectric measurement mechanism.

1.3 How is the counteracting moment set up and what is it equal to at electromechanical measurement mechanisms?

1.4 What is the purpose of yoke, placed between permanent magnet's poles at magnetoelectric measurement mechanism?

1.5 Construction and operation principle of magnetically-inductive oscillations damper.

1.6 Construction and operation principle of electrical measurement devices of straightened system.

1.7 Construction and operation principle of measurement device of electromagnetic system.

1.8 Construction and operation principle of measurement device of electrodynamic system.

1.9 What is the curve form coefficient of the current and voltage? Why does it influence devices readings?

1.10 Which measurement mechanisms may be used for direct measurement of alternating current and its voltage.

1.11 Why does ambient temperature influence electromechanical devices readings.

1.12 Why is the scale of devices of straightened system is non-linear in range of 0-10% of upper limit?

1.13 Why does measured current frequency and temperature influence readings of devices of straightened system? How can this influence be decreased?

1.14 Construction and operation principle of measurement device of electrostatic system.

1.15 Why does ambient temperature, frequency and current curve shape have small influence on electrostatic device readings?

1.16 What is the device sensitivity and sensitivity threshold.

1.17 How can internal resistance of ammeter and voltmeter be measured?

1.18 How should the coils of electrodynamic measurement device be connected when measuring low current; high current; power of the current.

Laboratory work №2

Expansion of measuring limits of ammeters and voltmeters by means of shunts and additional resistors.

Aim of the work: to cope with methods of calculation and usage of additional resistors and shunts, methods of devices check and notions about measurement errors and their regulation.

Program of the work.

Internal resistance determination by means of voltmeter and additional resistor calculation. Voltmeter check. Results work-out and arrangement of report.

Short theoretical information.

Electromechanical measurement mechanisms at direct connection to measurement circuit has limited range of current and voltage measurement. For example, measurement mechanism of of magnetoelectric system, depending on frame's constructional parameters may have measurement range between 10^{-6} and 10 A or voltage between 10^{-3} and 1 V. In practice, there is necessity to perform measurements in wider range: from 10^{-9} A to 10^6 A and from 10^{-6} V to 10^6 V. To enlarge the measurement range of electromechanical measurement devices scale measuring transformers are used: shunts and additional resistors, voltage divisors and measurement amplifiers, current and voltage transformers.

Type of measurement converter is chosen depending on measurement mechanism's system and current or voltage measurement range.

When it is necessary to measure direct current, which is less, then 10 A or more then 7500 A with an ammeter of magnetoelectric, electromagnetic or electrodynamic system, shunts are used. Ammeters with shunts represent millivoltmeters, which measure voltage drop on shunts (fig.2.1).

Shunt has two pairs of clumps – current ones I-I to be plugged in current circuit; and potential U-U - to plug millivoltmeter, which is calibrated in amperes.

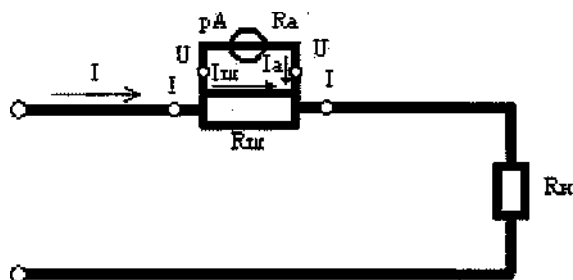


Figure 2.1 – Scheme of devise and shunt connection

Shunts are made of manganin – alloy of copper, nikel and manganese, that has low temperature resistance coefficient and relatively low specific resistance. To measure low currents (less, then 30 A) shunt is placed in the corps of ammeter. Such shunt is called an internal one. To measure currents less, then 7800 A external shunts are used. When measuring shunt resistance, notions, which flow out from Kirchhoff's laws are used:

$$I = I_A + I_{III}; \quad I = I_A n; \quad \frac{I_{III}}{I_A} = \frac{R_{III}}{R_A}, \quad (2.1)$$

where $I = I_A n$ – upper boundary of measuring of ammeter with shunt; I_A – upper boundary of measuring of ammeter without shunt.

Consequently from (2.1):

$$R_{III} = R_A \frac{1}{n-1}, \quad (2.2)$$

where n – number, which shows it in how many times has the measuring limit of ammeter increased with application of shunt.

When shunts are used at alternating current, additional error occurs because of current frequency measurement. That's why shunts are mostly used at direct current with devices of magnetically-electric system. To increase the upper measuring limit of voltmeter additional resistors are used, they are connected to voltmeter in series and in couple they represent voltage divisor(fig. 2.2).

When counting additional resistor resistance, the following correlations are used

$$U = U_{\text{доб}} + U_v; \quad U = nU_v; \quad \frac{U_v}{R_v} = \frac{U_{\text{доб}}}{R_{\text{доб}}}, \quad (2.3)$$

where U - upper boundary of measuring of voltmeter with additional resistor;
 U_v - upper boundary of measuring of voltmeter without additional resistor.

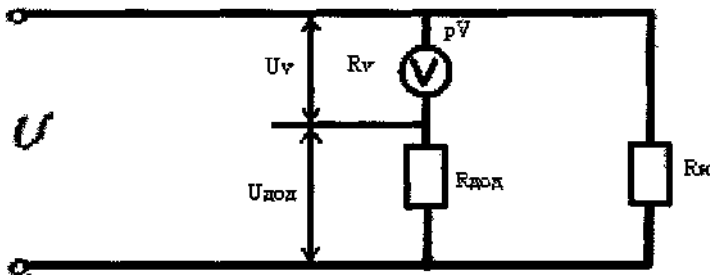


Figure 2.2 – Additional resistance connection

From (2.3)

$$R_{доб} = R_v(n-1), \quad (2.4)$$

where n – number, which shows it in how many times has the measuring limit of voltmeter increased with application of additional resistor.

Additional resistors are usually made of manganese wire and used at both AC and DC with devices of magnetoelectric, electromagnetic, and ferrodynamical systems within the frequency to 20 kHz. To reduce the inductance in the manufacture of additional resistors bifilar way winding is used. Accuracy class of standard additional resistors is from 0,01 to 1,0, rated current from 0.5 to 30 mA, boundary voltage - 30 kV.

Measuring devices check

All the measuring instruments that are used have to be verified. Verification - determination of measurement instrument error by metrological authority and establishing its suitability for use. There are primary and periodic checks: the primary is at issue or after repair of measuring device; periodic - the testing of measurements carried out during its operation and preservation at regular intervals. Contents, methods and means of verification of each type of equipment are to be set by the developer and should be contained in this measurement device manual or in separate instructions.

In all cases, testing involves a number of operations, one of which is to determine the basic reduced error of measurement. This error of measurement instrument, used under normal operating conditions.

Deviation from normal operating conditions cause additional errors. Normal operating conditions of measurement instrument are indicated in its passport.

Absolute error of measuring device - the difference between the readings and the true value of measuring parameter:

$$\Delta x = x_n - x, \quad (2.5)$$

where x_n - instrument readings; x - the real value of measured parameter.

Due to the fact that the true value of the measured value can not be known exactly, in practice actual value of the measured parameter is used instead. During the check the same value measured value X is measured twice: once by the device that is being checked, the second time – by exemplary device. The absolute error is defined as the difference between the readings to be checked and an exemplary unit.

Reduced error of measuring device - is the ratio of the absolute error to the normalizing value. Normalizing value is assumed to be the difference between the highest $A_{\max}$ and the lowest $A_{\min}$ measure. The reduced error is established to be expressed as percentage. For most devices $A_{\min}=0$, then

$$\delta_n \% = \frac{\Delta x}{A_{\max}}, \quad (2.6)$$

where δ_n - reduced error of the device; $A_{\max}$ – upper measurement limit.

The limit of permissible error of measurement device- the biggest (no regard to sign) error of measurement, at which it can be considered as appropriate and permitted for usage.

The limits of permissible error of measurement device are determined by its accuracy class. Class of accuracy of measuring instruments - a generic characteristic, which is determined by limits of main and additional errors of measuring instruments.

Determination of error at check is carried out not at one point of the peak, but at each label of digital scale, changing the measurement value from the lower to the upper limit, and then - from upper to lower. As a result a series of values of absolute error of this device is obtained: $\Delta x_1, \Delta x_2, \dots, \Delta x_n$ one of which is the largest (without regard to sign).

