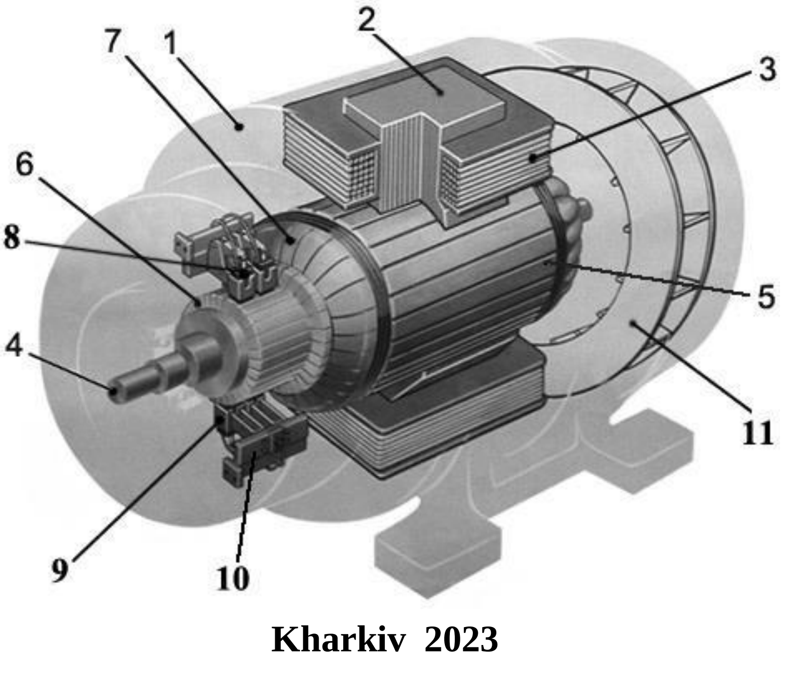
MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE

NATIONAL TECHNICAL UNIVERSITY
«KHARKIV POLYTECHNIC INSTITUTE»

ELECTRIC AND MAGNETIC DEVICES

LABORATORY WORKS
ON ELECTRICAL ENGINEERING
PART 2



Kharkiv 2023

EDUCATION AND SCIENCE MINISTRY OF UKRAINE

NATIONAL TECHNICAL UNIVERSITY
«KHARKIV POLYTECHNIC INSTITUTE»

DEPARTMENT OF APPLIED ELETRICAL ENGINEERING

ELECTRIC AND MAGNETIC DEVICES

LABORATORY WORKS
ON ELECTRICAL ENGINEERING
In three parts
Part II

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ISBN

The progress of five laboratory works from the section "Electric and magnetic devices" of the discipline "Electrical engineering, electronics and microprocessor technology" is presented in the form of a complex independent work for preparation for the performance of laboratory works. The calculation method of different electric devices is presented. It is intended for independent work of students in the preparation and execution of laboratory, calculation and graphic work, preparation for tests and exams.

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INTRODUCTION

The proposed methodological instructions are a component of the educational process and are intended for full-time students.

They provide for the consistent acquisition of knowledge related to research and calculation of electrical devices.

The purpose of laboratory classes is to consolidate theoretical knowledge and acquire practical skills in drawing up electrical circuits for switching on electrotechnical devices, measuring currents, voltages, powers, etc.

On the basis of these studies, calculations of electric devices and analysis of research results are carried out.

The methodical instructions provide safety rules for performing laboratory work, the order of their execution, theoretical provisions, format and content of the report, and schematic diagrams of electric devices.

DESCRIPTION OF THE UNIVERSAL LABORATORY BENCH FOR LABORATORY WORKS ON ELECTRICAL ENGINEERING

The universal laboratory bench is intended for conducting laboratory works on the “Electrical engineering” course by the frontal method.

The laboratory bench includes:

- an assembly bench with electrical measuring devices and electrotechnical elements;
- an electric machine bench, which contains electric machines of direct and alternating current, mechanical brakes of electric machines, a load rheostat R_H.

The placement of devices and terminals of the main devices on the front panel of the assembly bench is shown in Fig. 1.

Buttons for magnetic starters and terminals of the following electrical supply sources that are located in the lower part of the bench are:

- a three-phase voltage source of 220/380 V (phase and line value);

- a direct voltage source of 230 V;
- a single-phase alternating voltage source of 127 V;
- a regulated alternating voltage up to 250 V with the help of a laboratory autotransformer (LATR) T1, and also a direct voltage source up to 250 V, which is formed by means of rectifier *VA*;
- a three-phase voltage source of 22/36V (phase and line values).

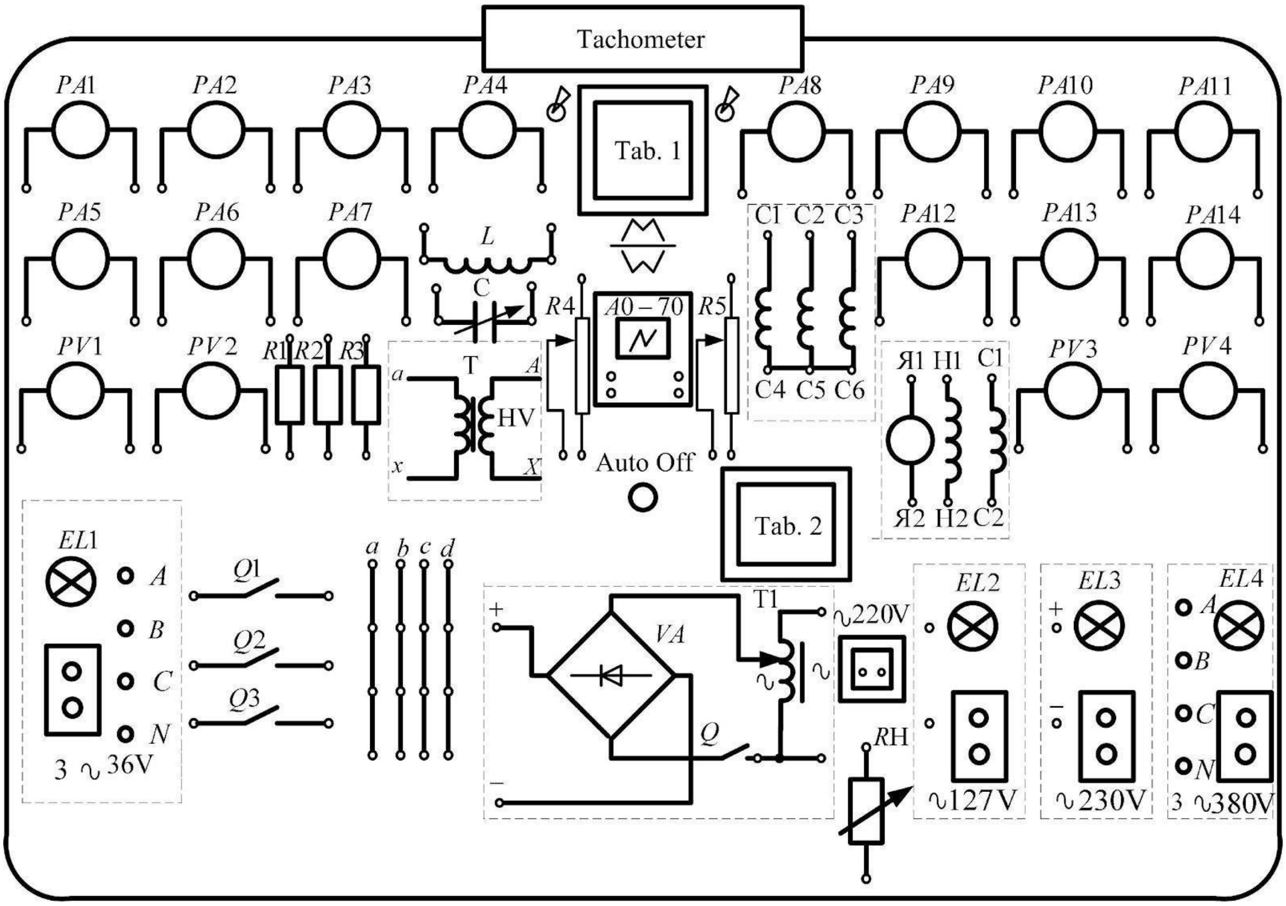


Figure 1

On the bench there are:

- electrical measuring devices: ammeters *PA*1–*PA*14 and voltmeters *PV*1-*PV*4 of direct and alternating current;
- fixed resistors *R*1, *R*2, *R*3;
- rheostats *R*4, *R*5 (with regulated resistance);
- an inductor *L*;
- a capacitor *C*;
- a single-phase transformer T;

- an electron-beam oscilloscope type “ЛО–70”;
- terminals of stator windings of an induction (asynchronous) electric motor “C1-C6”;
- terminals of a direct current machine windings: of the armature “Я1–Я2”; of the separately excitation H1-H2; of series excitation “C1-C2”;
- terminals of the load rheostat R_H;
- four connection terminals *a, b, c, d* – four clips in each for convenient assembly of experimental schemes;
- keys *Q*1, *Q*2, *Q*3;
- an emergency button for removing all types of voltage from the terminals of the bench – “Auto Off” (“EMERGENCY DISCONNECT”);
- signal lights of supply sources *EL*1-*EL*4;
- an AC power outlet 220V;
- a digital tachometer for measuring the frequency of electric machine rotation.

