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ALMATY UNIVERSITY OF POWER ENGINEERING & TELECOMMUNICATIONS

Department of Electrical Drive and Automatization

ELECTRICAL MACHINERY. SYNCHRONOUS AND ASYNCHRONOUS MACHINES

Methodical guidelines for performing laboratory works
for students of specialty 5B071800 - Electrical engineering

Almaty 2018

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The Methodical guidelines contain the necessary technical information about stands, the work program, methods of preparation, control questions, conducting experiments and analysis of results.

The Methodical guidelines are designed for students of specialty 5V071800 - Electrical engineering.

Illustrations - 10, tables - 15, bibliographies - 7 titles.

Reviewer: Cand.sc., associate professor G.Sh. Ospanova.

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Content

1 Description of the laboratory stand. Purpose and composition of the stand

The Laboratory stand "Fundamentals of Electrical Machines and Drives" is designed to teach students of different specialties of specialized secondary and higher educational institutions, students of the discipline "Electrical machines", "Electrical machines and basics of the electric drive", "Electric Drive", “Drive and control systems”.

The stand can also be used for teaching students of vocational schools and students of industrial training centers of professional development of engineers and technical workers.

The stand includes:

- stand (power) supply module (SSM);
- (power) supply module (SM);
- module of additional resistances №1 (MAR1);
- module of additional resistances №2 (MAR2);
- measuring module (MM);
- power module (PM);
- module of the frequency converter (FC);
- thyristor converter module (TC);
- regulator module;
- single-phase transformer module;
- cage 2x5;
- electric machinery unit;
- methodological description;
- technical description.

Brief description of the stand modules is presented in Appendix A.

2 Methodological guides for laboratory works

2.1 Description of circuit assembly

To facilitate fulfillment of the laboratory works there are given an example of starting an asynchronous motor with a short-circuited rotor. It is recommended to read these instructions before starting the laboratory work. To start an asynchronous motor, it is necessary to feed three-phase voltage 3x380V to the stator. Three-phase adjustable resistance is introduced to reduce the starting current in the stator winding, which is deduced in sequence from "yes" to "0" position.

Supply voltage to the laboratory stand will be integrated by circuit breaker QF1 of the stand supply module. Supply 3x380V voltage conducting will be done by the circuit-breaker QF2 of the supply module (terminals A, B, C).

Asynchronous motor connected to the power module, has the terminals of the windings on the front of power module. The electric motor marked accordingly on the front panel of the module. The stator circuit includes additional resistors of module additional resistances №1. For the current and voltage control, ammeter and voltmeter of AC are switched to the measurement module.

In order to improve the visibility of a set of circuits in the laboratory work, there are not presented module style electric schemes, and circuit diagrams are simplified. An option of such a scheme is seen in figure 1.

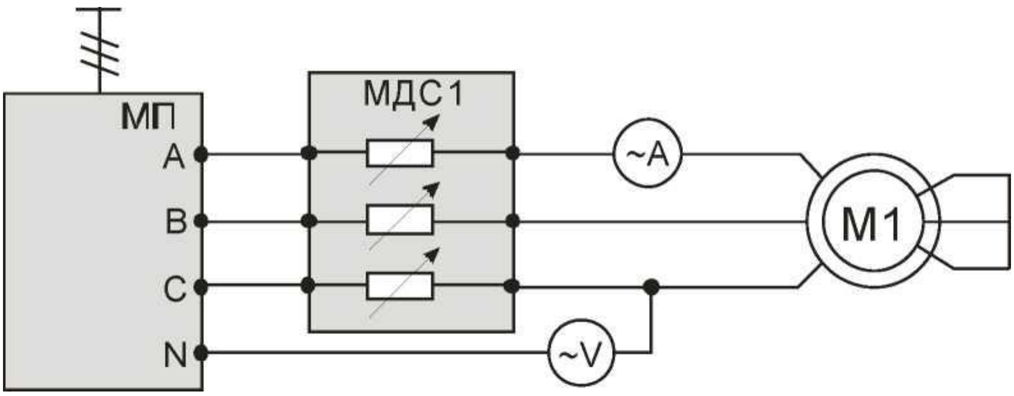

Figure 1 - Simplified electrical circuit

In this scheme, the stand supply module is not shown because power module stand panels do not perform any connections. Although the windings of the stator and rotor windings of an induction motor, the conclusions of the windings of the armature and the excitation DC motor part of the power module, however in the diagram, the engine shows as a separate element. This is done in order to avoid cluttering the figure. Measuring devices of measuring module also shown by the individual elements.

Work 1. Research of the double-wound single phase transformer

The purpose of the work: Experimental research of the properties of a single-phase two-winding transformer.

The work program: *T*ake the external characteristics of the transformer with a resistive load and compare it with theoretical calculated value.

Explanatory notes:

The laboratory work uses the following modules:

- stand power supply module (SPSM);
- (power) supply module (SM) (PM in figure 1.1);
- single-phase transformer module (SpTr);
- measuring module (MM).

Before carrying out the work it is necessary to bring the modules to the initial state. To do this, when the circuit breaker QF1 is switched off:

- establish SA2 single-phase transformer module switch to the position «∞».

In work the single-phase two-winding transformer is used, catalog data of which are given in appendix G.

External characteristic of the transformer. The external characteristic is the secondary voltage of the transformer from the load current $U_2=f(I_2)$ at $U_1=U_{1N}$=const. The circuit for taking the external characteristic is shown in figure 1.1.

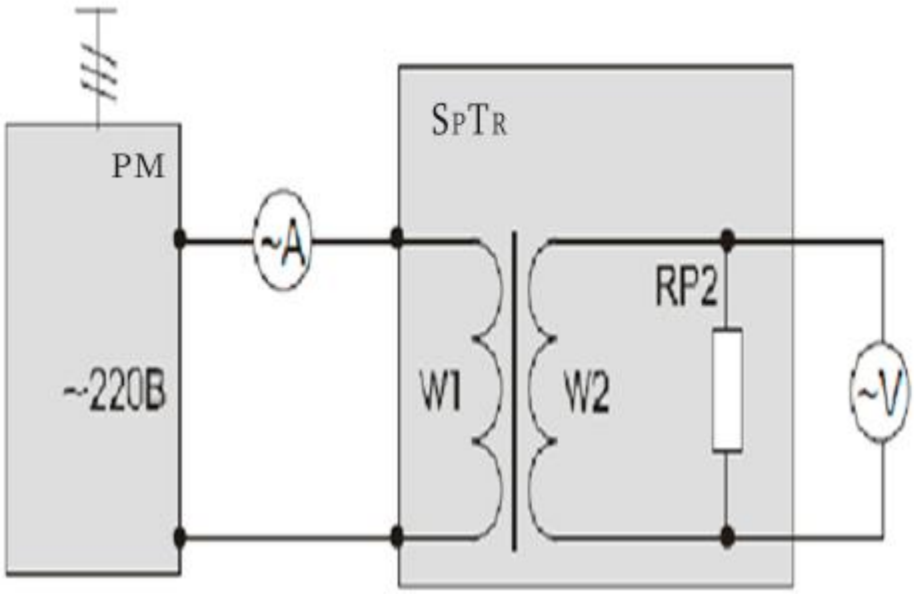

Figure 1.1 - Scheme for taking the external characteristics of the transformer

A single-phase transformer is connected to an unregulated ~ 220 V AC power source of the power module. To create a load in the secondary circuit of the transformer, the adjustable resistance RP2 is switched on. Parameter monitoring in the primary and secondary windings is carried out with the help of devices RU and RA of the module MM (measurement module).

