MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
Zaporizhzhia National Technical University

METHODICAL INSTRUCTIONS

to laboratory works on
"THEORY OF ELECTRICAL DRIVE"

in English for students of the branch "Electrician" 141 (specialty "Electrical energy, electrical engineering and electromechanics") for all forms of education

Part 1

2018

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CONTENT

1 LABORATORY WORK №1
Research of electromechanical and mechanical characteristics of direct current motor with independent excitation at different modes of braking and speed regulation

The purpose of the laboratory work is to study physical processes and properties of direct current motor with independent excitation; research operation modes of motor and also ways of braking and speed regulation by analyzing of electromechanical and mechanical characteristics equations on different conditions; experimentally research operation modes of motor and build their characteristics; perform analysis of experimental and calculated data.

1.1 General theory

Properties of direct current motor with independent excitation (DCM IE) are expressed by its mechanical and electromechanical characteristics. Electromechanical characteristic of DCM IE specifies relation of motor angular velocity ω to its current of armature circuit $I_я$ that is why it is also called speed characteristic.

$$\omega = \frac{U}{C_e \cdot F} - \frac{R_a}{C_e \cdot F} I_a , \qquad (1.1)$$

where U – voltage of source, V; C_e – construction coefficient, which includes construction features of motor and defines value of its EMF

$$E_a = C_e \cdot F \cdot \omega ;$$

F – magnetic flux, Wb; R_a – total resistance which includes armature winding resistance R_a and additional resistance of external rheostat R_{add}, Ohm; I_a – current of motor armature circuit.

Mechanical characteristic of DCM IE specifies relation of motor angular velocity to its rotating electromagnetic moment *ω=f(M)*:

$$M = C_м \cdot F \cdot I_a , \qquad (1.2)$$

where M – electromagnetic moment of motor, [Nm];

C_M – construction coefficient.

Analytical expression for mechanical characteristic of DCM IE can be specified from equation (1.1) by substitution I_a=M/C_MF, expressed from (1.2). After substitution, we will obtain:

$$\omega = \frac{U}{C_м \cdot F} - \frac{R_a}{(C_м \cdot F)^2} M \ . \qquad (1.3)$$

First component in equations (1.1) and (1.3) specifies speed of DCM IE ideal idling mode, [rad/s]. If we consider supply voltage and magnetic flux F being constant, idling speed in (1.1), (1.3) will be constant too: ω = U/$C_м$F = A. Let us suppose, that another component of equation (1.1) R_a and Φ are constant, then we take R_a / $C_м$F = B and we will obtain new look of DCM IE electromagnetic characteristic equation:

$$\omega = A - BI_a \ . \qquad (1.4)$$

One can see that for conditions U=const, Φ=const, R_a=const values A and B are constant.

For these conditions in equation (1.3) we specify R_a /($C_м$Φ)^2 = C and will obtain:

$$\omega = A - CM \ . \qquad (1.5)$$

It is easy to see that mechanical characteristic is graphically represented as the same straight line. Limitations U=const, Φ=const, $R_я$ =const are caused by static notion about electric drive operation, that's why electromechanical and mechanical characteristics of DCM IE are called static characteristics. As U=U_{nom}, Φ=$Φ_{nom}$, $R_я$=$R_{яв}$ are called natural static characteristics.

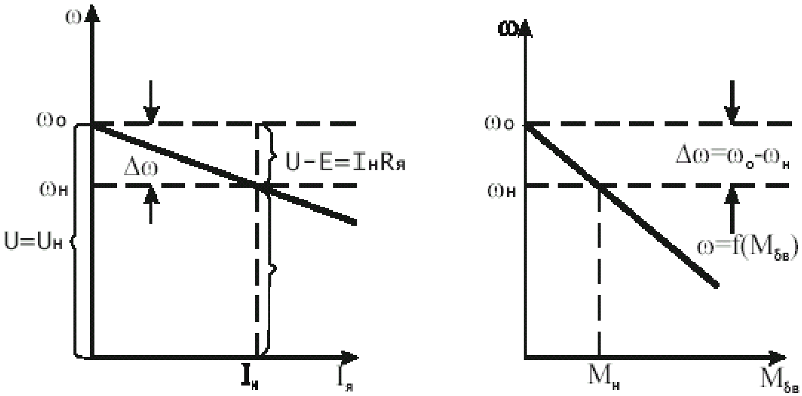
Natural electromechanical (speed) characteristic (figure 1.1, *a*) is a locus for which the equation of motor armature electric balance is true:

$$U_n = E + I_n R_a \ .$$

Static angular velocity drop on the motor shaft is affected by load action,

$$\Delta\omega = \omega_0 - \omega_n$$

what equals (3…7) % from velocity of idling. That is why natural characteristics of DCM IE are called hardening characteristics. Constant coefficients B та C in equations (1.4) and (1.5) specify angle of inclination to horizontal axe of DCM IE characteristics and for absolute value C>B.



a) electromechanical characteristic *b*) mechanical characteristic

Figure 1.1 – Electromechanical and mechanical characteristics

According to the principle of reversibility, DCM IE can operate in motor and generator modes. For generator mode equation of electric balance looks like:

$$U = E - I_a R_a,$$

or

$$E = U + I_a R_a.$$

Motor EMF becomes bigger than supply voltage and consequently armature current changes its direction. Hence, equation of speed characteristic will look like:

$$\omega = \frac{U}{C_м \cdot F} - \frac{R_a}{C_м \cdot F}(-I_a)\,. \tag{1.6}$$

As $E>U$, then we have conditions for return (regeneration) of energy to the net. Substituting in (1.6) $I_a = -M/C_м F$, we obtain equation of mechanical characteristics for this mode

$$\omega = \frac{U}{C_м \cdot F} - \frac{R_a}{(C_м \cdot F)^2}(-M)\,. \qquad (1.7)$$

From the analysis of equation (1.7) it is possible to see that motor moment M<0, that is why it is called a braking moment. As the result, such mode of electric machine operation is called regenerative braking mode.

If we switch off the motor from supply voltage and add in armature circuit a resistance R_T, keeping excitation constant, in this case electric machine will work in generator mode. After substitution in equation (1.1) $U/C_м F=\omega_0=0$, we'll obtain equation for electromechanical characteristic:

$$\omega = -\frac{R_a}{C_м F} I_a = \frac{R_a + R_T}{C_м F}(-I_a) \qquad (1.8)$$

where

$$I_a = \frac{U-E}{R_a + R_T} = -\frac{E}{R_a + R_T}\,; \qquad (1.9)$$

R_T – braking resistance, Ohm.

So, machine operates in generator mode. After substitution in (1.3) $U/C_м\Phi=\omega_0=0$, equation of mechanical characteristic for this mode will look like:

$$\omega = \frac{R_a + R_T}{(C_м F)^2} \cdot (-M)\,. \qquad (1.10)$$

As in this case $M<0$, this mode is called electrodynamic braking mode.

Characteristics of DCM IE, which were obtained by variation of parameters U, Φ, and $R_я$ from their nominal values, are called artificial characteristics. Let us add to armature circuit of motor that lifts load, considerable resistance $R_{дод}$. Increasing of resistance $R_я=R_{яв}+R_{дод}$ turns motor from natural characteristic to rheostat one, which has greater inclination. In this case, current and moment of motor are limited and velocity will decrease. If the load is quite large, direction of motor rotation can change. In this case, motor current and moment do not change their sign, as motor was turned on to lift the load. But as load motion is slowed down, such operation mode of DCM IE is called plugging mode. In such conditions, motor EMF change sign and acts according to the supply voltage:

$$U = (-E) + I_a(R_a + R_{add}) \qquad (1.11)$$

or

$$U + E = I_a(R_a + R_{add})\,. \qquad (1.12)$$

Speed and mechanical characteristics of DCM IE differ from expressions (1.1) and (1.3) only by presence of negative sign in angular velocity.

All examined DCM IE modes for one direction of rotation are shown on general diagram (figure 1.2).

