

МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ
Національний університет «Запорізька політехніка»

МЕТОДИЧНІ ВКАЗІВКИ

до виконання лабораторних робіт студентами
з англійською мовою навчання денної форми
на першому (бакалаврському) рівні вищої освіти навчання при
вивченні дисципліни

«Електричні апарати автоматики та керування»
для підготовки бакалаврів за спеціальністю
141 «Електроенергетика, електротехніка та
електромеханіка»

з подальшим навчанням за освітньою програмою
«Електричні та електронні апарати»

Частина 2

Методичні вказівки до виконання лабораторних робіт студентами з англійською мовою навчання денної форми на першому (бакалаврському) рівні вищої освіти навчання при вивченні дисципліни «Електричні апарати автоматики та керування» для підготовки бакалаврів за спеціальністю 141 «Електроенергетика, електротехніка та електромеханіка» з подальшим навчанням за освітньою програмою «Електричні та електронні апарати». Частина 2 / Укл.: Жорняк Л. Б., Василевський В. В., Войтенко С. В. – Запоріжжя: НУ «Запорізька політехніка», 2022. – 78 с.

Укладачі:

Л. Б. Жорняк, доцент, к.т.н.
В. В. Василевський, ст. викладач
С. В. Войтенко, ст. викладач

Рецензент:

О. І. Афанасьєв, доцент, к.т.н.

Відповідальний
за випуск:

В. В. Василевський, ст. викладач

Затверджено
на засіданні кафедри
“Електричні і електронні апарати”.
Протокол № 1
від 29 серпня 2022 р.

Рекомендовано до видання
НМК ЕТФ.
Протокол № 1
від 8 вересня 2022 р.

CONTENT

General requirements for the execution, design and presentation of reports on the laboratory work.....	5
1 Laboratory work # 9 Direct current contactor.....	9
1.1 The purpose of the work.....	9
1.2 General notes.....	9
1.3 Description of the laboratory setup.....	16
1.4 Task.....	17
1.5 Methodical instructions.....	17
1.6 Questions for self-control.....	20
2 Laboratory work # 10 Alternating current contactor.....	21
2.1 The purpose of the work.....	21
2.2 General notes.....	21
2.3 Work preparation.....	26
2.4 Task of laboratory work.....	26
2.5 Material, tools, appliances, equipment.....	28
2.6 Methodical instructions.....	28
2.7 Content of the report.....	30
2.8 Questions for self-control.....	31
3 Laboratory work # 11 Electromagnetic time relay with magnetic and mechanical damping.....	32
3.1 The purpose of the work.....	32
3.2 General notes.....	32
3.3 Description of the laboratory installation.....	34
3.4 Task.....	35
3.5 Methodical instructions.....	36
3.6 Questions for self-control.....	39
4 Laboratory work # 12 Bimetallic thermal relay.....	40
4.1 The purpose of the work.....	40
4.2 General notes.....	40
4.3 Preparation for the work.....	47
4.4 Material, tools, devices, equipment.....	48
4.5 Methodical instructions.....	49

4.6 Contents of the report.....	50
4.7 Questions for self-control.....	50
5 Laboratory work # 13 Automatic circuit breaker.....	51
5.1 The purpose of the work.....	51
5.2 General notes.....	51
5.3 Description of the laboratory setup.....	54
5.4 Task.....	55
5.5 Methodical instructions.....	55
5.6 Questions for self-control.....	57
6 Laboratory work #14 Magnetic starter.....	58
6.1 Purpose of work.....	58
6.2 General notes.....	58
6.3 Description of the laboratory setup.....	60
6.4 Task.....	61
6.5 Methodical instructions.....	61
6.6 Questions for self-control.....	65
7 Laboratory work #15 AC thyristor contactor.....	66
7.1 The purpose of the work.....	66
7.2 General notes.....	66
7.3 Description of the laboratory setup.....	72
7.4 Task.....	73
7.5 Methodical instructions.....	74
7.6 Questions for self- control.....	76
List of references.....	77

GENERAL REQUIREMENTS FOR THE EXECUTION, DESIGN AND PRESENTATION OF REPORTS ON THE LABORATORY WORK

Electrical automation and control devices include various electronic and electromechanical relays, sensors and various executive devices (electromagnetic valves, couplings, converters, hangers, supports), command equipment (limit and limit switches, rotary switches, etc.).

Automation devices are low-current relays, sensors, amplifiers, converters, controllers, etc. widely used as means of automation in all branches of technology. They operate under conditions of low voltage (up to hundreds of volts) and currents (up to 5 A) and usually perform the functions of monitoring any electrical parameter (for example, relays) and non-electrical input parameter (for example, sensors). When the input (controlled) parameter of the relay reaches the set value, the electrical relay is activated and the output "signals".

The control devices are designed for frequent operational disconnections and inclusions of normal load currents and infrequent disconnections of load currents, which usually exceed the nominal ones by 5...20 times. To improve the conditions of current switching in control devices, sometimes semiconductor devices are used, which shunt mechanical contacts. In such hybrid devices, long-term current conduction is carried out by contacts, while semiconductor devices are actually de-energized.

Automatic switches, fuses, thermal relays, devices controlled by differential current are often divided into a separate group – protection devices.

The purpose of conducting laboratory work in the discipline "Electrical devices of automation and control" (EAA and K) is:

- deepening, expanding and consolidating students' knowledge of the main sections of the course, namely knowledge of the principles of operation and structure of the most common automation and control devices, as well as knowledge of the physical processes that occur during their work;
- study of laboratory stands of the auditorium of the EEA department, conducting research with electrical and electronic devices;
- study of the principle of operation and the structure of devices and devices, research of the physical essence of phenomena occurring in low-voltage electrical devices in general, as well as in device diagrams;

- acquisition of testing and research skills of automation devices;
- improvement of processing skills and design of experiment results;
- the formation of students' skills and abilities, which will allow them to design, manufacture and operate electrical automation and control devices in practice, and to use the acquired knowledge to create more modern and advanced electrical devices.

For all laboratory works, universal stands are used, which are equipped with mobile units for various laboratory works, which allows you to use them when conducting all laboratory works on the course. When performing all laboratory work, it is necessary to be attentive and comply with all the requirements of the teacher and technical staff of the laboratory related to the performance of laboratory work. It is also necessary to strictly observe the rules of safety and behavior prescribed for laboratory premises of the university, as well as general norms of behavior. Before performing the laboratory work, it is necessary to carefully familiarize yourself with the description of the laboratory work and the stand. Do not turn on the device without the permission of the teacher conducting the class. In case of detection of an abnormal situation (burning smell, appearance of smoke, sparks, etc.), it is necessary to turn off the QF automatic switch on the front panel of the stand and notify the teacher about it. Do not eliminate malfunctions that occurred during the work on your own. After finishing work, turn off the QF automatic switch.

Laboratory work can be carried out by students in the educational laboratory or remotely, as well as independent study of theoretical material in the recommended literature, which can be viewed at the links <http://eir.zp.edu.ua/handle/123456789/488> on the university website, or <https://zp.edu.ua/kafedra-elektrichnih-ta-elektronnih-aparativ> on the website of the EEA department. Active independent work is a determining factor in the effective perception of the content of laboratory classes.

The laboratory work execution consists of the student's work in the laboratory, as well as on independent work. Active independent work is a determining factor in the understanding of the laboratory work content.

Student's independent work involves:

- theoretical preparation;
- preparation of the answers to the questions, given in the end of each laboratory work;

- analysis of the experiments results that are carried out in the laboratory;
- report design.
- Theoretical preparation to the laboratory work involves:
 - study of the theory sections that are determine the content and methodology of the research;
 - study of the methodical instructions for the laboratory work using recommended textbooks and manuals;
 - report design;
 - student's work in the laboratory involves:
 - admission to the laboratory work;
 - admission to turn on the laboratory setup;
 - steps execution with the investigated object in accordance to the methodical instructions; monitoring of the factors affecting the object; carrying to of the experiments and recording of the measurement results;
 - report presentation.

Reports on the laboratory works are prepared individually by each student in one notebook.

Each report of students must consist of:

- the purpose of the work, investigation object;
- task to the laboratory work execution;
- a circuit diagram of the experiment;
- Tables of experimental data;
- graphs of dependencies built on experimental data;
- conclusions on work;
- answers to control questions.

The protection of reports on the performance of laboratory work is carried out by students or at the same time by a team (provided full-time education is provided), or remotely by each student personally in the system <https://moodle.zp.edu.ua> with his personal password, but the assessment of answers to control questions and quality each student receives the performance separately. Students who have not completed all laboratory work, or have not defended all reports on the completion of laboratory work

provided for by the curriculum and work program of the academic discipline, are not allowed to pass the test and the examine:

- presentation of the reports on the laboratory works is carried out by the group members at the same time, but the questions and the assessment of the performance quality are received by each student separately;
- students who have not presented two reports on the laboratory works are not allowed to the the next one;
- students who have not executed or presented all the provided laboratory works are not allowed to credit and exam.

Remarks:

- the laboratory works in the laboratory are carried out according to the schedule approved by the vice-rector for academic affairs;
- missed works in the laboratory are carried out before the modular week according to the schedule approved by the head of the department;
- laboratory work testings are carried out by the group members together.

1 LABORATORY WORK #9 DIRECT CURRENT CONTACTOR

The duration of the laboratory work – 2 hours.

1.1 The purpose of the work

The main work purpose is to study operation principles, design and basic parameters of DC contractor, as well as an experimental study of its main parameters and characteristics.

1.2 General notes

The contactor is an electric apparatus designed for frequent switching of load currents of power electric circuits, as well as infrequent switching of currents exceeding the load current several times (up to $10 \cdot I_{\text{nom}}$). Contactors are not switching short-circuit current.

The main contactor parameters are next:

- a) rated current;
- b) rated voltage;
- c) mechanical wear resistance - determines the permissible number of switches without repair or replacement of any of its knots or parts (without taking into account electric wear of the main contacts of the contactor as a result of the electric arc);
- d) commutation wear resistance - determines the permissible number of commutations for the given parameters of the electrical circuit. The switching capacity is determined in relation to two modes:
 - 1) normal switching mode determines commutation wear resistance at a given switching frequency;
 - 2) rare switching mode determines the contactor ability to turn off overload or the starting currents of the drive motors;
- e) switching on and off time. The contacts distinguish between the own and the total switching on / off time. Contactor own switching on time is the time from the swithing on moment till the collision of its main contacts; the total switching on time consists of the own switching on time and the time for processing of contact displacement and contact force formation. Contactor own switching off time is the time from the swithing off moment

(switching off time of the electromagnetic mechanism coil) till the contacts opening; the total switching off time consists of the own switching off time and the arc-extinguishing time of the main contacts.

Depending on the kind of switching current, there are DC and AC contactors. The main design elements of the contactors are: conductive circuit; main contactssystem; arc system; electromagnetic mechanism; auxiliary contactssystem.

The investigation object of the laboratory work is the DC contactor of the KIIB-600 series. They are used for switching generators power circuits and small and medium power DC motors.

The investigated contactor is a two-position apparatus with self-resetting, intended for frequent switching of currents of power electrical circuits under normal operating conditions of electrical equipment.

The contactor has two switching positions corresponding to the switched on and off states.

The rated current of the contactor is a current commutated by its main contacts. It is in the range from a few to several hundred amperes. The rated voltage of the contactor is the voltage commutated by the main contacts of the contactor. It can be 220 V, 440 V and 750 V at constant current.

There is wear of contactor and its contacts during switching processes. Distinguish mechanical and electrical wear resistance. The mechanical wear resistance is determined by the closing and opening number of contractors without the repair and replacement of it's assembles and details. Current of the main contacts will be equal to zero. There are very high requirements to mechanical wear resistance of modern contactors: 10...20 million of switchings.

The electrical wear resistance is determined by the number of closing and opening of the circle with the current, after which replacement of the worn contacts is required. The electrical wear resistance of modern switching contactors is within the limits of 0,5 ... 2 million operations.

The make-time and opening time of contractors may be divided on their own and total time make-time (opening). The own make-time of contractor is the time between the moment of closing operation command and the moment of contractor contact touching. The total make-time consists of the own time and the time for processing of contact displacement. The own opening time of the contractor is the time between the moment of disconnection operation command (time to switch off the electromagnet coil)

and the moment of contractor contact opening. The total opening time consists of the own opening time and arcing time on the main contacts.

In addition to high mechanical and electrical wear resistance, contactors must have a small mass and dimensions. The exhaust zone of the heated arc gases should be as small as possible, thereby reducing the size of the device as a whole. Details should be readily available to replace.

The contactor designs improved primarily to increase their durability, as well as simplicity and convenience in the setting and operation. Naturally, the cost of the device should be as low as possible. To increase the mechanical wear resistance of the apparatus, the following main measures are used:

- use knife-edge supports;
- use a of friction details pair "metal-plastic";
- improving the balance between opposing force and the tractive characteristics;
- correct an impact in the supports, etc.

The electrical wear resistance can be improved by:

- a) reduction or elimination of time the arc existence between moving and fixed contacts;
- b) reduction of the inertia moment of the moving parts;
- c) use of hard-wearing materials;
- d) reduction of contact vibration during the commutation;
- e) use of the perfect arc interruption system.

The most accurate DC contactors for heavy mode of operation can be considered contactors KIIB-600series. Let us exam their assemblies, operation and design of DC contractor (Figure 1.1).

Contactors have the following main assemblies: contact system, arc interruption system, electromagnetic mechanism, and an auxiliary contact system.

The basis of the contactor design is a core bracket (6). All elements and assemblies of the contractor are mounted on it, after that they are tested. The contactor is mounted on the panel by several bolts connected with the bracket (6). The bracket has an insulating plastic base 1 that holds the arcing system. An electromagnet coil (20) with a core and armature (17) is also provided on the bracket, on the shaft of which, using the bracket (8), a system of a movable contact (7), together with a contact spring (12), and also a flexible current carrying coupling (10) are fixed.

When the electromagnet coil (20) is energized the contactor is making. If the electromagnet coil is deenergized, contactor is break down. The force of return spring (13), force contact springs, as well as mobile system weigh make a required speed of moving system for breaking.

Appeared electric arc between contacts (1) and (7) is blown out to area of horns (2) and (11). It is extinct in the arc chamber (14). Expansion (Increasing) of the arc length up to critical one (condition of arc extinction) is provided by blow-out coil (3), a core and steel wall poles (15).

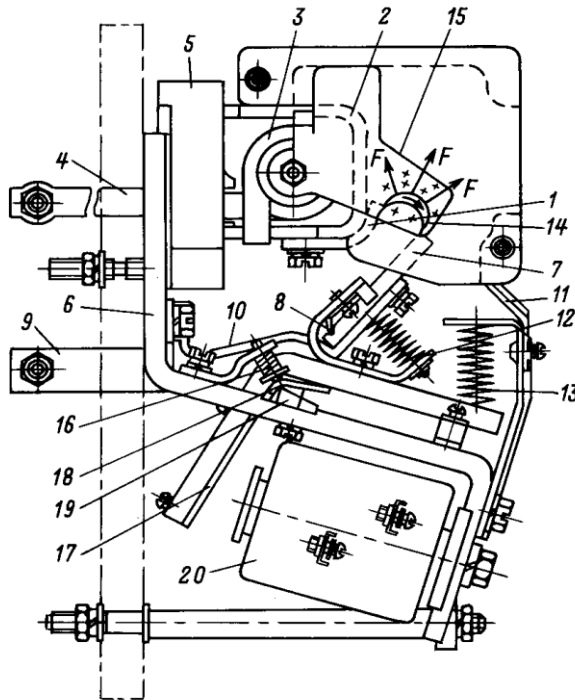


Figure 1.1 – DC contactor

The vertical arrangement of the insulation details reduces dust accumulation on them during maintenance and provides high electric strength of isolation. Contactor has a high mechanical wear resistance (more than 20 million operation cycles).

Contactors КПБ-600 series had produced for the nominal currents from 63 A up to 630 A. They are intended for switching power circuits in most cases at a voltage of 220 V. But for its infrequent operations they can switch electric circuits at a voltage up to 400 ... 600 V. The peculiarity of the КПБ-600 series contractor construction is moving contact (9) electric network with the enclosure (core bracket (18)). But it could be dangerous for personal's life.