Additionally, portable phasometers, watt-meters, ammeters and voltmeters can belocated on the table.

On the bench (Fig.1) there are plates with rules on the basics of electrical measurements (Tab. 1), as well as with the rated parameters of electrical equipment (Tab.2).

SAFETY RULES DURING LABORATORY WORKS

Laboratory benches are operating electric and electromechanical installations, which under certain conditions can become sources of electric shock. To create safe conditions for laboratory work and prevent the possibility of damage to electrical equipment, students must know and strictly follow the rules:

1. Before starting work, a student must receive evidence that all sources of voltage are in the “OFF” position, and the auto-transformer slider is set to zero.
2. It is strictly forbidden to touch uninsulated wires, connecting clamps and other parts of the electric circuits under voltage.
3. Installation of the electric circuit and any re-connections should be

carried out with switched-off all the voltage sources.

4. It is strictly forbidden to enable the installation without conducting a circuit check by the lecturer.

5. If the applied voltage disappears during operation, immediately turn off the laboratory installation and place the autotransformer slider in a position that corresponds to the minimum voltage.

6. Disassembling of the circuit should be only performed with permission of the lecturer.

7. If any malfunction is detected in an electrical device under voltage, it is necessary to immediately switch off the bench from the network with the emergency shut-off button. This case should be immediately reported to the class lecturer.

LABORATORY WORK PROCEDURE

For a laboratory work, academic groups of students are divided into subgroup of 2-4 students. Laboratory works are carried out by the frontal method, that is, all the students simultaneously perform the same work, but at different benches.

To perform a laboratory work, one preliminary test report (draft) must be prepared for each student, it must contain the electrical scheme of the experiment and the measurement tables. Before starting the experiments, the subgroup should get acquainted with the workplace that contains the experimental installation, supply sources used, loads of electrical energy and devices.

When assembling a circuit, it is first recommended to make the main circuit with the loads to be studied and the current circuits of ammeters, wattmeters and phase meters.

Then you can connect circuits of voltmeters, wattmeters and phase meters, which are connected in parallel with loads. It is necessary to remember the rule that terminals of devices are used only for their connection to the circuit. Nothing else can be connected to these terminals, and all additional connections are performed with free terminals on the bench panel.

The assembled circuit must be shown for verification; voltage sources should be turned on only by the permission of the lecturer.

Results of all primary observations, measurements and calculations should be recorded in pre-prepared tables.

After the experiment, the power sources should be turned off, and the measurement results should be given to the lecturer for verification.

If the results of the experiment are recognized as correct by the lecturer, the electric circuit should be disassembled and passed for the assembly of the following circuit. After completing the research, the work place should be organized, the conductors and the equipment should be transferred to the place of their storage.

LABORATORY WORK REPORT CONTENTS

The report on laboratory work is completed by each student individually and must be neat, executed according to the established form.

The report begins with the title page, a sample of which is given in Fig. 2.
On the following pages, please indicate:

- an schematic diagram of an electric circuit of the experiment;
- the rated data of researched devices, necessary for the report;
- formulae and dependency graphs used for calculations;
- observation data tables and results of calculations in accordance with the requirements presented in the guidelines for each laboratory work;
- graphic material (graphs, diagrams, drawings).

Students draw the circuits using tools according to The Ukrainian State Standard.

Legend of typical elements and their sizes is given in Table 1.

Resulting dependency graphs should be drawn on the millimeter paper, indicating standard letter designations of values and measurement units on the axes.
Phasor diagrams should be built on the selected scale.

The report is received by the lecturer on the day the next work is carried out. During this, the student must analyze the results, answer the control questions and solve the exercises on the topic of the work.

Ministry of Education and Science of Ukraine

National Technical University
«Kharkiv Polytechnic Institute»

Department of Applied Electrical Engineering

Laboratory report №

____

(full title of the work)

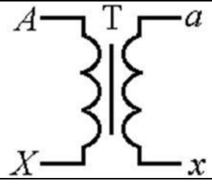
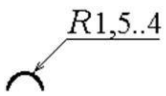
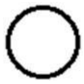
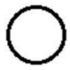
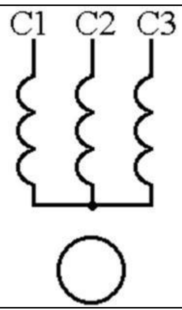
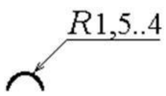
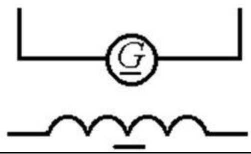
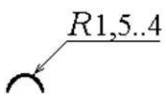
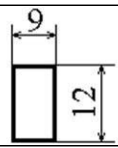
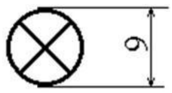
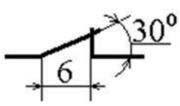
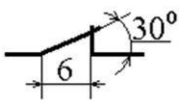
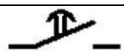
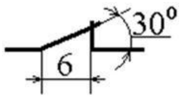
Work was performed by:
student______________; group___________;__________________________
(surname, initials) (index) (execution date)

The report was accepted on____________Lecturer____________________
(date) (position, surname, initials)

Kharkiv NTU «KhPI» 2023

Figure 2

Table 1 – Legend of functional elements in electric circuits

Title of elements	Designation on a schematic diagram	Dimensions
1	2	3
Single-phase two-winding transformer		
Electric machine stator		
Electric machine rotor		
Cage induction (asynchronous) machine (a wye-connected winding)		
Separately excited DC generator		
Relay coil		
Filament lamp		
Make contact		
Break contact		
Make contact with time delay	 OR 	

Laboratory work 6

MAGNETIC CIRCUIT RESEARCH

6.1. Formulation of the problem

The purpose of the work is to consolidate theoretical knowledge about the structure of magnetic circuits and electromagnetic processes occurring in them. Problem of the lesson is experimental measurement of volt-ampere characteristics (VAC) in magnetic circuits on the example of an inductor with an iron core and a separable armature, determination of the parameters of the substitution scheme and construction of a phasor diagram.

6.2. Object of study

The object of study is an inductor with an iron core, which is powered by an alternating current and a separable armature and is in the designation scheme. The schematic diagram of the experiment is shown in Fig. 6.1. The inductor input terminals are marked with digits 1 and 2. The separable armature has a measuring coil having output terminals 3 and 4. The rated data of the inductor coils are given in Table 1.1, where I_r is the rated current of the main inductor coil; W_c is the number of turns of the main coil; W_m is the number of turns of the measuring armature coil.

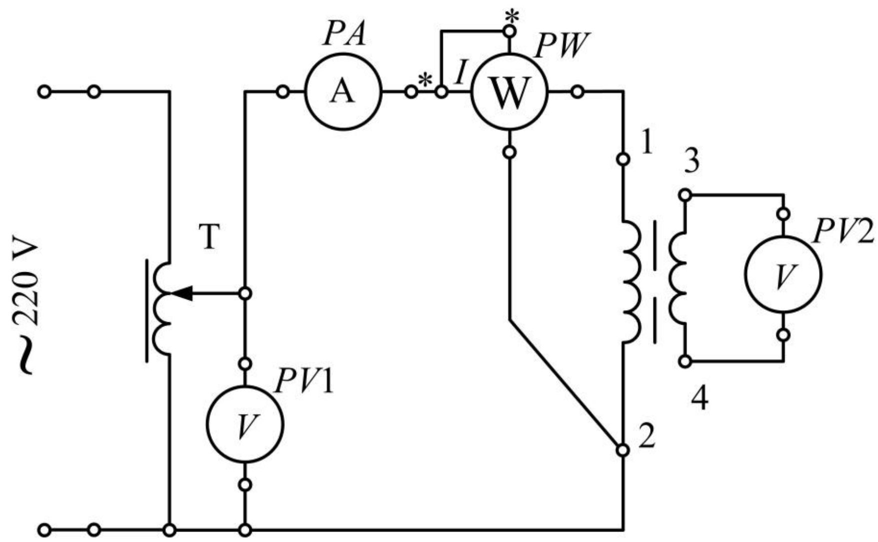


Figure 6.1 – Schematic diagram for the inductor with an armature

Table 6.1

I_r, A	W_c	W_m
0,4	1000	200

The inductor is powered, voltage and current regulation is carried out by an autotransformer (LATR) T, the input terminals of which must be connected to an AC source of 220V.