Accuracy class of the checked device is set by the largest reduced error:

$$\delta_{\text{max}} \% = \pm \frac{|\Delta x_{\text{max}}|}{A_{\text{max}}} 100 \leq K. \quad (2.7)$$

If the obtained value δ_{max} is less, then K value of the given device, then the unit under this parameter meets the requirements of inspection and may be found suitable.

With the growth and decay of measuring value in the same point of the scale you can get different readings, the biggest difference between the indications in the same point of the scale of growth and decrease is called the variation (v). For some devices the variation is normalized metrological characteristics and is determined it during testing.

One of the main requirements of the test is that the accuracy class of exemplary device should be greater, then accuracy class of inspected device at least at 2 orders. For example, if the tested instrument is class 1.5 accuracy, the exemplary unit should have accuracy class not lower than 0.5.

Instruments and equipment

The list of instruments and equipment is presented in table 2.1

Table 2.1 – Instruments and equipment

Name of device	Type of device	Accuracy class	Features
Voltmeter	3-30	1.5	0-50 V
Voltmeter	3-59	0.5	0-75-150-300-600 V
Shop of resistances	P517	0.1	0,01-10 ⁴ Om
Autotransformer	Laboratory	-	

The task.

2.1 Set the scheme according to Fig. 2.3, which adopted the following notation: R_m – shop of resistances; PV_0 – exemplary voltmeter; PV_x – tested voltmeter.

2.2 Determine the internal resistance of the voltmeter being checked. For that, adjusting the voltage with LATR, set the voltage 80-100 V at voltmeter PV_0 . By adjusting the resistance R_m , set PV_x voltage equal to

half of U_0 . According to the formula (2.4) internal resistance of voltmeter will be equal to R_V .

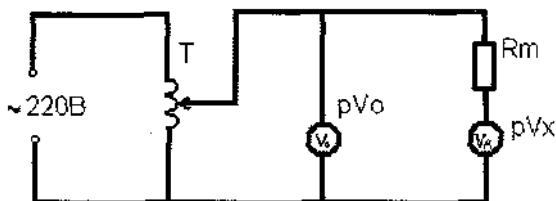


Figure 2.3 – Laboratory work scheme.

2.3 Select $n = 2, 3, 4 \dots$ as directed by the teacher and identify additional resistance by (2.4). Set the found resistance $R_{до6}$ on the resistance shop.

Check the voltmeter PV_x with the additional resistance connected to it in the next way. Regulating voltage with LATR, set the checked voltmeter arrow, sequentially at each digitized tag peak, first increasing the voltage from zero to the upper limit, and then reducing to zero. It should be followed that the arrow has to fit the appropriate scale marks from one side only. With the exemplary voltmeter, measure the actual measured voltage on these labels. Record the results in table 2.2

Table 2.2 – Measured results

Measured		Calculated				
Readings PV_x, V	Readings PV_0, V		$\overrightarrow{\Delta x} =$	$\overleftarrow{\Delta x} =$	$\overrightarrow{\delta_n}, \%$	$\overleftarrow{\delta_n}, \%$
	$\overrightarrow{x_0}$	$\overleftarrow{x_0}$	$x_n - \overrightarrow{x_0}$	$\overleftarrow{x_n} - \overleftarrow{x_0}$		$v = \overrightarrow{\Delta x} - \overleftarrow{\Delta x}$

Results proceeding and content of the report

2.1 According to above mentioned formulas determine the absolute error, reduced error and variation in each row of tabl.2.2. With regard to fact that amendment of the systematic error is the absolute error with the opposite sign, determine the amendments in each point of the scale. The readings of exemplary device should be taken as:

$$x_0 = \frac{\overrightarrow{x_0} + \overleftarrow{x_0}}{2}.$$

Construct a graph of dependence of the amendment on device readings.

2.2 Compare the highest reduced error (with respect to sign) with the limit of acceptable error of the device to be checked and make conclusion about the suitability of its usage.

Contents of the report of the laboratory work.

The contents of the laboratory work should include the topic, the aim of laboratory work, short theoretical information, laboratory setup scheme, filled table 2.1 and 2.2, the calculations, graph of the amendment of device readings, conclusions of laboratory work.

Control questions

2.1 Purpose, Structure and switch circuit of shunt. How to calculate the resistance of shunt?

2.2 Purpose, Structure and switch circuit of additional resistor. How to calculate the resistance of additional resistor?

2.3 Why usage of shunts is limited at AC?

2.4 There are two ammeters, one of which with a known internal resistance, the other is unknown. How should the ammeters be connected to a circle, to find the resistance of another ammeter?

2.5 There is a voltmeter with unknown internal resistance and a resistor of known resistance. How to determine resistance voltmeter?

2.6 What is the relative reduced error of measuring device? What is an absolute error?

2.7 How to determine the limit of permissible absolute error of the device if its class of accuracy is known?

2.8 What is an instrument check and how is it carried out?

2.9 What is the variation?

Laboratory work №3

Measuring of power and electrical energy in three-phase circuits.

Aim of the work: to learn and practice the methods of measuring active and reactive power in three-phase power circuits. Obtaining skills of making up schemes of connection of wattmeter and energy meter.

Program of the work.

Introduction to the workplace. Measuring: active power by method of one device; active power by two devices method; reactive power by method of one device; reactive power by two devices method.

Short theoretical information.

Instantaneous power of three-phase system equals the sum of powers of individual phases (fig.3.1).

$$P = P_A + P_B + P_C = U_A I_A + U_B I_B + U_C I_C. \quad (3.1)$$

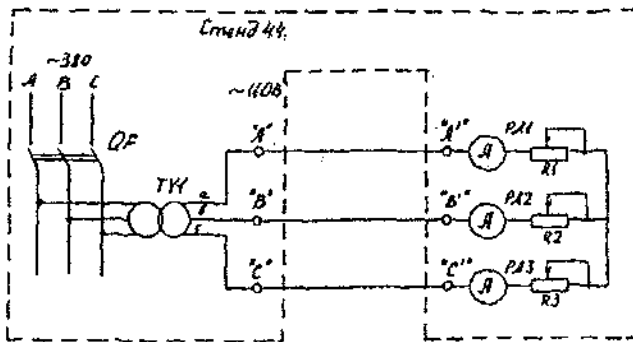


Figure 3.1 – Laboratory work scheme.

At uniform loading of phases active or average power of three-phase system equals to the sum of active powers in separate phases.

$$P = \frac{1}{T} \int_0^T p dt = 3P_\Phi = 3U_\Phi I_\Phi \cos \varphi = \sqrt{3}UI \cos \varphi, \quad (3.2)$$

where U , I - line voltage and current; φ - phase shift angle between phase voltage and phase current.

Active energy at time t_2-t_1

$$W = \int_{t_1}^{t_2} P dt = Pt . \quad (3.3)$$

Reactive power is defined as sum of jet reactive powers of individual phases:

$$Q = 3U_{\phi} I_{\phi} \sin \varphi = \sqrt{3} UI \sin \varphi . \quad (3.4)$$

Full power at a symmetrical load of phases:

$$S = \sqrt{P^2 + Q^2} = 3U_{\phi} I_{\phi} \sin \varphi = \sqrt{3} UI \quad (3.5)$$

Power factor of three-phase system with symmetrical load and sinusoidal voltage:

$$\alpha = \cos \varphi = \frac{P}{S} .$$

In equation (3.1) on the basis of the first Kirchhoff law we can eliminate one of the currents and provide instantaneous value of power through the line voltage in three forms:

$$P = U_{AC} i_A + U_{BC} i_B ; \quad (3.6)$$

$$P = U_{AB} i_A + U_{CB} i_C ; \quad (3.7)$$

$$P = U_{BC} i_B + U_{CA} i_C . \quad (3.8)$$

Thus, the instantaneous power of three-phase system can be presented as a sum of only two components. Equation (3.1) - (3.6) permit to use one, two or three instruments (meter or wattmeter) for measuring power and energy. Wattmeter is an electromechanical multiplier of current and voltage. Moving part of its measuring mechanism rotate on an angle, proportional to the average instantaneous power, that it measured.

Readings of wattmeters are generally defined by the product of current flowing through its series winding to the voltage attached to its parallel circuits, and the cosine of angle between vectors of current and voltage, i.e. in terms of single phase AC wattmeter readings P_w correspond to active (average) power:

$$P_w = U_{\phi} I_{\phi} \cos(U_{\phi}, I_{\phi}) = U_{\phi} I_{\phi} \cos \varphi = P . \quad (3.9)$$

In the three-phase circuits with the help of wattmeters active and reactive power are measured separately.