The opposing force and tractive characteristics of contractor are the main characteristics. The dependence of the force generated by the electromagnet on the clearance (gap) $F=f(\delta)$ (or the dependence of the the restoring moment on the armature solution angle $M=f(d)$) is called the traction characteristic of the contactor. Electromagnetic force developed by contactor must secure its switching even at conditions of network voltage up to $0,85U_{rat}$. It is necessary to overcome the opposing forces. The opposing force characteristic of contractor means the dependence of the total resistance force opposing the moving system displacement on the armature stroke. The typical opposing force $F_{op}=f(\delta)$ and a tractive force $F_{tr}=f(\delta)$ characteristics are shown in Figure 1.2.

These characteristics are given for the air running clearance (gap) δ of the electromagnet. Running clearance (gap) δ_2 corresponds to pulled armature and the gap δ_0 is an attracted armature of a contractor electromagnet. The total opposing is opposing force of breaking (opposing) spring, moving system weight, friction forces of bearings and joints between moving details, opposing forces of contact springs.

$$F_{op} = F_{2,4} \pm F_1 \pm F_3,$$

where $F_{2,4}$ – are forces caused by contact breaking (opposing) and contract springs;

F_1 – is the weight of moving system depending on the contractor design. Weight can oppose (+) or assist to making (-);

F_3 – are friction forces for making is (+), for breaking is (-).

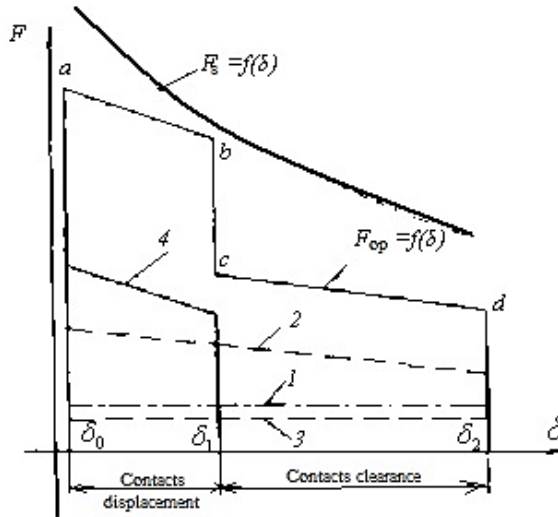


Figure 1.2 – The opposing force $F_{op}=f(\delta)$ and a static tractive force $F_s=f(\delta)$ characteristics of the contractor

In general, opposing force characteristic is a broken line $abcd$ (Figure 1.2), where simplest case is shown without taking into account the characteristics of forces created by springs of auxiliary contacts.

The weight of the moving system (Curve 1), the forces of pre-compression opposing springs (Curve 2) and friction (Curve 3) operate at point δ_2 . When armature is moving force F_{op} increases as a result of additional compression of breaking (return) springs. At point δ_1 contacts are touched, at this moment the force F_{op} increases abruptly as a result of the initial compression, and then steplessly as a result of additional compression of contact springs (Curve 4). Clearance (gap) of contractor contacts given for axis of electromagnet corresponds to distance $\delta_1 - \delta_2$, contacts displacement, that is also given for axis of electromagnet corresponds to the distance $\delta_0 - \delta_1$. A tractive characteristic is the dependence of the electromagnet traction force of the clearance (gap) (or, respectively the dependence of the the restoring moment on the armature solution angle).

There are static and dynamic traction characteristics.

Static tractive characteristic $F_s = f(\delta)$ describes electromagnet contractor traction at the fixed position of the armature. When armature is

moving the inductance of the system is changing and dynamic characteristic $F_{dyn} = f(\delta)$ will be slightly different from static one, basically having its character. For example, when contractor is closed its dynamic characteristic will slightly lower static one.

In order to ensure the positive and reliable closing of contractor a tractive characteristic should lie above opposing force and corresponds to it. From this perspective, the difference between the forces should be sufficiently big. Thus, it is necessary to ensure reliable electromagnet closing at low voltage. At increasing of interval between the tractive and opposing force characteristics, the reset ratio K_{res} is decreasing. This ratio is equal to relationship of the electromagnet drop-out current and the operate one. Usual contactors have value $K_{res} = 0,3...0,6$.

Traction electromagnet strength is calculated by the so-called energy formula:

$$F = \frac{1}{2} (IW)^2 \delta \frac{dG\delta}{d\delta}, \quad (1.1)$$

where $(IW)^2 \cdot \delta$ – is attracted force per air running clearance (gap), A;
 $G\delta$ – is a magnetic conductivity of an air running clearance (gap), Hn;
 Δ – is air running clearance (gap), m.

For the homogeneous magnetic field in the clearance (which may be at conditions of small clearances δ and big area of poles S) it have been

$$G_\delta = \frac{\mu_0 S}{\delta}; \quad \frac{dG \cdot \delta}{d\delta} = -\frac{\mu_0 \cdot S}{\delta^2}.$$

After substituting in (9.1) we obtain the Maxwell formula for the electromagnetic traction force.

$$F = \frac{\Phi^2 \delta}{2\mu_0 S}; \quad \text{or} \quad F = \frac{B^2 \delta S}{2\mu_0}.$$

When δ is reduced the force value is increased, and when $\delta = 0$ - force takes infinitely large value. At practice when $\delta = 0$ value of system flow is determined by the magnetic circuit resistance, which increases very sharp as core is saturated, and the force is a finite value. The sharp curve of an experimental traction characteristic measured at this laboratory work at

condition $\delta = 4$ mm, due to the contact springs. Dynamometer, which made the countdown, shows the difference between the F_s and the preliminary pressure force of contact springs.

1.3 Description of the laboratory setup

The circuit of the researched contactor is shown in Figure 1.1. It consists of a standard power supply that is available on all laboratory Tables and a laboratory installation that connects to the power supply with short crosspieces. The rest of the circuit is assembled and mounted on the paper-based laminate panel. The contactor, which is investigated in the work, is fixed on its face part. Power to the contactor winding is fed through a millistopwatch Φ -209, which connects to the laboratory unit with the help of split contacts X. It is used to measure the proper switching on and off time of the contactor. To measure the current in the contactor control circuit in ammeter mode, a desktop universal instrument PA, connected to terminals 14 and 15 of the laboratory installation, is used.

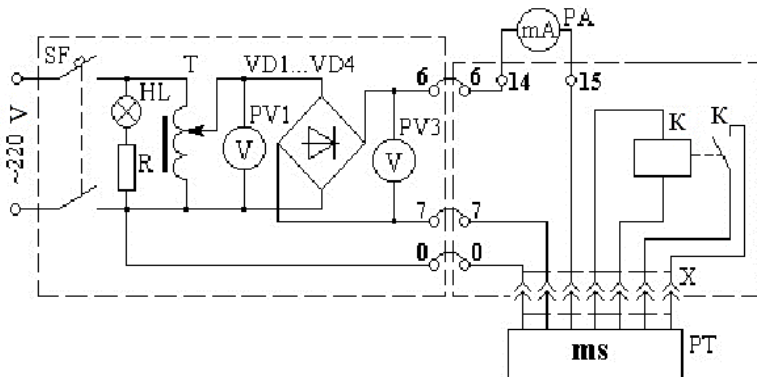


Figure 1.3 – Electrical circuit of the contactor laboratory stand

The power supply is supplied by switching on the circuit breaker SF, and the indicator light HL must light up. Supply voltage regulation is carried out using the autotransformer T.

1.4 Task

1.4.1. Study the design of the contactor KTIB-600, determine the parameters of its main circuit and control circuit and compile its kinematic scheme.

1.4.2 Experimentally determine reset and reserve coefficients of the contactor, as well as the power consumed by the contactor in the switch on position.

1.4.3 Experimentally determine the dependence of the current in the coil of the electromagnet from the magnitude of the working air gap of the electromagnet.

1.4.4 Experimentally determine the dependence of the closing time of switching on and off from the value of supply voltage.

1.5 Methodical instructions

1.5.1. The parameters of the main and control contactor circuits are determined by the data indicated on the contactor and winding shield. Build the kinematic circuit of the contactor by determining the mutual movement of its moving parts, manually moving the armature to the contact with the cores. At that moment the installation should be switched off.

1.5.2. To carry out an experimental part of the work it is necessary:

a) to connect the laboratory unit with the power supply with short switches 0-0, 6-6 and 7-7;

b) use the split contacts X, connect the millistopwatch to the laboratory panel;

c) connect the desktop universal device to terminals 14 and 15 and set it to ammeter mode with the required measuring limit.

1.5.3. To fulfill the task 4.2 it is necessary to:

a) set autotransformer T in zero position;

b) switch on SF, the indicator light HL should light up;

c) turn on the tumbler switch "Start" located on the face panel of the millistopwatch;

d) steplessly increase the supply voltage of the autotransformer T, fix the voltage and current at which the contactor is switched on;

e) when the voltage increases up to rated value (220 V) students have to measure the current and power consumed by the electromagnetic drive at the switched off position of the contactor;

f) when the voltage reduces students have to measure the voltage and current at which the contactor is disconnected;

g) repeat tasks *d–f* not less than three times, the received data should be written down in the Table 1.1;

Table 1.1 – Parameters of turning on and off of the contactor

# of measure	U_{on}, V	I_{on}, A	U_{rat}, V	I_{rat}, A	U_{off}, V	I_{off}, A	P_c, W	K_{reset}	$K_{reserve}$
1									
2									
3									
Average									

h) set the autotransformer T to zero, turn off the switch "Start" and SF.

1.5.4. In order to fulfill the task 1.4.3, it is necessary to:

a) remove the switching spring and install one of the bounding gaskets instead of it, providing the required value of the working air gap;

b) switch on SF and use the autotransformer T to set the rated voltage on the drive winding (220 V);

c) turn on the toggle switch "Start" and after turning on of the contactor to fix the current on the winding drive;

d) turn off the switch "Start" and SF;

e) replace the bounding gasket and make the measurement of the current in the winding of the drive with other values of the working air gap in accordance with items *b–d*;

f) set autotransformer T in the zero position;

g) according to the measurements, to build the dependence of the current in the winding of the drive from the value of the working air gap.

1.5.5 Measurement of the main (closing) time of the switching of the contactor is carried out in the following sequence:

a) connect the power cord of the millisecond measuring instrument Φ -209 to the "220 V" socket and switch it on with the help of "Network" button;

b) reset the readings of millistopwatch by pressing the "Reset" button, turn on the "Vibration" button, set the switch "Mode" to position "1" and warm up the device for 5 minutes;

c) switch on the circuit breaker SF and with the help of the autotransformer T set the given voltage, which should be greater than the

voltage of the contactor (see task 1.4.2);

d) turn on the tumbler switch "Start", after turning on the contactor take the readings of the millistopwatch and write them down to the Table 1.2;

e) turn off the switch "Start", reset the millistopwatch readings by pressing the "Reset" button and repeat the measurement at the same supply voltage;

f) measure the main (closing) time of switching on of the contactor at other voltage values in accordance with paragraphs *c–e*.

Table 1.2 – Closing time of the switch on of the contactor

Supply voltage, V	190	200	210	220	230
№					
1					
2					
3					
Average					

1.5.6 Measurement of the closing time of switching off of the contactor is carried out in the following sequence:

a) set "Mode" in the position "3";

b) with the help of the autotransformer T to set the voltage sufficient for its switching on (see task 1.4.2) and switch on the contactor with the switch "Start";

c) set the given voltage on the contactor winding, reset the readings of the millistopwatch with the "Reset" button and turn off the "Start" switch;

d) after disconnecting of the contactor, take the readings of the millistopwatch and write them down to the Table 1.3;

e) repeat tasks *b–e* at least three times, without changing the voltage;

f) measure the closing time of switching off of the contactor at other voltages.

1.5.7. To determine experimentally the opposing characteristic, determine the previous and final pressure of the pull-back and contact springs by means of a dynamometer and, with the help of a kinematic circuit, bring the readings of the dynamometer to the axis of the electromagnet.

Table 1.3 – Closing time of switching off of the contactor

Supply voltage, V	80	120	160	200	230
№					
1					
2					
3					
Average					

1.5.8 The laboratory work report should contain:

- a) the name and purpose of the work;
- b) the kinematic circuit of the contactor;
- c) electric circuit of the contactor (laboratory setup);
- d) Tables with experimental data of researches and graphic dependences constructed in accordance with the task;
- e) conclusions.

1.6 Questions for self-control

1.6.1 What is a contactor and what are its main functions?

1.6.2 What are the main parameters of contactors?

1.6.3 What is the mechanical wear resistance of the contactor?

1.6.4 What is the switching wear resistance of the contactor?

1.6.5 Main elements of the contactor design and their functions.

1.6.6 Principle of operation of the arc-suppressing system of DC contactors of the KTIIB-600 series.

1.6.7 What is the closing time of switching on (off) of the contactor?

1.6.8. Explain the dependence of the closing time of switching on (off) from the value of the supply voltage.

1.6.9 What is the total time of switching on (off) of the contactor and how does it differ from its closing time?

1.6.10 Explain the dependence of the current in the winding of the contactor drive from the value of the working air gap.

2 LABORATORY WORK #10 ALTERNATING CURRENT CONTACTOR

The duration of the laboratory work – 2 hours.

2.1 The purpose of the work

The purpose of the work: to study the operating principle, design and the main contactor assemblies of KT-6013 AC contractor, its purpose; to learn the meaning of contactor series conventional signs; to determine the number of current-carrying circuits contact clamps; to regulate the initial pressing of contact springs, openings and gaps of contacts; to build the contactor kinematical scheme and the opposing force characteristic, to explain the dependence of current in the coil of the electromagnet to the AC contactor in the function of the working air gap.

2.2 General notes

In the laboratory work, the AC contactor of the KT-6013 series is studied and investigated. It is a two-position machine with self-rotation designed for remote on and off switching of electric circuits with rated voltage up to 660 V, with a frequency of 50 Hz in general-purpose stationary electric drives. Connection diagram of KT-6013 contactor to start and stop the asynchronous motor is shown in Figure 2.1.

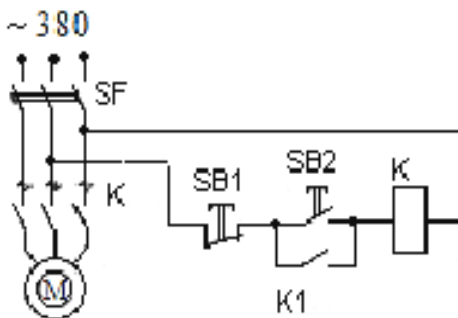


Figure 2.1 – The circuit to start and stop the asynchronous motor by KT-6013 contractor

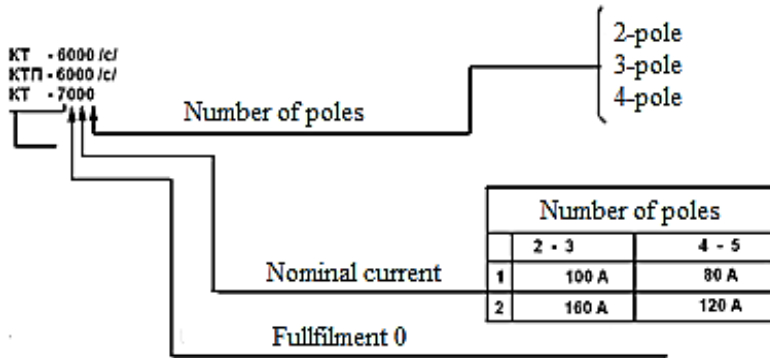


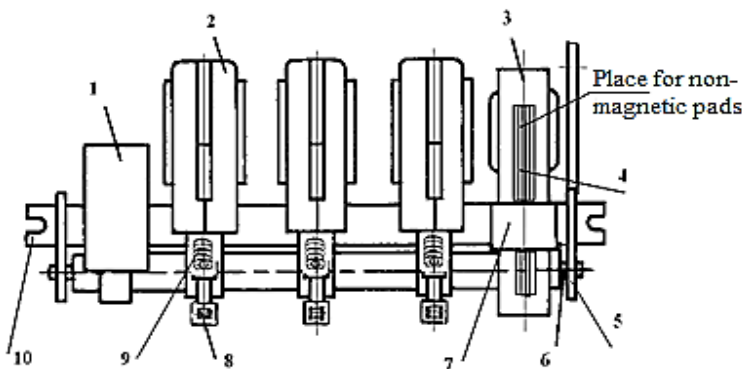
Figure 2.2 – Standard designations of the contactors

Notes:

1. The letter "c" is added for the type designation in case when the main contacts are made with the cerametallic cover plate on the silver basis.
2. Index "XJ" is added for the type designation of contactors that are used for the operation in areas of frigid climate.
3. Contactors of KT-6000 and KTII-6000 series are made with the main make contacts and deionized arc extinction.