6.3. The order of the experiment execution

6.3.1. Assemble the circuit for experiments shown in Fig. 1.6 and remove the armature from the main part of the inductor.

6.3.2. Before starting each experiment, set the LATR to zero (by turning the knob anti-clockwise until it stops). After applying the voltage across the input terminals of the LATR it is necessary to make sure on the voltmeter that the voltage across the output terminals of the LATR equals zero.

WARNING! Control of adjustment of the measured values by the current in the main inductor coil! Manipulate with the armature when the SOURCE VOLTAGE is OFF!

6.3.3. Carry out an experiment to measure the volt-ampere characteristic of the coil with the armature removed (Fig. 6.2). Adjusting the LATR current from zero to the maximum value in 0,1 A increment, make measurements and record the results in Table 1.2. Make active power P measurement when a current value is I_r = 0,4 A.

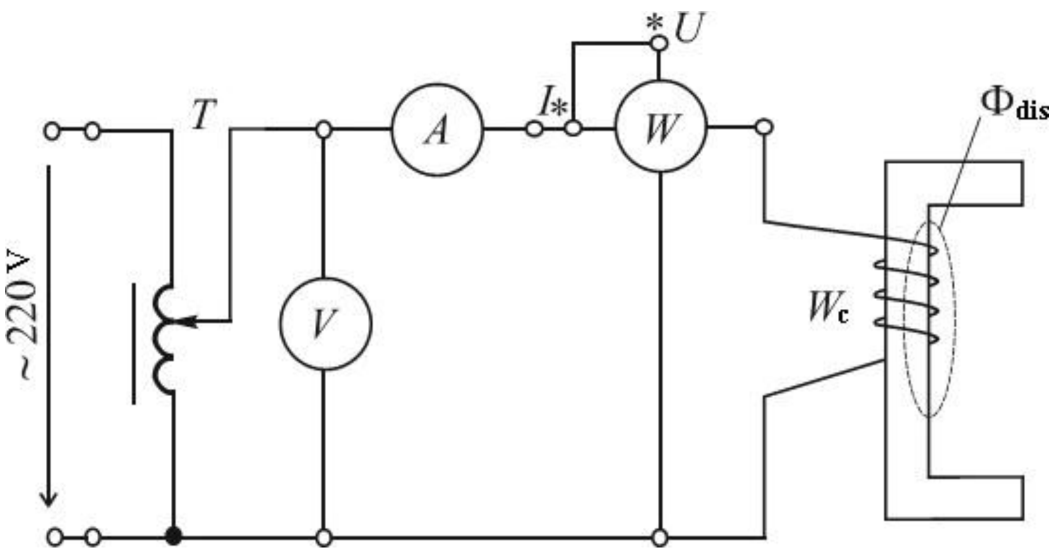


Figure 6.2 – Schematic diagram for the inductor without the armature

6.3.4. Attach the armature to the inductor core and conduct an experiment to measure the VAC of the main coil (Fig. 6.3). Adjust the current by the LATR from zero to the maximum value in 0,1 A increments, make measurements and record the results in Table 6.3. Only measure the active power *P* and EMF E_0 at I_r = 0,4 A.

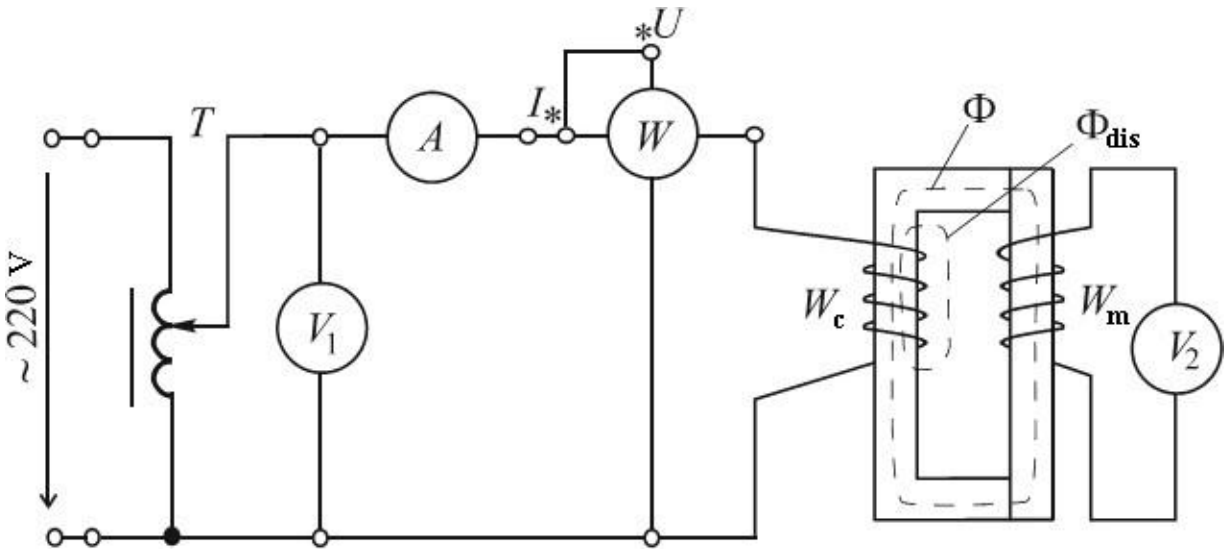


Figure 6.3 – Magnetic fluxes in the inductor with the armature

Table 6.2

I_0, A	0	0,1	0,2	0,3	0,4	0,5	0,6	0,7
U_0, V	0							
P_0, W	0	-	-	-		-	-	-

Table 6.3

I, A	0	0,1	0,2	0,3	0,4	0,5	0,6	0,7
U, V	0							
P, W	0	-	-	-		-	-	-
E_m, V	0	-	-	-		-	-	-

6.4. Processing of results of experiments and preparing a report on the work

6.4.1. According to the Table 6.2 and 6.3, draw in the same coordinate system the VAC *U* (*I*) for the respective inductor test duties. For an example in Fig. 6.4

presents a qualitative VAC of the inductor: 1 – with an armature attached to the core, 2 – with an armature removed from the core.

6.4.2. Display the inductor replacement diagram.

6.4.3. According to the Table 6.2 and 6.3 calculate the parameters of the substitution circuit R, X_p, X_0, R_0 for the rated current of the coil I_r = 0,4 A.

6.4.4. Draw a phasor diagram of the inductor for the rated current.

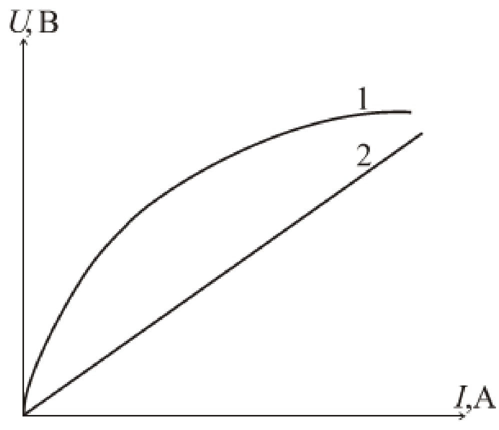


Figure 6.4

1 – with armature attached to the inductor core;
2 – with the armature removed from the core

Control Questions

1. What is a magnetic circuit, which quantities characterize the physical state and processes in it?

2. Formulate Faraday's law (law of electromagnetic induction).

3. Formulate Lenz's rule.

4. What processes occur in the inductor with an iron core when the inductor is energized by alternating voltage?

5. Record the equilibrium equation in the circuit of the inductor, as well as the physical content of the quantities included in these equations.

6. What is the structure of the inductor replacement circuit? Explain the physical content of these elements.

7. Draw the volt - ampere characteristics of the inductor.

8. What are the power losses for the inductor with an iron core when powered by an alternating current?

L a b o r a t o r y   w o r k   7

RELAY RESEARCH

7.1. Formulation of the problem

The purpose of the work is to consolidate theoretical knowledge about the structure and the principle of operation of the electromagnetic relay of automatics and the time relay. The problems of the lesson are to determine the parameters and characteristics of the electromagnetic relay of automatics and the time relay.

7.2. Object of study

7.2.1. Investigation of electromagnetic relay of automatics

The object of the study is an electromagnetic relay of automatic control type MKU48-C with rated data: operating voltage 220 V; current is direct; winding resistance R = 20±3 kOhm; trigger voltage U_{on} = 187 V; release voltage U_{off} = 36 V.

Contact set: two make (closable) contacts (1: 6) and two break contacts (9: 4). The permissible contact switching power must not exceed 50 W for DC current and 500 V A for AC current.

The scheme of the study of the electromagnetic relay is shown in Fig. 7.1.