In laboratory practice electrodynamic wattmeters of accuracy classes 0,1; 0,2; 0,5 are used. In technical measurements ferrodynamic single-, double- and three-element wattmeters of accuracy classes 1,0; 1,5; 2,5 are used.

The method of one wattmeter for measuring of active power is used in symmetrical three-phase circuits. We assume that the receiver is connected as a wye, because the triangle can always be replaced equivalent wye.

If neutral point is available, wattmeter can be connected to one of the phases. For obtaining the active power of the entire system according to (3.2) P_w readings of wattmeter should be tripled:

$$P_{\Sigma} = 3U_{\Phi} I_{\Phi} \cos \varphi. \quad (3.10)$$

If neutral is isolated, the scheme of wattmeter connection with an artificial neutral or the scheme, showed on fig.3.2 is applied.

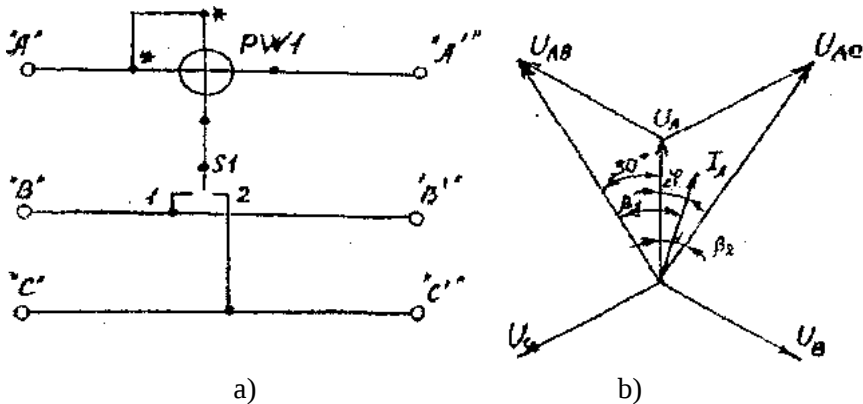


Figure 3.2

Active power of three-phase system is defined as the sum of wattmeter readings in two positions of switch:

$$P_{\Sigma} = P_{W1} + P_{W1}.$$

In accordance with the enabling circuit diagram (fig.3.2) we define:

$$P_{W1} = I_A U_{AB} \cos \beta_1$$

$$P_{W1} = I_A U_{AC} \cos \beta_2$$

$$\begin{aligned}
 P_{W1} + P_{W2} &= IU [\cos(30^\circ + \varphi) + \cos(30^\circ - \varphi)] = \\
 &= IU (\cos 30^\circ \cos \varphi - \sin 30^\circ \sin \varphi + \cos 30^\circ \cos \varphi + \sin 30^\circ \sin \varphi) = \\
 &= 2IU \cos 30^\circ \cos \varphi = \sqrt{3} UI \cos \varphi = P.
 \end{aligned}$$

Method of two wattmeters for measuring of active power is used in asymmetric three-phase circuits based on (3.6) - (3.8) by one of the three schemes (fig. 3.3). Active power is defined as the algebraic sum of readings P_{W1} wattmeter and P_{W2} :

$$P_{\Sigma} = P_{W1} + P_{W2} \quad (3.11)$$

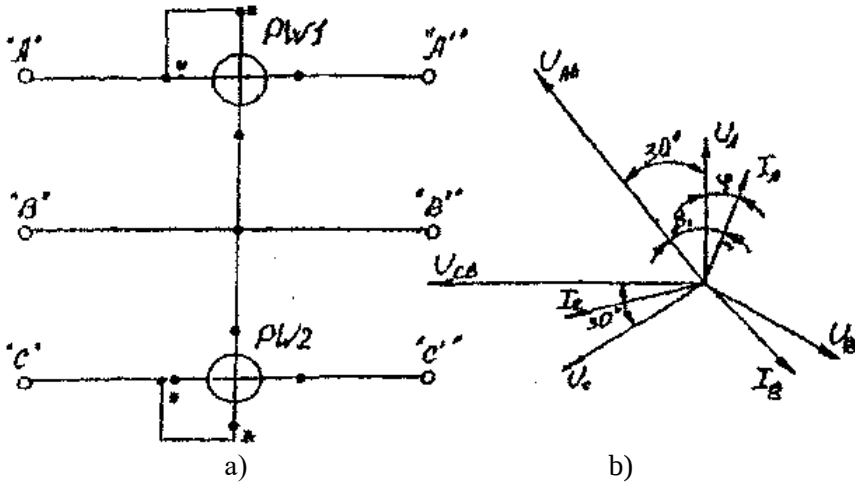


Figure 3.3.

The method of one device for measuring reactive power is used in symmetric circuits using wattmeter connection circuit shown on fig.3.4.

Reactive power of three-phase system through wattmeter readings:

$$Q = \sqrt{3} P_W.$$

Indications of wattmeter in the scheme (fig.3.4) considering vector diagram can be written as:

$$P_W = I_A U_{BC} \cos \beta = I_A U_{BC} \cos(90^\circ - \varphi) = IU \sin \varphi.$$

Since reactive power of the system (3.4):

$$Q = \sqrt{3} IU \sin \varphi,$$

then through the voltmeter readings:

$$Q = \sqrt{3}P_W. \quad (3.12)$$

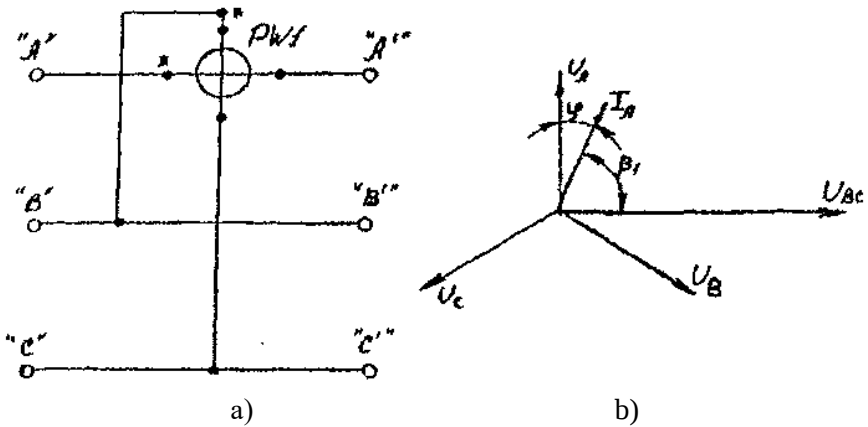


Figure 3.4.

Method of two devices for measuring reactive power is used in three-phase circuits with negligible asymmetry. Wattmeter's connection is performed according to the scheme depicted in fig.3.5.

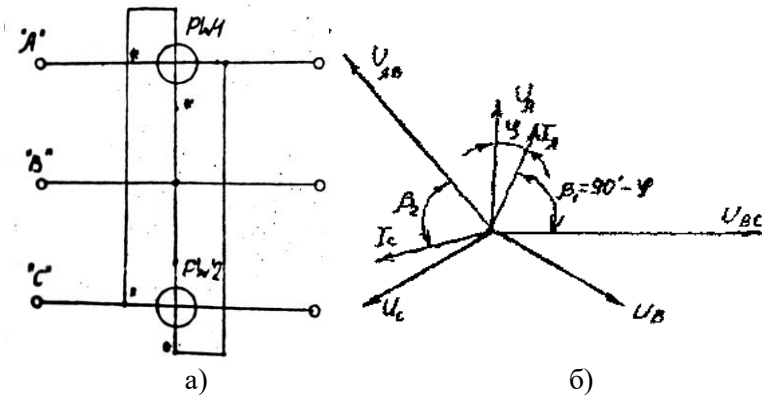


Figure 3.5.

Reactive power is determined based on a connection circuit and vector diagrams (see fig.3.5) through the wattmeter readings:

$$Q = \frac{\sqrt{3}}{2} (P_{W1} + P_{W2}). \quad (3.13)$$

The method of the three devices is used for measuring active and reactive power in the three-phase circuits with asymmetry, including the four-wire system. Measurement of active and reactive power in three phase circuits is performed by means of two-element (or three-phase) induction meters. The counters are connected according to wattmeters connection circuit.

Devices and equipment

The list of instruments and equipment listed in the table. 3.1.

Table 3.1

Marking in a scheme	Name of device	Type of device	Accuracy class	Features

The task.