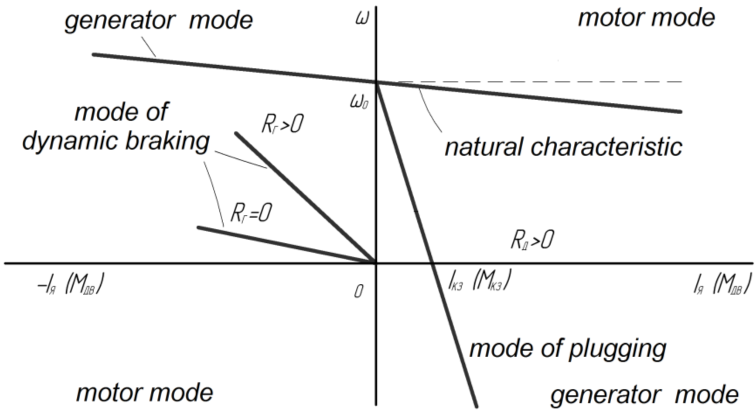


Figure 1.2 – Characteristics of DCM IE

1.2 Program of the work

1.2.1 Study electric circuit diagram of laboratory setup and features of its element operation.

1.2.2 Take and build electromechanical characteristics of DCM:
– in motor mode ω=$f(I_a)$, when $U=U_n$=220V, $F=F_n$, R_{add}=0;
– rheostat characteristics $\omega=f(I_a)$, when $U=U_n$=220V, R_{add}>0;
– mode of regeneration braking $\omega=f(I_a)$, when $U=U_n$=220V, $F=F_n$, R_{add}=0;
– mode of plugging $\omega=f(I_a)$, when $U=U_n$=220V, $F=F_n$, R_{add}>0;
– mode of dynamic braking $\omega=f(I_a)$, when U=0, $F=F_n$, R_{add}>0;
– case of motor supply voltage changing, when U=var, R_{add}=0 and $F=F_n$;
– case of magnetic flux decreasing $\omega=f(I_a)$ when F=var, R_{add}=0 and $U=U_n$=220V.

1.2.3 Calculate and build natural and artificial characteristics.

1.2.4 According to the results of experimental research and calculations it is necessary to make short conclusion.

1.2.5 If $F=F_n$ ($I_{ex}=I_{ex.n}$), R_{add}=0, $M_c=const$=0 ($I_a=const\approx 0$) it is necessary to take regulation characteristic of motor $\omega=f(U)$ in case of armature voltage variation from 20 to 220 V and build separately this characteristic. Using this static characteristic $\omega=f(U)$ coefficient of transmission K must be calculated (figure 1.3)

$$K=\frac{\Delta\omega}{\Delta U_a}=\frac{750-500}{167-107}\approx 40\text{s}^{-1}\cdot V^{-1}.$$

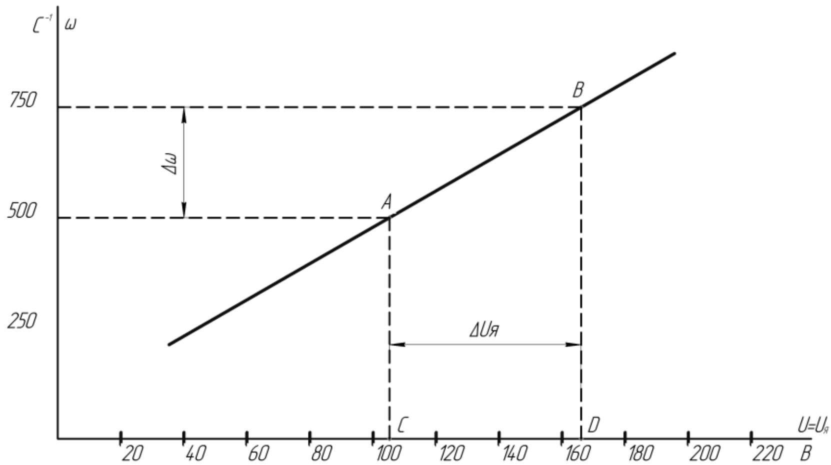


Figure 1.3 – Static regulating characteristic and calculation of the transformation coefficient K.

1.2.6 Take and build electromechanical (load) characteristic in motor mode $\omega=f(I_a)$ when $U=U_a=U_n=220$V, $F=F_n$ ($I_{ex}=I_{ex.n}$), $R_{add}=0$, M_c=var (I_a=var) and by this static characteristic, transmission coefficient S must be calculated (figure 1.4).

$$S=\frac{\Delta\omega}{\omega_0}=\frac{1000-750}{1000}=0.4\ .$$

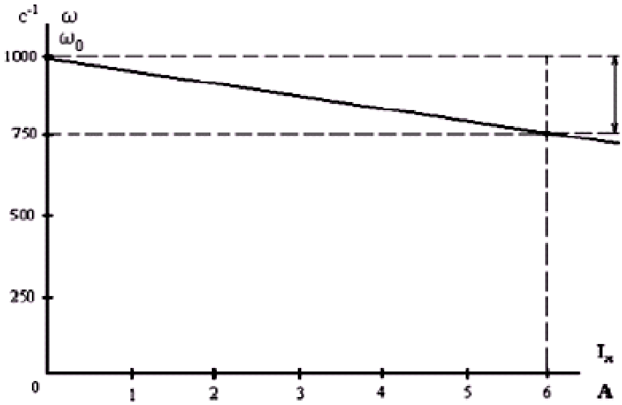


Figure 1.4 – Static loading characteristic and calculation of the transformation coefficient S.

1.2.7 According to the results of previous characteristics building and determinations of coefficients K and S, static model of DC motor with independent excitation in motor mode must be built (figure 1.5).

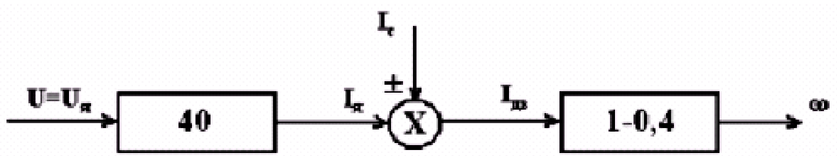


Figure 1.5 – Static model of the drive.

$$R_{add}=0;\ F=F_n\ (I_{ex}=I_{ex.n})$$

Above-listed points 1.2.5, 1.2.6 and 1.2.7 are executed for any mode (according to teacher's appointments): rheostat, regeneration braking, decreasing of magnetic flux and other characteristics.

1.3 Description of the laboratory installation

Circuit diagram of laboratory installation is shown on figure 1.6. Its main elements are: investigating DC motor (DM) and loading generator (НГ). They are marked on electric circuit as M3 and M4 correspondently. НГ is dedicated for creation of regulating mechanic load on ДМ shaft, that is why they are connected with the same shaft. Speed of their consistent rotation is measured by tachometric device, which consists of tachometer generator ТГ and tachometer ТХ, marked on circuit as BR and BE.

Electric machine converters P1 та P2 are dedicated for power supplying of machines M3 and M4. Each of named machines convert AC supply energy into DC, which powers armature circuit of investigating and loading machine. Excitation of DCM starts from rectifiers UZ1, UZ2 by regulation of one-phase autotransformers TV1 and TV2 from AC side.

For accomplishing of all ДМ operation modes, which are listed in chapter 1.2 and for regulation of angular velocity, commutation and electric measurement elements are located in circuit.

Regulation elements:

TV1, TV2 – laboratory autotransformers, which are used as regulators of DCM excitation voltage;

R1, R3, R4, R5 – variable resistances for current limitation and for regulation of DCM excitation;

R2 – variable resistance, which is used as starting, regulating or braking rheostat, according to ДМ operation mode.

Commutation elements:

SB1, SB2 – buttons for energizing of laboratory installation and its turning off;

QF1, QF5 – switches, which are used for starting of asynchronous motors M1 and M6 and their protection from maximum current;

QF2 – switch, which is used for connection ДМ armature circuit to terminals of generator M2 for all above-listed modes, except of dynamic braking mode;

QF3 – switch, which is used only in dynamic braking mode. In this case, switch QF2 must be off state;

QF4 – switch, which is dedicated for switching DCM M4 and M5 in parallel operation mode;

SA3, SA6 – switches for sending excitation to DCM;

SA4 – switch for changing the direction of magnetic flux in case of DCM braking in plugging mode;

SA5 – switch of changing the direction of tachometer rotation.

Electric measurement elements are dedicated for obtaining numerical information about experimental investigations (table 1.1).

Table 1.1 – Passport data of electric machines, which are used in laboratory installation.

Designation	Type	Nominal data			
		Voltage, V	Power, kW	Current, A	Revolution frequency, rev/min
Researched motor M3	П-32	220	1.0	5.7	1000
Loading generator M9	11-32	220	1.0	5.7	1000
Generator M2	1114-75	230	1.3	5.7	1000
Generator M5	111-85	230	6.8	29.6	1460
Motor M1	A02-4	380	2.8	6.8	1420
Motor M6		380	5.0	14.25	1420

1.4 Preparation for the work

Before the beginning of the laboratory work student must:

– study theory and analyze the equations of electromechanical and mechanical characteristics if values R_{add}, U, F are variated;

– study the scheme of laboratory installation and order of laboratory work execution (look chapter 1.5), and also write down the report;

– get permission for laboratory work execution from the teacher, after showing necessary knowledge of this theme and safety rules testing; not prepared student is not allowed to laboratory work execution and works it off in established order.