Experience is carried out in the following order:

- turn on the circuit breakers QF1 and QF2 modules MPS and MP respectively, the transformer operates at idle, this point is put in the table 1.1;
- switch SA2 of the OtDr module to change the current of the secondary winding until the current in the primary winding is equal to

$$I_{1\text{H}} = \frac{S_\text{H}}{U_{1\text{H}}},$$

where S_H –total power, кVA;

U_{1H} – nominal secondary voltage, V.

Do not put the switch SA2 to the "0" position. Data experience to bring in the table 1.1.

After carrying out the experiment, move SA2 to the "∞" position, turn off the QF2, QF1 automata.

By the experimental data, it is possible to construct an external characteristic of the transformer and calculate the load and transformations factors.

Table 1.1 - Study of a single-phase double-winding transformer

Experimental data		Calculation data		
U_2	I_1	K_{tr}	K_{lo}	I_2
B	A			A

The coefficient of transformation,

$$K_{tr} = \frac{U_2}{U_1},$$

where U_2, U_1 - the voltage of the secondary and primary windings at idle.

Secondary winding current, A

$$I_2=I_1K_{tr}.$$

The load factor,

$$K_{lo} = \frac{I_2}{I_{2N}}.$$

Control questions.

1. Why is the idle current of the transformer very small and makes just a small percent of the rated current?

2. How can one explain that the efficiency of a transformer is usually determined by the calculation method?

3. Operation of a single-phase transformer under load.

4. Physical working conditions of the transformer under load. Equations of voltages.

5. Vector diagram of magnetic motive force and currents.

6. Substitution schemes of the transformer.

8. Equations of voltages and currents of the transformer.

Work № 2. Research of the direct current generators of independent and parallel excitation

The purpose of the work: Research of the working properties of DC generators by taking experimental characteristics.

The work program:

1) To study the scheme for the experimental study of a direct current generator (hereinafter referred to as DCG), the composition and purpose of the modules used in the work.

2) In the laboratory, to collect a scheme for carrying out each experiment and to perform a trial switch.

3) Take the external characteristic of the direct current generator of parallel excitation (with self-excitation) $U_{lo}=f(I_{an})$ with the control resistance in the circuit excitation $r_p=0$.

4) Take the short-circuit characteristic of the DC generator of independent excitation $I_{lo}=f(i_V)$ for $U_{lo}=0$ and n=const.

5) Take the external characteristic of the direct current generator of independent excitation $UAN=f(I_{AN})$ for i_{AN}=const.

6) Take the control characteristic of the DC independent-current generator $I_e=f(I_{an})$ at U_{an}=const.

7) Process the results of the experiments and present a report on the work.

Explanatory notes:

In the laboratory work the following modules are used:

- stand (power) supply module (SSM);
- (power) supply module (SM);
- module of additional resistance number 1 (MAR1);
- module of additional resistance number 2 (MAR2);
- power module (PM);
- measuring module (MM).

The direct current generator (M2) is a part of the electric machine aggregate including an asynchronous alternating current machine (M1) and also a pulse rotation speed sensor (M3).

1. External characteristic of a direct current generator of parallel excitation.

The external characteristic is the dependence $U_{an}=f(I_{an})$ for $r_{pr}=0$ and n=const and is taken by a voltage decrease.

The scheme for taking the characteristic is shown in figure 2.1.

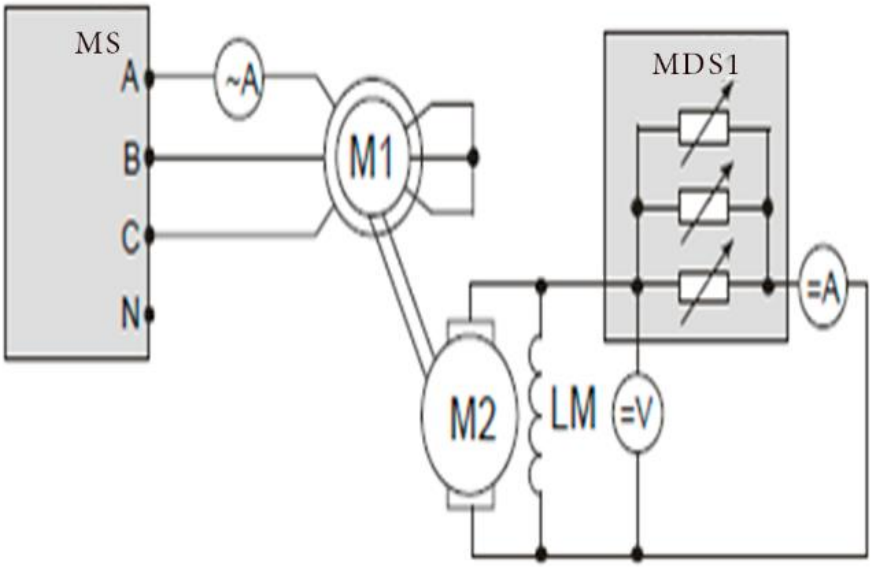

Figure 2.1 - Scheme for taking of the external characteristic of a direct current generator of parallel excitation.

The drive motor is presented by an induction motor with a squirrel-cage rotor M1, powered by a three-phase voltage of 3x380 V. The armature circuit of the DC generator is connected to the adjustable resistance of MAR1

The LM excitation winding is connected in parallel with the armature circuit.

To monitor the stator current I_C of the drive motor, the load current I and the voltage of the generator $U_{я,}$ the arrow devices of the measuring module ~ A, =A, =V are used.

The experiment is carried out in the following order:

- set switch SA1 of (MAR1) to position "∞";
- turn on the automata (circuit breakers) QF1 and QF2 of supply modules. The generator is driven into rotation with the load switched off. The voltage is controlled at the generator terminals. If there is no voltage U_{an}, it means that the magnetic flux generated by the excitation winding current is directed towards the remnant induction, and it is necessary to change the polarity of the excitation winding of the DC machine when the automata QF1 and QF2 are disconnected. The voltage of the generator at the load current $I_{load}=I_{an}=0$ is entered into Table 1;
- after taking of the idle point by the switch SA1 of the module MAR1 to change the resistance in the direction of decreasing, to increase the load current. Change the load current up to 1,5A, and record the experimental data in table 2.1.

Attention! Do not put SA1 in the "0" position.

Table 2.1

U_{an}, B								
I_{an}, A								
I_s, A								

After conducting the experiment, set all module switches to the starting position.

Characteristics of idling of the generator of direct current of independent excitation.

This characteristic is the dependence $E_{an}=f(i_e)$, $I_{lo}=0$, n=const.

The scheme for taking the idling characteristics of a DC generator of independent excitation is shown in figure 2.2.

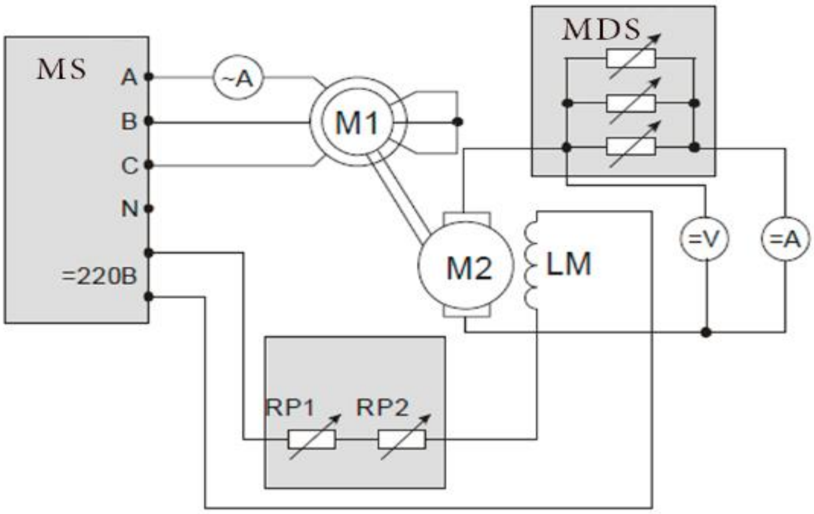

Figure 2.2 - Scheme for taking of the characteristics of a DC generator of independent excitation

The drive motor is represented by an asynchronous motor with a short-circuited rotor M1, powered by a three-phase voltage of 3x380 V. The excitation winding of the DC machine is switched on through the series-connected resistors RP1 and RP2 of the MAR2 (MDS2) module to "= 220" of the supply module SM.