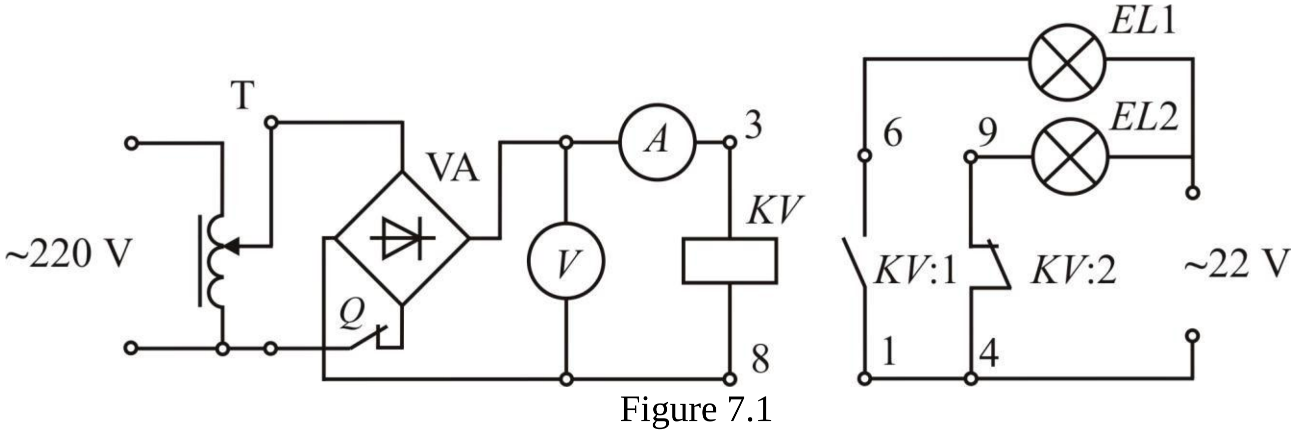


Figure 7.1

The relay coil *KV* (3: 8 clamps) is supplied by a direct current supplied to it through the rectifier VA and the autotransformer T (LATR) from the AC 220V terminals , respectively, through the make contact *KV*: 1 (1: 6 clamps), and the break contact *KV*: 2 (4: 9 clamps).

Measurement of actuation voltages U_{on} and release U_{off} relay is carried out with by the help of voltmeter *V*. Measurement of currents of actuation and release Ivid relay is carried out using milliammeter *A*.

7.2.2. Research of the relay

The object of the study is a time relay type EV144 with rated data: time delay t_{st} = 0… 20 s; rated voltage across the coil is 220 V; the kind of current is direct; voltage of relay $U_{on} \leq$ 154 B; absolute delay time delay Δt = 0,8 s; release voltage $U_{off} \leq$ 11 V; the end and instant contacts can operate in DC and AC circuits with a voltage of 250 V with a permissible value of DC up to 2 A and AC up to 5 A at cos $\varphi \geq$ 0,5.

The schematic diagram of the relay study is shown in Fig. 7.2.

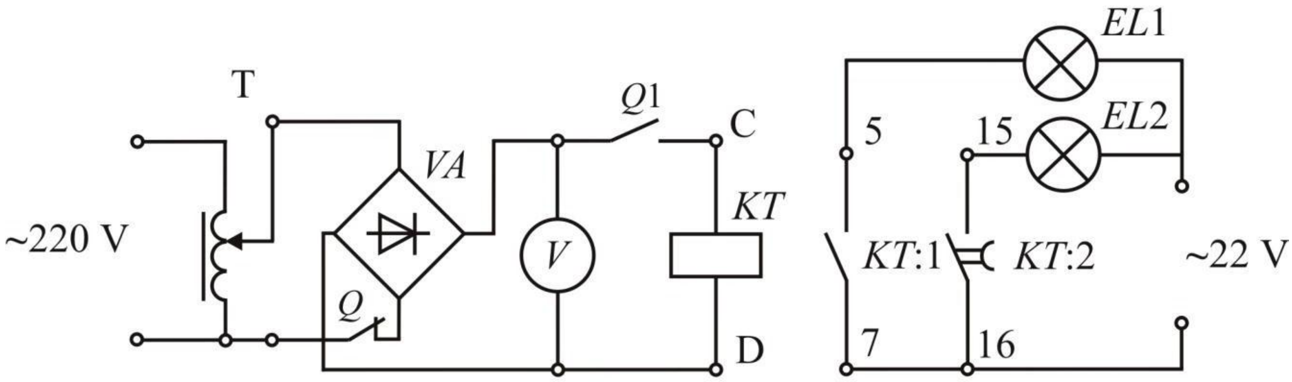


Figure 7.2

The power supply of the *KT* relay coil (clamps C: D) is provided by a direct current, which is supplied to it through the rectifier VA and the autotransformer T from the AC 220V voltage source and measured by the voltmeter V. The filament lamps *EL*1 and *EL*2 are switched on to the AC voltage 22 by the instant (no time delay) make contact *KT*:1 (5: 7 clamps) and the end (with time delay) make contact *KT*:2 (15:16 clamps).

In this work, the holding time t_{st} of the relay operation and the absolute scattering Δt of this time are experimentally determined.

The time delay of the relay is performed by means of a clock mechanism.

To determine the holding time t_{st} of the relay and the absolute scattering Δt of this time, the filament lamps *E*L1 and *EL*2 and the stopwatch (or a clock with a second hand) are used.

7.3 The order of experiments

7.3.1. Review the design and operation principle of the MKU48-C automatic relay.

7.3.2. Draw a circuit diagram for exploring the relay in Fig. 7.1.

Set autotransformer T to zero. Lock the key *Q*. Supply voltage to autotransformer T from ~ 220 V. Apply ~ 22V to the lamps, the EL2 lamp will light up. Slowly increase the voltage by turning the LATR knob clockwise until the relay armature is engaged, determine the voltage U_{on} and the current I_{on} of the relay. Under these conditions, the *KV*: 1 contact is closed and the *KV*: 2 contact is opened, which is fixed by the ignition of the *EL*1 lamp and at the same time the *EL*2 lamp is extinguished. Record the measurement results in Table 7.1.

Determine the input voltage U_{on} and current I_{on} and output values U_{off} and I_{off} of the relay. Use the T transformer to reduce the voltage before releasing the relay armature. The moment of release is fixed by the illumination of the *EL*2 lamp with the simultaneous extinguishing of the *EL*1 lamp. Record the measurement results in Table 7.1.

Table 7.1

Parameters	Measurement results			Calculation results		
	Experiment № 1	Experiment № 2	Experiment № 3	Average value	K_r	R_c, Ohm
U_{on}, V						
I_{on}, mA						
U_{off}, V						
I_{off}, mA						

Repeat the experiments 3 times and enter the data in Table 7.1.

After the experiments, set the T-handle T to the end position by turning it counter-clockwise as far as it will go. Turn off the power to the circuit and open up the *Q* key. Obtain the results show to the lecturer.

2.4.3. See the design and operation principle of the EV144 or PB143 time relay.

2.4.4. Draw a circuit diagram for exploring the relay in Fig. 7.2.

Set the time delay of the relay t_{st} within the range of 2… 6 seconds specified by the teacher. To do this, unscrew the screw that secures the end contacts to the timeline, put them in the set position, and secure with the same screw. Enter the indicated time-keeping t_{st} in the Table 7.2.

Table 7.2

The time delay is set t_{st}, s	Measurement results holding time, s			Calculation results	
	t_{st1} Experiment № 1	t_{st2} Experiment № 2	t_{st3} Experiment № 3	Average time delay t_{st}, s	Exposure time variation Δt, s

Close the key *Q*. When the key *Q*1 is open, apply a voltage to the auto transformer T and use the latter to set the output of the rectifier *VA* to a voltage of 220 V. Apply the voltage source of ~ 22V to the lamps, the lamps will not light up. Close the *Q*1 key and turn on the stopwatch at the same time. The make contact *KT*:1 will close instantly and EL1 lamp will light.

Expect the *EL*2 lamp to light up. At the moment of ignition, stop the second measure and record the time corresponding to the closing of the terminal contacts of the *KT*: 2. Open the *Q*1 key. Enter the stopwatch measurements in Table 7.2.

Repeat the experiments three times for the teacher's exposure time t_{st}.

Set the time delay of the relay set by the teacher within 8… 12 seconds and perform the experiment similar to the previous one. Repeat the experiment for the teacher’s set time delay of 16… 20 seconds.