The main contacts are finger type made of copper. In case of contactors designed for occasional circuit switching (for long-time operation), it is advisable to apply contacts with the cerametallic cover plate on the silver basis. Contactors of KT-6000 and KT-7000 series are produced only with AC coils, and the contactors of KTII-6000 series – with DC coils. KT-6000, KTII-6000 are rotating type contactors.

Figure 2.4 shows a contact-arc system of KTP-6000. Moving contact 4 with a spring 8 is fixed to the contact holder 9. The moving contact 1 and the armature of the magnet are connected by a shaft 6 (Figure 2.3). The disconnection of contacts occurs due to the action of the contact springs and the mass of the moving parts of the contactor. Contact spring 8, as well as in the direct current contactor, has a pre-pressing that is 30-50% less of final contact pressing. All parts of the apparatus mounted on insulating rail 10 (Figure 2.3). The lever 5 of the movable contacts mounted on the shaft 6, is covered with an insulating material.



Figure

2.3– Scheme of KT-6000 series contactor:

- 1 – block of auxiliary contacts; 2 – arc chute; 3 – electromagnet;
 4 – magnetic conductor armature; 5 – lever; 6 – shaft; 7 – support;
 8 – bracket with the location of the dynamometer to determine the strength of previous
 compression of contact spring; 9 – contact spring; 10 – lath.

Contactors of KT-6000 and KTH-6000 series (Figure 2.4) have a system of arc control, which consists of arc coil 2, the magnetic circuit 15, the horns 13 of fixed contact 3 and arcchute 1. The winding 8 connected in series with fixed contact 12 and movable contact 1 (one half of the camera is removed). The main contacts are connected to an external circuit by terminals 11 and 14. The movable contact 4 connects to the output 11 by a flexible connection 7. To improve the accuracy of the contact press installation after replacing the contact pressure formed by contact spring, contact may be regulated by tightening of screws 16.

The axis of rotation of the movable contact coincides with the axis of rotation of the moving system, and therefore the contacts are not re-rolling and slipping. Movable contact is rotated on a cylindrical lug of plastic contact holder. Arc-suppressing device is mounted on a plastic block 12 installed on the contactor lath. On the bottom of this block the terminal 11 is attached connected to the movable contact by flexible connection 10. The output of fixed contact 3 is soldered to the coil 2. The sides of the magnetic circuit of the arc-suppressing system are isolated from the current-conducting parts and are fixed to the horn 13 of the fixed contact. Arc chute is held with sides of magnetic arc-suppressing system. To fix the camera on one of the

sides the flat spring 6 is designed, the hole of which includes a special camera nut.

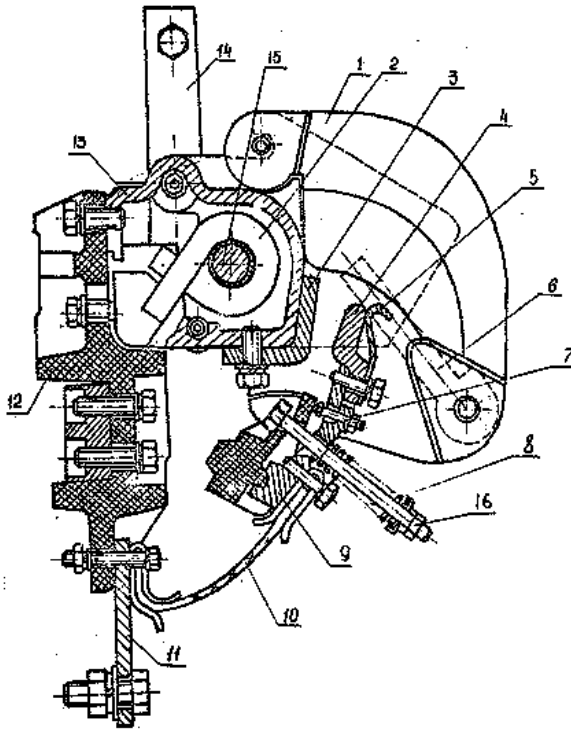


Figure 2.4 – Arcing-contact system of KTH-6000 contactor

Contactors allow the installation of two make and two breaks, or three make auxiliary contacts, mounted as a separate node (Figure 2.5). The node of auxiliary contacts consists of a pressed body 6 with fixed contacts and a pressed traverse 10, which moves moving contacts (bridges). Traverse movement occurs in metal guide ways. The bottom guiding is removable, so that the traverse can be removed from the body for inspection or stripping of the contacts. The clamps of the auxiliary contacts are designed to connect the straight ends of the conductor (without rings).

In the design of auxiliary contacts, adjustment of openings and gaps is foreseen, for which a gasket 7 with an inset is installed between the bracket 9 and the frame 6. The same inset exists on the body 6, which allows the

frame to be shifted relative to the bracket 9 with the released screws 8 that fasten it, and securely fix it when the screws are tight. In contactors the closing and execution time of on and off switching is distinguished. Closing time of switching off is an interval of time from the moment of issuing the out code command to the moment of disconnection of pole contacts which are the last ones that break the circuit.

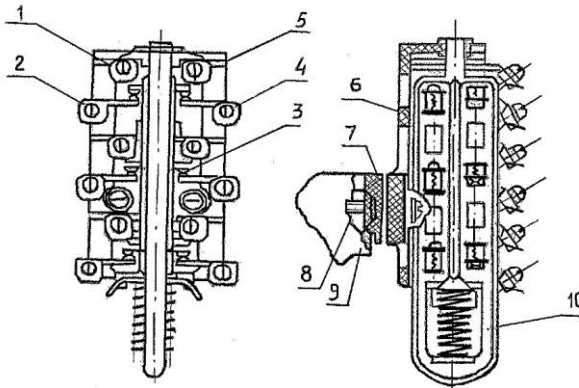


Figure 2.4 –Auxiliary contact assemble:

1, 2, 4, 5 –contact plate; 3 –contact bridge; 6 –case; 7– laying;
8 – the screw; 9 – clip; 10 – traverse.

Total own time of switching off is the interval of time from the moment of issuing the out-code command to the moment of de-energizing of all poles of the apparatus.

Closing time of switching on is an interval of time from the moment of issuing the triggering command of the contact apparatus to the moment of touch of one of the contacts.

On-time of the apparatus is an interval of time from the moment of issuing the triggering command of the contact apparatus until the appearance of the specified conditions for passing the current in its main circuit.

Mechanical wear resistance is determined by the number of inclusions (disconnections) of contactor without repair and replacement of its parts and components without current in the main circuit and free contacts. For modern devices mechanical wear resistance is determined by the number

$(10 \dots 20) \cdot 10^6$ of operations, for KT-6013 with the highest permitted rate of inclusions of $1200 \dots 10 \cdot 10^6$ cycles at a frequency of $600 \dots 5 \cdot 10^6$ cycles.

Switching durability determined by the number of switching on and off the circuit with a current, after which the replacement of worn contacts is required; for the KT-6013 it is $200 \cdot 10^3$ cycles, although modern devices switching durability can reach $(2 \dots 3) \cdot 10^6$ operations.

Operating voltage (current) is the lowest voltage (current) at the terminals of the electromagnet coil in which the armature starts to move to full pressing to the core without intermediate stops.

2.3 Work preparation

The home preparation for work includes the preparation of a report, containing the purpose of work, the scheme of the electrical laboratory installation, as well as study of theoretical issues in the section "General Information" and the recommended literature.

Schematic of the installation for research is shown in Figure 2.5, where the following notations are taken:

- T – autotransformer;
- PT – electromechanical stopwatch;
- PW – watt meter;
- HL1, HL2, HL3 – neon lamps (signaling);
- R1, R2, R3 – resistances;
- S1 – rotary switch;
- S2 – three-position switch;
- K – contactor coil;
- K1, K2, K3 – main contacts of the contactor;
- K4 – auxiliary contact of the contactor;
- S4 – button (key) switch;
- S3 – single-pole switch;
- SF – automatic air switch.

2.4 Task of laboratory work

2.4.1. Learn the construction of the contactor KT-6013.

2.4.2 Determine the number of contact clamps of the current-carrying circuit (on one pole).

2.4.3. Adjust the initial press and contact gap contacts according to the

passport data.

2.4.4. Achieve the simultaneous operation of the main contactor contacts.

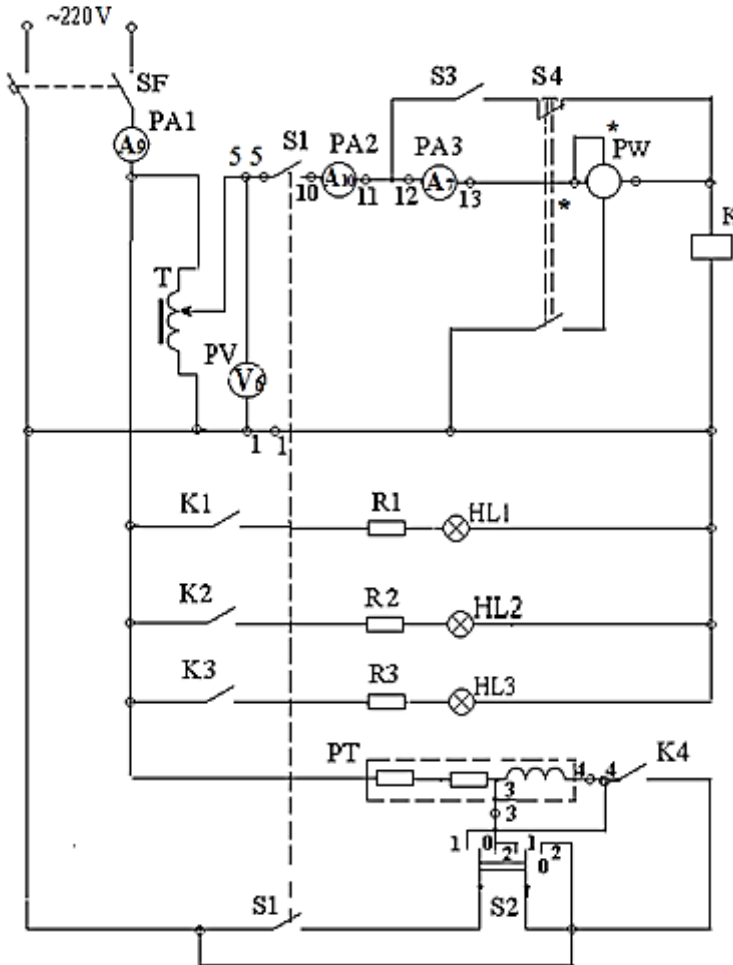


Figure 2.5 –Circuit of electrical laboratory installation

- 2.4.5. Plot the kinematic scheme of the device.
- 2.4.6. Measure the final pressure of the contact spring.
- 2.4.7. Plot the characteristic of opposing forces.
- 2.4.8. Determine the rotation rate of contacts.
- 2.4.9. Plot dependences of the current and the inductance of the contactor coil as the function of the operating air gap.
- 2.4.10. Determine the closing on and off time of the contactor.

2.5 Material, tools, appliances, equipment

Laboratory model of contactor KT-6013; non-magnetic gasket with thickness of 1, 3, 5 ... 10 mm; dynamometer; screwdriver.

2.6 Methodical instructions

For the execution of the task 3, it is important to study carefully Figures 2.7, 2.8; to unscrew the nut 2, with the screw 1 establish a contact gap $A = 7.5 \dots 8.5$ mm.

Turn the contactor on with the lever 5 (Figure 2.3), measure the clearance "B" with a probe. If $B = 1.7 \dots 2$ mm, the gap is set correctly, if not, then adjust it with the screw 1. At the same time, the opening of contacts should change too. It must be adjusted with the help of support 7 (Figure 2.3) by turning it at 90° around the axle.

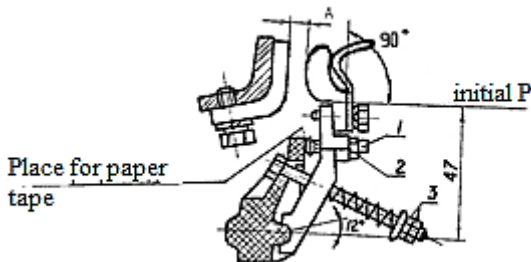


Figure 2.7—Checking of the initial press:

1 – screw to regulate the gap; 2 – locknut; 3 – nut and locknut of the spring.

The initial press of the contacts is checked with open contacts in such

a way: a thin paper tape is inserted between the lug of the shaft and the adjusting screw 1 (Figure 2.7), and then the tension of the dynamometer determines the effort at which the paper strip can be easily drawn out. This effort should be equal to 7...15 N. The initial contact press of the contact spring is regulated with the nut and the locknut 3.

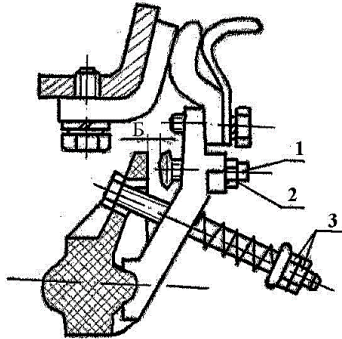


Figure 2.8— Gap "B" controls the failure

The force of previous pressing of the contact spring recalculated by the ratio of shoulders according to the kinematic scheme. Nonsimultaneity of the touch is allowed to be 0.3 mm, and this is achieved by the regulation of gaps by the screw 1 (Figure 2.7). To perform the task 6, it is necessary to turn on the contactor and with the help of the dynamometer (in the same way to the determination of the initial contact press) to determine the effort at which the HL1 (HL2, HL3) light goes out. Then, according to the ratio of the shoulders, reduce this effort to the axle of the contact spring.

To build the characteristics of opposing forces (task 7), it is necessary to determine the initial and final values of the opposing forces when choosing the opening of the contacts. The initial value of the opposing forces is determined by the tension of the dynamometer fixed on the lever 9 before the shift of the contact (determined visually). The final value of the opposing forces is also determined by the dynamometer until the touch of the contact (at least one signal lamp HL1, HL2, HL3 lights up).

Then these efforts should be led to the axis of the working air gap. When performing task 9, it is necessary to turn on the contactor with the lever and, holding the lever 9 by hand, turn on S1. Press the button S4, note the

readout of the devices and write them down into the Table. Turn off S1 and S4. The gap is set with paddings made of non-magnetic material. The pads are installed between the armature 4 and the cores of the magnetic conductor of the electromagnet (Figure 2.3).

This measurement must be carried out fast to avoid the overheating of the coil!

To measure the closing time of the switching on of the contactor in task 10, the switch S2 should be in the position "1". Turn S1 on and off several times without resetting the stopwatch. Divide the total time by the number of switching on of S1 when the voltage of the coil is equal to 220 V. Measure the closing time of the switching off in the same way, but the switch S2 should be in the position "2".

Calculate the parameters of the AC coil according to the diagram in Figure 2.9.

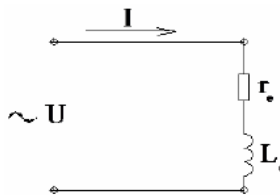


Figure 2.9– Equivalent circuit of a coil of an electromagnet with steel cores

$$Z = \frac{U}{I}; Z = \frac{W}{U \cdot I}; \omega = 2\pi f; r_e = Z \cdot \cos\varphi; L_e = \frac{Z}{\omega} \sin\varphi,$$

where Z - is the impedance of the coil.