MAR1 resistance is added to the armature circuit of the DC motor.

With the QF1, QF2 automata switched off, set all the modules to the initial state:

- set switch SA1 of the module MAR1 to the position "∞".
- set switch SA2 of the module MAR2 to the position "0".

The experiment is carried out in the following sequence:

- Switch on the QF1 and QF2 automata of the SSM and SM modules. The DC generator is driven into rotation, and at i_{exc}=0 the voltage from the residual induction flow is measured.

The data should be entered into table 2.2;

- set the switch SA1 of the module MAR2 to the position "0";
- change the excitation current by the SA2 switch of the MAR2 module.

Enter the data of the experiment into table 2.2.

Table 2.2 - Results of the experiment

I_{ex}, A								
U_{an}, B								

After the experiment, set all module switches to their home position, turn off the QF2, QF1 automata.

The calculation data.

Excitation current of the generator, A:

$$i_{ex} = \frac{U_{in}}{r_{ex} + R_{ma}}.$$

Using the data obtained during the experiment, build the idling characteristic and determine the saturation degree of the magnetic circuit of the direct current generator with nominal EMF:

$$E_{an} = U_{lo} + I_{an} r_{an},$$

where U_{lo} is the rated voltage;

r_{an} - is the resistance of the armaturte circuit (appendix B).

The saturation coefficient k_{μ} is determined by the ratio of the segments AC to AB (figure 2.3),

$$K_{\mu} = \frac{AC}{AB},$$

where AC is the EMF of the entire magnetic circuit, AB is the EMF of the air gap.

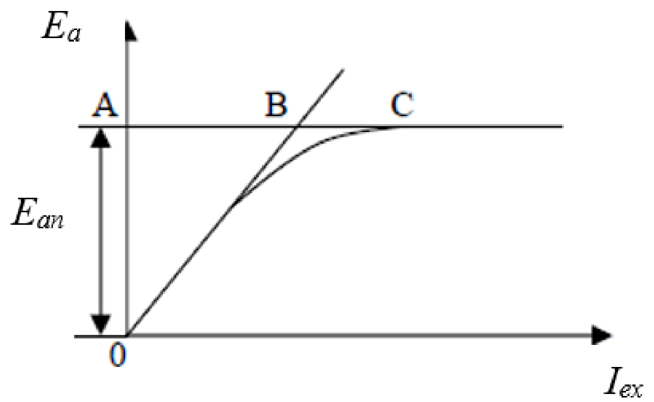

Figure 2.3 - Characteristics of idling of the generator of direct current of independent excitation

At K_μ <1.2 the magnetic circuit is weakly saturated, at K_μ=1.2...1,35 - moderately saturated and at K_μ>1,35 - strongly saturated.

Characteristic of short-circuit of the generator of a direct current of independent excitation. This characteristic is the dependence $I_{ex}=f(i_{ex})$ for $U_{an}=0$ and n=const and is taken when the output terminals of I_{ex} enerator armature circuit are short-circuited.

Set the modules to the initial state:

- set the switch SA1 of the module MAR1 to "∞".
- set the switch SA2 of the module MAR2 to the position "1100".
- turn on the QF1 and QF2 automata of the SSM and the supply module respectively, the drive motor will start;
- at $i_{ex}=0$, take the value of I_{an} (because of the presence of a residual magnetic flux, the armature current may be different from zero), enter the given point into Table 3;
- by the switches SA1 and SA2 of the MAR2 module increase the excitation current until $I_{an}=I_{an}$.

The data should be entered in table 2.3.

Table 2.3

I_{ex}, A	0								
i, A									

After conducting the experiment, set all module switches to their home position, turn off the QF2, QF1.

External characteristics of a direct current generator of independent excitation

This characteristic $U_{an}=f(I_{an})$ is taken by a voltage drop at a constant excitation current i_{ex}=const.

In order to compare the external characteristics of a direct current generator of parallel and independent excitation, it is necessary that they start from the same point, i.e. at $I_{an}=0$ the voltage U_{an} should be the same.

Set the modules in the initial state:
- set the switch SA1 of the module MAR1 to the position "∞";
- set the switch SA2 of the module MAR2 to the position "1100".

The experiment is carried out in the following sequence:
- turn on the automata switches QF1 and QF2 of the SSM and the supply module, respectively;
- with switches SA1 and SA2 of the module MAR2 (MDS2) set the excitation current, at which the U_{an} would be equal to the voltage of the generator of parallel excitation at I_{an}=0 (table 2.4) and this excitation current would be kept constant.
- using the switch SA1 of the MAR1 (MDS1), change the resistance to increase the load current or the generator current to I_{an}=1,3 A.
Attention! Do not set SA1 to the position "0".
Enter the experimental data into table 2.4.

Table 2.4

I_{an}, A								I_{ex}
U_{an}, B								

After the experiment, set all the module switches to the initial state, turn off the QF2, QF1 automata.
Regulating characteristic of a direct current generator of independent excitation. This characteristic represents the dependence $i_{ex}=f(I_{an})$ for U_{an}=const and n=const.
- set the witch SA1 of the module MAR1 to the position "∞";
- set the switch SA2 of the module MAR2 to the position "1100".
The experiment is carried out in the following sequence:
- turn on the circuit breakers QF1 and QF2 of the SSM and SM modules, respectively;
- using the switches SA1 and SA2 of the module MAR2, set the U_{an} which was at the nominal current of the I_{AN} when the external characteristic was taken (table 4.4). This point is entered in table 4.5;
– changing the position of the switch SA1 of the module MAR1 from «∞» in the direction of decreasing, increase the armature current, until the generator voltage is constant. This is achieved by increasing the excitation current.
Attention! SA1 of the module of additional resistance number 2 should not be set to position "0".
The data of the experiment are entered into table 4.5.

Table 4.5- Results of the study

I_{an}, A								U_{an}
$i_в$, A								

After the experiment, set all the module switches to their home position, turn off the QF2, QF1 automata.

Control questions.

1. Under what conditions does self-excitation of the direct current generator of parallel excitation take place?

2. Why is the external characteristic of the generator of parallel excitation softer, i.e. the voltage at the generator terminals decreases significantly with load in comparison with the generator of independent excitation?

3. Determine the saturation coefficient of the magnetic system of the DC generator at the voltage, which corresponds to the rated current of the generator of independent excitation.

4. Classification, construction of DC electric machines and the design of their main units.

5. The principle of the DC machine, the role of the collector. EMF and electromagnetic moment of the DC machine. Methods of excitation of direct current machines.

6. Definition and essence of the switching process, types of commutation. Causes of arcing on the collector. Ways to improve the switching.