3.1 Review stand, measuring circuits and devices on work-place.

3.2 Connect three-phase energy meter according to scheme fig.3.1. Reset pulse remote counter readings by pressing red button. After the entire program execution determine the number of consumed energy.

3.3 Set up scheme, fig.3.2. switch on wattmeter after the counter. Set the load current on the stand $I_A = I_B = I_C$ equal 3A, 4A or 5A, using the handles of resistors R1... R3... Measure line voltage on load by voltmeter. Record the results of all measurements in the table. 3.2.

3.4 Set up scheme fig.3.3. Make measurements and record them in table. 3.2.

3.5 Set up scheme fig.3.4 . Make measurements and write them in the table. 3.2.

3.6 Set up scheme fig.3.5 . Make measurements and write them in the table. 3.2.

3.7 According to the results of measurements calculate active and reactive power, and $\cos\varphi$ for each circuit .

3.8 Make conclusions based on experimental data.

Table 3.2

Method of measurement	Measured				Calculated		
	$U_{AB},$ V	$I_{\phi},$ A	$P_{w1},$ Wt	$P_{w2},$ Wt	P, Wt	Q, VA	$\cos\phi$
Method of one device:							
measuring P							
measuring Q							
Method of two devices:							
measuring P							
measuring Q							

Contents of the report of the laboratory work.

The contents of the laboratory work should include the topic, the aim of laboratory work, short theoretical information, laboratory setup scheme, filled table 3.1 and 3.2, the calculations, conclusions of laboratory work.

Control questions.

3.1 By wattmeters of which systems can power of AC and DC be measured?

3.2 Which methods can be used to calculate $\cos\phi$ in this work?

3.3 How to determine the upper limit of measurement of wattmeter, unit value and the maximum error that allowed, in watts?

3.4 In which case the method of one, two and three-phase devices are used in three-phase circuits?

3.5 Why according to scheme fig.3.3 with symmetrical load by the readings of two power meter active and reactive power can be determined?

Laboratory work №4

Research of instrument current transformers.

Aim of work: the study of current and voltage transformers and how they are connected. Introduction to the verification method of instrument current transformers.

Program of work.

Introduction to the workplace. Demagnetization of current transformers. Check of the investigated current transformers. Research of idling rate of current transformers.

Short theoretical information.

Instrument transformers of current and voltage are purposed for conversion of high alternating currents and voltages into lower ones, suitable for measurement, and also for separation of measurement devices circuits from high voltage circuits. With the help of transformers, devices with low rated current and voltage (ex: 5A and 100V) at high voltage circuits with high currents can be used.

Unlike common power transformers, instrument transformers operate at boundary modes: current transformer – in the mode, close to short circuit mode; voltage transformer – to idling rate. Instrument transformer contains magnetic system and two windings – primary one (with W_1 number of turns) and secondary one (with W_2 number of turns). Primary winding of current transformer is connected in series with load Z_H in the circuit; and primary winding of voltage transformer – in parallel with load or line (fig.4.1) Secondary circuit of current transformer is connected to ammeters, current windings of wattmeters and counters, relay and control circuits; in voltage transformer secondary winding is connected to voltmeters, parallel circuits of wattmeters and counters.

In standard current transformers terminals of primary winding are marked as J1 and J2, and secondary winding terminals - U1 and U2. In voltage transformers primary winding terminals are marked as A and X, secondary ones – as a and x. In current transformers primary current I_1 is greater then the secondary one I_2 , that's why primary winding has less turns, then secondary one and is made of thick wire or copper bus.

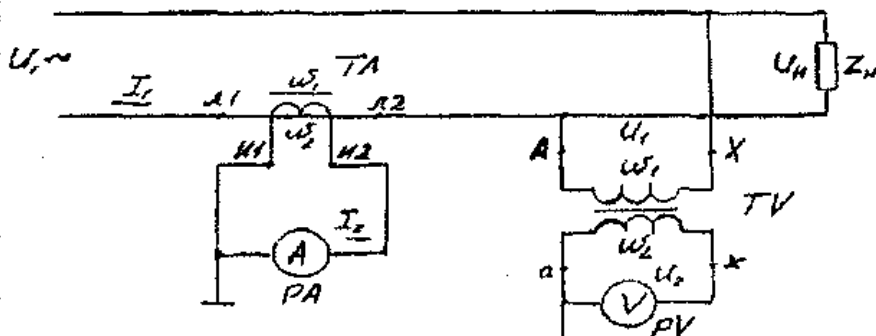


Figure 4.1

According to GOST 7746-78E secondary rated current may be 1A; 2A; 2,5A; 5A with $I_{1H} = 0.8A \dots 40 \text{ kA}$. In voltage transformers primary winding U_1 is greater than secondary U_2 , that's why $\omega_1 > \omega_2$, both windings are made of relatively thin wire. Secondary rated voltage U_{2H} may equal 100V, 150V, 100/3 V, 100/ $\sqrt{3}$ V at $U_{2H} < 750 \text{ kV}$.

According to purpose, instrument transformers are divided into laboratory ones and stationary ones. Laboratory transformers are multiranged ones, have various values of primary values and one or few values of secondary values and have accuracy class: 0,01; 0,02; 0,05; 0,1; 0,2 – for current transformers; 0,05; 0,1; 0,2; 0,5 - for voltage transformers.

Instrument current transformers operate at mode, close to short circuit mode, because resistance of ammeter, which is loaded is extremely small (ex: 0,01 Ohm).

Line measured current

$$I'_1 = \frac{I_{1H}}{I_{2H}} I_2 = K_{1H} I_2, \quad (4.1)$$

where K_{1H} – nominal transformation ratio for the current; I_2 – current, shown by ammeter in secondary circuit.

Rated current transformation coefficient value:

$$K_{1H} = \frac{I_{1H}}{I_{2H}} \quad (4.2)$$

Is shown on its case and in passport data.

The actual value of current in the line:

$$I_1 = K_1 I_2,$$

where K_1 - actual transformation coefficient, equals I_1/I_2

Actual transformation coefficient - is the unknown value, which depends on the operation mode, i.e. the values of currents and voltages, the nature and magnitude of resistance load current frequency and so on.

Relative error, which occurs because of actual and rated transformation disparity is called the current error:

$$\beta_1 = \frac{K_{1n} - K_1}{K_1} 100\% = \frac{I'_1 - I_1}{I_1} 100\% \quad (4.3)$$

In an ideal transformer without losses, the vector of the secondary current I_2 , shifted in phase relative to the primary current vector I_1 by 180°. Angle δ is called the angular error of the transformer. Angular error affects only the testimony of those devices, which deviation depends on phase shift between current and voltage measurement circuits in these devices - power meter, counters and phase meters.

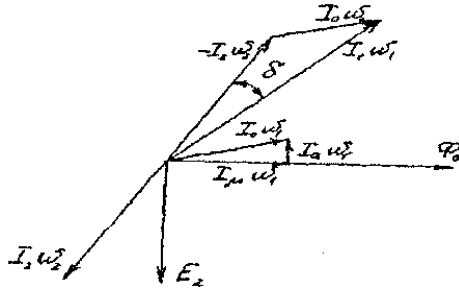


Figure 4.2

Based on the vector diagram of current transformer (fig. 4.2), can be folded the equation magnetomotive forces (MMF) transformer:

$$I_0 \omega_1 = I_1 \omega_1 + I_2 \omega_2. \quad (4.4)$$

MMF $I_2 \omega_2$ creates demagnetizing effect through displacement between the vectors $I_1 \omega_1$ and $I_2 \omega_2$ by almost 180°. Consequently, the magnetic flux Φ_0 y creates MMF $I_0 \omega_2$, which is called total transformer MMF.

In its turn, MMF $I_0\omega_1$ consists of reactive component $I_\mu\omega_1$ which creates flux Φ_0 and coincides with it by phase and active component $I_a\omega_1$, which leads flux Φ_0 by 90° and considerable hysteresis and eddy currents. At nominal operation mode of the transformer $I_0\omega_1 < 1\% I_1\omega_1$ (or $I_2\omega_2$).

At sufficient power of primary circuit, opening of secondary winding causes considerable increase of Φ_0 , because from (4.4) it follows, that $I_0\omega_1 = I_1\omega_1$. Such case refers to an extreme mode. In this case EMF of secondary winding increases to several hundred volts, which is dangerous for staff and can lead to breakdown of insulation. An increase in losses foreddy currents and hysteresis, significant heating of magnetic core and windings.