2.7 Content of the report

- 2.7.1. The purpose and tasks.
- 2.7.2. Circuit of the laboratory installation.
- 2.7.3. Kinematic scheme of the KT-6000 contactor.
- 2.7.4. Calculations and experiments in Table and graphical forms.
- 2.7.5. Characteristic of resistance forces.
- 2.7.6. Results and conclusions.

2.8 Questions for self-control

2.8.1. Explain the principle of action and the appointment of the main contractor assemblies.

2.8.2. How to explain the vibration (strong buzz) of the armature when installing non-magnetic pads in the working air gap of the magnetic circuit?

2.8.3. Explain the dependence $L = f(\delta)$ and $I = f(\delta)$.

2.8.4. Compare the dependence $F_e = f(\delta)$ of AC and DC.

2.8.5. How to regulate the gap and failure of main and auxiliary contacts?

2.8.6. What kinds of arc systems are used in AC contactors?

2.8.7. How to explain the efficiency of arcing in the arc chamber; in the arc grating?

3 LABORATORY WORK #11

ELECTROMAGNETIC TIME RELAY WITH MAGNETIC AND MECHANICAL DAMPING

The duration of the laboratory work – 2 hours.

3.1 The purpose of the work

The purpose of the work is to study the basic principles of the formation of the delay of electromagnetic relays, as well as to confirm experimentally the basic regulation methods of the operating time and release time of the relay that are serially produced.

3.2 General notes

The time relay is a logical relay with a normalized response time. They are intended for the formation of specified delays during the transmission of signals from one circuit to another and become widespread in the circuits of the automated electric drive, automatic devices, telemechanics, relay protection, etc.

Among time relays, electromagnetic time relays are the most widely used. They use magnetic systems of direct and alternating currents. The operation time t_{op} of electromagnetic relays, both when turned on or off, has two components:

$$t_{op} = t_{sh} + t_m,$$

where t_{sh} – is the time of shift;

t_m – is the time of movement.

Time of shift is a period of time from the moment when power is fed to the winding (when the relay is switched on) or released (when the relay is switched off) to the beginning of the movement of the moving parts of the relay, that is, the time when the armature is immovable during the change of the magnetic flux when relay winding is turned on or off.

Time of movement is the time of armature movement until is full pull (when the relay is switched on) or until it is completely depressed (when the relay is disconnected).

Reducing the operation time of the relay is accomplished by increasing the start to move time t_{st} or the time of movement t_{mov} . In the first case, the increase in the time of the start to move (and hence the time of the operation of the relay) can be achieved by magnetic damping, and in the second case due to mechanical damping.

Magnetic damping is a method of influencing on the rate of change in the magnetic flux in a magnetic circuit when the relay is switched on or off. The principle of magnetic damping is based on the use of magnetic fluxes formed by eddy currents that appear in the massive details of the magnetic circuit when the main magnetic flux is changed. Magnetic fluxes of eddy currents in accordance with the Lenz rule are directed in relation to the main magnetic flux in such a way as to support the previous state of the magnetic system. Consequently, when the winding is turned on or off they reduce the rate of change of the magnetic flux. The magnetic damping efficiency is higher, the higher the absolute magnitude of the main magnetic flux, therefore, the greater effect is achieved when the electromagnetic time relay is switched off. This is due to the fact that when the armature is pulled, the magnetic flux is much bigger than when it is released.

For amplification of magnetic damping, electromagnets are supplemented by short-circuited (damping) turns, which are executed in most cases in the form of massive copper or aluminum sleeves or windings, which are planted on a magnet and increase eddy currents. The largest effect with the least expense of material is achieved if the length of the sleeve is equal to the length of the core.

With the help of magnetic damping, it is possible to obtain the time delay of order 0,1...0,5 s at switching on and 0,2...10 s at switching off. The principle of magnetic damping is used in the time relay of types PЭВ-800, PЭ-500, PЭ-100 and others that are widely used for controlling electric drives.

Adjusting the time delay when the magnetic damping time relay is switched off can be accomplished by changing the tension of the pull-back spring and, thus, the magnetic flux of release or the value of the working air gap (for example, using non-magnetic pads), which has a little effect on the constant magnetic flux, but significantly influences the speed of its reduction.

An increase of the operation time of an electromagnetic time relay can also be achieved by increasing the movement time. The influence on the movement time of the relay is achieved mainly due to mechanical damping.

In such relays, the moving parts of the electromagnet operate on the contact system through the retarder (pneumatic damper, clock mechanism, etc). Mechanical damping is used in the relay of the ЭВ-110, ЭВ-120, ЭВ-130 series and others, which are widely used in relay protection circuits. Ways of regulating the time of operation of the time relay with mechanical damping are different and determined by the specific design of the relay.

The subjects of the study of this laboratory work are electromagnetic relays of the РЭ-511 series, in which the principle of magnetic damping is used, and ЭВ-130 series, in which time delay is generated by the clock mechanism.

3.3 Description of the laboratory installation

The device for studying of the time relay consists of a standard power supply, which is available on all laboratory Tables, and a laboratory installation. The time relays, which are researched in the work, are fixed on the front of the paper-based laminate panel of the laboratory installation. The principal electrical circuit for studying the time relay is shown in Figure 3.1.

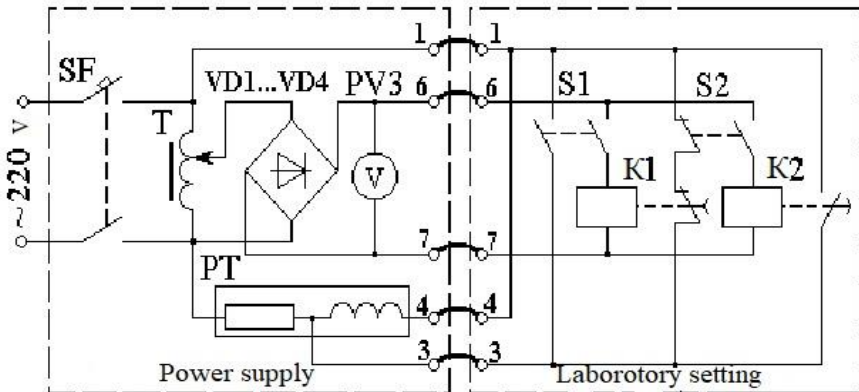


Figure 3.1 – Electrical circuit of the time relay measuring

The laboratory installation is connected to the power supply unit with short conductors. The rest of the circuit is assembled and mounted on the laboratory panel. To measure the operating time of the relay, an electromechanical stopwatch PT, installed on the power supply panel, is used. The control circuit for the K1 time relay (РЭ-511) is turned on and off

by the toggle switch S2, and K2 (ЭВ-130) – by the toggle switch S1.

The power is fed by turning on the SF automatic circuit breaker installed on the power supply panel, at the same time the HL indicator light is lighted up. Adjustment of the supply voltage is carried out using the autotransformer T.

When measuring the operating time of relay K1 during the disconnection, the circuit works in this way. In a deenergized state, the electromechanical stopwatch PT does not work because its winding is shunted by the uncoupling contacts, relay K1. When switching on S2, the K1 relay contacts are broken, but the PT does not work, because its winding is shunted by S2 contacts. When S2 is switched off, the PT operates as long as its winding is not shunted by the broken contacts, relay K1, that is, the relay operation will not occur.

When measuring the operating time of the K2 relay, the circuit works in this way. In the initial position, the winding of PT is shunted by the contact of the toggle switch S1. When it is switched on, the power is fed to the coil K2 and PT starts working because the second pair of contacts S1 is working on disconnection. When closing the closing contact, the K2 relay, PT winding is shunted and it stops working.

3.4 Task

3.4.1. To study the principles of the formation of time delay with the help of magnetic and mechanical damping.

3.4.2. To study the work of the circuit of the laboratory installation when measuring the time of operation of the researched time relays.

3.4.3. Study the construction of the time relay with magnetic damping РЭ-511. Specify its main elements and their purpose in the report.

3.4.4. Experimentally determine the dependence of the operating time when the relay РЭ -511 is switched on from the pull-back spring tension, the operating air gap and the supply voltage. Build graphs of the obtained dependencies.

3.4.5. Study the design of the time relay with mechanical damping ЭВ -130. Specify its main elements and their purpose in the report.

3.4.6. Experimentally determine the dependence of the operating time when the relay ЭВ -130 is switched on from its time setting, as well as the relative error of its settings (average value). Build a graph of the received dependence.

3.5 Methodical instructions

3.5.1. When performing task 3.4.1, you should use the materials of the lecture on the relevant topic and the recommended literature.

3.5.2. The circuit of the laboratory installation and the principle of its operation are given in section 3.3.

3.5.3. When executing tasks 3.4.3 and 3.4.6 you should use the recommended literature.

3.5.4. In order to perform the experimental part of the work, it is necessary to connect the laboratory unit to the power supply unit by connecting the terminals with the help of short conductors: 1-1, 3-3, 4-4, 6-6 and 7-7.

3.5.5. The execution of the task 3.4.4 is performed in the following sequence:

a) to set the given tension of the pull-back spring of the relay, which is regulated by step with the help of plates with the thickness of 1,5 mm; plates are laid between a Figure nut and a washer; tension of the spring is measured by the number of installed n plates;

b) to set the given value of the working air gap, which is regulated by means of non-magnetic (brass or copper) gaskets of thickness 0,1; 0,2; 0,4 and 0,6 mm, put in a pocket fixed on an armature;

c) switch on the circuit breaker SF, HL signal light should lights up;

d) switch on S2 and, by increasing the supply voltage with the help of the autotransformer T, get the operation of the time relay;

e) using the autotransformer T to set the given value of the voltage supply;

f) set the arrow of the PT to zero;

g) turn off S2 and take the PT readings;

h) turn off the circuit breaker SF;

i) when you execute tasks $a-z$, take the dependence in accordance with task 3.4.4, write down the readings to Tables 3.1, 3.2 and 3.3;

g) after taking all dependencies it is necessary to turn off SF and set autotransformer T to zero.

Table 3.1 – Dependence of the operating time of the relay from the tension of the pull-back spring $\delta =$ mm; $U =$ V

Spring tension, n	0	1	2	3	4	5
Operating time, s						

3.5.6. The execution of task 3.4.6 is carried out in the following sequence:

a) set the setting of the operating time of the relay ЭВ-130; it is done by installing and fixing the relay contacts in one of the positions according to the setting, which is determined by a scale (the plastic pointer is placed against the corresponding stroke on the scale);

Table 3.2 – Dependence of the relay operating time from the working air gap $n =$ mm; $U =$ V

The air gap, mm	0	1	2	3	4	5
Operating time, s						

Table 3.3 – Dependence of the relay operating time from the supply voltage $n =$ mm; $U =$ V

Supply voltage, V	0	0	20	50	100	120
Operating time, s						

b) switch on the circuit breaker SF and, using the autotransformer T, set the rated voltage of the relay winding to 220 V according to the PV3 device;

c) reset the readings of the milistopwatch PT;

d) turn on S1 and after stopping of the arrow of PT, write down its indications to the Table 3.4;

e) turn off S1 and SF;

f) when you perform tasks a-d, take the dependence in accordance with the task;

g) determine the absolute and relative errors according to the

following formulas:

$$\Delta t = |t_{op} - t_s|;$$

$$\delta_t = \frac{\Delta t}{t_{op}},$$

where t_s – is the setting oft he operating time.

h) write down the results of calculations to the Table 3.4.

3.5.7. After taking the dependence, it is necessary to set the autotransformer T to zero and switch off SF.

3.5.8. The obtained experimental dependencies need to be agreed with the teacher, after what the circuit can be disassembled.

Table 3.4 – Dependence of the operating time and errors from the setting of relay ЭВ-134

Setting of operating time, s	0	1	2	3	5	7
Operating time, s						
Absolute error, s						
The relative error, %						

3.5.9. Report to the laboratory work should contain:

- a) the name and purpose of the work;
- b) the electric circuit of the time relay;
- c) experimental data in the form of Tables and graphic dependences built upon them;
- d) calculation of the errors of the operating settings of the time relay with mechanical damping;
- e) conclusions on work.

3.6 Questions for self-control

3.6.1. What is a time relay and where is it used?

3.6.2. What components has the operating time of the electromagnetic relay?

3.6.3. In what ways can the operation time of the electromagnetic relay be increased?

3.6.4. What is the principle of magnetic damping?

3.6.5. How can the operating time of the relay with magnetic damping be controlled?

3.6.6. Explain the dependencies $t_{op} = f(n)$; $t_{op} = f(\delta)$ and $t_{op} = f(U)$.

3.6.7. How is mechanical damping executed in time relay?

3.6.8. Explain the existence of a fault in the operation of the time relay with mechanical damping.

4 LABORATORY WORK # 12 BIMETALLIC THERMAL RELAY

The duration of the laboratory work – 2 hours.

4.1 The purpose of the work

To study main principle of design of thermal relays; to study the design and take the time characteristic of the relay TPH-25 series by the experiment; to learn the operation principles of thermal relays all types, as well as types of bimetal strips heating used in thermal relays; materials used to manufacture bimetallic strip; methods of controlling the current of thermal relays operation in narrow and wide ranges; to learn depicting the thermal protection relay circuit for the electric motor; take and build up timing characteristic of the thermal relay.

4.2 General notes

The durability of the electrical equipment mostly depends on the overloads that take place during its operation. If durability of an electric motor at the normal operating mode is equal to 20 years, at thermal overload up to 180% is reduced durability up to one month.

Thermal relays with bimetallic strips are used to protect electrical equipment such as electric motors from the heating produced by overload current higher than the permissible value.

The thermal protection relay diagram for an asynchronous motor with short-circuited rotor is shown in Figure 4.1.

The main element of the thermal relays is bimetal strip, which consists of two metals with different temperature coefficients of linear expansion. Metal with high coefficient of linear expansion α_1 is called active; with low coefficient α_2 is passive. In place of connection, they are tightly sealed as a result of hot-rolled.

The maximum deflection of the loose end of the bimetallic strip is calculated by the formula:

$$X_{\max} = \frac{3}{4}(\alpha_1 - \alpha_2) \cdot \frac{l^2 \cdot \tau}{\delta}, \dots \dots \dots (4.1)$$

where α_1 and α_2 - are coefficients of linear expansion under active and passive layers, $1/^\circ\text{C}$;

l - is length of the strip, mm;

τ - is excess of the heating strip temperature above ambient temperature, $^\circ\text{C}$;

δ - is the total thickness of the strip, mm.

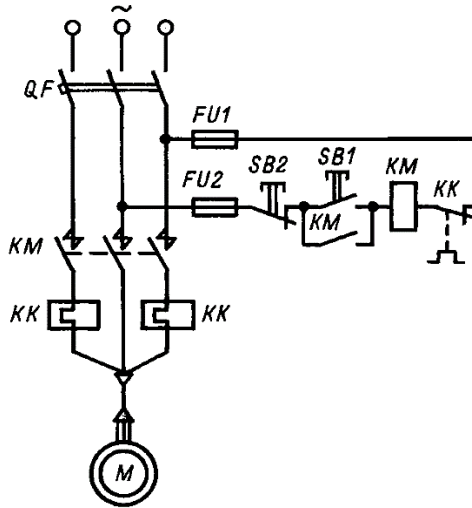


Figure 4.1 – Diagram of the electric motor and the protection against overload via the thermal relay

The loose end of the strip develops such force:

$$F = \frac{3}{16} (\alpha_1 - \alpha_2) \cdot \frac{b \cdot \delta^2}{l} \cdot E \cdot \tau, \dots\dots\dots (4.2)$$

where b – is width of the strip, mm;

E – is average modulus of the strip elasticity, N / mm^2 ;

$$E = \frac{E_1 + E_2}{2}.$$

From equations (4.1) (4.2) it is clear, that the deflection and the force will be greater, when the difference $(\alpha_1 - \alpha_2)$ will be greater. For active layers, iron-nickel-molybdenum alloys with $\alpha = (18 \dots 19) \cdot 10^{-6} \text{ } 1/^{\circ}\text{C}$ are used, as well as copper-based alloys brass, constantan, aluminum and beryllium bronze with $\alpha = (16 \dots 23) \cdot 10^{-6} \text{ } 1/^{\circ}\text{C}$.