7. Classification of DC generators by excitation method, their structure and principles of operation.

8. Characteristics of generators with independent, parallel, sequential and mixed excitation.

Work №3. Study of the DC motor of independent excitation

The program of the work:

1) To study the scheme for experimental research DC motor of independent excitation (hereinafter referred to as DCMIE), the composition and purpose of the modules used in the work.

2) Collect the scheme for an experimental research of the DCMIE. Perform a trial switch.

3) Take the natural mechanical characteristic.

4) Take the artificial mechanical characteristic with addition of resistance in the armature circuit.

5) Take the artificial mechanical characteristic at weakening of the magnetic flux.

6) Take the artificial mechanical characteristic at a lower voltage of the armature circuit.

7) Take the workings characteristics of the DCMIE.

8) Take the adjusting characteristics of the motor when changing voltage applied to the motor terminals.

9) Take the adjusting characteristics of the motor by weakening of the magnetic flux.

10) Conduct the experimental data processing, compile a report and make a conclusion on the work.

Explanatory notes: In the laboratory work the following modules are used:
- Stand (power) supply module (SSM);
- suply module (SM);
- thyristor converter module (TC);
- power module (PM);
- module of additional resistance number 1 (MAR1);
- module of additional resistance number 2 (MAR2);
- measuring module (MM).

Before conducting the laboratory work, you must bring the modules to their initial state:

- the button "Power" of the thyristor converter module is brought to the lower position, switch SA6 - to the lower position. Thyristor converter must be set to the speed control mode (appendix E);

- the switch SA1 of the MAR1 should be set to the position "∞";

- set the switches SA1, SA2 of the MAR2 to the position"0".

The DC machine under study is part of the electro machinery unit, which includes the actual DC machine under investigation M2, the loading machine - AC machine M1 and pulse speed sensor M3.

The scheme for investigating the DC motor of independent excitation is shown in figure 3.1.

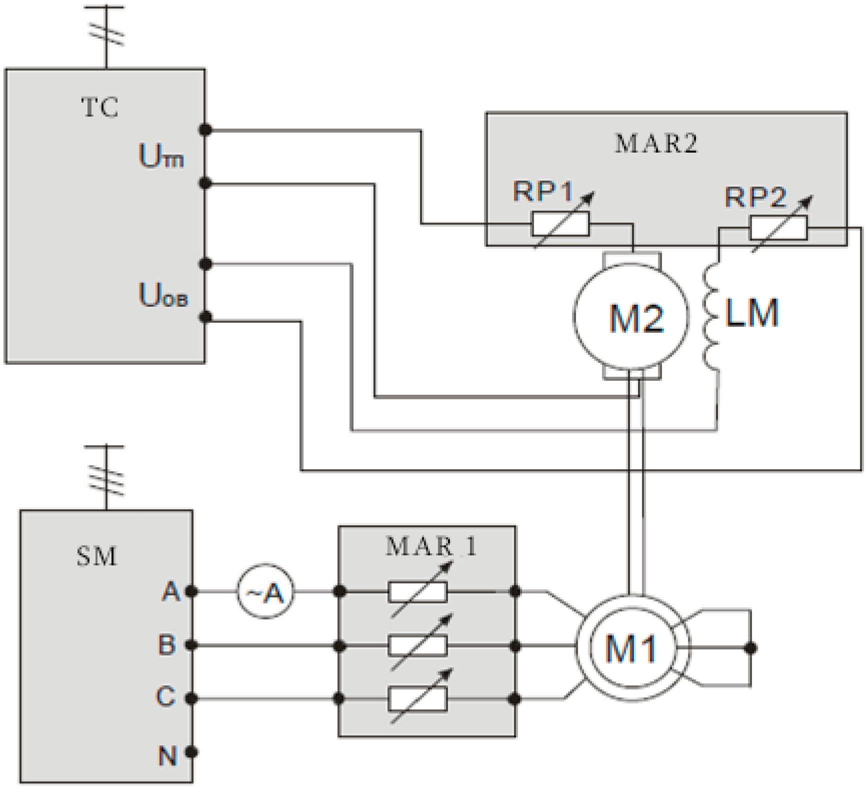

Figure 3.1 – The scheme for investigation of a DCMIE

The armature circuit of the DC motor, through the additional resistance RP1 of the MDS2 module and the current and voltage sensors, is connected to the terminal of the U_{tc} of the thyristor converter. The exciting coil is connected, through the additional resistance RP2 of MAR2, to the nonregulated source of DC U_{we} of the TC module.

The asynchronous motor is connected, through the additional resistance (MAR1), directly to the power network SM. DC motor parameters are controlled by using the thyristor converter module CM. The current of the stator I_s is measured by means of the ammeter of the MM module.

3.1 Determining the direction of rotation of motors

Before carrying out experiments it is necessary to determine the direction of rotation of the motors:

- switch on the QF1 and QF2 automata of the SSM and SM modules, respectively;
- set the enabling switch for operation of the TC (SA6) and, having chosen the direction of rotation, set the voltage 200V by the potentiometer RP1; remember the direction of the motor rotation;
- move the RP1 of the TC module to the most counterclockwise position, set off the enabling switch for TC (SA6) operation;
- remove the resistance from the stator circuit of the squirrel-cage induction motor, start the motor, remember the direction of rotation. It must be opposite to the direction of rotation of the DC motor. If this is not the case, switch SA1 of module MAR1 to the position "∞", change the phases "A" and "B" on the power module and check the direction of rotation.

3.2 The natural mechanical characteristic of a DC motor of independent excitation

The natural mechanical characteristic of a DC motor of independent excitation represents dependence of the rate on the load moment at a constant value of the voltage at the motor terminals and with absence of additional resistance in the armature circuit: $n=(M_{lo})$ at U_{an}=const, i_{ex}=const and $R_{add}=0$.

The experiment is carried out in the following sequence:

- switch on the QF1 and QF2 automata of the SSM and SM modules, respectively;
- set the enabling switch for operation of the TC (SA6), and, after selecting the direction of rotation by the potentiometer RP1, set the voltage 200V;
- use the switch SA1 of the module MAR1 to enter resistance, keep loading the DC motor until the armature current reaches 1.5A or the stator current reaches $I_C=I_{lo}$.

Enter the data of the experiment into table 3.1.

Table 3.1 - Results of the experiment

n, turn/min.				
I_{an}, A				
M, N·m				

After the experiment, set all the module switches to their original state.

The calculation data.

Moment on the motor shaft, N·m.

$$M = C_м \Phi I_{an},$$
$$С_м \Phi = \frac{U_{lo}}{\omega_0},$$

where U_{lo} - the rated voltage of the DC motor (appendix A);

ω_0 - the synchronous rotational speed of the DCM (appendix A).

By the data of table 3.1 build characteristics n=f(M_{lo}), n=f(I_{an}).

3.3 The artificial mechanical characteristic of a DC motor of independent excitation with introduction of resistance into the armature circuit

The artificial mechanical characteristic of DCMIE represents the dependence of the on the load moment with additional resistance in the armature circuit:

n = f(M_{lo}) at U_{an}=const, i_{ex}=const.

The experiment is carried out in the following order:

- switch on the QF1 and QF2 automata of the SPM and PM modules, respectively;
- set the switch SA1 of the module MAR2 to a non-zero position, make the first measurement;
- set the enabling switch for operation of the TC (SA6), and, after choosing the direction of rotation by the potentiometer RP1, set the voltage 200V;
- use the switch SA1 of the module MAR1 to enter resistance, keep loading the DC motor until the armature current reaches 1.5A or the stator current reaches I_C=I_{lo}.

Enter the experimental into the table 3.2.