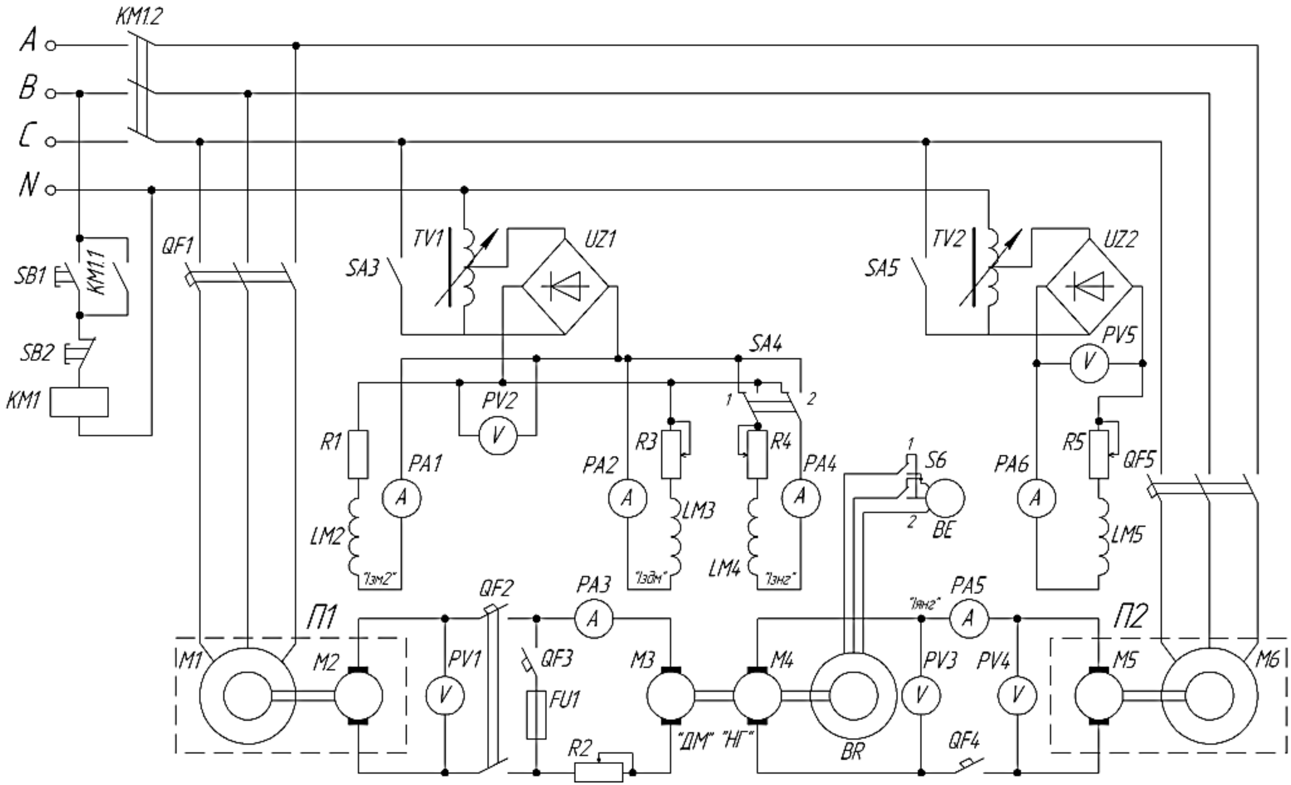


Figure 1.6 – Circuit of the laboratory installation.

1.5 Order of the laboratory work execution

1.5.1 Before the beginning of the work it is necessary to provide output conditions of circuit. All commutation elements must be turned off, but switches SA4 and SA5 must be in position “1”.

Maximum resistance of rheostat R2 and R3, R1, R4, R5 must be set in middle position. Handles of autotransformers TV1, TV2 must be in “min” position.

After making sure that these requirements are performed, voltage must be sent on laboratory set with a help of button “Вкл.” And by switching QF1 we start drive asynchronous motor of converter ПІ. After acceleration of generator M2, with a help of switch SA3, voltage must be sent on autotransformer TV1 and with its help excitation circuits voltage of machines M2, M3, M4 must be risen up to 220 V. For control of this process voltmeter PV2 is used.

In compulsory order it is necessary to make sure that switch QF3 is in on state. In this case QF2 must be switched on too, then investigated machine will start moving. Controlling is performed by voltmeter PV1, amperemeter PA3 and tachometer BE, which will show the voltage, current of armature circuit and angular velocity of ДМ. Next task is slowly set minimal value of rheostat R2, after that make voltage of ДМ armature circuit reach 220 V. Rheostat R1 is used for this purpose. The mode we obtained is called real idling of ДМ. Pay attention on sign and value of current $I_{аДМ}$.

Then converter П2 is turned on. After that QF5 must be switched on and after acceleration of machines M5 and M6 which are connected with the same shaft one must energize autotransformer TV2 by switching on SA6. Using the handle of autotransformer TV2 it is necessary to make equal voltages of machines M4 and M5 armature circuits. QF4 is switched on only after fixing balance of voltages. Both machines will be turned on parallel operation. In such a way laboratory installation is ready to work.

1.5.2 Motor mode of ДМ operation is provided in such a way. Turning slowly handle of the rheostat R5 to “max” position and with a help of rheostat R1 set voltage of ДМ circuit equal to 220V. Current of armature circuit will be equal to: $I_{аДМ}$=+(1-2,5) A.

Controlling is provided by PV1 and PA3. With a help of tachometer angular velocity of ДМ must be checked and all data of measurements in motor mode must be written down in table 1.2. (Pay attention on operation mode of investigating and loading machines: ДМ is motor, НГ is generator)

1.5.3 Ideal idling mode is not possible to achieve in real conditions, because of losses (for instance, to overcome friction in bearings). But it can be achieved with a help of additional mechanical energy, which delivers on ДМ shaft. Its source in laboratory installation is machine M4, which must work in motor mode. In this case it in necessary to increase aggregate speed, which consists of machines M5 and M6. Therefore, handle of rheostat R5 is moved to “min” position. Current of ДМ armature circuit is decreased till the value $I_{аДМ}$=+(1-2,5) A, but the voltage in this moment can be over 220V (watch the PA3 and PA1).

Table 1.2 – Experimental and calculated data for building of electromechanical and mechanical characteristics of DCM IE.

Mode of ДМ operation	Experiment				calculation		
	U, V	$I_{адм}$	$I_{здм}$	R2, Ом	n, rev/min	ω, rad/s	M, Nm
		A					
Motor	220		0,6	0			
Ideal idling	220	0	0,6	0			
Generator	220		0,6	0			
Rheostat characteristic 1	220		0,6	30			
Rheostat characteristic 2	220		0,6	60			
Plugging	220		0,6	60			
Dynamic braking	220	-	0,6	60			
	220	-	0,6	30			
Characteristics when U=Var	180	0	0,6	0			
	180		0,6	0			
	160	0	0,6	0			
	160		0,6	0			
Characteristics when Ф=Var	220	0	0,5	0			
	220		0,5	0			
	220	0	0,4	0			
	220		0,4	0			

Then rheostat must be turned to maximum resistance until voltage will be equal to 220V. In the same time current of investigating machine will tend to zero. Data of measurements, when $I_{аДМ}$=0, must be written down in the table 1.2. Pay attention on loading generator operation mode: With increase of M5-M6 aggregate speed, it is changed to motor.

1.5.4 Further energy delivering from the П2 will turn ДМ in generator mode, and current $I_{aДМ}$ will change its direction: $I_{aДМ}$<0. Keep moving handle of rheostat R5 to “min” position until current of ДМ armature will be equal $I_{aДМ}$=-(1-2.5) A. Then voltage of ДМ armature circuit must be set on the value 220V by turning handle of rheostat R1 to “max” position. Measurement data must be written down in the table 1.2. In this case investigating machine is generator, loading generator is motor.

1.5.5 For getting rheostat characteristics it is necessary to switch ДМ from generator to motor mode: handle of rheostat move in “max” position. After that one have to set min resistance of rheostat R1 and switch on the first section of rheostat R2 (30 Ohm). Voltage of ДМ armature circuit will be much more than nominal value. It must be decreased to 220V by setting rheostat R4 in position “Виведений”, and then turn handle of autotransformer TV2 to “min” position. Current of ДМ armature circuit will be equal to $I_{aДМ}$ = 3 A.