For passive layers iron-nickel alloys with 36% nickel content and $\alpha = (1 \dots 7) \cdot 10^{-6} \text{ } 1/^{\circ}\text{C}$ have become more common.

Bimetallic strips can be heated by electric current, which flows directly on the strip (direct heat), as well as by the individual heating elements (indirect heat). Some devices combined direct and indirect heating (combined heat).

With direct heating, the wide control of the thermal relay operation current is carried out by the selection of the corresponding resistances (shunts), which are turned on in parallel to the bimetallic strip. Wide regulation of the operation current at indirect heating is usually carried out by replacing the heating elements.

The regulation of the operation current is achieved by changing:

- deflection of the bimetallic strip, required for the disconnecting mechanism actuation;
- forces, developed by the bimetallic strip.

In the relay TPH-25 possible deflection of bimetallic strip is regulated by eccentric 3. The adjustment range of the setpoint current equals to $\pm 25\% \cdot I_{rat}$.

The basic requirements for thermal relay design are:

- 1) small dependence of these t point operation on the ambient temperature;
- 2) rapid opening and closing of the contacts in the circle. Also should be provided sufficient pressure in close contacts.

The first requirement is usually satisfied by an increasing of the operating temperature in the bimetallic device in which it operates. The second requirement in modern constructions is satisfied, as a rule, with the help of springs - cylindrical, screw or plate.

Figure 4.2 shows several fundamental constructive performances of thermal relays bimetallic mechanisms.

Opening contacts 9 in the mechanism, shown in Figure 4.2, a) is under the action of the spring 1 in a time when the bimetallic strip 3, which bends

when heated, release latch 5. Opening contacts 9 in the mechanism, shown in Figure 4.2, a) is under the action of the spring 1 in a time when the bimetallic strip 3, which bends when heated, release latch 5. Bimetallic strip is heated element 4. Emphasis 2 limits latch 5 progress when closing the contacts. This mechanism does not provide automatic contact closing after cooling bimetallic strip. The return of the relay to its original position is carried out manually by pressing the button 6, complete with a spring 7.

With the control lever 8 changes the distance that must bend bimetallic strip to release the latch 5. The greater the distance x , the higher the current in the heating element, in which the relay is operates at the same time.

The operation of the mechanism shown in Figure 4.2, b) is similar to the mentioned mechanism.

The plate element 8 heats the bimetallic strip 7, which bends, turns the frame 9 rigidly connected to the thermo-compensator 6. The thermo-compensator compresses the spring 4 and removes the latch 5 from the stop 2, there by releasing the spring 10, which, pushing up the insulation traverse, releases the contacts 11. Reverse closing of the contacts is carried out manually by pressing on the traverse 1 (after cooling the bimetallic strip), with the latch 5 set to the stop 2. The set point relay current in the small range is controlled by changing the distance between the latch 5 and the heaters thermo-compensator 6 by eccentric device that is equipped with a pointer 3. By turning emphasis pointer 2 moves, changing the distance from the latch 5 to the temperature compensator 6.

The temperature compensator 6 is a conventional bimetal strip and serves to reduce the effect of ambient temperature on the setpoint relay current. With the change in the ambient temperature compensator bent to the side, back bending bimetallic strip 7.

In the mechanism (Figure 4.2, c), the opening of the contacts 2 is carried out by a plate spring 6 whose efforts, when bent on the bimetallic strip 4, change their direction by the jump on a certain value. Strip 4 is heated by element 5.

Depending on the location of stop 3, this mechanism can return to its original position automatically when cooling the strip 4. The lever 1 changes the bend of the spring 6, which changes the current at which the relay operates. Among the main disadvantages of such a mechanism should be reduced pressure in the contact 2, depending on the bend of the bimetallic strip 4.

In the mechanism (Figure 4.2, d), when heated by the element 4, the bimetallic strip 3 first straightens. In this case, the strap 5 deviates, and the spring 2 stretches. After the strip 3 starts to bend in the opposite direction, its forces coincide with the force of the spring 2 and there is a quick bend of the strip and the opening of the contacts 7. The support 6 restricts the sliding of the contacts, and with the help of the screw 1 it is possible to change in certain limits the relay operation current and its timing characteristic

In the mechanism shown in Figure 4.2, e, depending on the bending of the bimetallic strip 4, the direction of action of the spring that was pre-compressed 9 is changed relative to the axis of rotation of the contact pad 1. In the cold state, the edge of the strip 4 is pressed to the stop 8, and the force of the spring will act on the closing of the contacts 10. With the heating of the element 5, it together with the upper edge of the spring will bend towards the stop 2. The direction of the force of the spring 9 will change, and it will act on opening of contacts during the transition through pad 1 central axis line.

The current of the relay is regulated by the lever 6, which is rearranged along the toothed sector 7, fixing its position. When you move the lever 6 the bend of the bimetal strip changes. The return of the relay to its original position may occur automatically when the plate is cooled. However, if you remove the stop 11, then the contact pad may return so that it will not be possible to return to the starting position. In the designs of such relays provides a return button 3.

Mechanism of V.A. Alekseevsky (Figure 4.2, f) is a meaningful combination of the bimetallic element 1 with the jumping contact group 5. In the cold state, the bimetallic strip is pressed against the upper stop 2 by a flat-spring 3 which is pressing on the contact 5 by its second edge. It can be freely rotated in its mounting position to the strip and the pad with contacts. With the heating of the bimetallic strip, its forces at the end overcome the force of the flat-spring, and the strip will bend. As soon as the edge of the flat-spring, fixed on the plate, will be below the edge, which is fixed on the contact pad, there will be an opening of the contacts.

The moving contact will be pressed with the flat-spring to the stop 4. Depending on the location of the stop 4, the mechanism will be comfortable returning or self-turning. If the stop 4 is located below the stop 2, then the strip is cooled automatically by closing the contacts 5. Otherwise, it is only possible to manually return to the original position.

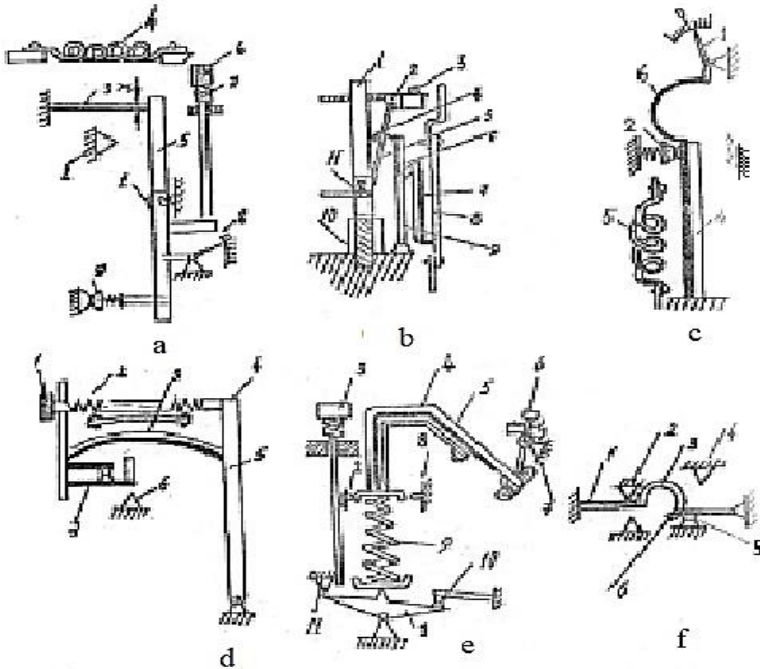


Figure 4.2 - Pictures of bimetal mechanisms of thermal relays:

- a, b - mechanisms with release latch; c - mechanisms with jumping contact;
- d - the mechanism with a jumping bimetal strip;
- e - the mechanism for changing the direction of cylindrical spring force;
- f - the mechanism of V.A. Alekseevsky.

Strength of the operation current in the mechanism V.L. Alexeyevsky is regulated by a change in the length of the flat-spring 3. For this purpose, several special punches have been made on the edges of the flat-spring, with which it is applied to the bimetallic strip 1 and also the contact pad 6.

The main characteristic of thermal relays is their timing characteristic, which shows how the operation time varies depending on the current change in the circuit. In the general case, the timing characteristic has a hyperbolic character. Protection of electrical devices occurs when the timing characteristic of the thermal relay is slightly below the protective characteristic of the electrical device throughout the range of possible overload currents.

In order to protect the electric device from current overload, thermal relays of TPA, TPB, TPII, PT, TPH, TPT types have been widely used.

The TPA relay serves to protect motors of low and average power of AC and DC under difficult starting conditions (prolonged startup, high multiplicity of starting current). Issued to 23 performances at rated currents of 7 ... 215 A.

Relay TPB serves to protect motors with easy starting conditions. Issued up to 20 executions at nominal currents of 7 ... 200 A.

The TPA and TPB relays have a combined heating system with flat non-chromium heating elements, which are connected in parallel with the bimetal strip. Starting from 50 A and above, shunts are used which are connected externally in parallel with the package of bimetal and non-chromium strips. Shunts have nine performances, the same for the relay types TPA and TPB.

As a bimetal mechanism in the relays of these types, the mechanism of V.A. Alekseevsky (Figure 4.2, f) is used, which ensures return to the original position after the operation for no more than 3 minutes. Relay contacts provide disconnection of current up to 1 A at 220 DC and 10 A at 380 V AC. The relay location on the device is arbitrary.

The PT series relays (PT-1 and PT-3) are mostly devices with the open operation (the PT-1 relay is also of a closed operation) with an indirect heating system. The principle mechanism of this series relays are similar to the mechanism shown in Figure 4.2, a). Wide control of the operation current is carried out by replacing the relay heating element 4. In total 56 numbers of heating elements on nominal currents of 0,64 ... 40 A. The selection of necessary number of the heating element is carried out on a special Table. The relay does not work when starting the electric motors having a multiplicity of starting current $K = 7$ and a start-up time of 1.5 s, in the case when before and after the start of the electric motor through the relay flows a current equal to the nominal current of this heater.

Thermal relays series TPII at currents 1 ... 600 A in most cases are used in magnetic actuators of the IIA type. They are made of one-pole at nominal currents 25, 60, 80, 150, 600 A. The basic device of the bimetallic mechanism is shown in Figure 4.2, e). The TPII relay (with the exception of the TPII-600 without a heater) has a combined heating. The connection of the bimetallic strip and the heater is performed in parallel. Slow change of operation current within (0,75 ... 1,25) In is carried out by the transfer of a spring lever in the toothed sector, which fixes its position. A wider change of

the setpoint current is made by replacing the heating element. The control circuit can be executed with one opening or one closing contact. Contacts allow the circuit disconnection of AC up to 500 V and current up to 10 A and circuit of DC voltage $U = 220$ V and current $I = 0,5$ A.

Thermal relays TPH series with the currents 0,4 ... 40 A, two-phase and thermocompensation are mostly used in magnetic actuators ПМИ, П6 and ПА-300series. All thermal relays of this series have indirect heating with the help of plate non-chromium heaters.

Principal TPH relay shown in Figure 4.2, b).

TPH relay has a symmetrical layout of two thermal elements, included in two phases of the electric motor main circuit. The dependent influence of the each polecurrent on the contacts closing mechanism is provided. Adjustment of the nominal setpoint current using an eccentric device is within the range (0.75 ... 1.25).

Thermal relays TPT-100 series for currents 1,75 ... 550 A are used in ПМtype magnetic starter and magnetic operation stations. The TPT-100 series relay consists of five types, each of which has a number of executions. Type 1 relays (except for the TPT-115 relay) have direct heating, and relays of the 2nd, 3rd and 4th types, as well as the TPT-115 have flat heaters that additionally heat the bimetal strip. The heaters can be included with the bimetal strip sequentially, in parallel, parallel - sequentially. Relays of the 5th type do not have heaters and are manufactured together with a current transformer.

The electrical circuit for the building the timing characteristics of the researched relay is shown in Figure 4.3.

The circuit provides four relays with identical heating elements KK0, KK1, KK2, KK3 in order to get the timing characteristic faster. The heating element KK0 serves to set the required current value. The timing characteristic is taking on the relay KK1, KK2, KK3.

4.3 Preparation for the work

Get acquainted with the theoretical part, set out in the "General information" section and complete the workpiece for the laboratory work. It contains of the work title; purpose of the work; circuit of switching on and electric motor protecting from overloads with the help of thermal relays; workout Table.

4.4 Material, tools, devices, equipment

A stand with a TPH-25 type thermal relay and controls in accordance with the testing electrical circuit; connecting conductors – 7 pcs.

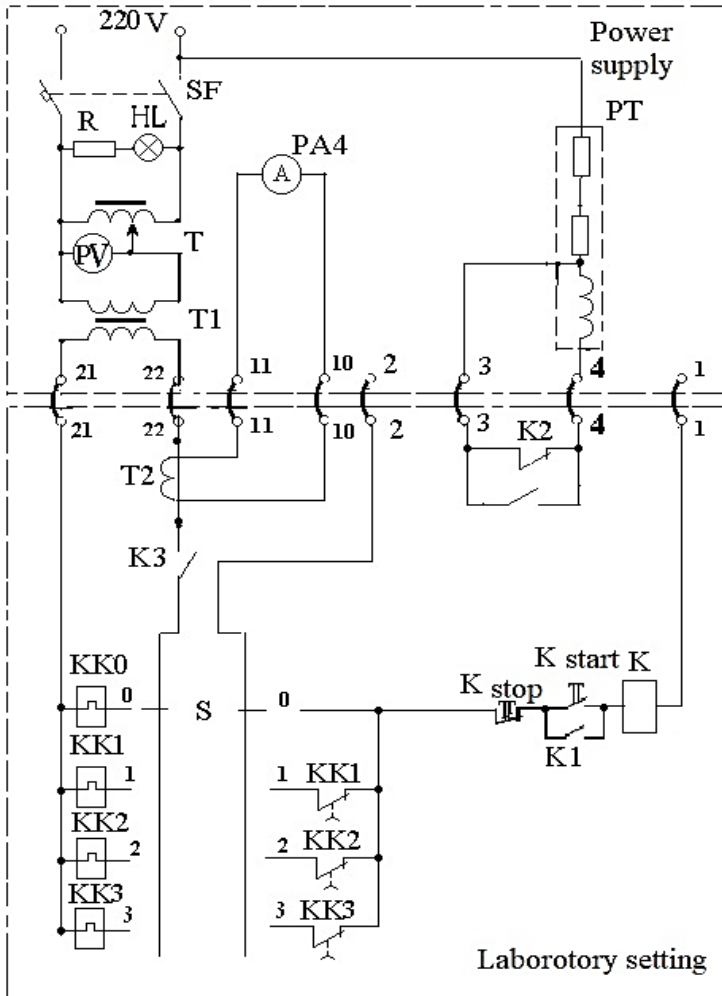


Figure 4.3 – Testing electrical circuit of thermal relay

4.5 Methodical instructions

For the determination of the timing characteristic of the TPH type relay it is necessary:

- a) bring autotransformer to zero;
- b) switch S put at zero position, turn on SF;
- c) push the "Start" button and slowly increasing current via transformer, bring it to a value according to Table. 4.1 (the current readings of PA 4 multiplied by 3);
- d) press "Stop";
- e) S switch in the position "1". In relay KK1 eccentric screw 3 is set far right (-);
- f) readings of the electroscondometer at zero. Press the "START" button and follow the indications of the electroscondometer (one turn of the small arrow reaches 10 seconds). Autotransformer T maintain the set value of the current value. Put the readings of the electroscondometer in Table. 4.1 after it stops when the relay is operated;
- g) switch S to "2". On the KK2 relay, the eccentric screw is set to the leftmost position (+). Indications of an electroscondometer should be reduced to zero and repeat p.6);
- h) switch S to "0". Press the "START" button and set the new current value according to Table. 4.1.
- i) repeat the test, starting with p.d), but now with the relay PT3, the eccentric of which is oriented to the extreme right position (-);
- j) repeat the test for the new current values, starting with p.d) and g), thus switching sequentially the relay KK1 (or KK3 when cooling KK1) and KK2. Readings put in the Table 4.1 in the appropriate line.