Table 3.2 Results of the experiment

R_{add}=				
n, turn/min.				
I_{an}, A				
M, N·m				

By the data of table 3.2 construct the characteristics $n=f(M_{lo})$, $n=f(I_{an})$.

3.4 Artificial mechanical characteristic of the DCMIE with magnetic flux attenuation

The artificial mechanical characteristic of a DCMIE represents dependence of the rate on the load moment at a constant value of the voltage at the motor terminals and introduction of additional resistance into the armaturte circuit: $n=f(M_{lo})$ at U_{lo}=const, i_{ex}=const.

The experiment is carried out in the following order:

- switch on the QF1 and QF2 automata of the SSM and SM modules, respectively;
- set the enabling switch for operation of the TC (SA6), and, after choosing the direction of rotation by the potentiometer RP1, set the voltage 200V;
- set the switch SA2 of the module MAR2 to a non-zero position, make the first measurement;
- use the switch SA1 of the module MAR1 to enter resistance, keep loading the DC motor until the armature current reaches 1.5A or the stator current reaches $I_C=I_{lo}$.

Enter the experimental data into the table 3.3.

Table 3.3 - Results of the experiment

R_{add}=				
n, turn./ min.				
I_{an}, A				
M, Hm				

After the experiment, set all the module switches to their original state. By the data of table 3.3, construct the characteristics $n=f(M_{lo})$, $n=f(I_{an})$.

3.5 The artificial characteristic with reduced voltage of the armature circuit

The artificial mechanical characteristic of the motor of independent excitation is taken at reduced voltage of the armature circuit and nominal excitation flux of the machine: $n=f(M_{an})$ at U_{an}=const, i_{ex}=const.

The experiment is carried out in the following sequence:

- switch on the QF1 and QF2 automata of the SSM and SM modules, respectively;
- set the enabling switch for operation of the TC (SA6), and, after choosing the direction of rotation by the potentiometer RP1, set the voltage according to the teacher’s instruction;

- use the switch SA1 of the module MAR1 to enter resistance, keep loading the DC motor until the armature current reaches 1.5A or the stator current reaches $I_C=I_{lo}$.

The data of the experiment should be entered into table 3.4.

Table 3.4 Results of the experiment

U_{an}=				
n, turn./ min.				
I_{an}, A				
M, Hm				

After the experiment set all switches modules into the initial state. By the data of table 3.4 construct the characteristics $n=f(M_n)$, $n=f(I_{an})$.

3.6 Performance characteristics of the DCMIE

Working characteristics of the motor are represented by the dependences of the frequency of rotation, electromagnetic moment, armature current and efficiency on the useful power on the motor shaft at constant value of the voltage at the motor terminals n or ω; M, I_{an}, $\eta=f(P2)$ with $U_{an}=U_{anн}$=const, i_{ex}=const.

The experiment is carried out in the following order:

- turn on the automata QF1, QF2;
- set the enabling switch for operation of the TC (SA6), and, after selectng the direction of rotation by the potentiometer RP1, set the voltage $U_{an}=0{,}75\cdot U_n$;
- use the switch SA1 of the module MAR1 to enter resistance, keep loading the DC motor until the armature current reaches 1.5A or the stator current reaches $I_c=I_n=1{,}3A$. $I_C=I_{lo}$;
- as you increase the load using the potentiometer RP1 of the TC module, keep the output converter voltage at the given level.

Enter the experimental data into table 3.5.

Table 3.5 - Results of the experiment

Experimental data			Calculation data											
U_{an}	I_{an}	n	ω	I_{exc}	Pan	$\Delta P_{em.}$	P_1	$C_м$	M	I_{an0}	M_0	M_2	P_2	η
В	А	rpm	1/с	А	Вт	Вт	Вт		Нм	А	Нм	Нм	Вт	%

After the experiment set all module switches in the initial state.

Calculation data.

Power, supplied to the motor armature, W:

$$P_{an} = U_{an}\cdot I_{an}.$$

Electrical losses in the excitation circuit, W:

$$P_э = i_{ex}^2 r_{ex20},$$

where r_{ex} - resistance of the excitation winding (appendix B);
i_{ex} - the excitation current of a DC motor, A

$$i_{ex} = \frac{U_{ex}}{r_{ex}} = \frac{200}{r_{ex}}.$$

Power supplied to the DC motor, W:

$$P_1 = P_{AN} + \Delta P_{el}.$$

Electromagnetic moment, N·m:

$$M = C_м I_{an},$$

where C_M is taken depending on the angular frequency of rotation (appendix B). The moment of the idling engine, proportional to mechanical losses and losses in steel, N·m,

$$M_0 = C_M \cdot I_{an0},$$

where I_{an0} - is accepted depending on the angular frequency of rotation (appendix B).

Useful moment on the shaft of the DC motor, N·m:

$$M_2 = M - M_0.$$

Useful power on the motor shaft, W

$$P_2 = \omega M_2.$$

Efficiency, %

$$\eta = \frac{P_2}{P_1} 100\%.$$

By the data of table 3.5 build the working characteristics.

3.7 Adjustment characteristics of the motor with the change of the voltage applied to the motor terminals

The frequency of rotation of DC motors is defined by:

$$n = \frac{U_{an} - I_{an} R_{an}}{C_e \phi}.$$

The experiment is carried out in the following order:

- switch on the QF1 and QF2 automata of the SSM and SM modules, respectively;
- set the enabling switch for operation of the TC (SA6), and, after choosing the direction of rotation by the potentiometer RP1, set the voltage U_{an}=200V;
- use the switch SA1 of the module MAR1 to enter resistance, keep loading the DC motor until the armature current reaches approximately $I_{AN}≈0.5I_{an}$, and this switch position remains unchanged, which corresponds to M_2≈const;
– change the RP1 position of the TC module in such a way that the voltage at the terminals of the armature circuit U_{AN} decreases to about $0.5U_{ANH}$.

The obtained data should be entered in Table 3.6.

Table 3.6 - Results of the experiment

Experimental data			Calculation data											
U_{an}	I_{an}	n	ω	I_{ex}	Pan	ΔP_{el}	P_1	C_M	M	I_{an0}	M_0	M_2	P_2	η
V	A	rpm	1/s	A	W	W	W		N·m	A	N·m	N·m	W	%

After the experiment, set all module switches to their original state.

Calculation data are calculated in the same way as when taking the working characteristic.

By the data of Table 3.6, construct the dependences n=f(U_{AN}) and η=f (U_{an}).

3.8 The motor adjusting characteristics by attenuation of the magnetic flux

Taking the adjusting characteristic by attenuation of the magnetic flux is performed with no additional resistance in the armature circuit and with constant voltage at the motor terminals: U_{an}=const and R_{ana} = 0.

The frequency of rotation of DC motors is defined by:

$$n = \frac{U_{an} - I_{an}R_{an}}{C_e\Phi}.$$

Taking of the adjusting characteristics by attenuation of the magnetic flux is conducted in the following order:

- switch on the QF1 and QF2 automata of the SSM and SM modules, respectively;
- set the enabling switch for operation of the TC (SA6), and, after choosing the direction of rotation by the potentiometer RP1, set the voltage U_{an}=200V;
- use the switch SA1 of the module MAR1 to enter resistance, keep loading the DC motor until the armature current reaches approximately $I_{AN}≈0.5I_{an}$, and this switch position remains unchanged, which corresponds to M_2≈const;

- use the switch SA2 of the module MAR2 to introduce resistance into the circuit of the excitation winding, thereby weakening the magnetic flux; the rotation frequency should not exceed 2000 rpm; if during the experiment the excitation current is reduced below the minimum, the thyristor converter will turn off, and the LED “Zashchita” (Protection) will trigger. In this case, you should turn off the power of TC, increase the excitation current.