1.5.6 Before turning ДМ in plugging mode it is necessary to ensure that both sections of rheostat R2 in armature circuit are switched on (60 Ohm) and voltage of ДМ and НГ armature circuits are not over 100 V (watch voltmeters PV1 and PV3). This is provided by moving handle of rheostat R1 in position “Введений”. Only after that one can switch SA5 and SA4 in position “II”. Then one have to set min resistance of rheostat R1 and all measurement data must be written down in the table 1.2. Special feature of this method is the fact that investigated machine windings are switched on previous direction of rotation, but its armature rotates in opposite direction making braking moment, because of active moment action, which is created by aggregate П2. Plugging mode of ДМ arises through changing of current direction in excitation circuit of machine M4.

1.5.7 In dynamic braking mode armature circuit of ДМ is switched off from power source and is shunted by resistance R2. As ДМ is rotated with a help of aggregate П2, it works in generator mode. For switching in dynamic braking mode it is necessary to set maximal resistance of rheostat R1 and switch off QF2. Then, switches SA4 and SA5 must be rotated to position “I” and switch QF3 must be closed; moving handle of rheostat R1 to position “Виведений”, rise ДМ voltage up to 220 V. Rotating handle of autotransformer TV2 to “max” position value $I_{aДМ}$=-(1-2.5)A must be set and data of measurements must be written down in table 1.2. Switch off one of rheostat R2 sections and repeat measurements when R2=30 Ohm.

1.5.8 Characteristics of motor mode when supply voltage is decreased U<220V demand taking two values of ДМ angular velocity: when $I_{aДМ}$ =0 and $I_{aДМ}$=(1…5)A. For this reason ДМ must be switched from dynamic braking mode to motor mode. It is necessary to set maximum resistance of rheostat R1, then open switch QF3 and close QF2. Then, move haft of rheostat R1 to “min” position, until *U1*=220 V, and set min resistance of rheostat R2. Voltmeter PV1 and amperemeter PA3 must register values *U*≈220 V, a $I_{aДМ}$≈(1-2)A. Moving haft of rheostat R1 in position “Введений”, one must ensure that current $I_{яДМ}$ tends to zero when *U*=180 V. When current $I_{aДМ}$ will reach zero results of measurements must be written down in table 1.2. For taking another value of angular velocity ДМ must be loaded, and U=180V. For this purpose with a help of autotransformer TV2 it is necessary to decrease voltage to value U=180V and also move haft of rheostat R1 to position “Виведений” until *U*=180 V. In this moment $I_{aДМ}$=(1…3)A. Measured results must be written down in table 1.2. For taking another electromechanical characteristic when U=var it is necessary to perform similar operations. One have to set maximal resistance of rheostat R1, and in his moment *U*=160 V, $I_{aДМ}$=0. Write down the data in table 1.2. Then, with a help of autotransformer TV2 voltage of armature circuit must be sharply decreased to value *U*=140 V, and after that, moving handle of rheostat R1 to “min” position, restore its value to *U*=160 V. In this moment $I_{aДМ}$=(1…3)A. Results must be written down in table 1.2.

1.5.9 For taking ДМ characteristics when *Ф*=var first of all with a help of autotransformer TV2 is necessary to restore supply voltage to the value *U*=220V, then limit current of ДМ excitation to some value in this range (0,4…0,5) A (watch amperemeter PA2) and provide $I_{aДМ}$=0. Results of measurements must be written down in table 1.2. Move handle of rheostat R1 to “min” position, until *U*=220 V, and $I_{aДМ}$=2 A, after that with a help of autotransformer set U=220V and $I_{aДМ}$=(1…3) A. Results of measurements must be written down in table 1.2.

1.5.10 Building all electromechanical characteristics, except of characteristics when U=var and *Ф*=var must be done on one graph. (Necessary information is given in the figure 1.2, and results of experimental investigations are in table 1.2). Before the building it is necessary to convert frequency of rotation which was taken by tachometer (rev/min) to angular velocity (rad/s):

$$\omega = \frac{\pi \cdot n}{30}. \qquad (1.13)$$

Regulated electromechanical characteristics for conditions U=var and F=var must be built together with natural characteristics on another graph. Student must know form of these characteristics by the results of equations (1.1) and (1.5) self-analyzing, when parameters U and F are variated. . In such a way, for building of electromechanical characteristics is enough to have results of experimental measurement, shown in table 1.2.

Final result of work is building of mechanical characteristic. ω=f(M) (except of characteristics, when ДМ magnetic flux is damped). Hence, transfer from values {n; $I_{aДМ}$ } to parameters {ω,M} is necessary. For this purpose one must use equations (1.8), (1.2), (1.1) to determine angular velosity and then from (1.1) get values for nominal parameters.

$$C_м \Phi_n = \frac{U_n - I_{a.n} R_a}{\omega_n},$$

After that

$$M = C_м \Phi_n I_a.$$

Internal resistance of motor armature circuit could be found approximately:

$$R_a = 0{,}5(1 - \eta_n)\frac{U_n}{I_{a.n}},$$

where efficiency of motor

$$\eta_n = \frac{P_n}{U_n \cdot I_{a.n}}.$$

1.6 Content of the report

Report of the laboratory work must contain:

– tables with passport data of electric machines, results of measurements and calculations and also electric circuit diagram of laboratory installation;

– graphs of electromechanical and mechanical characteristics of DCM IE;

– short conclusions about features of studied DCM IE operation modes, calculations and analysis of obtained graphical material;

– static model, shown by regulating and loading characteristics with coefficients K and S calculation;

static model of motor with written value of transmission coefficients and conditions under what model was built.

1.7 Control questions

1.7.1 State operation of laboratory installation in general and explain purpose of its elements.

1.7.2 In correspondence to electric circuit diagram state sense of each operation mode of DCM IE.

1.7.3 Conditions of taking correspondent characteristics of DCM IE.

1.7.4 What is the difference and relation of electromechanical and mechanical characteristics.

1.7.5 How to build DCM IE nature mechanical characteristic by passport data.

1.7.6 What is the difference between natural and rheostat characteristics.

1.7.7 Compare the ways of DCM IE speed regulation.

1.7.8 Compare the braking modes, which were studied in laboratory work.

1.7.9 What is the difference between real and ideal idling of DCM IE.

1.7.10 Explain the linearity of DCM IE static characteristics.

1.7.11 How to determine hardness of any DCM IE characteristic.

1.7.12 Name the industry brunches where DCM IE is used

1.7.13 What characteristics are called static.

1.7.14 What characteristics are called regulating.

1.7.15 What characteristics are called loading.

1.7.16 For what purpose static characteristics are built.

1.7.17 For what purpose static models of motors, operating machines and operating processes are built.

1.7.18 How is voltage transmission coefficient K calculated.

1.7.19 How is static coefficient(S) calculated.

1.7.20 In what a way nonlinear characteristics of DCM IE are linearized [1; 2; 3].

2 LABORATORY WORK № 2

Research of electromechanical and mechanical characteristic of direct current motor with series excitation in different modes of operation, speed regulation and braking

The purpose of the laboratory work is to study physical processes and properties of direct current motor with series excitation by taking electromechanical characteristics, calculation of mechanical characteristics and also by analysis of these characteristics in motor and braking modes.

2.1 General theory

For direct current motor with series excitation (DCM SE) general look of electromechanical characteristic equation, which specifies relation between angular velocity ω and armature circuit current I_a, is the same as for direct current motor with independent excitation (DCM IE):

$$\omega = \frac{(U - I_a R_a)}{C_м \cdot F_n}, \tag{2.1}$$

where U – voltage of motor power supply, V; I_a – current of motor armature circuit, A; R_a – total armature circuit resistance, which includes resistance of armature winding R_{ex}, resistance of excitation winding $R_з$ and resistance of external rheostat R_p, Ohm; $C_м$ – is constant coefficient which is take for motor construction features; F – magnetic flux, Wb; ω – motor angular velocity, s^{-1} .

Unlike DCM IE, in this motor magnetic flux F is a function of current I_a, which is graphically represented by magnetizing curve of motor steel and has non-linear form:

$$\omega = f(I_a),\ \omega = f(M),$$

where M – is moment of motor shaft, Nm, which is specified by relation

$$M = C_м \cdot F \cdot I_a .$$

If for analysis simplification we neglect magnetic system saturation and assume that relationship between flux and armature current is direct ($F = \beta \cdot I_a$), the moment of motor is:

$$M = C_м \cdot F \cdot I_a = \beta \cdot C_м \cdot I_a^2 . \qquad (2.2)$$

In this case from equation (2.1) by substitution of current values (2.2) we'll obtain expression of mechanical characteristic:

$$\omega = \frac{U}{\sqrt{C_м \beta \cdot M}} - \frac{R_a}{C_м \beta} . \qquad (2.3)$$

Hence, when magnetic circuit is saturated, magnetic characteristic is drawn as a curve. Y-axis is asymptote for it. Equation (2.3) gives only general idea about mechanical characteristic of DCM SE. For more exact calculations is impossible to use this equation, because in modern practice there is almost no machines with not saturated magnetic system. Mechanical characteristic, obtained for normal switching circuit, when parameters of voltage supply are nominal and there are no additional resistances is called natural.