Errors of current transformers are mainly determined by $I_0\omega_1$. Current I_0 depends on the quality of core material, size, number of turns, the nature and the load.

Load current transformers should not exceed the rated load, characterized by full rated power of secondary winding S_{2H} [VA], and are indicated on the panel.

$$\text{Rated load resistance is } Z_{2H} = \frac{S_{2H}}{I_{2H}^2}.$$

To reduce the losses of magnetic core is made of circular shape made of fine high-grade electrical steel sheet or permanganate.

Instrument voltage transformers operate in a mode close to the idle operation mode, the secondary winding is connected to voltmeter, the resistance is large.

Measuring voltage transformers are characterized by an angular error, which is similar to current transformers and voltage accuracy:

$$\beta_u = \frac{K_{uH} - K_u}{K_u} 100\% = \frac{U'_1 - U_1}{U_1} 100\%,$$

where $K_u = U_1/U_2$ – actual transformation coefficient, equals U_1 i U_2 ; $K_{uH} = U_{1H}/U_{2H}$ – nominal rate of transformation for the voltage; U'_1 – measured voltage; U_2 – voltmeter readings in the secondary winding.

The greatest influence on the error has the load in terms of the transformer secondary winding, and, unlike the current transformer, its resistance is limited to removal, that condition shall be implemented $Z_2 \geq Z_{2H}$.

Determination of errors of current transformers. Identification of errors can be one of two methods - an easier method of comparing working and exemplary transformers and differential-zero method.

We will use the first method, in which devices are enabled by the scheme fig.4.3 and error determined by the formula

$$\beta_1 = \frac{I_{2n}K_{1nn} - I_{23}K_{1n3}}{I_{23}K_{1n3}}, \quad (4.5)$$

where I_{2n} , I_{23} - ammeters evidence, turn in circles secondary transformer tested model transformer respectively; K_{1nn} , K_{1n3} - nominal transformation ratio of the transformer, which is checked and model of the transformer, respectively.

Devices and equipment

Basic devices' list is shown in table 4.1.

Table 4.1

Marking in the scheme	Name of device	Type of device	Accuracy class	Technical data

The task.

4.1 Review the stand, measuring circuits and devices in the workplace. Fill in the tabl.4.1 with passport data in measuring current transformers and appliances.

WARNING! When work do not allow breaking the terminals U1 and U2 in the secondary windings of current transformers. This leads to dangerous voltage on the terminals.

Before plugging the stand knob LATRa “PEI.TOKA” in extreme position – counterclockwise.

4.2 To make a degaussing of transformers of a current

4.3 Make calibration of current transformers. Calculate the nominal load impedance for each current transformer that is validated for his passport data.

Set up fig.4.3 scheme for calibration of transformer TA1. Other transformer secondary winding that is verified TA2 and TA3 at this time are short-circuited. Note that the range of primary current that flows through J1 and J2 clip of all current transformers are always locked and folding.

Set on the shop resistances R1 appropriate load impedance Z_H . Verification transformer should be done by digital ammeter PA1, adjusting the primary current I_1 from 0 to 5 A by LATRa TV1. Install load impedance $Z=kZ_H$, where coefficient k is given by the teacher. Repeat verification transformer. Similarly, perform verification of transformers TA2 and pelvis, Results of measurement put in tabl.4.2.

Table 4.2

	Readings						Calculated errors					
Type TA	TK-20		TILJM		TΦH		TK-20		TILJM		TΦH	
Loaded	Z_H	KZ_H	Z_H	KZ_H	Z_H	KZ_H	Z_H	KZ_H	Z_H	KZ_H	Z_H	KZ_H
	0,2	0,4	0,4	0,8	1,0	2,0	0,2	0,4	0,4	0,8	1,0	2,0
PA1, A	PA0, A						$\beta_1, \%$					
1												
2												
3												
4												
5												

Calculate the current error β_1 . Construct graphical dependences $\beta_1 = f(I_1)$ and define the class of accuracy for all current transformers according to their maximum error.

4.4 Research idling rate of current transformers. Remove the idle operation voltage dependence in the secondary winding of investigated current transformer on current in line $U_{20} = f(I_1)$; $I_1 = \{1,2,3,4,5\}$ A and plot its graph.

For the experiment of idle operation scheme fig.4.3 must be used, but subject to modifications: the terminals of the investigated transformer secondary winding connect voltmeter scheme fig.4.4.

Voltmeter PV1 is available from the transformer TA2 and PV2 - from TA2 and TA3.

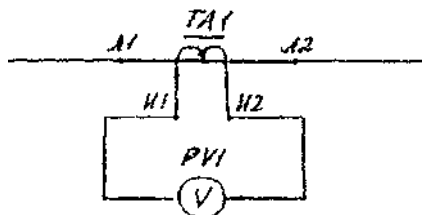


Figure 4.4

4.5. Make a conclusion on the results of experiments.

Contents of the report of the laboratory work.

The contents of the laboratory work should include the topic, the aim of laboratory work, short theoretical information, laboratory setup scheme, filled table 4.1 and 4.2, the calculations, plots of graphs $\beta_1 = f(I_1)$, $U_{20} = f(I_1)$ for each of the two transformers, conclusions of laboratory work.

Control questions.

4.1 Appointment of instrument current and voltage transformers and peculiarities of their work.

4.2 Errors of current transformers and their causes.

4.3 Vector diagram of current transformer and the equation MMF.

4.4 Rated current of secondary winding and the nominal transformer load current.

4.5 Differences between nominal and real transformation coefficients.

4.6 Means aimed at reducing errors of current transformers.

4.7 Selection of current and voltage transformers: check current transformers for emergency regimes.

Laboratory work №5

Investigation of induction energy meters.

Aim of work: familiar with the structure and principle of induction meter, the methods of its inspection, investigation of error depending on load current meter.

Program of work.

The absence of self-driving and defining the threshold of sensitivity meter. Study of regulation counter. Check meter and determine its load curve. Processing of measurement results and ordering a report.

Short theoretical information.

The most common device for measuring power AC induction meter is a measuring tool with tangential type. The structure of the meter and switch circuit shown in figure 5.1, and vector diagram - pas figure 5.2.

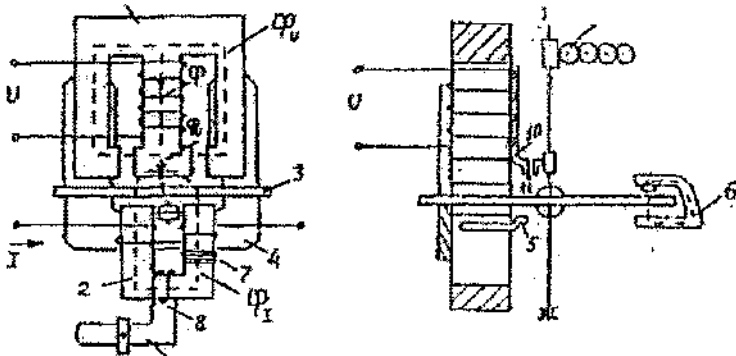


Figure 5.1

Induction meter measuring mechanism consists of the following units and parts: III-shaped magnetic core and winding of voltage 1, II-shaped magnetic core 2 with magnetic winding current, aluminum disc 3 fixed to the axis, protypolyusu 4 by soft magnetic steel, steel snood 5 to create a compensation moment, the magnet 6 to create a braking torque, short-circuited turns 7, additional windings 8, closed on wired resistor 9, plate with

flag 10, made of soft magnetic steel, steel hook 11, the counting mechanism 12.

When unlocking a meter to the voltage U attached to the winding tension, winding creates a current I_U which lags by a phase to an angle close to 90° due to the inductive coil resistance.

The current I_U creates a magnetic flow Φ average magnetic core rods I. The flow Φ is divided into two streams Φ_U and Φ_L ; workflow Φ_U crosses disk 3 and focuses on magnetic and protypolyus through 4; Φ_L closes off flow through the side magnetic cores and a large part in creating a torque meter not. Flows Φ_U i Φ_L lagged current I_U at angles of α_U and α_L , respectively, and $\alpha_U > \alpha_L$ because it crosses through the disk and closes against the policy. When I switch on the load current creates a magnetic 2 in magnetic flux physics that drive and double-crosses through mahnitoprovod 2. The flow physics - behind the current I and the angle. F_u and magnetic flux crossing the disc physics, it is determined in EMF, so that the disc is a short leader, in disk flow eddy currents. The disc has a couple of forces that creates a torque moment of:

$$M_{o6} = Cf\Phi_U\Phi_I \sin \psi, \quad (5.1)$$

where f - frequency of the alternating current network; Ψ - the angle between the flows.