The obtained data should be entered in table 3.7.

Table 3.7 - Results of the experiment

Experimental data			Calculation data												
U_{an}	I_{an}	n	ω	I_{ex}	P_{an}	ΔP_{el}	P_1	C_M	M	I_{an0}	M_0	M_2	P_2	η
V	A	rpm	1/s	A	W	W	W		N·m	A	N·m	N·m	W	%

After conducting the experiment, set all module switches to the initial state, turn off the QF2, QF1 automata.

Calculation data.

Excitation current, A:

$$i_{ex} = \frac{U_{ex}}{r_{ex} + R_{em}} = \frac{200}{r_{ex} + R_{em}}.$$

Power supplied to the motor, W:

$$P_1 = U_{an} \cdot I_N + i_{ex}^2 i(r_{ex\,20} + R_{em}).$$

The rest of the calculated data is calculated in the same way as when taking the working characteristics.

By the data of table 3.7, construct the dependences n=f(i_{ex} and η=f(i_{ex}).

Control questions.

1. How can the direction of rotation of the DCM be changed?

2. Why does the armature current of the DCM (Direct current motor) increase with increase of the load on its shaft?

3. Why, with decrease of the excitation current, the rotational speed of the DCM increases?

4. How should the armature current change with decreasing excitation current and constant resistance moment on the motor shaft?

5. How will the appearance of the mechanical characteristics of the motor change if additional resistance R_{ad} is introduced into the armature circuit?

6. Parallel operation of generators. Equation of emf and moments for the generator.

7. Areas of use of direct current motors. Design, technical characteristics and operating principles of current machines.

8. Equations of EMF and moments for DC motors. Starting the engine. DC speed control, their braking and reversing. Types of losses in DC machines, their dependence on load and efficiency.

9. Purpose, application, operating principles of direct current machines, the special purpose and performance.

Work №4. Research of an asynchronous electric motor with a short-circuited rotor

Purpose of the work.

Research of the working properties of the asynchronous electric motor.

The program of the work.

1. Study the schemes for the research of an asynchronous electric motor with a short-circuited rotor (hereinafter referred to as AEM).
2. Take the natural mechanical characteristic.
3. Take the engine performance by the direct load method.
4. Conduct experimental data processing, compile a report and prepare a conclusion on work.

Explanatory notes.

In the laboratory work the following modules are used:

- stand power supply module (SSM);
- supply module (SM);
- power module (PM, ru: CM);
- module of the frequency converter (FC);
- module thyristor converter (TC);
- measuring module (MM).

Before conducting the laboratory work, you must bring the modules to their original state:

- set the switch SA1 of MAR1 to the position "∞";
- the "Power" button of the TC module is brought to the lower position, the switch SA6 - to the lower position. The TC must be turned to the torque control mode (appendix D).

The investigated asynchronous motor is a part of the electromechanical unit, which includes the AEM itself, the load generator - the DC machine - M2 and the pulse speed sensor M3.

The scheme for examining the asynchronous motor is shown in figure 4.1.

The induction motor is connected directly to the FC.

The armature circuit of the DC motor is connected to the regulated source of DC current U_{tc} of the TC module.

The DC motor excitation winding is connected to the unregulated DC power source U_{ex} of the TC module.

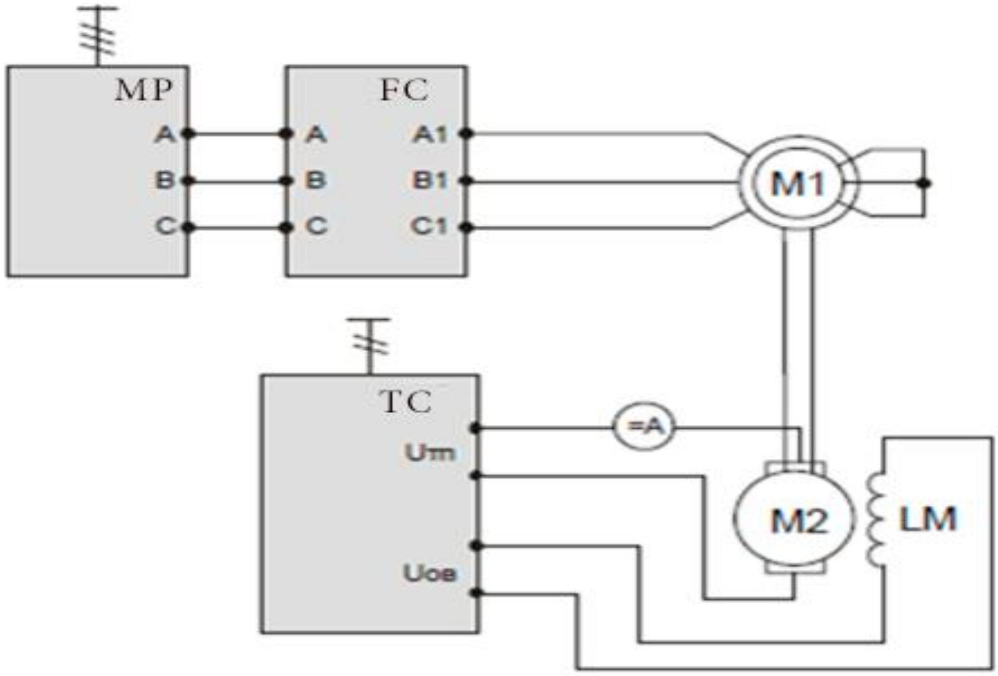

Figure 4.1 - Scheme for the research of an asynchronous motor

To measure the frequency of the output voltage of the stator, the motor power and the torque of the induction motor, the frequency converter is used.

The stator current, armature current and voltage at the armature are measured by the TC module.

The current value of the speed of the unit is monitored on the PM indicator.

4.1 Natural mechanical characteristic of AEM

The natural mechanical characteristic of an asynchronous electric motor is the dependence of the speed on the load moment at nominal values of voltage and frequency: $n=f(M_n)$ at $U_C=U_n$=const, $f=f_n$=const.

The experiment is carried out in the following order:

- turn on the circuit breakers QF1, QF2 SSM and SM;
- adjust the FC to the speed control mode (appendix D);
- power the TC by pressing the "Power" button;
- use switch SA1 of the FC module to select the direction of rotation of the motor;
- using the potentiometer RP1, set the nominal frequency of 50 Hz, enter the first measurement into table 4.1;
- set the enabling switch for operation of the TC, select the required direction of rotation;

- set the load moment by the potentiometer RP1 of the module, fixing indications in table 4.1. The value of the stator current is monitored on the FC screen. After carrying out the experiment, take the load (set the RP1 of the TC module to the most counter-clockwise position, set the SA6 to the lower position). Set the switch SA1 of the FC module to the median position.

Table 4.1

I_{an}, A								
U_{an}, V								
I_C, A								
n, rpm								
ω, rad/s								
M, N·m								
S								

Calculation data.

Electromagnetic moment, N·m:

$$M_{em} = C_m \cdot I_{an},$$

C_m – is taken from the calibration curve, C_m=f(ω) (appendix B).

The moment of idling mode, N·m

$$M_0=C_m \cdot I_{an0},$$

I_{an0} – idling current (taken from the calibration curve of the machine (Appendix B), proportional to the mechanical losses and losses in the steel).

Moment on the motor shaft, N·m:

$$M_{ex} = M_{em} + M_0.$$

Angular speed, rad / s

$$\omega = \frac{2\pi}{60} n.$$

Slip,

$$s = \frac{w_0 - \omega}{\omega_0},$$

where ω_0 – synchronous angular speed, rad/s

$$\omega_0 = \frac{\omega_0 - \omega}{\omega_0} n,$$

where n_0 – synchronous speed, rpm.