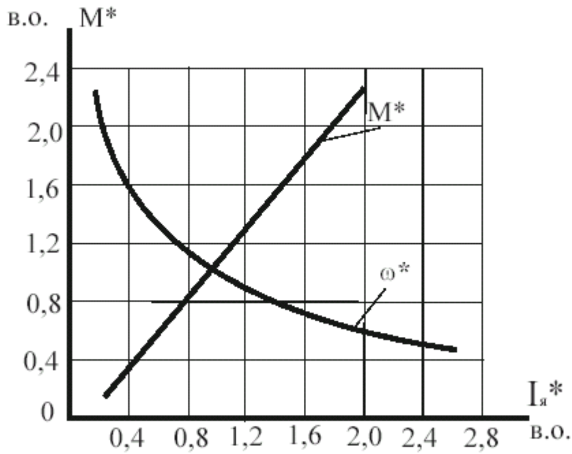


Figure 2.1 – Universal characteristic of DC drive of the series ПБ.

In figure 2.1 is shown approximated general characteristic of DCM SE. Regulation of DCM SE speed is performed either by changing of supply voltage U, or by regulating resistance of armature circuit rheostat R_e. And using rheostats which shunt armature winding it is possible to regulate excitation current I_{ex} and speed.

In figure 2.2 is shown scheme of DCM SE switching with rheostats $R_{шя}$ and $R_{шз}$, what provide taking forced characteristics of motor.

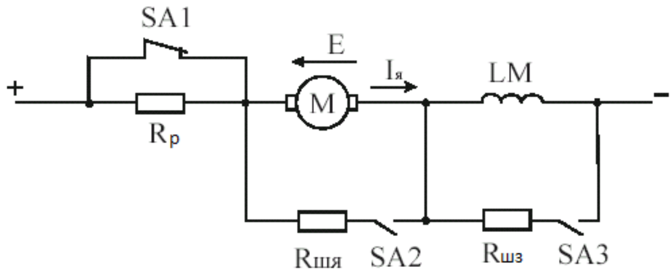
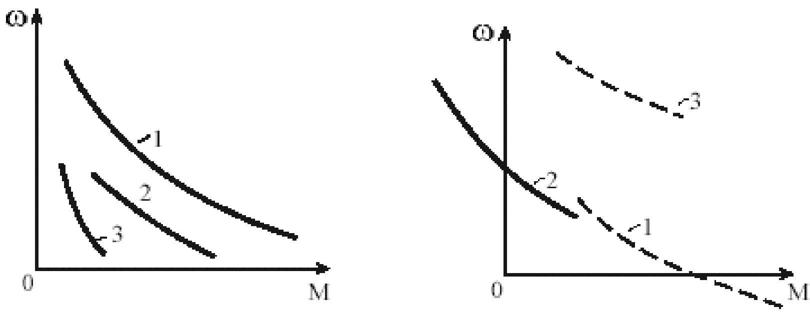


Figure 2.2 –Scheme of powering of the DC drive of the PE.

In figure 2.3 approximate look of DCM SE mechanical characteristics is shown. Analogous look have electromechanical characteristics.

DCM SE does not have end value of idling speed at all modes, except of armature circuit shunting. Because, when we decrease loading moment on the shaft and decrease current of armature circuit I_a, magnetic flux F damps greater then angular velocity ω increases. That's why motor EMF $E=C_м F\omega$ can't be over the value of supply voltage U and motor can't be turned in generator mode and send energy in circuit (look at curve 1 on the figure 2.3, *a*)



a) 1- natural
2- at the lowered voltage
3- rheostatic

b) 1- breaking by opposite connection
2- shunting of the armature winding
3- shunting of the excitation winding

Figure 2.3 – Forced characteristics of the DC drive of PE.

Angular velocity of motor shaft rotation sharply increases because of sufficient non-linearity of DCM SE mechanical and electromechanical characteristics. That is why it is prohibitive to operate drive in this mode.

When DCM SE armature winding is shunted by rheostat R_{sh} (look at figure 2.2) current decreases to zero value (end value of EMF) and excitation winding is powered by current, passing through shunt rheostat.

This provides crossing mechanical characteristic of this mode and Y-axis (characteristic 2 in figure 2.3, *b*). DCM SE operates in generator mode with shunt rheostat.

For DCM SE two braking modes are possible: plugging and dynamic. Under the action of braking moment in plugging mode motor shaft rotates in opposite direction to that one, which corresponds to supply voltage polarity (curve 1 on figure 2.3, *b*)

In dynamic braking mode armature winding is short-circuited with external rheostat. In this situation occur conversion of drive mechanical energy into electrical, which is lost in external rheostat. So, DCM SE operates in generator mode. DCM SE are used in electric drives, where in case of small load, speed rising is prohibitive as a result of little hardness of mechanical and electromechanical characteristics.

Shunting of DCM SE armature circuit winding is used, when it is necessary to provide stable motor operation under low load moment.

2.2 Program of the work

2.2.1 Study electric circuit diagram of laboratory installation and its elements operation features.

2.2.2 Take electromechanical characteristics of DCM SE in motor mode at different values of armature circuit rheostat resistance.

2.2.3 Take electromechanical characteristics in plugging mode.

2.2.4 Take electromechanical characteristics in case of armature winding shunting.

2.2.5 Take electromechanical characteristics in case of excitation winding shunting.

2.2.6 Using the results of DCM SE electromechanical characteristics it is necessary to calculate and build natural and rheostat mechanical characteristics.

2.2.7 Make short conclusions about the results of investigations.

2.2.8 Set motor mode, when armature circuit rheostat resistance is maximal and changing armature voltage take static regulating characteristic.

Perform linearization of regulation characteristic and calculate transmission coefficient “K”. Value of rheostat resistance and range of armature circuit voltage measurement is set by teacher.

2.2.9 Using taken mechanical characteristic of DCM SE in motor mode, when armature circuit rheostat resistance and voltage are the same it is necessary to build loading characteristic, perform its linearization and calculate transmission coefficient “S”. Values of rheostat resistances must be the same as in section 2.2.8.

2.2.10 Using the results of coefficients K and S calculation build static model of direct current motor with series excitation.

2.3 Description of the laboratory installation

Electric circuit diagram is shown in the figure 2.4. Investigating machine (ДМ) is direct current motor with series excitation, passport data of which is in the table 2.1. ДМ armature circuit resistance R2 is used as staring, regulating or braking. It depends on operation mode. Loaded generator M3 is located on the same shaft with ДМ and it is intended for creation of regulating load on the shaft of ДМ. Electromachine converter П operates as load or power source of M3 (it depends on operation mode). This converter consists of drive asynchronous motor with short-circuited winding (M1) and direct current generator with independent excitation (M2). Passport data of these machines is also shown in the table 2.1.

Table 2.1 – Passport data of electrical machines and laboratory panel

Designation	Type	Nominal data			
		Voltage, V	Power, kW	Current, A	Revolution frequency, rev/min
Researched motor M4	ПБ-32	220	1,0	5,5	1500
Loading generator M3	ПН-45	320	2,6	8,1	1440
Generator M2	ПН-45	230		14.4	1440
Motor M1	АД/2/31/4	380		3	1430

For ДМ power supply one-phase autotransformer TV3 and rectifier UZ3 are used. Switch QF4 is dedicated for armature winding shunting, QF3 –for shunting of ДМ excitation winding, QF2 – for switching armature circuits of M2 and M3 on parallel operation. Excitation windings of machines M2, M3 are powered from rectifiers UZ2 and UZ3, which are switched to alternating current circuit via autotransformers TV2 and TV3 correspondently. Regulation of load moment on ДМ shaft in motor mode is performed by regulation of machines M2, M3 armature circuit current. For this purpose voltage variation on the terminals of generator M2 is necessary. For turning ДМ in plugging mode, polarity of M3 excitation current is changed and M3 starts operation in motor mode. In order to measure frequency of rotation, tachometric device is used. It consists of sensor (3-phase asynchronous tachometer generator BR, located on the one shaft with ДМ) and receiver BE which is mounted on the one shaft with ДМ. Switch SA4 is used for changing the direction of generator M3 magnetic flux. Because of sharp ДМ speed rising, when there is low load on the shaft, one must watch velocity in order to prevent it from being more than in 1.25 times over nominal (2000 rev/min).