7.4 Processing the results of the experiment

7.4.1. According to the measurements of the Table 7.1 determine the average voltages U_{on}, U_{off} and currents I_{on}, I_{off} the actuation and release of electromagnetic relay automatics. On the average value of the obtained values, calculate the coefficient of return of the relay K_r and the resistance of the coil R_c by the formulas:

$$K_r = \frac{I_{off}}{I_{on}}, \; R_c = \frac{U_{on}}{I_{on}}.$$

7.4.2. Compare the obtained values with the nominal relay data.

7.4.3. According to the results of the experiment, draw a control characteristic of the electromagnetic relay of automatics.

7.4.4. According to the results of Table 2.2 determine the average time delay of the time relay by the formula $t_{av} = \frac{t_{st1} + t_{st2} + t_{st3}}{3}$ and the delay time $\Delta t = t_{st} - t_{av}$.

7.4.5. The calculated results are compared with the rated relay data.

Control Questions

1. What is a relay called and what are they intended for?
2. How are relays classified?
3. What are the basic relay parameters you know? Explain their physical content?
4. What is the relay return factor? Write the formulae by which it is determined?
5. Explain the purpose and the principle of operation of the electromagnetic relay automatics.
6. Name the main components of the MKU48-C automatic relay electromagnetic relay and explain their purpose.
7. How to obtain the necessary time delay in the electromagnetic time relay?
8. What block contacts are in the relay, what are they needed for and how are they indicated in the schematic diagrams?
9. Explain the purpose and the principle of operation of the relay.
10. Name the main units of the relay EC 144 and explain their purpose.
11. What is the characteristic of the control of the electromagnetic relay?
12. Explain how the time delay in the relay EC 144 is carried out?

L a b o r a t o r y   w o r k 8

STUDYING OF A SINGLE PHASE TRANSFORMER

8.1. Formulation of the problem

The purpose of the work is to consolidate theoretical knowledge about the structure and the principle of the transformer and obtain practical skills, calculations and experimental studies of its main parameters and performance characteristics.

Problems of the laboratory lesson are tests of single-phase transformer in no-load (NL), load mode (from NL to the rated current value) and experimental short circuit (SC) for the purpose of subsequent determination of basic parameters and obtaining of its operational characteristics.

8.2. Object of study

The object of the study is a single-phase transformer with known rated data given on the bench. The conventional image of the transformer T, which is explored, and the schematic diagram for conducting experiments are shown in Fig. 8.1.

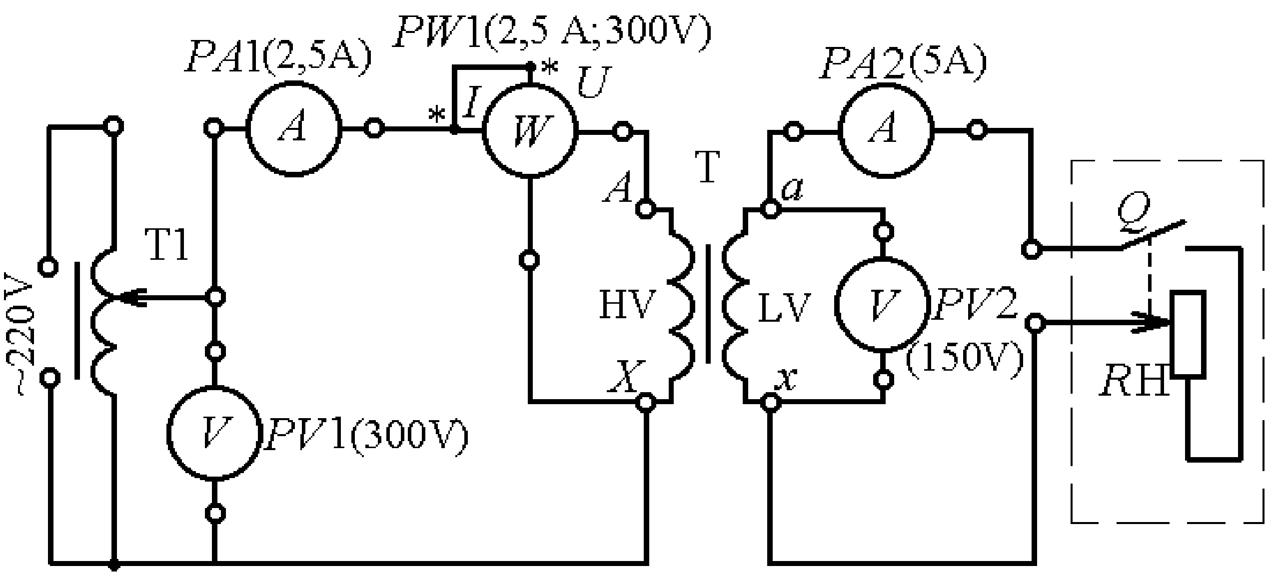


Figure 8.1 – The schematic diagram of the experiments with measuring devices

The high-voltage winding (HV) or the primary winding of the transformer T is connected to the laboratory autotransformer (LATR) T1, which, in its turn, is activated in the AC network with an RMS voltage value of 220 V. A load connected to the lower voltage (LV) winding or the secondary winding is connected – the RH rheostat with the built-in contact Q.

Measuring instruments, their functional purpose and the designation of measured values, are given in Table 8.1.

Table 8.1

Appointment of the device	Measurement value	Designation of quantities
*PV*1	Voltage of the primary winding	U_1
*PA*1	Primary winding current	I_1
*PW*1	Active power coming from the network to the primary winding of the transformer	P_0, P_1, P_{SC}
*PV*2	Voltage of the secondary winding and load	U_2
*PA*2	Load current of the secondary winding	I_2

Measuring instruments, their functional purpose and the designation of measured values, are given in Table 8.1.

8.3. The order of the experiment execution

8.3.1. Record the rated data of the transformer in Table 6.2, where S_r is total power; U_{1r}, U_{2r}, I_{1r}, I_{2r} are the rated voltages and currents of the windings.

8.3.2. Select the devices according to the rated data of the transformer, as shown in Table 8.2.

Table 8.2.

S_r	U_{1r}	U_{2r}	I_{1r}	I_{2r}
кVA	V	V	A	A

8.3.3. Assemble a basic electric circuit for Fig. 8.1.

8.3.4. Bring the equipment to the initial state: set the LATR to zero; set the RH rheostat to the extreme left position by turning the knob counterclockwise to the stop, which will ensure that the contact *Q* is unlocked; switches of devices – in a position that will provide the limits of measurements that exceed the given currents and voltage of the transformer T (Table 8.1).

8.3.5. Run the experiment in the NL mode. To do this, with the open circuit of the secondary winding of the transformer, apply voltage to the LATR and use it to install the clamps of the primary winding, the rated voltage U_1 = 220 V. Measured values of I_{10}, P_0 and U_{20} you will write in Tab.8.3 (adding the index "0" corresponds to the designation the values of NL).

Table 8.3

Given	Measured				Calculated					
$U_{10}=U_{1r}$	I_{10}	P_0	U_{20}	I_{20}	N	Z_0	R_0	X_0	i_{nl}	P_m
V	A	W	V	A	-	Ohm	Ohm	Ohm	%	W
220				0						

8.3.6. Conduct an experiment in the load mode. The initial state for the first experiment is the previous mode of NL, the data of which is written in Table 8.4. When adjusting the load, you are guided by the value of current I_2, which is set by a constant step, equal to approximately 1 A in the range from NL to I_{2r}. By supporting the constant value of the voltage U_{10} = 220 V across the primary winding, install with the RH rheostat as the load of the transformer in the recommended range and measure in 4-5 fixed positions of the *R*H. Write down the measurement results in Table 8.4.

8.3.7. Conduct an experiment in SC mode, strictly adhering to the sequence of the actions specified below, as the deviation from it can lead to an accident or the output of the equipment from the working condition.

First, disconnect the LATR from the voltage source of 220 V. Secondly, bring the necessary equipment to its initial state, as indicated in clause 8.3.4.

After that, turn on the LATR for a voltage of 36 V and check with voltmeter *PV*1 that the voltage at the input LATR is zero.

Table 8.4

Given	Measured				Calculated			
$U_{10}=U_{1r}$	I_1	P_1	U_2	I_2	β	$\cos\varphi_1$	P_2	η
V	A	W	V	A	-	-	W	-
220								
220								
220								
220								
220								

Turn off the power supply temporarily, short circuit the secondary winding of the transformer T with a conductor that connects parallel to the *R*H to its clamps.

Turn on the LATR power supply and slowly increase the current I_1 slowly in the primary winding of the transformer T to the value of I_{1r}, because the criterion for the short-circuit mode is the rated current of this winding. In this position, make the measurements $U_{1\text{k}}$, P_{k} and $I_{2\text{k}}$ and enter the results in Table 8.5 (the index "SC" corresponds to the short-circuit).

Disconnect the power supply and turn the equipment to its initial state.