Table 4.1

Eccentric in the extreme position (-)	I, A	6	8	10	12	15
	s					
Eccentric in the extreme position (+)	I, A	6	8	10	12	15
	s					

4.6 Contents of the report

4.6.1. The aim of the work.

4.6.2. Circuits of switching on and motor protecting from the overload with the help of thermal relays.

4.6.3. The results of studies (see Table 4.1) and the timing characteristics built on them.

4.6.4. Conclusions.

4.7 Questions for self-control

4.7.1. The principle of thermal relays operation (Figure 4.2).

4.7.2. What types of heating of bimetallic strips are used in thermal relays?

4.7.3. What materials are used for the manufacture of bimetallic strips?

4.7.4. How the operation current of the thermal relay with direct and indirect heating in the large and small ranges is regulated?

5. What influences the length, thickness and width of the strip on the force and deflection of the strip?

6. What are the requirements for thermal relays?

7. What is the temperature compensator of the thermal relay and how does it work?

8. Draw and explain the circuit of electric motor protection from overloads with the help of thermal relays.

9. How are the timing characteristics of the thermal relay сщцквштфey with the protecting characteristics?

5 LABORATORY WORK #13

AUTOMATIC CIRCUIT BREAKER

The duration of the laboratory work – 2 hours.

5.1 The purpose of the work

The purpose of the work: to study the design of the automatic circuit breaker АП -50, the principles of operation and structure of its individual elements, to determine experimentally the operating characteristics of the uncouplers.

5.2 General notes

Automatic circuit breaker is an electric apparatus, designed to automatic switching off of electrical circuits in case of emergency situation, as well as for infrequent operational switching of load current. Automatic circuit breakers perform the functions of protection of electrical equipment from short circuits, overload, unacceptable reductions or voltage drops. With the help of automatic circuit breaker, operative circuit commutations are performed within the nominal load, they are often used instead of magnetic starters for the infrequent start-up of asynchronous motors. In this case, they also replace the fuses, performing the function of protection of the electrical installation from short circuits. The main parameters of the circuit breakers are:

- a) rated current;
- b) rated voltage;
- c) mechanical and commutation wear resistances, but it should be noted that automatic circuit breakers in quantitative terms have considerably lesser mechanical and switching wear resistances than contactors;
- d) limit switching capacity is the ability of automatic circuit breakers to switch off reliably the electric circuit when short-circuit fault occurs; in quantitative terms, it indicates the maximum current value of current that the machine can switch off reliably, remaining in a safe and efficient state;
- e) time of operation (operation speed): it is distinguished the closing operating time of the breaker, which is the time interval from the moment of beginning of short circuit till the opening of its main contacts, and the total

time of operation (until the total switching off of the circuit), that also takes into account the time of arcing.

The most commonly used automatic circuit breakers are those, which do not have special requirements for operation speed; they are universal and adjusting breakers, the operating time of which is within 10-100 ms limits. Multi-purpose machines do not have a protective casing and are usually installed in boxes of low voltage dispatch devices. They usually have two types of protection: maximum current and protection against loss or drop of voltage. Adjusting breakers have a plastic protective casing and can be installed in public buildings and residential areas, they have only the maximum current protection. There are no other fundamental differences between universal and adjusting breakers.

In order to protect the power semiconductor devices and devices that are based on them, fast-acting automatic circuit breakers are used, because widespread universal breakers cannot provide their protection due to the lack of operation speed. The closing operating time of fast-acting automatic circuit breakers is 0.5...5 ms; they have the property of current limitation at short circuit.

The main elements of automatic circuit breakers are:

- a) arc-extinguishing system;
- b) the mechanism of free uncoupling;
- c) uncouplers for protection of the electrical equipment from overloads and short circuits;
- r) drive circuit breakers with a rated current up to 100 A have manual control; breakers with a higher rated current have electromagnetic or electric drives.

One of the most commonly used adjusting breakers is the automatic circuit breaker of the АП-50 series with manual control, nominal current up to 50 A, rated voltage up to 220 V (in DC circuits) and up to 500 V (in AC circuits). The automatic breakers АП-50 are divided: by the number of poles (two- and three-pole); by the availability of uncouplers of maximum current on each pole (MT – electromagnetic and thermal, M – electromagnetic, T – thermal); by nominal current of uncouplers automatic circuit breakers АП-50 have performance for all series of standard values (1,6; 2,5; 4; 6,4; 10; 25; 40; 50 A); on the multiplicity of the operation of the cut-off (of electromagnetic uncoupler), the availability of additional uncouplers, etc.

The object of research in the laboratory work is an automatic circuit breaker АП-50-3MT. It is a three-pole breaker, with an uncoupler of the

maximum current, nominal current of the uncoupler is 1.6 A, the operating current (setting) of the cut-off, which is equal to 11-fold value of the uncoupler nominal current. The design scheme of the circuit breaker is shown in Figure 5.1. The circuit breaker has a plastic case 3, that is fixed on the cap 2, where all components of the breaker are mounted: a switching apparatus which consists of fixed 4 and movable contacts 5; the start button 8, the position of which can determine the position of the contacts (when the circuit breaker is turned on, the power button is depressed, when turned off – goes beyond the lid); arc-control device, which is a deion grating, consisting of a series of steel coppered plates 6 with the thickness of 2-3 mm with air layers between them.

The free-uncoupling mechanism 7 provides the contact breaking with a constant speed, independent of the speed of the stop button 12. It also provides a disconnection of the circuit breaker under the condition of fault close-in when the start button is turned on.

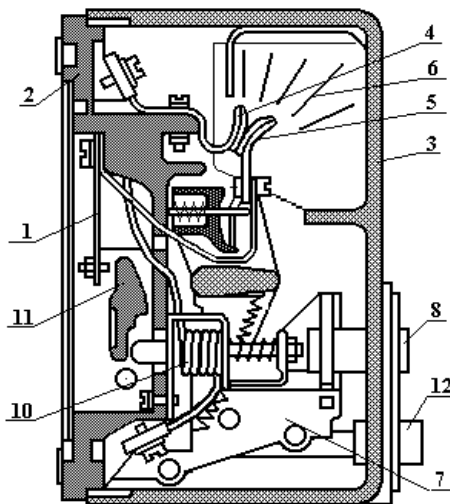


Figure 5.1 – The design scheme of automatic circuit breaker AII-50

The principle of the operation of thermal uncouplers 1 is similar to the principle of the operation of thermal relays. These uncouplers are used as a protection against overload currents with a delay, which has a reverse current dependence. To protect the electrical device, the time-current characteristic

of the thermal uncoupler of the circuit breaker must be located below the same characteristics of the protected device. It is desirable that they lie as close as possible to each other. When activated, the thermal uncoupler presses on the switching plate 11, and as a result, the mechanism of free uncoupling is activated and it closes the main contacts of the circuit breaker. The electromagnetic uncoupler is an electromagnetic coil 10 with a moving core. If the current value is sufficient for its operation, the core is tightened and it presses on the switching plate 11, which is connected with the mechanism of free uncoupling, and also breaks the main contacts of the circuit breaker. The circuit breaker provides the possibility of uncouplers' regulation in the small limits of the setting (operating current) with the help of a lever 7 which rotates the switching plate 11.

5.3 Description of the laboratory setup

On the facing part of the panel of the laboratory stand, the investigated SF1 circuit breaker is installed, as well as a showpiece of a circuit breaker (without plastic case). The real automatic circuit breaker has a thermal and electromagnetic uncouplers at each pole. These uncouplers are connected in series with the main contacts. But for the research, the circuit breaker is partially reconstructed: one of the poles has only a thermal uncoupler (electromagnetic one is removed), and the other has only electromagnetic uncoupler (thermal is removed).

The schematic circuit of the breaker is shown in Figure 5.2. The circuit contains a standard power supply and a laboratory setup that are connected with each other with short conductors. The rest part of the circuit is assembled on the underside of the laboratory panel. An electromechanical stopwatch PT, installed on the power supply panel, is used to measure the closing operating time of the circuit breaker. The circuit of the investigated breaker SF1 is switched with the rotary switch S1, and the circuit of the electromechanical stopwatch PT is commutated by its contacts. The commutation of the uncouplers is performed with the help of the switch S2. The power supply of the laboratory circuit is carried out by switching on of the circuit breaker SF. Adjustment of the supply voltage, which is fed to the circuit through a step-down transformer T1, is carried out with the help of the autotransformer T.

5.4 Task

5.4.1 Study the design of the automatic circuit breaker АП-50, and the principle of the operation of its uncouplers. Using the passport data determine the nominal current of the uncoupler and the cutoff current.

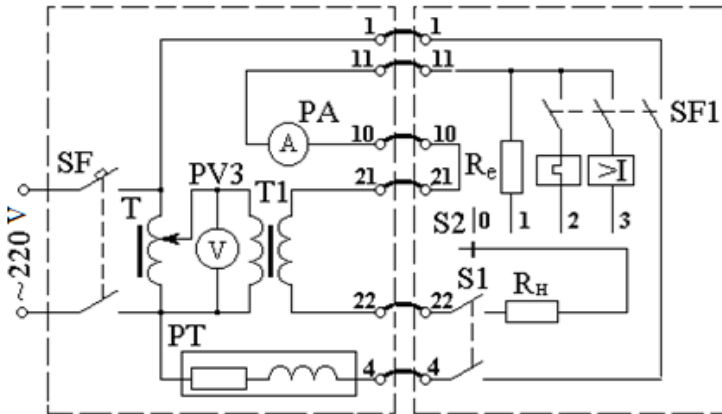


Figure 5.2 – Electrical circuit of the circuit breaker research

5.4.2 Experimentally get a time-current characteristic of the thermal uncoupler.

5.4.3 Experimentally determine the current and operation time of the electromagnetic uncoupler (cut-off).

5.4.4 On the basis of experimentally obtained data, to build a protective characteristic of the circuit breaker.

5.4.5 Draw conclusions on the work.

5.5 Methodical instructions

5.5.1. Execution of the task 5.4.1 is carried out in accordance with the design description given in the "General Information" section and the demonstration sample mounted on the laboratory panel.

5.5.2. To get the time-current characteristics of the thermal uncoupler, it is necessary:

a) connect the laboratory setup to the power supply unit by connecting

with the help of short conductors the following terminals: 1-1, 4-4, 10-10, 11-11, 21-21 and 22-22;

b) the switch S2, located on the laboratory panel, set to the position "1";
S1 – to the "off" position;

c) set autotransformer to zero position;

d) switch on the SF circuit breaker located on the power supply panel, and the HL light indicator should light up;

e) set the switch S1 to the "on" position and use the autotransformer T to set the given value of current within the limits of 6...15 A in accordance with Table 5.1 (with the help of ammeter PA8 located at the top of the stand, its indication must be multiplied by 3) , then set S1 to the "off" position;

f) switch on the experimental circuit breaker SF1 located on the laboratory setup panel;

g) put the readings of the stopwatch PT in zero position, then set the switch S2 to position "2", activate S1 and watch the PT readings before the operation of the thermal uncoupler (one turnover of the small arrow of the PT is equal 10 seconds); if the ammeter readings do not match the set value of the current, it is necessary to use the autotransformer T to adjust it to the set value;

h) switch off S1 and let the thermal uncoupler to cool down for 3-5 minutes;

i) repeat tasks *e* and *h* with other values of current, write down the results of PT to Table. 5.1;

j) turn off S1.

5.5.3. To measure the operating time of an electromagnetic uncoupler:

a) put the switch S2 in position "1";

b) turn on S1 and, using the autotransformer T, set the operating current according to the passport data of the circuit breaker АП-50 (by the ammeter PA8) and switch off S1;

Table 5.1 –Operating time of thermal uncoupler

Multiplicity of current overload	4	5	6	8
Operating time, s				

c) set S2 to position "2" and set PT readings to zero position;

d) switch on the circuit breaker SF1;

e) S1 set to "on", and it should be almost instantaneous automatic turning off of the circuit with the help of an electromagnetic uncoupler;

f) S1 set to "off";
 g) without the reset of PT readings repeat tasks d and f not less than 5 times;

h) the average value of the operating time of the electromagnetic uncoupler should be determined by dividing the total operating time by the number of switchings.

5.5.4. Turn off S1, set autotransformer T to zero and turn off SF.

5.5.5. Match the results with the teacher, after what the scheme can be disassembled.

5.5.6. Build the protection characteristic of the circuit breaker Table 5.1, taking into account the parameters of the operation of thermal and electromagnetic uncouplers.

5.5.7. The report to the laboratory work must contain:

- a) title and purpose of the work;
- b) passport data of the investigated circuit breaker;
- c) electrical circuit of the experiment (laboratory setup);
- d) tested data in Table form;
- e) protective characteristic of the circuit breaker;
- f) conclusions.

5.6 Questions for self-control

5.6.1. What is the appointment of the automatic circuit breakers and what functions do they perform?

5.6.2. Name the main parameters of the automatic circuit breakers.

5.6.3. What is the boundary switching capability of the circuit breakers?

5.6.4. What is the closing (total) time of operation of the circuit breakers?

5.6.5. What is the appointment of the fast-acting circuit breakers?

5.6.6. Name the main elements of the construction of the circuit breakers and their purpose.

5.6.7. What is the principle of the operation of thermal (electromagnetic) uncouplers?

5.6.8. What are the peculiarities of the design of the circuit breaker АП-50?

5.6.9. How is the arc extinguishing performed in circuit breakers АП- 50?

6 LABORATORY WORK #14 MAGNETIC STARTER

The duration of the laboratory work – 2 hours.

6.1 Purpose of work

The main purpose of the laboratory work is to study the design of the magnetic starter, as well as the principles of action, construction and characterization of its individual elements.

6.2 General notes

Magnetic starter is a switching device designed for frequent switching on and off of induction motors (IM) with short-circuited rotor. Magnetic starter includes, as a rule, a three-pole AC contactor and a thermal relay. A circuit of the start and control of IM with a magnetic starter is shown in Figure 6.1.

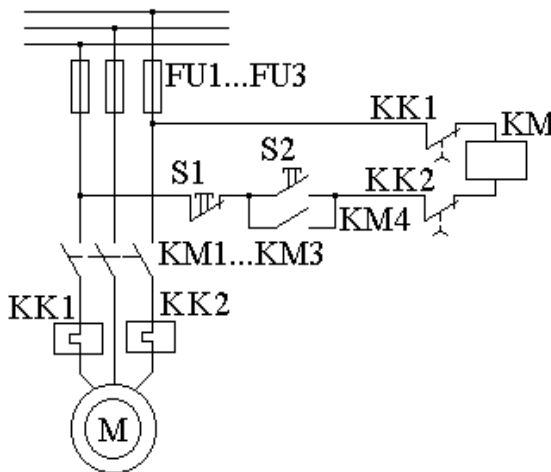


Figure 6.1 – Circuit of the start and control of IM with a magnetic starter

For protection against short circuits, the fuses FU1, FU2 and FU3 are

used in the circuit. The control circuit of the magnetic starter is powered by a linear voltage applied to the control motor M. The engine start is carried out by pressing the button SB1 ("Start"), as a result of which the power of the winding of the electromagnetic drive of the starter KM is received. After its operation, the main contacts of the starter KM1-KM3 are closed and the auxiliary contact KM4 closes (shunts) the buttons SB1 ("Start") as it returns to its original position when the effort is taken off. The engine is switched off by pressing the SB2 button ("Stop"), which removes the power from the winding of the KM. After the drive is triggered, the main contacts KM1-KM3 and the secondary contact KM4 are broken.

The main parameters of the contact system of switching devices, including the contactors of magnetic starters, are the openings and gaps of the contacts.

In the magnetic starters of the ПМЖІ series, as a rule, special arc devices are not used. The arcing in them is carried out at the expense of two successive gaps at each pole provided by the bridge contact system and the necessary opening of the contacts. High switching wear resistance of the contactor of the magnetic starter is provided with arc-resistant metal-ceramic contact soldering and the necessary gaps of the contacts.

In the operational process, a breakdown of one of the phases of the supply voltage occurs quite often, for example, due to the burnout of one of the fuses at a single-phase short circuit. In this case, the motor continues to receive power only from two phases, and the current in the stator is sharply increases. In order to avoid the engine failure, the thermal relays KK1 or KK2, which contacts turn off the circuit of the KM starter windings, should actuate, protecting the engine from the overload.