2.4 Preparation to laboratory work

Every student must be ready to the next laboratory work in time. For this purpose it is necessary to study theoretical course and all demanded questions, order of laboratory work execution and write the titles of report.

Before the beginning of laboratory work execution student shows teacher his report and answers on the questions about this laboratory work. Unprepared student is not allowed to execute laboratory work and works it off in established order.

2.5 Order of the laboratory work execution

2.5.1 Before the beginning of laboratory work it is necessary to check initial states of installation elements: switch SA5 and tumbler SA4 must be in position “I”, other switches must be in off state. Hafts of autotransformers TV1 and TV2 must be in left position (“min”), starting rheostat R2 in “min” position, haft of autotransformer TV3 in position “min”.

2.5.2 Switching of scheme is performed in such a way. For test bench powering is necessary to press the button “Вкл”. ДМ starting must be done with low voltage, starting from zero. For this purpose, when QF3 is in off state, it is necessary to switch on QF6. Assured that UДМ=0 (watch voltmeter PV4) one must switch on QF5. With a help of TV3 smoothly increase voltage $U_{ДМ}$ until motor frequency of revolutions will reach 900…1000 rev/min. Using QF1 start converter П. Switch on SA3 and,

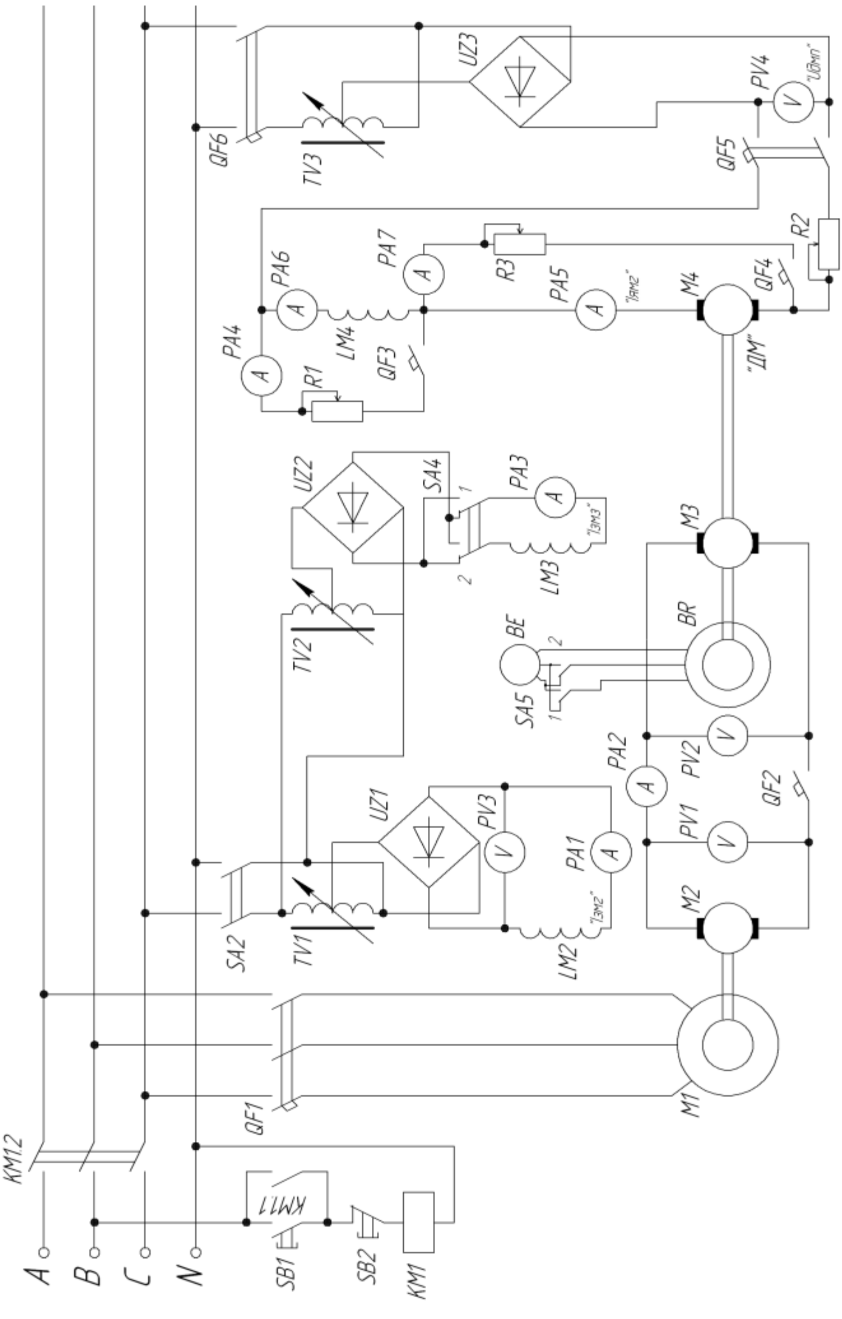


Figure 2.4 – Circuit of the laboratory panel.

rotating haft of autotransformer TV1, is necessary to rise excitation voltage $U_з$ to 100V (watch voltmeter PV3). With a help of autotransformer TV2 set voltage of loading generator U_2=160 V (watch voltmeter PV2) and using autotransformer TV1-set voltage of generator M2 U_1=160 V. "I" position of switch SA4 matches machines M2, M3 polarities, that's why when $U_1=U_2$ is necessary to switch them on parallel operation using QF2. After QF2 switching scheme is completely ready to work.

2.5.3 DCM SE characteristics in motor mode, when $R_M=R_2$ are changed in such a way. With a help of TV3 set voltage $U_{ДМ}$=60 V. Changing by autotransformer TV1 load moment of ДМ by variation of machine M3 voltage, which operates in generator mode, is necessary to take instrumentation indications: current $I_{aДМ}$ (watch amperemeter PA5) must be not over 7 A. Measurements are performed with step what is approximately equal to 1 A. Measurement data and results of further calculations must be written down in table 2.2. Repeat experiment, when voltage $U_{ДМ}$=70 V.

Table 2.2 – Measurement data and results of calculation for obtaining motor electromechanical and mechanical characteristics

№	Measurement						Calculation			
	$U_{ДМ}$=60 V			$U_{ДМ}$=70 V			$U_{ДМ}$=60 V		$U_{ДМ}$=70 V	
	IaДМ, A	I_{ex}, A	n, rpm	IaДМ, A	I_{ex}, A	n, rpm	ω, s^{-1}	M, Nm	ω, s^{-1}	M, Nm

2.5.4 Investigation of DCM SE characteristics in motor mode, when $R_M≠0$, is performed almost in the same way as in previous experiment. Voltage $U_{ДМ}$=70 V, but in ДМ armature circuit it is necessary to add rheostat R2. Experiment is done twice: first time when R2`=0,5*R2, second − when R2``=R2. Measurement is performed with step, which is approximately equal to 0,5 A. Measurement data and results of further calculations must be written down in table 2.3.

Table 2.3 – Measurement data and results of calculation for determination of electromechanical and rheostat mechanical characteristics in motor mode, when $R_M≠0$ and in plugging mode

№	Measurement						Calculation			
	R2'=0.5R2			R2"=R2			R2'=0.5R2		R2"=R2	
	$I_{aДМ}$, A	I_{ex}, A	n, rpm	$I_{aДМ}$, A	I_{ex}, A	n, rpm	ω, s^{-1}	M, Nm	ω, s^{-1}	M, Nm

2.5.5 Plugging mode is a resumption of previous mode, but with greater value of R2. For switching ДМ in this mode is necessary to switch M3 in motor mode and then M3, which gets power from generator M2, will rotate ДМ in opposite direction to ДМ moment. In such a way.

For ДМ switching in plugging mode is necessary to perform next steps:

– in correspondence to the circuit of previous experiment, when $U_{ДМ}$=70V, rheostat R2 resistance is max and ДМ velocity is close to zero, one must reduce excitation current I_{exM2} of machine M2 to zero value;

– turn SA4 in position "П";

– with a help of TV1 rise current I_{3M2} , and after that, system ДМ – M3 reversing will occur;

– switch SA5 on control panel, because the direction of tachometer generator(BE) rotation will be changed;

– using TV1 regulate voltage of generator M2 and moment of it, perform 3-4 measurements, after that return circuit to initial position. For this purpose with a help of TV1 decrease current I_{exM2} to zero and switch SA4 in position "I". Measurement and further calculations results write down in table 2.3.