Table 8.5

Given	Measured			Calculated								
$I_{1SC}=I_{1r}$	U_{1SC}	P_{SC}	$I_{2к}$	n_1	u_{SC}	I_{SC}	Z_{SC}	R_{SC}	X_{SC}	$\cos\varphi_{SC}$	φ_{SC}	P_E
A	V	W	A	-	%	A	Ohm	Ohm	Ohm	-	degree	W

8.4. Processing of experimental results and preparation of a report on laboratory work

8.4.1. According to the results of experiments NL and SC you must determine the following parameters of the transformer:

n – transformation ratio, $n = \frac{U_{10}}{U_{20}}$;

Z_0 – impedance in NL, $Z_0 = \frac{U_{10}}{I_{10}}$;

R_0 – resistance in NL, $R_0 = \frac{P_0}{I_{10}^2}$;

X_0 – inductance in NL, $X_0 = \sqrt{Z_0^2 - R_0^2}$;

i_{nl} – current of NL as a percentage of I_r, $i_{nl} = \frac{I_{10}}{I_{1r}} \cdot 100\%$;

P_m – magnetic loss of power in the iron core, $P_m = P_0$;

n_1 – current transformation ratio, $n_1 = \frac{I_{2SC}}{I_{1SC}}$;

u_{SC} – voltage of SC in percentage from U_1, $u_{SC} = \frac{U_{1SC}}{U_{1r}} \cdot 100\%$;

I_{SC} – emergency current SC at $U_1 = U_{1r}$, $I_{SC} = I_{1r} \frac{U_{1r}}{U_{1r}}$;

Z_{SC} – impedance in SC, $Z_{SC} = \frac{U_{1SC}}{I_{1SC}}$;

R_{SC} – resistance in SC, $R_{SC} = \frac{P_{SC}}{I_{1SC}^2}$;

X_{SC} – inductance in SC, $X_{SC} = \sqrt{Z_{SC}^2 - R_{SC}^2}$;

$\cos\varphi_{SC}$ – power coefficient in SC, $\cos\varphi_{sc} = \frac{P_{SC}}{U_{1SC} I_{1SC}}$;

φ_{SC} – phase difference angle between current and voltage in SC mode,

$$\cos\varphi_{SC} = \arccos\frac{P_{SC}}{U_{1SC} I_{1SC}};$$

P_E – electrical power consumption in the transformer windings,

$$P_E = P_{SC}\left(\frac{I_1}{I_{1SC}}\right)^2.$$

Calculated transformer parameters enter in Table 8.3, 8.4 and 8.5.

6.4.2. According to the results of measurements in load mode (see Table 4.4), calculate the values:

$$\beta = \frac{I_2}{I_{2r}},$$

where β – load coefficient;

$$\cos\varphi_1 = \frac{P_1}{U_1 I_1},$$

where $\cos\varphi_1$ – power factor of the transformer with load;

$$P_2 = U_2\, I_2 \cos\varphi_1,$$

where P_2 – active load power (taking into account the active nature of the load $\cos\varphi_1 = 1$);

η – coefficient of efficiency of the transformer $\eta = \frac{P_2}{P_1}$.

The results of calculations throughout the load range of the transformer, enter in Tab. 8.4.

8.4.3. According to the calculations of Table 5.4, draw the operational characteristics: $U_2(\beta)$ – external (load) characteristic; the dependence of $I_1(\beta)$ and $\cos\varphi_1(\beta)$, as well as the characteristic of the efficiency η(β). Draw the specified characteristics by using the common axis β, but with individual axes and scales for the specified parameters.

Control questions

1. Explain the structure and the principle of the operation of a single-phase transformer.

2. What is the transformation ratio and how does it connect the voltages and currents of the transformer windings?

3. What loss of power are allocated in the transformer during its operation under load, what is their physical nature and whether they depend on the value of the load of the transformer?

4. Write the equation of electrical equilibrium of the voltages and currents in the transformer windings and explain the physical content of the quantities included in these equations.

5. How did you conduct the NL and SC experiments of a single-phase transformer and what particular transformer parameters can be determined from these experiments?

6. How did you conduct the load mode of the transformer and what characteristics are obtained from the data of this experiment?

7. What are the typical graphs of these characteristics and what explains their character?

L a b o r a t o r y   w o r k 9

STUDYING OF A DIRECT CURRENT SEPARETELY EXCITATED GENERATOR

9.1. Formulation of the problem

The purpose of the work is to consolidate theoretical knowledge about the structure and operation principle of the direct current generator (DCG) and to obtain practical skills in experimental studies of the characteristics of the DCG.

Problems of the lesson are an experimental study of the properties of the DCG with independent excitation by removing and analyzing no-load, external and regulatory characteristics.

9.2. Object of study

The object of the study is a separately excited DCG, the rated data of which are given on the laboratory bench.

The obtaining of characteristics of the generator being investigated is carried out by at the installation, the electric circuit of which is shown in Fig. 9.1.

The armature (A) of the DCG is rotated by a three-phase cage induction motor (TIM), the rotor (R) of which is connected by a mechanical coupling (M) to the shaft (S) of the investigated generator. The stator winding is connected in wye (“Y”). The wye of phase windings of TIM (C_1, C_2, C_3) are connected to a three-phase AC network (A-B-C) with a linear voltage of 380 V.

The generator excitation winding (EW) through the terminals H1 - H2 is powered by a direct current from the rectifier (*VA*), which, in is turn, is powered by an AC voltage of 220 V (phase voltage of the same three-phase network is used) through the laboratory autotransformer LATR (T). It allows you to slowly adjust the current of the excitation winding from zero to the desired value.

A load of the generator is the rheostat *R*H with a built-in switch Q1, which in one of the extreme positions provides opening of the load circuit (by turning the handle of the rheostat counter clockwise to the stop). The *R*H rheostat is attached to the armature clamps A1-A2 and in the same circuit an ammeter *PA*1 is inserted, which simultaneously measures the load current of the I_L and the current of the armature, which are equal $I_a = I_L$. The voltage across the terminals A1 and A2 of the armature *U* is measured by the voltmeter *PV*, and the current in the excitation winding is measured by the milliammeter *PA*2. The limits of the values measured by the instruments are shown in Fig. 9.1.

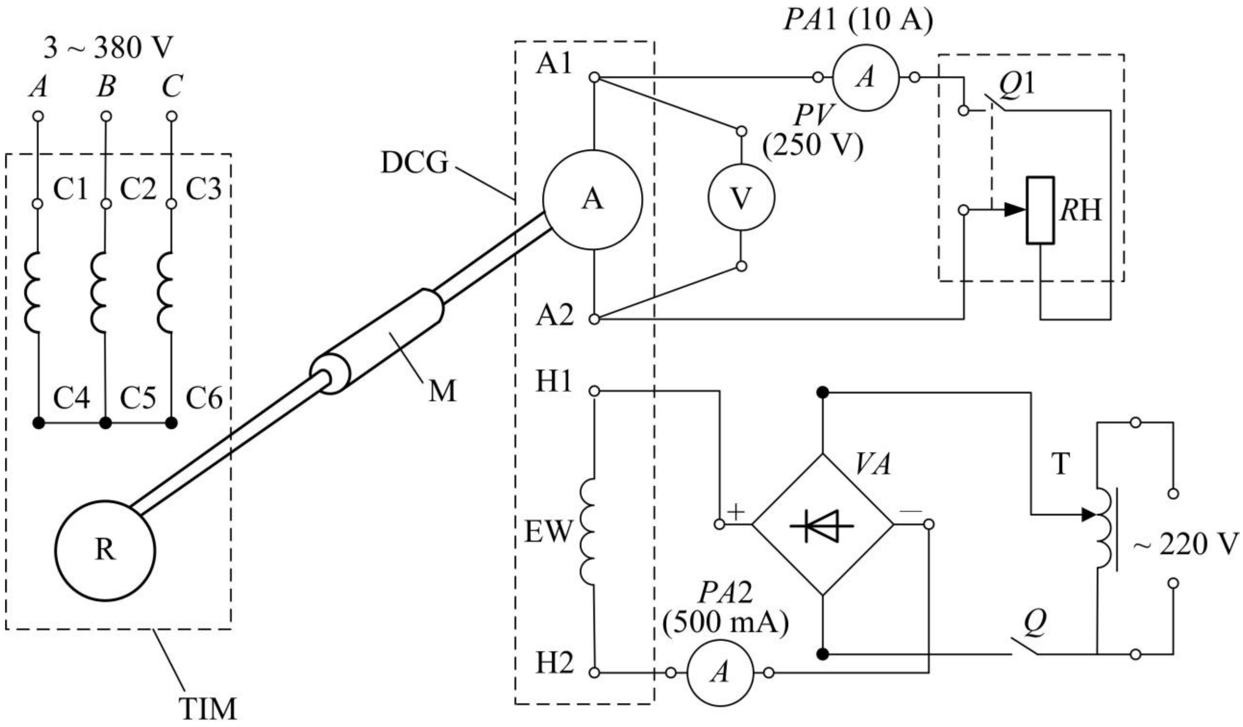


Figure 9.1

9.3. The order of the experiment execution

9.3.1. Check the rated data of the DCG being investigated, and add them in Table 9.1.

9.3.2. Assemble a circuit for conducting experiments according Fig. 9.1.

Table 9.1

$P_{2\ r}$, W	U_r, V	$I_{a\ r}$, A	$I_{e\ r}$, A	n_r, rpm.