The main element of the thermal relay is a bimetallic plate, which consists of two metals, which have different temperature coefficients of linear expansion. Metal with a larger coefficient of linear expansion is called active, with a smaller— passive. Plates rigidly fastened with hot rolling or welding. If one end of such plate is fixed permanently and heated, the bend of the plate in the direction of the passive element will occur.

This phenomenon is used in thermal relays, thermostats, etc. Bimetallic plates can be heated with electric current flowing through the plates (direct heating), as well as with separate heating elements (indirect heating). Some devices combine direct and indirect heating (combined heating). The main disadvantage of thermal relays is the effect on the current of the ambient temperature. To avoid it, thermal compensator is used in

thermal relays. In the simplest case, it is an ordinary bimetallic plate, which bends in the direction opposite to the bend of the main bimetallic plate.

The main characteristic of the thermal relay is its time-current characteristic, which is the dependence of the time of operation of the relay on the value of current that flows through the heater. Protection will be provided only when the time-current characteristic of the thermal relay is located below the characteristics of the protected object over the entire range of possible overloads. Thermal relay should not be triggered in case of technological overloads (for example, the start of an IM).

The subject of research in this laboratory work is a magnetic starter of series ПМJI, designed to work in a network of alternating current up to 660 volts, at nominal currents from 10 to 200 A, depending on the type of execution. The commutation durability of the starters of the ПМJI series is determined by the application category and ranges from $320 \cdot 10^3$ to $2 \cdot 10^6$ "turning on-off" cycles. The system of the main contacts of the magnetic starter, which is investigated in the work, contains 3 poles; the system of auxiliary contacts is performed as a separate block and can have depending on the type of execution up to 4 contacts. The pressure between the main and auxiliary contacts is carried out by means of an electromagnetic drive of a straight-axle type with E-shaped magnet. Magnetic starters of the ПМJI series are equipped with a tripolar thermal relay of the type PTJI, which has a temperature compensator, a mechanism for accelerated triggering of the relay when the loss of phase is occurred, non-breaking current regulator and manual reverse mechanism.

6.3 Description of the laboratory setup

The magnetic starter, which is investigated together with the device for measuring of openings and gaps of the contacts, is mounted on the panel (Figure 6.2).

The circuit of the laboratory installation is shown in Figure 6.3. The laboratory installation is connected to the power supply with short switches. Circuit power supply occurs after switching on the SF circuit breaker.

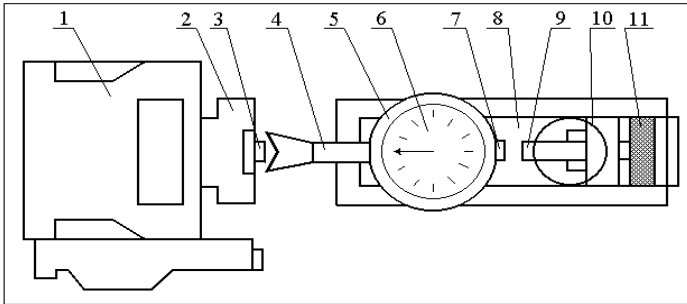


Figure 6.2 – Picture of the laboratory stand

6.4 Task

6.4.1. Study the design of the magnetic starter of series ПМЖ and the operation of the circuit for the start and control of IM with the help of a magnetic starter.

6.4.2. Experimentally determine return and reserve coefficients of the magnetic starter.

6.4.3. Measure the opening and gap of the main and auxiliary contacts of the magnetic starter.

6.4.4. Remove the time-current characteristic of the thermal relay PTJ and construct its graph.

6.4.5. Make conclusions on the work.

6.5 Methodical instructions

6.5.1. To perform the experimental part of the work, it is necessary to make the circuit by connecting terminals 1-1, 2-2, 3-3, 4-4, 5-5, 10-10, 11-11, 21-21 and 22-22 of the laboratory panel and stand with power supply and measuring devices.

6.5.2. To fulfill the requirement of 6.4.1, it is necessary to:

- a) set autotransformer T to zero;
- b) switch S1 and S2 to position "1"; S3, S4 and S5 –to zero position;
- c) turn on the circuit breaker SF;

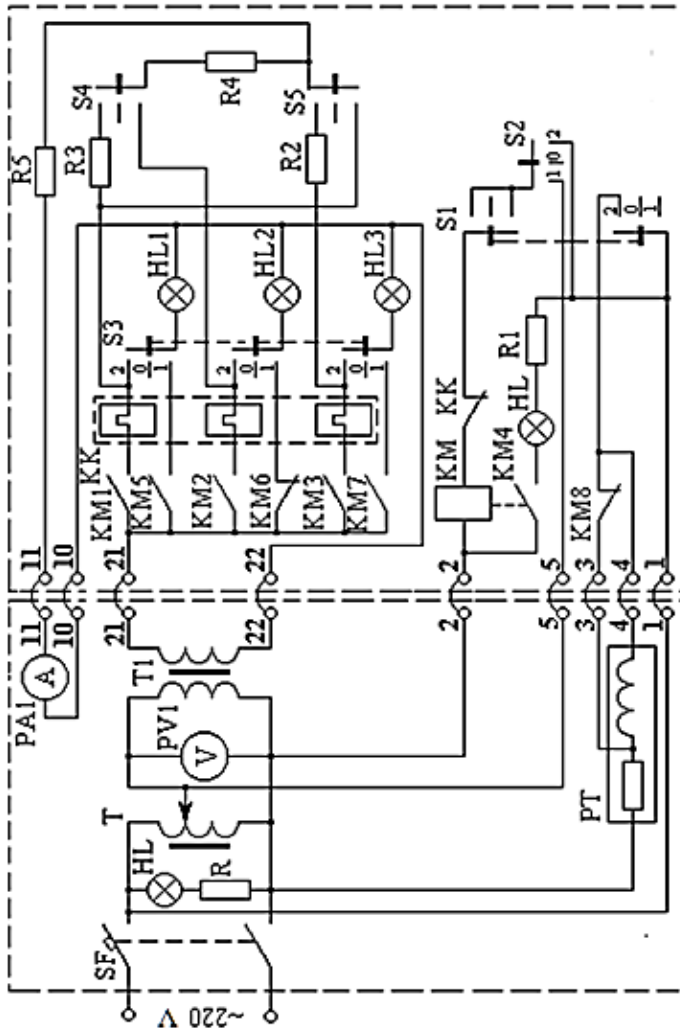


Figure 6.3 – Principal circuit of investigation of magnetic starter

d) steplessly increasing the voltage with the help of autotransformer T, with the help of the device PV2 fix the voltage U_{on} , which leads to the switching on of contactor;

e) steplessly reducing the voltage, fix the voltage U_{off} at which the

contactor of the magnetic starter is switched off;

f) set the autotransformer T to zero and turn off the SF;

g) return and reserve coefficients are determined by the formula

$$K_r = \frac{U_{off}}{U_{on}};$$

h) the received data should be written down in the Table 6.1.

Table 6.1 –Parameters for switching on and off of the contactor

U _{on} , V	U _{off} , V	U _n , V	K _r	K _{res}

6.5.3. To perform the task 6.4.2, it is necessary to set the switches S1 to S5 to zero, switch on the SF circuit breaker and set the voltage of 220 V (via the PV2 device) using the autotransformer T.

6.5.4. Determination of contact openings is carried out in the following sequence:

a) set switch S3 to position "2";

b) unscrew the locking screw 10 (see Figure 6.2) and bring the moving traverse 8 to the magnetic starter (until the rod 4 is pressed with the crossbar of the contact holder 3);

c) lock the screw 10 to fix the moving traverse 8;

d) turning the rim of the indicator of movement 6, set zero against its arrow;

e) turning the screw 11 clockwise, carry out the countdown of the opening on the scale of the indicator before the ignition of the signal lamps HL1, HL2 and HL3, recording the obtained data to the Table 6.2.

6.5.5. Gap of the the auxiliary contacts KM4, KM5 and KM7, as well as the openings of the auxiliary contact KM6 should be found in the same way, by setting the switch S3 to position "1". The obtained data should be included to the Table 6.2.

6.5.6. Determination of gap of main contacts is carried out in the following sequence:

a) set switch S2 to position "1", and switch S3 to position "2";

b) turn on the starter by setting the switch S1 to the position "2";

Table 6.2 –Values of opening and gap of main and auxiliary contacts

Parameters	Main contacts			Auxiliary contacts			
	KM1	KM2	KM3	KM4	KM5	KM6	KM7
Opening, mm							
Gap, mm							

c) bring the moving traverse 8 (see Figure 6.2) to the contact of the rod 4 with the traverse of the contact holder 3 and fix it with the locking screw 10;

d) indicator of motion 6 should be set to zero, with the screw 11 bring the pusher 10 to collide with the rod 7;

e) turn off the starter by setting the switch S1 to "0" position;

f) turning the screw 11 counterclockwise, take the indications of the moving indicator at the time of blowing out of the HL, HL1, HL2 and HL3 lamps;

g) received data should be written down to the Table 6.2.

6.5.7. Gaps of the auxiliary contacts KM4, KM5 and KM7, and the opening of KM6 should be found in the same way by setting the switch S3 to position "1".

6.5.8. Performance of 6.4.4 is made in the following sequence:

a) set switch S1 to position "2"; the switches S2, S3 and S4 are set to "0", and the switch S5 is set to "2";

b) set the thermal relay to its original position by pressing the thermal relay button 13 (see Figure 6.2);

c) using autotransformer T set the voltage 220 V (by the device PV2);

d) switch S2 to position "2", and S4 to "2"; reset the readings of the stopwatch PT to zero position;

e) set the switch S1 to position "2" and by the device PA8 (ammeter of an alternating current 10 A) fix the value of the current of overload;

f) after the operation of the thermal relay fix the indications of the stopwatch (one turn of the small arrow - 10 s);

g) set switch S1 to position "0";

h) give the thermal relay the opportunity to cool for 5-8 minutes, and then set it to its original position with the button 13 (see Figure 6.2);

i) set switch S4 to position "2", S1 switch to "2" and repeat the test at a new value of current of overload;

- j) set switch S4 to position "0" and remove two more points of the time-current characteristic by setting the switch S5 in turn to positions "1" and "2";
- k) plot the time-current characteristic in relative units

$$t = f\left(\frac{I}{I_s}\right),$$

where I - is the overload current,
 I_s - is the setting current of thermal relay operation.

6.5.9. The laboratory work report should contain:

- a) purpose of work and tasks;
- b) control and protection circuits of IM;
- c) return and reserve coefficients of the starter;
- d) results of measurement of the opening and gap of the contacts;
- e) time-current characteristic in the form of a Table and in a graphic form;
- f) conclusions on the work.

6.6 Questions for self-control

- 6.6.1. What is a magnetic starter and what functions does it perform?
- 6.6.2. Explain the operation of the starting and protective circuit of IM with the help of a magnetic starter.
- 6.6.3. What is the opening (gap) of contacts and why is it needed?
- 6.6.4. Name the main units of the magnetic starter and explain their purpose.
- 6.6.5. How is the protection of IM performed during overloads?
- 6.6.6. Explain the principle of the thermal relay.
- 6.6.7. Name the main nodes of the thermal relay and explain their purpose.
- 6.6.8. How is current setting of the thermal relay operation regulated?

7 LABORATORY WORK #15 AC THYRISTOR CONTACTOR

The duration of the laboratory work – 2 hours.

7.1 The purpose of the work

Study of the thyristor triggers operation. Investigation of a single-phase thyristor contactor with electromagnetic protection.

7.2 General notes

Along with contact switching devices, the industry manufactures and operates apparatuses on semiconductor devices, in particular thyristor contactors. They are used for starting, reversing and breaking the asynchronous motors, and for other active and active inductive loads.

Most heating units are supplied by us together with a total control system. To ensure complete compatibility and optimal design the complete manufacturing of both heating unit and control system is preferable. The efficiency of each heating system depends on the ability to control it accurately. Therefore, we have developed large expertise in offering the best solution for controlling each heating system application. A full range of control systems is available for hazardous areas utilising Ex d, Ex de and Ex p types of protection.

For applications where accurate control is not essential the on-off control is suitable. On-off control switches the entire heater load either on or off. The control devices can be thermostats or for slightly improved accuracy electronic controllers with a resistance thermometer PT100 or thermocouple as sensor. For loads above the switching capacity of thermostats or controller the load is switched via a contactor.

For more accurate control than on-off and for controlling high load heating systems step controlling is advisable. The heater load is divided into a number of steps. Each step is switched by a separate contactor. Depending on the temperature difference between set-point and process temperature the step controller selects the number of steps to be switched on.



Figure 7.1 – Thyristor Control Panels

Each thyristor is triggered once in every half cycle of the AC supply conducting ceasing at the end of the half circle as the current falls to zero. In this way the supply wave form is chopped resulting in a reduction on the RMS output of the thyristor stack. Phase-Angle fired thyristors give smooth, stepless control of the applied voltage, they are very suitable for heating elements with a large resistance difference between cold and operating temperature.

The thyristors are triggered at the beginning of a mains cycle and remain conductive for one or more complete cycles before being switched off for one or more cycles. This operation is continuously repeated thus limiting the average power input to the elements. Slow cycle thyristors generally have cycle times of several seconds and are not suitable for direct control of heaters with a great difference of the resistance between cold and operating temperature.

The optimum type of burst-fired thyristors is the single-cycle burst-firing type where the average power input is always reached over the minimum possible number of complete cycles (i.e. 50% power = cycle “on” + 1 cycle “of”). Resistive loads controlled by fast-cycle thyristors have a unity power factor and as only full mains cycles are delivered to the load there is no cumulative distortion of the mains supply. With heavy loads however, voltage drop may cause flickering lights and also affect sensitive equipment.

For very large loads or when the heater represents a significant proportion of the power generation capacity, the heater load is divided into a

number of small units each controlled by its own thyristor. A synchronising card control ensures that each thyristor is turned on and off consecutively during the set time period. There are no peak loads generated by a simultaneous controller action and load vleys are evened out.

The operation of thyristor contactors is based on the properties of thyristors within wide limits to change conductivity and to be in two states: on and off. The inclusion of the thyristor is carried out by the control signals, and disconnection is when the anode current reduced to the holding current (practically to the zero value). In particular, in AC circuits, this occurs when the natural current transition is zero. The thyristor can conduct current in one half-period, so for controlling the load in each phase of the device, two thyristors are switched on in parallel. The thyristor contactors are used for both single-phase and three-phase loads, and can be executed on thyristors, semistors and diodes. The variants of power thyristor switches are shown in Figures 7.2 and 7.3.

Each thyristor is conducting current during one half-period, therefore the allowable current through the load is:

$$I_l \leq \frac{\pi}{\sqrt{2}} I_{thy},$$

where I_{thy} is permissible average value of the current through thyristor.