When working on a linear magnetic field magnetization curve have:

$$\Phi_I = k_1 I; \quad \Phi_U = k_2 \frac{U}{Z_U} = k_2 \frac{U}{2\pi f L_U}, \quad (5.2)$$

where L_U - inductance of the winding voltage; k_1, k_2 - a constant.

Substituting the value of a constant flux, we obtain

$$M_{o6} = kUI \sin \psi. \quad (5.3)$$

If $\beta = \psi + \varphi + \alpha_I > \frac{\pi}{2}$, then adjusting α_I , possible to ensure, that

$\psi + \varphi = \frac{\pi}{2}$, scilicet, $\psi = \frac{\pi}{2} - \varphi$. That $\sin \psi = \cos \varphi$, and

$$M_{o6} = kUI \cos \varphi = kP, \quad (5.4)$$

where k – constant.

Equality $\psi = \frac{\pi}{2} - \varphi$ achieved by adjusting the angle α_1 , by changing the number of short coils 7 on magnetic cores 2 and the change of resistance wire resistor 9. To drive a winding with uniform speed proportional power consumption, torque has to be balanced by an equal M_r braking torque proportional speed drive. Deorbit time creates a permanent magnet field which crosses the disk. Number of revolutions of a disk:

$$N = AW_H, \quad (5.5)$$

where W_H - energy measured by the meter.

Coefficient A , numerically equal to the number of turns on (1kWt/hour), called the gear ratio meter. Gear Ratios counter points to his name plate. A value of the counter gear ratios, ie energy, accounted for 1 spin disc is called meter constant nominal C_H .

Nominal constant:

$$C_H = \frac{3600 \cdot 10^3}{A}, \quad (5.6)$$

where 10^3 , 3600 - conversion factor from kWt/hour до Wt/s.

The actual meter constant C_d is not equal to the nominal value of input current load is determined, so meter error depends on the load current

$$C_d = \frac{W_H}{N}. \quad (5.7)$$

The impact of error makes the friction moment in a clearing mechanism and resistance of moving parts. Obviously, time will reduce the friction torque and included energy meter will be less valid. To compensate for this systematic error in additional torque (compensation). In this construction the moment the counter is created using five leashes attached to the pole in the drive against the counter, through which the forks additional flow Φ_K . Transverse leash of radial direction arises additional torque that compensates for time friction.

When operating the meter equal compensatory time and moment of friction meter is broken and the disc may start rotating even when $I_H=0$, that's when energy consumption is not. This phenomenon is called self-driving. In his address in the box provided construction meter 10 and hook 11. Flag 10 magnetised flow Φ_K i, when the hook come to him, he holds it

by a magnetic connection. Interaction force between boxes and hooks should be adjusted so that the meter was permissible limit of sensitivity. The limit of sensitivity - is the smallest normalized value of current in percentage of rated current at which the rotation starts at the counter $U = U_H$ and $\cos\varphi=1$. For meters with accuracy class equal to 1,0, level of sensitivity must be not over 0,5%, when accuracy class is 2,5-1%.

Since the counter is integrating device, its accuracy is determined by the relative error

$$\delta\% = \frac{W_H - W_D}{W_D} 100\% = \frac{C_H N - C_D N}{C_D N} 100\% = \frac{C_H - C_D}{C_D} 100\%, \quad (5.8)$$

where W_H - energy is measured counter; W - real value of energy, defined by the testimony of exemplary devices; C - real counter constant.

Dependence of the error count of load current is called the loading curve.

Instruments and equipment

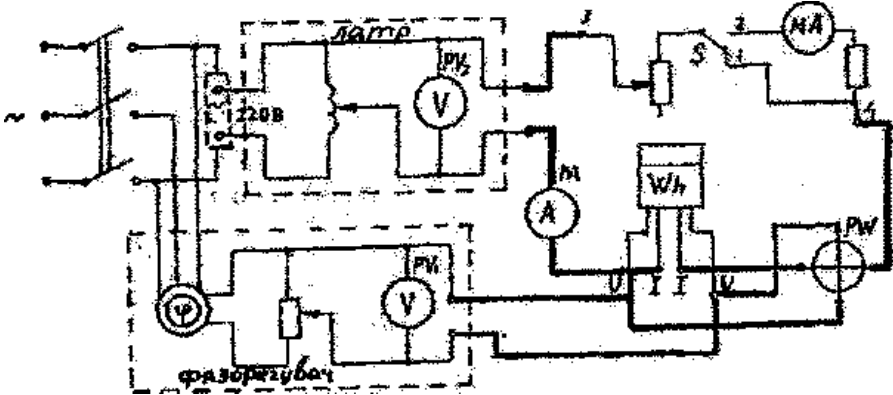
The list of devices and equipment is given in table 5.1

Table 5.1

Name of device, equipment	Type of device, equipment	Accuracy class	basic characteristics
Induction meter	CO-H446	2,5	$A=1200$; $U_H=220V$; $I_H=5...17A$
Ammeter	Э59	0,5	0-2,5-5,0 A
Milliammeter	Э34	1,0	0-70 mA
Voltmeter	Э-378	1,5	0-250 V
Laboratory autotransformer ЛАТФ	навальный		
phase responsive device	-	-	

The task.

5.1 Collect scheme (Figure 5.2). After the switch to establish the nominal current $\cos\phi = 1$. To set $\cos\phi = 1$ rotate the shifter knob to the maximum evidence kilowatt hour meters. Preheat meter nominal current for 15 minutes.



електричні кола

проводники, що підминаються виконавцями роботи

Figure 5.2

5.2 Check the lack of self-driving, for this set voltage 240 V at $I=I_H$ and by passing through a red label box end the current range switch S. If after this disc will perform no more than one rotation, the traverse is notand by passing through a red label box end the current range switch S. If after this disc will perform no more than one rotation, the traverse is not.

5.3 Determine the limit of sensitivity meter, check for this voltage $U=U_H = 220$ V and switch to position 2. Increase the current from 0 to, at which the disk begins to rotate counter. Limit of sensitivity will determine the formula

$$S_{\Pi} = \frac{I_{\Pi}}{I_H} 100.$$

5.4 Make a partial count verification in accordance with ГОСТ-1476769 of the following methods: kilowatt hour meters and stopwatch, with indications of which determine the real value of electricity, considered exemplary meter meter class accuracy is significantly crown meter accuracy

which inspection of. Meter calibration should be carried out under standard conditions, that's at ambient temperature $20\text{ }^{\circ}\text{C} - 3\text{ }^{\circ}\text{C}$, voltage $U_H \pm 1\%U$, deviation from vertical not more than ± 1 and so on.

Meters calibration in this paper the method of kilowatt hour meters and stopwatch at a nominal voltage of 220 V $\cos\varphi=1$ by determining the relative error count by (5.8) with current $I = 20, 40, 60, 80$ i 100% from $I_H = 5\text{ A}$.

Be satisfied $I = 0,2 I_H$ and record the readings - ammeter, kilowatt hour meters, voltmeters in table 5.2. To determine W stopwatch measure the length of time equal to approximately $50-60\text{ s}$ and count the number of revolutions N during this interval. Determine the time interval Δt , which corresponds to N , rotations, three times, with measured values of Δt and take the arithmetic mean of three measurements.

Results of measurements and calculations write in table 5.2.

Table 5.2

Measured				Calculated				
I, A	U, V	P_w , Wt	Δt , s	N, turn	$W_{\Delta} = P_w \Delta t$	$W_H = C_H N$	$C_{\Delta} = \frac{W_{\Delta}}{N}$, Wt/turn	δ , %

5.5 Build the load curve meter and explain in writing the reasons for increase and decrease errors at each site.

Contents of the report of the laboratory work.

The contents of the laboratory work should include the topic, the aim of laboratory work, short theoretical information, laboratory setup scheme, filled table 5.1 and 5.2, the calculations, plots of graph $\delta = f(I)$, conclusions of laboratory work.

Control questions.

5.1 What are the basic units of the induction meter and explain what forces create torque.

5.2 Under what conditions the disc rotates with uniform speed proportional power capacity?

5.3 What creates a braking torque acting on the disk? Why and how is it regulated?

5.4 What is the angle between the regulated flow of electromagnets range of current and voltage range?

5.5 What is required compensatory time? As he established and regulated?

5.6 What is a traverse count? How is it removed?

5.7 What is the limit of sensitivity of the counter?

5.8 How to determine the energy meter and considered a relative error count?

5.9 Explain the nature of the load curve counter.

Laboratory work №6

Measured resistance DC bridge.