According to table 4.1 build characteristics $n=f(M_{ex})$, $n=f(I_C)$.

4.2 Artificial mechanical characteristic of AEM when changing the stator voltage

The artificial mechanical characteristic of an asynchronous electric motor is the dependence of speed on the loading moment with the non-nominal value of the stator voltage and the nominal frequency: $n=f(M_n)$ at $U_C \neq U_n$=const, $f=f_H$=const.

To change the stator voltage at a frequency of 50Hz, set the value 220V in the parameter of FC E1-05.

The experiment is carried out in the same sequence as when taking the natural mechanical characteristic. The data of the experiment are entered into a table similar to table 4.1.

4.3 Taking the operating characteristics

Operating characteristics are graphically depicted dependences of the stator current, active power consumed from the network, speed of rotation, slip, electromagnetic moment, efficiency and power factor - on the useful power on the motor shaft: I_1, P_1, n, s, M_{em}, η, $\cos\varphi_1=f(P_2)$.

The experiment is conducted in the same sequence as the previous ones. It is necessary to set the stator voltage to 380V (E1-05 = 380). The experimental data, both of the asynchronous motor and the generator, should be entered into Table 4.2, table 4.3.

The linear voltage on the stator is assumed equal to 380V.

Table 4.2 - Data from the DCM

I_{an}, A						
U_{an}, V						
C_m						
M_{em}, N·m						
I_{an0}, A						
M_0, N·m						
M_2, N·m						
P_2, W						

Table 4.3 - Data from the asynchronous motor

f, Hz						
I_{1f}, A						

n, rpm						
U1, V						
cosφ1						
P1, W						
$\Delta P_{em.1}$, W						
$\Delta P_{st,\ W}$						
P_{em}, W						
s						
ΔP_{mex}, W						
ΣΔP, W						
P_{ex}, W						
M_{em}, N·m						
η, %						

After the experiment, install the modules in the initial state.

Calculation data on the part of the DC machine. Electromagnetic moment of the DC generator M_{emDCG}, N·m:

$$M_{emDCG} = C_m \cdot I_{an},$$

where C_m – is taken from the calibration curve, C_m=f(ω) (appendix B).

Idling mode moment of M_0, N·m

$$M_0 = C_m \cdot I_{an0},$$

where I_{an0} – idling current; is taken from the calibration curve of the machine (appendix B) and is proportional to the mechanical losses and losses in steel

The total moment on the DCG (ГПТ) shaft,

$$M_{2DCG} = M_{emDCG} + M_0.$$

Useful power on the shaft P_2, W,

$$P_2 = M_{2DCG}\omega.$$

Calculation data from the asynchronous motor. The useful power on the shaft of an AE motor is equal to the power on shaft of DCG:

$$P_{ex} = P_2.$$

Electromagnetic power of an induction motor (AEM), W:

$$P_{EM} = P_{ex} + \Delta P_{mex.ad},$$

where $\Delta P_{mex.ad}$ – mechanical losses of AEM (appendix B);

Electrical losses in the stator winding of AEM, W:

$$\Delta P_{em1} = m_1 I_{1\text{p}}^2 r_1.$$

where r_1 – active resistance of the stator phase (Appendix B), Ohm.

Losses in steel at voltage U_p, W:

$$\Delta P_{st} = \Delta \text{P}_{st.1}\left(U_\text{p}/U_{1n}\right)^2.$$

where $\Delta P_{st.1}$ – losses in stator core steel at rated voltage (appendix B), W;
U_{1n} – rated phase voltage, V;
U_p – phase voltage of the electric motor, V:

$$U_p = \frac{U_l}{\sqrt{3}}.$$

Output power of FC (power consumed by the AEM), W:

$$P_1 = P_{el} + \Delta P_{st} + \Delta P_{el.1.}$$

Slip

$$s = \frac{\omega_0 - \omega}{\omega_0} \text{ or } \frac{n_0 - n}{n_0},$$

where ω – actual angular speed, rad/s;
n – actual speed of rotation, rpm;
ω_0 - synchronous angular frequency of rotation, rad/s;
n_0 - synchronous speed of rotation, rpm;
$\Sigma\Delta P$ - total losses in the engine, W:

$$\Sigma\Delta P = \Delta P_{el.1} + \Delta P_{st} + \Delta P_{meh.ad.}$$

Electromagnetic moment of AEM, N·m

$$\text{M}_{em} = \frac{\text{P}_{em}}{\omega_0}, \text{ or } \text{M}_{em} = \frac{\text{P}_{em}}{\frac{2\pi n_0}{60}}.$$

The useful moment on the motor shaft, N·m:

$$M_2 = M_{EM} - M_0.$$

Useful power on the motor shaft, W:

$$P_2=P_1-\Sigma\Delta P.$$

Efficiency, %:

$$\eta=\frac{P_1}{P_1}100\%.$$

Power factor,

$$cos\varphi_1=\frac{P_1}{m_1 U_{1ф} I_{1ф}}.$$

According to table 4.2, build characteristics: I_1, P_1, n, s, M_{em}, η, $\cos\varphi_1=f(P_B)$ at f_1=const and U_1=const.

Control questions.

1. How can one change the direction of rotation of the induction motor?
2. How will the moment of the induction motor change when the mains voltage is reduced?
3. Can an asynchronous motor generate torque at synchronous frequency of rotation, i.e. can it rotate at a synchronous speed?
4. How does the motor stator current change with increasing voltage and constant load on the motor shaft?
5. Explain the physical meaning of the dependence cosφ=f(PB).
6. The principle of the asynchronous machine. Electromagnetic moment.
7. Mechanical and working characteristics of an asynchronous motor.
8. Nominal, maximum and starting moments.
9. Critical slip and overload capacity. Losses and efficiency of an asynchronous machine.
10. Effect of mains voltage and active resistance in the rotor circuit on electromagnetic moment and mechanical characteristic of an asynchronous machine.
11. Starting properties of an asynchronous machine.

Work № 5. Research of the asynchronous machine in the regime of the asynchronous generator

Purpose of the work.

Study of the way of switching an asynchronous machine for operation in the generator mode. Research of the operational properties of an asynchronous generator.

The program of the work.

1. Study the scheme for experimental research of an asynchronous generator.
2. Perform a test run of an AEM and a DCM.

3. Research the asynchronous motor in the asynchronous generator mode.

4. Conduct experimental data processing, compile a report and make a conclusion on work.

Explanatory notes.

In the laboratory work the following modules are used:

- stand power supply module (SPSM);
- power supply module (PSM);
- thyristor converter (TC);
- power module (MPM);
- measuring module (MM).

Before conducting laboratory work, you must bring the modules to their original state:

- set the "Power" button of the TC module to the lower position, set the switch SA6 to the lower position. Transfer the TC to the torque control mode (Appendix E);
- the investigated asynchronous machine is a part of an electric machine unit, which includes the M1 generator itself, the drive motor -a DC machine- M2 and a pulse speed sensor M3.

The scheme for taking the operating characteristics of an asynchronous generator is shown in figure 5.1.