9.3.3. Before starting each experiment, set LATR to zero.

9.3.4. Read off the open-circuit generator characteristic at the NL mode and $I_a = 0$. To do this shut down the switch Q and apply voltage to the LATR T. Set the current of the excitation winding $I_e = 0$, fix the voltage U voltmeter and bring it in Table 9.2. Read off the ascending branch of open-circuit characteristic. For this which increase gradually the winding current via AV to transformer T 50 mA increments to a maximum value $I_{e\,max}$ by which the voltage at the terminals of the armature $U = E$ becomes equal $(1,05...1,1)U_r$. Changes in the withdrawal of characteristics conduct monotonously (strictly in one direction). Make the measurement results in Table 9.2. After that, obtain the descending branch at the same values of the current of the excitation winding, reducing the current of this winding to zero. The results of measurements are also included in Table 9.2.

Do not turn off the power of the circuit and proceed to the obtaining of the following characteristics.

Table 9.2. n_r =___rpm; I_a =0

I_e, mA		0	50	100	150	200	250	$I_{e\,max}$
$U = E$, V	Ascending branch							
	Descending branch							

9.3.5. Reade off the load characteristic of the DC generator $U(I_n)$ at the rated I_{EW}, where I_L is the load current equal to the current of the armature I_a under independent excitation ($I = I_a$). Set with LATR T the rated current of the excitation winding. Set the rheostat RH knob to the leftmost position that responds $R_н \to \infty$. Secure the *PV* and *PA*1 devices, respectively, with the open-circuit speed $U_0 = E$ and the current of the armature $I_a = 0$. Enter measurement data in Table 9.3. Decreasing load resistance R_l by the handle of RH, load the generator to the value of the armature current $I_a = (1,05...1,2)I_{ar}$. Take 6-7 measurements and add the results in Table 9.3.

Table 9.3. I_e =__mA; n_r =___rpm

$I_L = I_a$, A	0					
U, V	U_0=					

9.3.6. Read off the regulator characteristic $I_e(I_L)$ for U_r = const and n_r. To do this, use the handle of the resistor RH to set the load resistance $R_L \to \infty$ ($I_a = 0$), but with the help of LATR T, increasing the current in the excitation winding, set the rated voltage to the armature U_r. Enter these results in Table 9.4. By reducing the value, load the DC generator with a uniform step I_L to the value $I_a = I_{ar}$. Under these conditions, with the help of LATR T, change the current of the excitation winding I_e so that at each value of the load current on the armature A1-A2 clamps the voltage remains constant and equal U_r. Spend 5-7 measurements at different values I_L. Enter data in Table 9.4.

Table 9.4. U_r =___V; n_r =___rpm

$I_L = I_a$, A	0					
I_e, mA						

9.4. Processing of the results of experiments and design work

7.4.1. According to the data of Tables 9.2, 9.3, 9.4, draw the characteristics of the DCG: $U(I_e)$, $U(I_L)$, $I_e(I_L)$.

Using the external characteristic $U(I_r)$, determine the rated percentage change in the armature voltage $\Delta U_r = \frac{U_0 - U_r}{U_r} \times 100$ %.

Control questions

1. What is the construction of a DCG?
2. Explain the principle of the operation of a separately excitation DCG.
3. Explain the purpose of the commutator in the DCG.
4. Write the main formulas that characterize the DCG operation.
5. Why does the voltage across the armature decrease when the load current increase?
6. Explain the nature of the change in no-load characteristic.
7. Draw the regulation characteristic of the separately excitation DCG and explain the nature of its change.
8. What kinds of power losses occur in the generator in the process of converting mechanical energy into electric one?

STUDYING OF A THREE-PHASE CAGE INDUCTION MOTOR

10.1. Formulation of the problem

The purpose of the work is to consolidate theoretical knowledge about the design and operation principle of a three-phase cage induction (asynchronous) motor (TIM) or three-phase induction motor with squirrel cage rotor, to obtain practical skills of calculation and to study the parameters and characteristics of TIM.

The objectives of the lesson are a studying of a three-phase TIM. The study means obtaining its mechanical and performance characteristics.

The experimental characteristics of TIM are compared with the calculated ones performed on the catalog data.

10.2. Object of study

The object of the study is a TIM with the rated data shown on the bench. The electrical circuit for conducting the experiment is shown in Fig. 10.1.

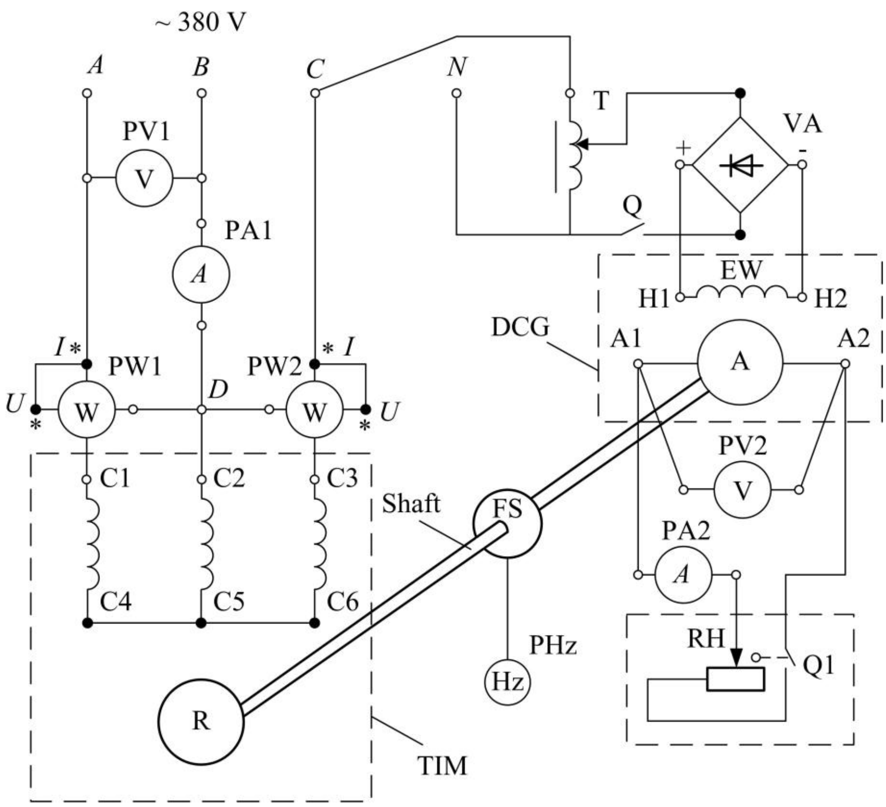


Figure 10.1

The motor is powered by a three-phase line with a voltage of 380 V. In this case, the stator winding is connected in wye. Appropriate devices are switched on in the circuit to measure the required values. The designations of these devices and the quantities they measure are given in Table 10.1.

Table 10.1

Designation of the device in the diagram	Measured value	Indication of the magnitude measured
PV	Line voltage of the stator winding	U_1
*PA*1	Line current of TIM stator winding	I_1
PH_z	Rotation speed of TIM rotor	n_2
PW	Phase power consumed from the network	P_{ph}
*PA*2	Armature current of direct current generator (DCG)	I_G

The braking torque on the induction engine shaft is created by a separately excited DC generator (DCG). Thus, the torque on the TIM shaft is equal to the brake torque of DCG. The DCG and TIM shafts are mechanically connected by a clutch. The brake torque is changed by changing the resistance of the RH load rheostat engaged in the armature of the circuit.

The DCG excitation winding is powered by an adjustable DC source. The DCG excitation current is changed by the T1 LATR, the secondary rectifier of which is enabled by the rectifier VA. The LATR is connected to the phase *C* of three-phase circuit. The rotor speed of TIM is measured by a digital tachometer (HZ) from the frequency sensor (FS) mounted on the TIM shaft.

10.3. The order of the experiment execution

10.3.1. Record the TIM rated data in Table 10.2.

Table 10.2.