2.5.6 For investigation of DCM SE characteristics in motor mode, when armature winding is shunted is necessary to perform next steps:

– set $U_{ДМ}$=70 V;

– set maximal resistance of rheostat R2 and rheostat R3, which shunts armature winding;

– switch on QF4;

– changing ДМ load by generator M2 voltage variation (use autotransformer TV1), perform 5-6 measurements. Measurement data and results of calculation write down in table 2.4.

Repeat experiment, when R3 resistance was changed in two times. This experiment gives the opportunity to get end value of idling speed, and equation $I_{aДМ}$=0 is correspondent to it. In case of further load reducing, current $I_{aДМ}$ changes its sign.

Table 2.4 – Measurement data and the results of calculations for electromechanical and mechanical characteristics determination, when armature winding is shunted.

№	Measurement						Calculation			
	R3’=0.5R3			R3”=R3			R3’=0.5R3		R3”=R3	
	$I_{аДМ}$, A	I_{ex}, A	n, rpm	$I_{аДМ}$, A	I_{ex}, A	n, rpm	ω, s^{-1}	M, Nm	ω, s^{-1}	M, Nm

2.5.7 Investigation of DCM SE in motor mode, in case of excitation winding shunting is performed in such a way:

– set scheme initial condition $U_{ДМ}$=70 V;
– switch off QF4;
– set minimum value of R2;
– set minimal resistance of rheostat R1;
– switch on QF3;
– as in previous case, changing of ДМ load is performed by generator M2 voltage variation (use autotransformer TV1), then is necessary to take 5-6 measurements and write down in the table 2.5 the results of measurements and further calculations; repeat experiment, when R_1 was reduced in two times. During the experiment it is important to watch frequency, because it must be not over than 2000 rev/min.

Table 2.5 – Measurement data and the results of calculations for electromechanical and mechanical characteristics determination, when excitation winding is shunted.

№	Measurement						Calculation			
	R1’=0.5R1			R1”=R1			R1’=0.5R1		R1”=R1	
	$I_{аДМ}$, A	I_{ex}, A	n, rpm	$I_{аДМ}$, A	I_{ex}, A	n, rpm	ω, s^{-1}	M, Nm	ω, s^{-1}	M, Nm

2.5.8 For building and determination of characteristics these guidelines are necessary. As electromechanical characteristics are relations $\omega=f(I_Я)$, their building could be done directly by measurement data. Also one must convert taken by tachometer frequency of revolutions (n, rev/min) in angular velocity, s^{-1}(in system CI):

$$\omega = \frac{2 \cdot \pi \cdot n}{60}. \qquad (2.4)$$

Natural mechanical characteristic of DCM SE $\omega=f(M)$ is built using general characteristics $\omega^*=f(I^*)$, $M^*=\varphi(I^*)$, shown in the figure 2.1. For this purpose using graph, shown on the figure 2.1, determine correspondent values for several (6-7) values of I^*:

$$\omega^* = \omega/\omega_n, \quad M^* = M/M_n.$$

After that, calculate absolute values $\omega = \omega_n \cdot \omega^*$, $M = M_n \cdot M^*$ taking in account, that

$$M_n = P_n/\omega_n,$$

де ω_n, P_n – motor passport data.

Forced mechanical characteristics must be built using correlation:

$$M_{for} = M\frac{I_a}{I_{ex}}, \qquad (2.5)$$

where M_{for} – requested value of artificial moment; M – motor moment at present $R1$; I_{ex}– current of DCM SE excitation winding.

Order of rheostat mechanical characteristics calculation and building:

– for preselected and experimentally taken K point of electromechanical characteristic, using graph of natural characteristic $M = \psi(I)$, (look in figure 2.1), it is necessary to find value of moment, which motor could have, if the current was equal to current, in other words, at current Iз, which passes via DCM SE excitation winding, when velocity is $\omega_к$ and switching circuit is the same;

– then by formula (2.5) determine M_{for}, using I_a quantities as indications of amperemeter PA5, and $I_з$ quantities as indications of amperemeter PA6, which are correspondent to selected point $\omega_к$;

– repeat listed operations for all experiments, build forced characteristics $\omega=f(M_{for})$

2.6 Content of the report

Laboratory work report must contain:

– tables with passport data of electrical machines, measurement data and results of calculations;

– graphs of general characteristics of DCM SE;

– graphs of electromechanical characteristics;
– graphs of natural and rheostat characteristics;
– short conclusion with motor characteristics analysis;
– linearize static regulating and loading characteristics of DCM SE;
– static model of DCM SE, which satisfies conditions, listed in sections 2.2.8 and 2.2.9.

Note. Guidelines of static model building are in application 1Д.

In order to avoid pilling-up of curves on the graph, it is necessary to build mechanical characteristics separately from electromechanical. Curves for modes listed in section 2.5.3-2.5.4 must be in one figure, curves for modes 2.5.5-2.5.7 – in another.

2.7 Control questions

2.7.1 State laboratory installation operation in general and features of its separate elements.

2.7.2 In correspondence to electric circuit diagram, state each investigated mode of DCM SE.

2.7.3 Sate main idea of mechanical and electromechanical characteristics, their correlation and difference.

2.7.4 How to build natural and mechanical characteristic of DCM SE using general characteristics $\omega=f(I_a)$, $M=f(I_a)$.

2.7.5 Explain non-linearity of DCM SE characteristics.

2.7.6 Does it possible to regenerate energy in plugging mode of DCM.

2.7.7 Does it possible to obtain end value of DCM SE idling speed.

2.7.8 Pros and cons of DCM SE in comparison with DCM IE.

2.7.9 Name the industry brunches, where DCM SE is used.

2.7.10 How does static regulating characteristic of DCM SE looks like.

2.7.11 How does static loading characteristic of DCM SE looks like.

2.7.12 In what way static loading characteristic is linearized.

2.7.13 How does static characteristic looks at different values of load.

2.7.14 Draw approximate look of static linearized regulating and loading characteristics at different operation modes of DCM SE [2,4,5].

3 LABORATORY WORK № 3

Research of mechanical characteristics of an induction motor with phase rotor

The purpose of the laboratory work: to study physical processes and properties of an induction motor with a phase rotor by taking of electromechanical characteristics, calculation and construction of mechanical characteristics, and also the analysis of these characteristics in generator, motor and braking modes.

As electric equipment of the stand of laboratory work № 3 does not contain the frequency converter with certain regulation principle it is not possible to take the real regulating characteristic of an induction motor with a phase rotor. So at model construction it is necessary to accept linear character of dependence of speed from voltage at f=const=50 Hz, that at the first approximation the proportional law of frequency regulation (figure 3.1) can be applied.

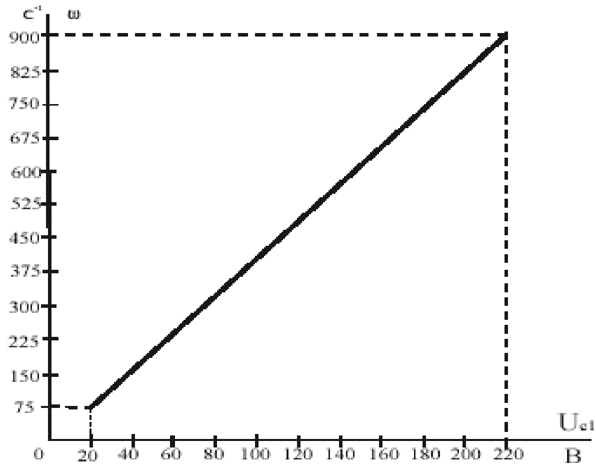


Figure 3.

The linearization point should match parameters of the electromechanical characteristic in a motor regime.

The linearization point (that is value of voltage on the motor stator) is set by the teacher.

3.1 General theory

Unlike a design of direct current and synchronous motors, the asynchronous motor is an induction one that is there is an electromagnetic connection between stator and a rotor, and it means that it is impossible to use a method of the theory of electric circuits for formation of an analytical form of a mechanical characteristic.

So the basic method of the analysis of processes in induction motors is the use of equivalent circuit designs in which electromagnetic connections are replaced by electric ones (a stator circuit is connected electrically with rotor circuit). Equivalent circuit of induction motor (figure 3.2) terminals is the most convenient, where U_1 – is a primary phase voltage; I_{1ph} – is a phase current of the stator; $I`_2$ – is an adjusted current of a rotor; $I_\mu$ – is a magnetization current; $X_1$, $X`_2$ – is inductive resistance of dispersion of primary and adjusted secondary windings; R_m, X_m – are active and inductive resistances of magnetizing contour; R_1, $R`_2$ – are active resistances of primary and adjusted secondary windings; $s = \dfrac{\omega_0 - \omega}{\omega_0}$ – sliding.