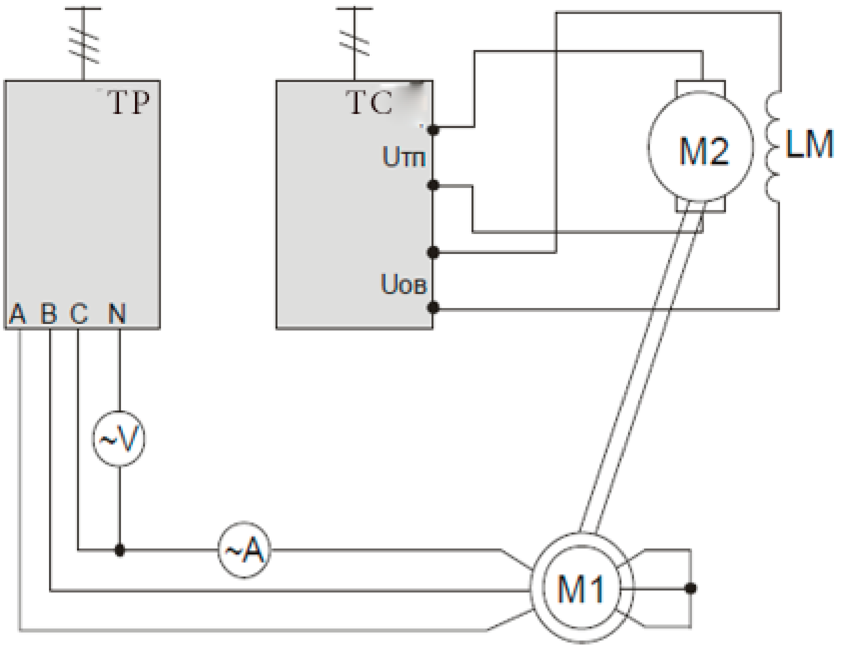

Figure 5.1- Scheme for taking the operating characteristics of an asynchronous generator

The DC motor is connected to the thyristor converter. The armature circuit is connected to the outputs of the regulated voltage source U_{tp}, the excitation winding is connected to the outputs U_{ex}.

The value of the speed ща rotation n is observed on the power module (MPM -CM) indicator. Values of armature current I_{AN}, armature voltage U_{AN} observe on the TC indicator, stator current $I_{Ф}$and stator voltage U_f are measured by the devices of the MM module.

5.1 Taking the operating characteristics

The operating characteristics is the dependence of input power applied to an asynchronous generator P1, phase current I_{ph}, efficiency, slip s - on total active power P2, given by the asynchronous generator to the network: I_p, P_1, s, η, cosφ1=f(P2).

The experiment is carried out in the following sequence:

- turn on the QF1 and QF2 automata of the SSM (ru: МПС) and SM (ru: МП) modules, respectively, the induction motor will start;
- switch on the "Power" button of the TC - the voltage is applied to the thyristor converter;
- set the enabling switch for operation of the TC (SA6) and select the direction of rotation (SA5);
- by setting the load moment with the potentiometer RP1 of the TC module, monitor the rotation speed of the unit. If it decreases, change the direction of the torque command;
- increasing the setting of the TC moment, change the speed of the unit. During the experiment it is necessary to monitor the current of the armature of the DCM. It should not exceed 1.5A.

Enter the data of the experiment into table 5.1, table 5.2.

Table 5.1 - Results of the experiment

From the side of the asynchronous generator							
Experimental data			Calculation data				
U_p	I_p	n	P_2	$\cos\varphi$	s	ω	η
V	A	rpm	W			Rad/s	%

Table 5.2 - Results of the experiment

On the part of DCM						
Experimental data		Calculation data				
U_{an}	I_{an}	M_{em}	I_{an0}	M_0	M_1	P_1
V	A	N·m	A	N·m	N·m	W

After the experiment, set all the module switches to the initial position.

Calculation data.

The electromagnetic moment produced by the DC motor, N·m:

$$M_{em}=C_M I_{AN},$$

where C_M – is taken from the calibration curve, $C_м$ = f(ω) (appendix B).

The moment of idling of the DC motor, N·m:

$$M_0=C_M I_{AN0},$$

I_{AN0} – idling current; is taken from the calibration curve of the DC machine (appendix B).

Useful moment on the DC motor shaft, N·m:

$$M_1=M_{em}–M_0.$$

The power supplied to the asynchronous generator from the DC motor is determined from the calculation data of this motor:

$$P_1 = M_1 \frac{2\pi n}{60} = M_1\omega.$$

Losses in the stator winding, W:

$$\Delta P_{em} = 3I_ф^2 r_c,$$

where r_c – stator winding resistance (appendix B).

The total active power supplied by the asynchronous generator to the AC network, W:

$$P_2=P_1–\Delta P_{mex.ad}–\Delta P_{em},$$

where $\Delta P_{mex.ad}$ – mechanical losses of an asynchronous machine (appendix B), W.

Asynchronous generator power factor:

$$cos\varphi = \frac{P_2}{m_1 U_p I_p}.$$

Slip of the asynchronous generator:

$$s = \left(\frac{n_0 - n}{n_0}\right).$$

where n_0 – synchronous rotation speed, rpm.

The efficiency of an asynchronous generator, %:

$$\eta = \frac{P_2}{P_1} 100\%.$$

According to the calculated data, construct the operating characteristics of an asynchronous generator: P_1, I_p, cosφ, η, s=f(P_2) at U_p=const and f=const.

Control questions.

1. What are the benefits and advantages of an asynchronous generator with respect to a synchronous generator?
2. Identify the disadvantages of an asynchronous generator.
3. Can the asynchronous generator work without AC power?
4. How is a magnetic field created in an asynchronous generator?
5. Areas of application of asynchronous generators.
6. Methods for starting an asynchronous motor with a phase rotor.
7. Methods for regulating the speed of a three-phase asynchronous engine.
8. The design and principle of operation of the single-phase asynchronous motor.
9. The design and principle of operation of a capacitor asynchronous engine.
10. Operation of a three-phase asynchronous motor from a single-phase network.
11. Asynchronous machines of special purpose and execution.

Appendix A

Passport and calculation data of electric machines

Table A.1 – Passport information of the DC machine

Parameter name	Value
Type	PL-072
Power, W	180
Rated supply voltage of armature winding, V	220
Rated supply voltage of the field winding, V	200
Rated speed, rpm	1500
Rated armature current, A	1,3
Efficiency	0,63
Mass, кg	7,65
Resistance of armature winding $R_{ап,20^0C}$ (calculation value), Ohm	17,5
Resistance of the field winding $R_{ов,\ 20}$ (calculation value), Ohm	820
Mechanical losses, $P_{мех.ДПТ}$, W	15

Table A.2 - Passport and calculation data of an AEM with a phase short-circuited rotor

Parameter name	Value
Type	AIS71BY3/АИР63В4У3
Power, W	370
Rated supply voltage of the stator winding, V, ΔY	380
Rated speed, rpm	1320/1370
Rated current of stator phase, A	1,18/1,37
$cos\varphi$	0.7
Rated torque, N·m	1,4
Active stator resistance $r_{1.27^0}$, Ohm	19
Mechanical losses, $P_{мех.\ АД}$, W	11
The moment of idling, M_0, N·m	0,07
Losses in the steel of the stator core at rated voltages, $\Delta P_{ст1}, W$	4,75

Bibliography

1 Voldek, A. I. Electric machines. AC machines. - M.: SP-b.- 2008.-580 p.

2 Goldberg, O. D. Engineering design and the system of automated design of electric machines. – M.: “Academia”, 2008.-450 p.

3 Ivanov-Smolensky, A.V. Electric machines. V.1. – M.: “Academia”, 2006.-610 p.

4 Ivanov-Smolensky, A.V. Electric machines. V.2. – M.: “Academia”, 2006.-590 p.

5 Katzman, M. M. A guide book on electrical machines. – M.: “Academia”, 2005.-620 p.

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