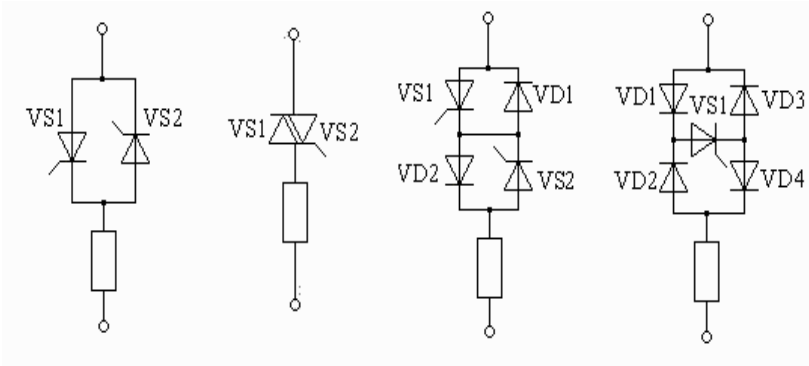


Figure 7.2 – Principal circuits of single-phase AC thyristor switches

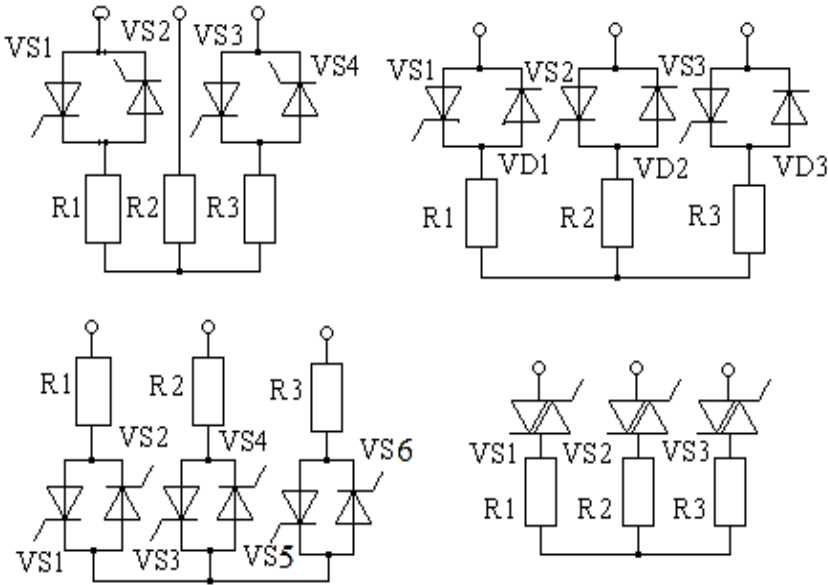


Figure 7.3 – Diagram of three-phase AC thyristor switches

For circuits with semistors and thyristors, conducting current during two half-periods, the permissible load current is as follows:

$$I_l \leq \frac{\pi}{2\sqrt{2}} I_{thy}$$

The maximum reverse voltage of the thyristor must not be less than the amplitude value of the network voltage:

$$U_{rev} \geq K_s \sqrt{2} U_n$$

where K_s – is safety factor, taking into account possible switching network overvoltages.

For switching devices with opposite-parallel thyristors connection, which is used most often, a simple and efficient control device can be created by connecting control electrodes with their anodes (or control electrodes with each other, which, in terms of the ongoing process, almost equivalent) with

any switch. In this case, the anode voltage applied to the thyristors is a source of control pulses. The principal diagram of this device is shown in Figure 7.4.

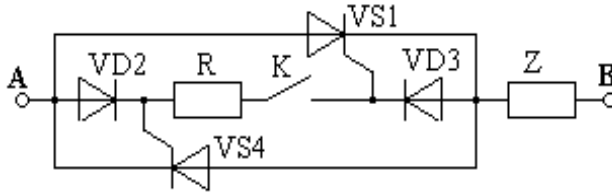


Figure 7.4 – Circuit diagram of thyristor switch

When the key K is closed in the half-period of the thyristor VS1 conductivity, under the action of the power supply positive polarity in the circuit of the control electrode of this thyristor, the current will be circled:

$A \rightarrow VD2 \rightarrow R \rightarrow K \rightarrow VS1 \rightarrow Z \rightarrow B$. After reaching the current in this circuit of magnitude sufficient to enable the thyristor VS1, the latter turns on. Starting from this moment, the voltage on the thyristors becomes equal to the direct voltage drop on the thyristor VS1, the current in the control circuit virtually disappears, but the thyristor remains in the open state until the end of the half-period. At the end of the half-period, the load current flowing through the thyristor VS1 decreases to zero, after which the thyristor closes until the next control pulse. In the next half-period, a similar process will take place with the VS4 thyristor.

Through the key K there are short current pulses, the amplitude of which is equal to the thyristor breakover current, and their duration can be determined (for the active load) by the formula:

$$t_u = \frac{1}{\omega} \arcsin \frac{I_b (R + R_l)}{U_{nmax}}$$

The time interval between the beginning of the half-period and the moment of the thyristor turning on is called the thyristor control angle α . When switching nominal loads, the value of α is set to the minimum. To reduce the overload current, the value of α increases. The curve of the current active load is similar to the voltage load curve (Figure 7.5, a).

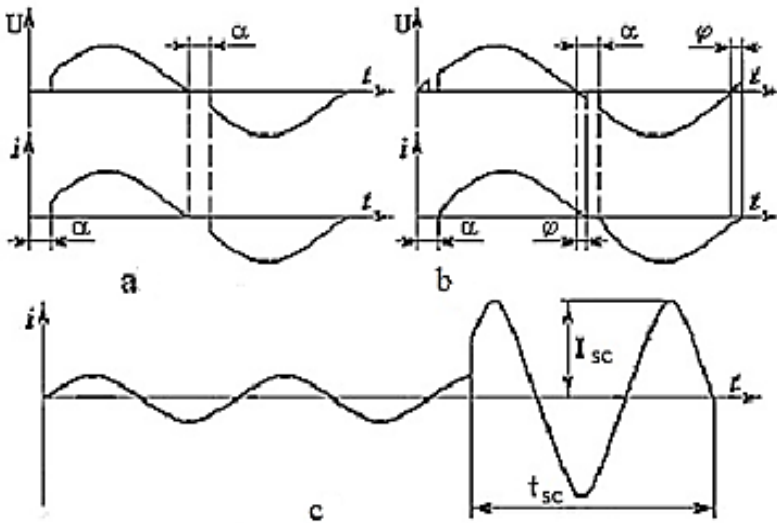


Figure 7.5 – Voltages and currents switched by thyristors:

a – at active load; b – at active-inductive load; c – when switching off the short circuit.

In circuits with active-inductive load the current lags behind the voltage phase, due to which the current curve does not coincide with the form of the voltage load curve. The current also flows when the network voltage is zero, as the result an idle pause is reduced (Figure 7.5 b).

When there is a short circuit, the switch-off is performed by removing control pulses from the thyristors, that is, by disconnecting their control circuits. The time off of short-circuit currents by the thyristor switch is smaller compared to the contact device, since in the absence of the control pulses the thyristor current takes less than one half-period of the power supply. The short-circuit switch-off time consists of the time of the security circuit elements operation.

time decreases, as well as the current value. After reducing the current to the nominal value, the circuit automatically returns to its original state. When the SB1 button is locked, a short circuit mode is formed.

In the circuit, begins to flow current sufficient for the operation of the K2 relay, contacts of which turning on the K4 relay, that is held in the operated state by one of its contacts. The remaining contacts of the K4 relay turn on the HL2 alarm and disconnect the thyristor control circuit, but the thyristor, while in the open state, continues to conduct the current until the end of the half-period, that is, to the current equals to zero. In this case there is a natural thyristor closing, resulting the circuit switching off. To return the circuit to the operating state, you need to press the SB4 button, thus the contact control circuit of K4 relay via thyristors is also actuated. The speed of electromagnetic protection is determined by the relay operating time, operated in the current protection circuit.

In parallel to the thyristor switch connected the contacts of the SF1. Switching on is occurred by the thyristor turn-switch and an automatic device for creation of the comparative study diagram. At the setup there are six control points of the investigated circuit for connecting the oscilloscope.

7.4 Task

7.4.1. Study the principle of single-phase thyristor contactor with electromagnetic protection.

7.4.2. Investigate the diagram given in Figure 7.5 when switching a circuit with a thyristor contactor:

- a) to get the voltage oscillograms from thyristors $U_{VS}(t)$:
 - in nominal mode with active and active-inductive load;
 - at the overload (active and active-inductive);
- b) get the oscillogram of the load voltage $U_1(t)$ as well as to determine the amplitude values, the switching angle α and the shift φ of the voltage and current phases:
 - in nominal mode with active and active-inductive load;
 - at the overload (active and active-inductive);
- c) to get the oscillogram of the load current $I_l(t)$, as well as to determine the amplitude values:
 - in nominal mode with active and active-inductive load;
 - at the overload (active and active-inductive);

d) get the oscillogram of the load $i(t)$ at short circuit and determine the time of the electromagnetic protection operation.

7.4.3. To investigate the circuit diagram given in Figure 7.5 when switching circuit by the circuit breaker in the modes specified in paragraph 7.4.2.

7.4.4. Calculate the parameters of load circuits.

7.4.5. Compare the received oscillograms and calculated parameters and determine the load type and magnitude effect, the protection operations, the type of switch (contact and non-contact) on the switching processes.

7.5 Methodical instructions

7.5.1. Prepare the oscilloscope.

7.5.2. Load type and operation mode set by the switches S2 and S3 (see Figure 7.5). Resistance R_{l1} corresponds to the nominal mode, R_{l2} - overload mode.

7.5.3. Turn on the SF laboratory setup and set 220 V

7.5.4. The input of the oscilloscope is connected to the control points of the circuit, depending on the investigated element of the circuit (see Figure 7.5). The current oscillograms $i(t)$ are to be taken with the help of R_{sh} shunt, the resistance of which is $3,75 \cdot 10^{-5} \text{ Ohm}$ (75mV – 20A).

7.5.5. Turn on the S5 switch and test the thyristor circuit according to p. 7.4.2 (the SF1 circuit breaker must be turned off).

7.5.6. Turn off S5 switch

7.5.7. Turn on the SF1 and test the circuit in accordance with p. 7.4.3.

7.5.8. The magnitude of the voltages u , the currents i and the time t on all oscillograms must be the same.

7.5.9. To measure the voltage on the elements of the circuit using an oscilloscope calibrator, or to calibrate the oscilloscope by the magnitude of the supply voltage of 16 V.

7.5.10. Measurement of the electromagnetic protection operation time is executed on the oscillogram $i(t)$ (S5 - switched on, SF1 - off): by alternating pressing the SB1 and SB4 buttons, obtain the oscillogram $i(t)$; according to the number of polar and nonpolar half-periods determine the minimum and maximum circuit switching off time.

7.5.11. Output data for the calculations are determined from the obtained oscillograms as a result of investigation. Calculations of the

required electrical parameters given in Table 7.1 are carried out using the formulas given below:

– for the given voltage and current:

$$A = \sqrt{\frac{1}{\pi} \int_{\alpha-\varphi}^{\pi+\varphi} A_m^2 \cdot \sin^2 \text{tgt}} = \frac{A_m}{\sqrt{2\pi}} \sqrt{\pi - \alpha + 2\varphi - \frac{\sin 2(\pi + \varphi)}{2} + \frac{\sin 2(\alpha - \varphi)}{2}};$$

where A_m – is amplitude value by oscillogram;

α - isthyristor switching angle (control angle);

φ - isphase shift between voltage and current.

For resistances, inductances and phase shift between voltage and current:

$$Z = U/I, R = Z \cdot \cos \phi, L = (\omega \cdot L)/\text{tg}\phi;$$

$$L = Z \cdot \sin \phi, L = \text{tg}\phi, L = \sqrt{(Z^2 - R^2)}/\omega,$$

$$\phi = \arcsin\left(\frac{\omega L}{Z}\right), \phi = \arctg(\omega L/R), \phi = \arccos\left(\frac{R}{Z}\right).$$

7.5.12. Fill in the Table 7.1 with the results of the calculations.

Table 7.1 – Electrical parameters of the investigated diagram

Mode	Protection	Type	$U_{\max}$, V	$I_{l \max}$, A	α , deg	φ , deg	Z, Ohm	R, Ohm	L, mH	U, V	I_l , A
Nominal		R									
		R-L									
Overload	Absent	R									
		R-L									
	Present	R									
		R-L									

7.5.13. The report should include:

- task;
- diagram of the thyristor contactor;
- oscillograms of the voltages and currents of the investigated circuit;

- d) Table, formulas and calculations;
- e) analysis of circuits, oscillograms and calculation results;
- f) conclusions.

7.6 Questions for self- control

7.6.1. The principle of operation of AC thyristor switches:

- a) controlled by contacts;
- b) controlled by pulse generator.

7.6.2. Advantages and disadvantages of AC thyristor contactors compared to contact.

7.6.3. Why does the pulse generator work at high frequency?

7.6.4. What single-phase (three-phase) contactors circuits exist?

7.6.5. Operation of electromagnetic protection of thyristor starter:

- a) for short-term overloads;
- b) with short-circuit loads.

7.6.6. What is the operation time of the thyristor contactor when occurs the short-circuit?

7.6.7. Explain the effect of the load type (active or active-inductive) on the shape of the current curve by the obtained oscillograms.

LIST OF REFERENCES

1. Агейкин, Д. И. Датчики контроля и регулирования [Текст]/ Д.И. Агейкин. – М.: Машиностроение, 1985. – 509 с.
2. Александров, Г. Н. Теория электрических аппаратов: учебник для вузов [Текст] / Г. Н. Александров. – М.: Высшая школа, 1985. – 312 с.
3. Александров, Г. Н. Проектирование электрических аппаратов: учебник для вузов [Текст] / Г. Н. Александров, В. В. Борисов, Г. С. Каплан и др.; под ред. Г. Н. Александрова. – Л.: Энергоатомиздат, Ленингр. отд-ние, 1985. – 448 с.
4. Андреев, В. А. Релейная защита и автоматика систем электроснабжения [Текст]/ В. А. Андреев. – М.: Высшая школа, 1991. – 495 с.
5. Аполлонский, С. М. Электрические аппараты управления: монография / С. М. Аполлонский, Ю. В. Куклев. – М.: РУСАЙНС, 2016. – 318 с.
6. Богородский, Н. П. Электрические материалы [Текст]/ Н. П. Богородский. – Л.: Энергоатомиздат, 1985. – 362 с.
7. Буль, Б. К. Электромеханические аппараты автоматики: учебник для вузов [Текст]: / Б. К. Буль, О. Б. Буль, В. А. Азанов и др.; под ред. Б. К. Буля. – М.: Высшая школа, 1987. – 162 с.
8. Гордон, А. В. Поляризованные электромагниты [Текст]/ А. В. Гордон, А. В. Сливинская. – М.: Энергия, 1994. – 240 с.
9. Диковский, Я. М. Магнитоуправляемые контакты [Текст]:/ Я. М. Диковский, И. И. Капралов. – М.: Энергия, 1970. – 152 с.
10. Жорняк Л. Б. Електричні апарати автоматики та керування / Л. Б. Жорняк, М. В. Антонова, В. В. Василевський.– Запоріжжя: НУ «Запорізька політехніка», 2022 - 414 с.
11. Клименко, Б. В. Електричні апарати. Електромеханічна апаратура комутації, керування та захисту. Загальний курс: навчальний посібник [Текст] / Б. В. Клименко. – Харків: Точка, 2012. – 340 с.
12. Коробков, Ю. С. Электрические аппараты автоматики [Текст]:/ Ю.С. Коробков, В. Д. Флора. – М.: Энергоатомиздат, 1991. – 344 с.

13. Розанов, Ю. К. Электрические и электронные аппараты [Текст] /Под ред. Ю. К. Розанова, Е. Г. Акимова и др. – М: Энергоатомиздат, 1998. – 160 с.
14. Сахаров, П. В. Проектирование электрических аппаратов [Текст]/ П. В. Сахаров. – М.: Энергия, 1977. – 560 с.
15. Снігірьов В. М. Електромеханічні апарати автоматики / В. М. Снігірьов, Л. Б. Жорняк. – Запоріжжя: ЗНТУ, 2016 –120 с.
16. Таев, И. С. Электрические аппараты автоматики и управления [Текст]/ И. С. Таев. – М.: Высшая школа, 1975. – 16 с.
17. Чунихин, А. А. Электрические аппараты [Текст]/ А. А. Чунихин. – М.; Энергоатомиздат, 1988. – 720 с.
18. Snigirov V. M. Electromechanical devices of automation / V. M. Snigirov , L. B. Zhornyak. – Zaporizhzhia: ZPNU, 2020 – 113 p.
<http://eir.zntu.edu.ua/handle/123456789/6833>
19. <http://eir.zp.edu.ua/handle/123456789/488>
20. <https://zp.edu.ua/kafedra-elektrichnih-ta-elektronnih-aparativ>
21. <https://moodle.zp.edu.ua>
22. <https://reلسis.ua/ua/about-us/reلسis>
23. <http://elektrik.info/main/school/1537-chto-takoe-tverdotelnoe-rele-i-kak-ego-pravilno-ispolzovat.html>
24. <https://www.sinusjevi.com/products/thyristor-control-panels>