$P_{2\,r}$	$U_{1\,r}$	$I_{1\,r}$	f_1	n_1	n_{2r}	η_r	$\cos\varphi_{1\,r}$	λ_m	λ_{st}	λ_i
kW	W	A	Hz	rpm	rpm	-	-	-	-	-

The table shows:

P_{2r} – useful mechanical power on the IM shaft;

U_{1r} – line TIM voltage;

I_{1r} – line TIM current;

f_1 – frequency of network voltage;

n_1 – the number of revolutions of the magnetic field;

n_{2r} – rated rotor speed;

η_r – coefficient of performance;

$\cos\varphi_{1\ r}$ – motor power factor;

$\lambda_m = M_{\max} / M_r$ – motor overload capacity;

$\lambda_{st} = M_{start} / M_r$ – multiplicity of starting torque;

$\lambda_i = I_{1start} / I_{2\ r}$ – frequency of starting current;

M_r, $M_{\max}$, M_{start} – respectively the rated, the maximum and the starting torques on the shaft of the IM;

$I_{1\ r}$, I_{1start} – respectively, the rated and the starting currents of TIM.

10.3.2. Assemble the electric circuit according Fig. 10.1.

10.3.3. Set the LATR to zero. Set the RH rheostat handle to the far left, which corresponds to no-load mode of the DC generator armature winding circuit. Start the TIM by turning on the three-phase 380V AC power source.

10.3.4. Use the LATR slowly to increase the excitation winding current of the DCG until you reach the rated voltage across the armature of the DCG $U_{G\ r}$.

10.3.5. By changing the load rheostat RH with the load current of the DCG I_L from zero to the rated value at intervals specified by a lecturer, clear the readings of all devices and the measurement results are not included in the Table 10.3. Increasing the current in the winding of the DCG armature, increases the torque of the TIM shaft, respectively, the TIM rotation decreases.

Fill in the “measured” columns of the Table 10.3.

Table 10.3

Measured							Calculation							
TIM					DCG									
U_1	I_1	n_2	P'	P''	U_G	I_G	P_{1E}	P_{2G}	$\eta_Г$	$P_{1G} = P_{2E}$	M_2	S	η_E	$\cos\varphi_1$
V	A	rpm	W	W	V	A	W	W	-	W	N·m	-	-	-

10.4. Processing the results of the experiment

10.4.1. Make the necessary calculations of the values given in Table 10.3 in the calculated columns, based on the following relationships:

active power supplied from the network to the TIM,

$$P_{1E} = P' + P' ;$$

generator power output (*R*H rheostat)

$$P_{1E} = U_G I_G ;$$

Mechanical power supplied to the generator from the TIM

$$P_{1G} = \frac{P_{2G}}{\eta_G},$$

where η_r is determined by the curve η_r (P_{2G}) date shown on the laboratory bench for each P_{2G} value. You have to draw an efficiency curve η_r (P_{2G})

Mechanical power is given to the generator by TIM

$$P_{2E} = P_{1G} ;$$

Torque $M_2 = 9{,}55 \frac{P_{2E}}{n_2}$, where P_{2E} measured in watts and n_2 in rpm;

slip $s = \frac{n_1 - n_2}{n_1}$;

TIM efficiency $\eta = \frac{P_2}{P_1}$;

power factor $\cos\varphi_1 = \frac{P_1}{\sqrt{3} \cdot U_1 \cdot I_1}$.

10.4.2. Determine the rated, maximum and starting torques, rated and critical slip and critical speed according to the formulas below, and record the results in Table 10.4:

$$M_r = 9{,}55\frac{P_{2r}}{n_{2r}}; \qquad M_{max} = \lambda_m M_r; \qquad M_{start} = \lambda_{st} M_r;$$

$$s_r = \frac{n_1 - n_{2r}}{n_1}; \qquad s_{cr} = s_r\left(\lambda_m + \sqrt{\lambda_m^2 -}\right); \qquad n_{2cr} = n_1(1 - s_{cr}).$$

Table 10.4

M_r	M_{max}	M_{start}	s_r	s_{cr}	n_{2cr}
N·m	N·m	N·m	-	-	rpm

10.4.3. Draw an approximate mechanical characteristic $n_2(M_2)$ for the TIM by the example of Fig. 10.2 on points a, b, c, d with coordinates a (0, n_1), b (M_{2r}, n_{2r}), c (M_{2r}, n_{2cr}), d (M_{2start}, 0), using the data in Table 10.2 and 10.4.

Compare the results of the experiment with the calculation.

10.4.4. Draw an approximated mechanical characteristic for the TIM by the example of Fig. 10.2, and at points a, b, c, d with coordinates a (0, n_1), b (M_{2r}, n_{2r}), c (M_{2max}, n_{2cr}), d (M_{2start}, 0), using the data in Table 10.1 and 10.3. Compare the results of the experiment with the calculation.

10.4.5. Draw for the induction motor an estimated approximation of the torque dependence on the slip $M_2(S)$ for the example of Fig. 10.5, b at points 0, a, b, c with coordinates a (S_r, M_{2r}), b (S_{cr}, M_{2max}), c (1, M_{2start}). Compare the results of the experiment with the calculation.

10.4.4. Draw an approximated mechanical characteristic $n_2(M_2)$ for the TIM by the example of Fig. 10.2, and at points a, b, c, d with co-ordinates a (0, n_1), b (M_{2r}, n_{2r}), c (M_{2max}, n_{2cr}), d (M_{2start}, 0), using the data in Table 8.1 and 10.3. Compare the results of the experiment with the calculation.

10.4.5. Draw for the induction motor an estimated approximation of the torque dependence on the slip $M_2(S)$ for the example of Fig. 10.5, b at points 0, a, b, c with coordinates a (S_r, M_{2r}), b (S_{cr}, M_{2max}), c (1, M_{2start}). Compare the results of the experiment with the calculation.

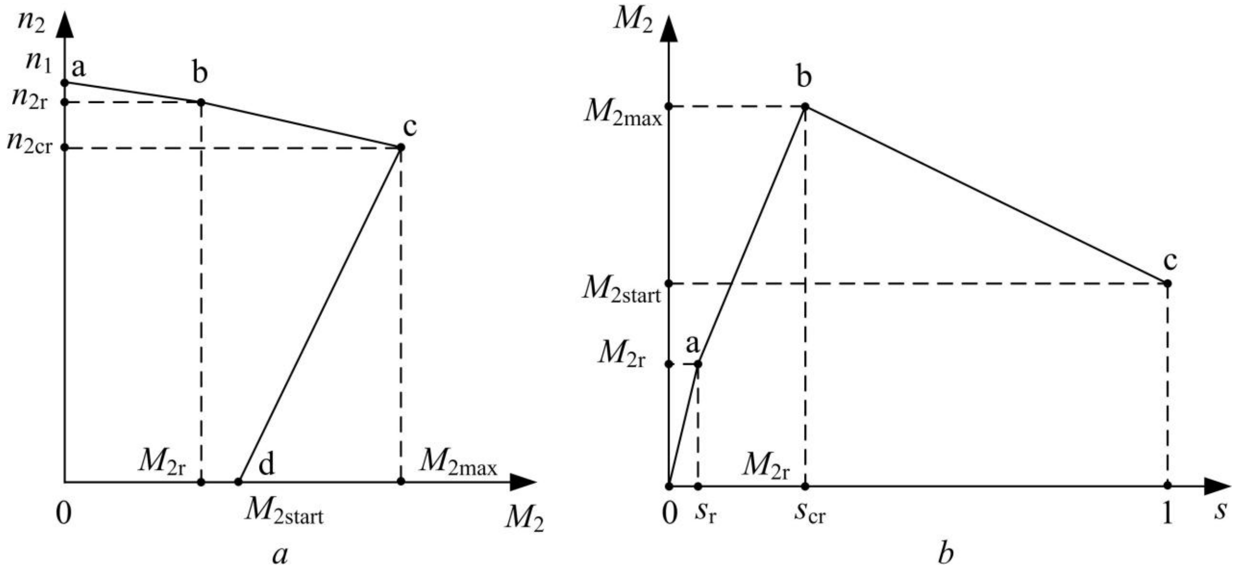


Figure 10.2

Control questions

1. Explain the construction of a three-phase cage induction motor (TIM) and the principle of its functioning.

2. What conditions provide for the creation of a rotating magnetic field in a TIM? What formula determines the speed of this field?

3. Explain the difficulties encountered when starting a TIM and what are the possibilities to overcome these complications in practice?

4. What power losses occur in a TIM during its operation?

5. What is called the slip of a TIM? What expression does it define and to what extent does it change when an electric machine is running in motor mode?

6. How does the magnitude of the supply voltage affect the torque of a TIM?

7. Draw the mechanical characteristics of a TIM, specify the characteristic points: no-load, rated load, maximum and starting torques.

8. Draw and explain the appearance of mechanical characteristics of a three-phase TIM at different values of the supply voltage.

9. Under what conditions does a TIM run steadily and which section of the mechanical characteristic meets this condition?

10. What are the methods for adjusting the TIM speed?

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CONTENTS

For notes

Навчальне видання

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