Aim of work: familiar with the bridge resistance measurement techniques and master the technique of measurement.

Program of work.

Single measurement bridge resistances within the definition of average values and the resistivity of the material guide. Measurement of double bridge resistances within small values. Processing of measurement results and ordering a report.

Short theoretical information.

The scheme is shown in figure 6.1, a bridge or bridge DC Uitstona; points A, B, C and D - top of the bridge; range between adjacent vertices A and C, and D, etc. - behind the bridge, and the code between the opposite vertices A and B. C and D - the diagonal. In one of the diagonals submitted voltage U , and the second turn on the measuring device.

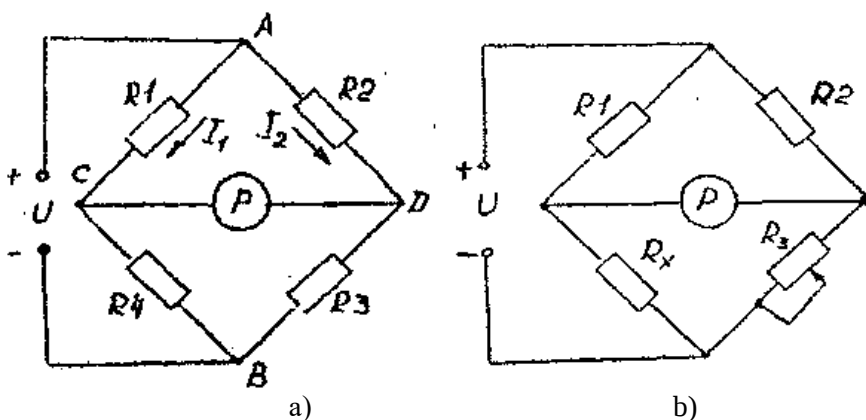


Figure 6.1

Bridge scheme has the following property: if $U_{BC} = U_{BD}$, in the current measuring diagonally missing. This state of equilibrium is called the bridge, and the equation $U_{BC} = U_{BD}$ equilibrium condition.

$$U_{BC} = I_1 R_4; \quad U_{BD} = I_2 R_3; \quad I_1 = \frac{U}{(R_1 + R_4)}; \quad I_2 = \frac{U}{(R_2 + R_3)}.$$

Then

$$R_2 R_4 = R_1 R_3. \quad (6.1)$$

This equation balance bridge DC. Properties bridge circuits are widely used for measuring resistances. If instead one of the resistors, for example instead of R_4 (figure 6.1 a) connect a resistor of unknown resistance in R_h (figure 6.1, b), one of the other resistors, for example R_3 , make it adjustable by adjusting R_3 , cities can lead to equilibrium state. Then

$$R_x = R_3 \left(\frac{R_1}{R_2} \right). \quad (6.2)$$

From (6.2) shows that the measurement result does not depend on the applied voltage or current in a circle. Thus, the balanced bridge circuit provides very high accuracy measurement.

Bridge circuits are also used to convert resistance to voltage in the unbalanced mode. If the unbalanced bridge, the current in the measuring diagonal

$$I_p = \frac{U(R_2 R_4 - R_1 R_3)}{R_p(R_2 + R_3)(R_1 + R_4) + R_2 R_3(R_1 + R_4) + R_1 R_4(R_2 + R_3)} \quad (6.3)$$

At constant voltage power supply and resistances R_1, R_2, R_3 current in the diagonal, and hence the voltage drop

$$U_{CD} = f(R_4). \quad (6.4)$$

Most such schemes are used to convert electric quantities - displacement, strain, temperature and so on at their electrical measurements. The device P, in unstable bridges hraduyuyetsya in measuring values.

Measurement error balanced resistance bridge depends on the error model calibration resistors R_1, R_2, R_3 that's the degree of error and the error due to incomplete equilibration of the bridge.

Uncertainty due to incomplete equilibration of the bridge depends on the sensitivity of bridge circuits.

The sensitivity of the bridge - ratio increased deflection measuring Δa to the relative resistance change:

$$S_M = \frac{\Delta \alpha / \frac{\Delta R}{R}}{\frac{\Delta R}{R}} \quad (6.5)$$

The sensitivity of the bridge is a product of the sensitivity of the measuring circuit for measuring sensitivity, that's

$$S_M = \frac{\Delta\alpha}{\Delta R/R} = \frac{\Delta I}{\Delta R/R} \cdot \frac{\Delta\alpha}{\Delta I} S_{CX} S_B. \quad (6.6)$$

The sensitivity of bridge circuits depends on the ratio of shoulder bridge, the internal resistance measuring device and power supply voltage value. If the measuring device is a voltmeter or galvanometer of high resistance, the maximum sensitivity of the bridge will have the

$$R_2 \approx R_3; R_1 \langle R_2; R_2 \rangle R_x. \quad (6.7)$$

In small resistance galvanometer sensitivity will be maximum at

$$R_3 < R_2; R_1 < R_2; R_2 > R_x. \quad (6.8)$$

To ensure high sensitivity of the bridge when measuring the resistance in a wide range in standard bridges can change the resistance arms in a wide range.

Shoulder R_x in balanced bridge circuit (figure 6.1, b) is executed as many stores decade resistance of $10 \cdot 100 \text{ OM}$; $10 \cdot 10 \text{ OM}$; $10 \cdot 1 \text{ OM}$; $10 \cdot 0,1 \text{ OM}$; $10 \cdot 0,01 \text{ OM}$ and is called the comparison arm. Shoulders R_1 and R_2 , (each consisting of resistances $10, 10^2, 10^3, 10^4$ ohms) are called shoulders attitude.

A scheme called the four shoulder bridge. These bridges provide high accuracy measurement of relatively large resistance of 10 to 10^5 ohms. Taking these bridges resistances between 1 and 10 ohms of error amounts to 1% and above, and such bridges measuring less than $0,1$ ohm resistance over large errors do not. This case, transitional support contacts and supports the connecting wires are measurable levels of resistance. For measurement of small resistances in the range of 10^{-6} to 10 ohms used double bridges DC.

Double Bridge (bridge Thomson) shown in figure 6.2. Measured resistance R_x clamp should have four - two current used to switch the R_x range in power bridge, and two potential between which the measured resistance. The same clip has an exemplary resistor R_n . Transitional support current terminals are in range of a connector wire R_0 and wires that go to the power source. Transitional support potential clamp and corresponding interconnections of the wires are turned on sequentially supports shoulders bridge R_1, R_2, R_3, R_4 to exclude the influence of transient resistance and

resistance wire interconnections bearing shoulder bridge. R_1, R_2, R_3, R_4 are selected by double bridges greater than 10 ohms.

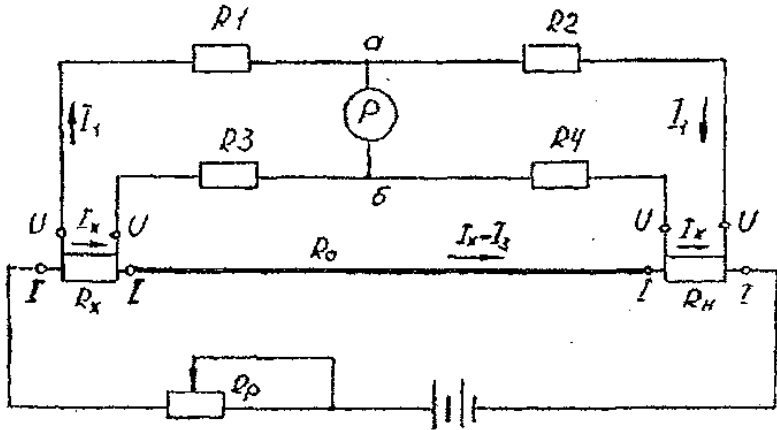


Figure 6.2

At balance dual bridge when $U_{ab}=0$, can make the following equations:

$$\begin{aligned} I_1 R_1 - I_x R_x - I_3 R_3 &= 0; \\ I_1 R_2 - I_x R_4 - I_3 R_4 &= 0; \\ I_3 (R_3 + R_4) - (I_x - I_3) R_0 &= 0. \end{aligned} \quad (6.9)$$

From these equations follows

$$R_x = \frac{R_1}{R_2} R_H + \frac{R_4 R_0}{R_3 + R_4 + R_0} \left(\frac{R_1}{R_2} - \frac{R_3}{R_4} \right). \quad (6.10)$$

If

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}, \quad (6.11)$$

Then

$$R_x = \frac{R_1}{R_2} R_H. \quad (6.12)$$

To carried out the condition (6.11), double bridges are performed so that each pair of resistance changes at once, or by mechanical coupling of

resistors handle plug or permutation Male stores. For better implementation of equality (6.11), resistor R_0 should have little resistance; so do it as a piece of copper bus.

Errors measuring of dual resistance bridge measurement error than average resistance chotyrohplechym bridge and can reach several percent.

Instruments and equipment.

Universal instrument P4833, designed to measure resistance, voltage and EMF constant and verification technology for example.

Accuracy class 0,1; power supply: 220V; 50 Hz

Resistances set consists of 5 decades: a degree of resistance 100; 10; 1; 0,1; 0,01 Ohm - they are back comparison. Shoulders attitude made as delytelya, resistors which are situated on the decade switches 10^3 , 10^2 , ..., 10^{-3} , 10^{-4} . Zero - an indicator is a galvanometer, with the on button "rude", "exactly". buttons MO-2, MO-4 - code work. Clips T1, T2, П1, П2 - Connectivity resistance. Button "Сеть" to connect the appliance.

The task.

6.1 Resistance measurement of 10^2 to 10^6 Ohm.

Turn gauge measuring the resistance leaders to clamp " П1" and "П2". Handles decade switches set resistance value resistor. Click the " MO-2" and " Г ".

Turn the unit, turn on the machine, click the "Сеть". Set the arrow on the galvanometer zero rotation handles decade switches shoulders comparison, initially - when button is "rough", then - "Exactly".

Define resistance resistors $R_x = NR_M$ Ohm, where N - the ratio of resistances shoulders attitude. R_M - Resistance Value shoulders comparison. Remove the Power to install controls in the home position switch stand.

6.2 Measuring resistance 10^{-4} to 10^2 Ohm. Enable resistor to clamp "T1", " П1", " П2", "T2"; click the "MO-4" and " Г ", set value of resistance, Switch the appliance, set the arrow galvanometer to zero. Determine $R_x = NR_M$ Drop device.

6.3 Give the results of measurements and calculations in table 6.1.

Table 6.1

Type resistor	Measured		Calculated	
	N	R_x , Ohm	Δ , Ohm	δ , %

Contents of the report of the laboratory work.

The contents of the laboratory work should include the topic, the aim of laboratory work, short theoretical information, laboratory setup scheme (fig. 6.1, 6.2), filled table 6.1, the calculations, conclusions of laboratory work.

Control questions.

6.1 Single-bridge circuit to give DC and formulate the equilibrium condition of the bridge.

6.2 Why do small dimension single error resistance bridge great?

6.3 establish a scheme of double bridge and write equations for determining the measured resistance.

6.4 Put four methods of measurement of resistance with a single bridge.

6.5 What is the error of measurement of resistance bridge method?

6.6 What is the sensitivity of the bridge?

6.7 What is the condition of maximum sensitivity of the bridge when it is switched on diagonal voltmeter, ammeter?

6.8 For what used unbalanced bridge circuit? How to get results by measuring unbalanced?

6.9 Classification of bridges.

LIST OF REFERENCES

1. Метрологія та вимірювальна техніка: підручник / Є. С. Поліщук, М. М. Дорожовець, В. О. Яцук та ін. ; за ред. Є. С. Поліщука.- 2-ге вид., доп. та перероб. – Львів : Львівська політехніка, 2012. – 544 с.
2. Электрические измерения: учебник для студ. электроэнерг. и электротехн. спец. вузов / Л. И. Байда, Н. С. Добротворский, Е. М. Душин и др. ; под ред. А. В. Фремке, Е. М. Душина.- 5-е изд., перераб. и доп. – М. : Энергоатомиздат, 1980. – 392 с.
3. ДСТУ 2708:2006 Метрологія. Повірка засобів вимірювальної техніки. Організація та порядок проведення. – К., Держстандарт України, 2006.
4. Шишкин И. Ф. Теоретическая метрология: учеб. для вузов. Ч. 1. Общая теория измерений / И. Ф. Шишкин.- 4-е изд. – СПб. : Питер, 2010. – 192 с.
5. Сергеев А. Г. Метрология: учеб. пособие для вузов / А. Г. Сергеев, В. В. Крохин. – Москва : Логос, 2002. – 407 с.
6. Тартаковский Д.Ф. Метрология, стандартизация и средства измерения: Учеб. для вузов / Д.Ф. Тартаковский, А.С. Ястребов – М.: Высш. шк., 2001.– 205 с.
7. Тарасова В.В. Метрологія, стандартизація та сертифікація. Підручник / В.В. Тарасова, А.С. Малиновський, М.Ф. Рибак. За заг. ред. В.В. Тарасової. – К.: Центр навчальної літератури, 2006. – 264 с.
8. Коваленко І. О. Метрологія та вимірювальна техніка: навчальний посібник / І. О. Коваленко, А. М. Коваль. – Житомир : ЖІТІ, 2001. – 651 с.
9. Цюцюра В. Д. Метрологія та основи вимірювань: навч. посібник / В. Д. Цюцюра, С. В. Цюцюра. – Київ : Знання- Прес, 2003. – 180 с.
10. Основи метрології та електричних вимірювань: підручник : затв. МОНУ / В. В. Кухарчук, В. Ю. Кучерук, Є. Т. Володарський, В. В. Грабко. – Херсон : Олді-плюс, 2013. – 538 с.
11. Пустовая О. А. Электрические измерения: учебное пособие / О. А. Пустовая. – Ростов н/Д : Феникс, 2010. – 247 с.

12. Осадчий, В. В. Лабораторный стенд для исследования микропроцессорных систем управления двухмассовым электроприводом / В. В. Осадчий, Е. С. Назарова, В. В. Брылистый, Р. И. Савилов // Електротехнічні та комп'ютерні системи. – 2016. – № 22(98). – С. 33-38. <http://dx.doi.org/10.15276/eltecs.22.98.2016.05>

13. Осадчий, В. В. Исследование позиционного электропривода на основе шагового двигателя в микрошаговом режиме / В. В. Осадчий, Е. С. Назарова, С. Ю. Тоболкин // Електротехнічні та комп'ютерні системи. – 2015. – № 19(95). – С. 24-27. <http://dx.doi.org/10.15276/eltecs.19.95.2015.06>

14. Назарова, Е. С. Математическое моделирование электромеханических систем станов холодной прокатки / Е. С. Назарова // Технічна електродинаміка. – 2015. – Вип. 5 – С. 82-89.

15. Назарова, Е. С. Учет эффекта обрыва прокатываемой полосы при моделировании электроприводов двух смежных клеток стана холодной прокатки / Е. С. Назарова, А. В. Пирожок, А. С. Нечпай, П. А. Подпружников // Електротехніка та електроенергетика. – 2011. – №2. – С. 37-41. DOI: <https://doi.org/10.15588/1607-6761-2011-2-6>

16. Назарова, Е. С. К вопросу разработки систем диагностирования электромеханических систем станов холодной прокатки / Е. С. Назарова // Електротехніка та електроенергетика. – 2013. – № 1. – С. 36-41. DOI: <https://doi.org/10.15588/1607-6761-2013-1-6>

17. Новое в моделировании и исследовании электромеханических систем станов холодной прокатки : монографія / А. В. Садовой, Е. С. Назарова, В. И. Бондаренко, А. В. Пирожок; Запорізьк. нац. техніч. ун-т, Дніпродзерж. держ. техніч. ун-т – Запоріжжя: «Просвіта», 2014. – 144 с.

18. Осадчий, В. В. Лабораторный стенд для исследования алгоритмов микропроцессорных систем управления шаговыми двигателями / В. В. Осадчий, Е. С. Назарова, С. Ю. Тоболкин // Електромеханічні і енергозберігаючі системи. – 2014. – Вип. 2/(26). – С.102-108.

19. Бондаренко, В. И. Моделирование систем управления взаимосвязанных электроприводов процесса прокатки с учетом упругостей первого и второго рода / В. И. Бондаренко, А. В. Пирожок, Е. С. Назарова // Техническая электродинамика. Спецвып. – 2010. – Ч. 1. – С. 129-134.