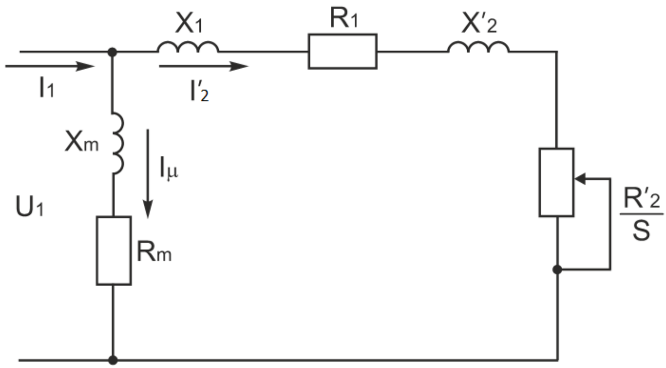


Figure 3.2 – Equivalent circuit of induction motor.

The execution of the equation of a mechanical characteristic is carried out from conditions of balance of losses in a rotor for the real motor and for an equivalent circuit:

$$\Delta P_2 = 3 \cdot (I_2^{'})^2 \cdot R_2^{'};$$
$$\Delta P_2 = P_{EM} - P_n = M \cdot \omega_0 - M \cdot \omega = M \cdot \omega_0 \cdot S;$$
$$\Delta P_2 = \Delta P\ ;$$
$$M\omega_0 s = 3(I_2^{'})^2 R_2^{'},\ M = \frac{3(I_2^{'})^2 R_2^{'}}{\omega_0 s} \qquad (3.1)$$

де $\Delta P`_2$ – losses in a rotor for equivalent circuit;
P_2 – losses in a rotor for the real motor;
P_{EM} – electromagnetic power;
P_n – useful power (shaft power of the motor);
ω_0 – synchronous speed (speed of ideal idling of the motor);
ω – speed of a rotor of the motor.
From equivalent circuits (figure 3.1):

$$I`_2 = \frac{U_{1ph}}{Z} = \frac{U_{1ph}}{\sqrt{\left(R_1 + \frac{R_2^{'}}{S}\right)^2 + \left(X_1 + X_2^{'}\right)^2}}\ . \qquad (3.2)$$

Solving according to (3.1) and (3.2), we obtain the equation for mechanical characteristic of induction motor:

$$M = \frac{3 \cdot U^2_{1ph} \cdot R_2^{'}}{\omega_0 \cdot \left[\left(R_1 + \frac{R_2^{'}}{S}\right)^2 + \left(X_1 + X_2^{'}\right)^2\right] \cdot S}\ . \qquad (3.3)$$

According to the equation (3.3) it is possible to build a mechanical characteristic if supports of stator and rotor circuits are known. For this purpose the equation (3.6) gained after defining of an extremum and simplifications of (3.3) is more convenient:

$$M = \frac{2 \cdot M_{\max} \cdot (1 + a \cdot S_{xr})}{\frac{S}{S_{cr}} + \frac{S_{cr}}{S} + 2 \cdot a \cdot S_{cr}}\ . \qquad (3.4)$$

where M_{max} – the maximum value of the moment in motor regime that matches to critical value of sliding (S_{cr}), it is defined from the overload ability $\lambda = M_{max}/M_n$, specified in the catalogue; $a = R_1/R'_2$`.

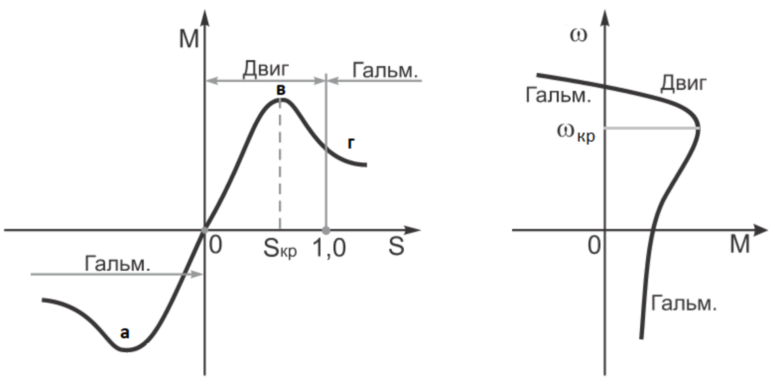
For ordinary induction motors the parameter a is close to unit, so for usual engineering calculations it is possible to use more simplified formula gained from expression (3.4):

$$M = \frac{2 \cdot M_{\max} \cdot (1 + S_{кр})}{\frac{S}{S_{кр}} + \frac{S_{кр}}{S} + 2 \cdot S_{кр}} . \qquad (3.5)$$

If we assume (3.3) in equation $R_1=0$, that is small in that comparison with value $X_2 + X_2^1$ (especially for large induction motors), the mechanical characteristic equation gets even more simplified aspect:

$$M = \frac{2 \cdot M_{\max}}{\frac{S}{S_{cr}} + \frac{S_{cr}}{S}} . \qquad (3.6)$$

Expression (3.6) with sufficient for practice accuracy matches to physical processes in motors. These sections of a mechanical characteristic are shown in figure 3.2 in $M=f(S)$ (figure 3.3, a) та $\omega = f(M)$ (figure 3.3, b).



a) mechanical characteristic $M=f(S)$ b) mechanical characteristic $\omega=f(M)$

Figure 3.3 – Mechanical characteristics of induction motor

The first section *ав* ($|S|<|S_{cr}|$) is in limits of small (for its absolute value) sliding. This section of the characteristic is linear. For a motor regime it is an operating part of the characteristic, there is a point of a nominal regime of operation. The second section of the characteristic – *вг* represents a curve similar to equilateral hyperbolas and it is in limits of the large sliding ($|S|>|S_{cr}|$). The section is a non-working part of the characteristic (regimes of engine starting and braking).

For the motor with a phase rotor as it was already noted, value *a* is close to unit, so it is possible to S_{cr} from (3.5) for nominal regime define ($M=M_{ном}$; $S=S_{ном}$; $\lambda=M_{max}/M_{ном}$) with sufficient accuracy:

$$S_{cr}=\frac{S_n\cdot\left[\lambda\pm\sqrt{\lambda^2-2\cdot S_n\cdot(1-\lambda)-1}\right]}{1+2\cdot S_n\cdot(1-\lambda)} \qquad (3.7)$$

Approximate value of S_{cr} for induction motor with phase rotor also can be defined according to formula (3.6):

$$S_{cr}=S_n\cdot\left(\lambda\pm\sqrt{\lambda^2-1}\right).$$

For induction motor with short-circuited rotor S_{cr} and *a* can values be found, using equation (3.4) for two regimes:

– starting ($M=M_n$; $S=1{,}0$),
– nominal ($M=M_n$; $S=S_n$).

Obtained system of equations

$$M=\frac{2\cdot M_{max}\cdot(1+a\cdot S_{cr})}{\frac{1}{S_{cr}}+S_{cr}+2\cdot a\cdot S_{cr}},\quad M=\frac{2\cdot M_{max}\cdot(1+a\cdot S_{cr})}{\frac{S_n}{S_{cr}}+\frac{S_{cr}}{S_n}+2\cdot a\cdot S_{cr}}$$

is solved concerning S_{cr} and *a*, the $M=f(S)$ is calculated for motor regime, taking into account values of sliding $S(0\le S\le 1)$, and mechanical characteristic $\omega=f(M)$ is built.

In given formulas nominal value of sliding is taken, calculated according to formula of units of SI-system:

$$S_n = \frac{\omega_0 - \omega_n}{\omega_0}$$, - through the angular velocity

where $\omega_0 = 2 \cdot \pi \cdot f / p$, [$s^{-1}$] – synchronous angular velocity.

In practical system of units this formula looks as follows:

$$S_n = \frac{n_0 - n_n}{n_0},$$

where $n_0 = 60 \cdot f / p$ [rev/min] – synchronous frequency of rotation.

Connection between synchronous velocity in practical and SI-systems looks as follows:

$$\omega_0 = \frac{2\pi}{30} \cdot n_0 \text{ [1/s].}$$

3.2 Program of the work

3.2.1 Study the circuit of laboratory setup and features of operations of its separate elements.

3.2.2 Take electromechanical characteristics in generator, braking and motor regimes.

3.2.3 According to results of measurements calculate and build artificial and natural mechanical characteristics.

3.2.4 Identify separately one of the load (electromechanical) characteristics (natural), make its linearization and calculate the coefficient "S".

3.2.5 Construct a static model of an IM with a phase rotor at specified conditions.

3.2.6 When load on the test engine M4 (DM) is about 40% of the nominal, measuring the resistance of rotor rheostat from maximum to minimum, take regulating characteristic and build it.

3.2.7 Calculate the transmission coefficient “K” from the regulating characteristic.

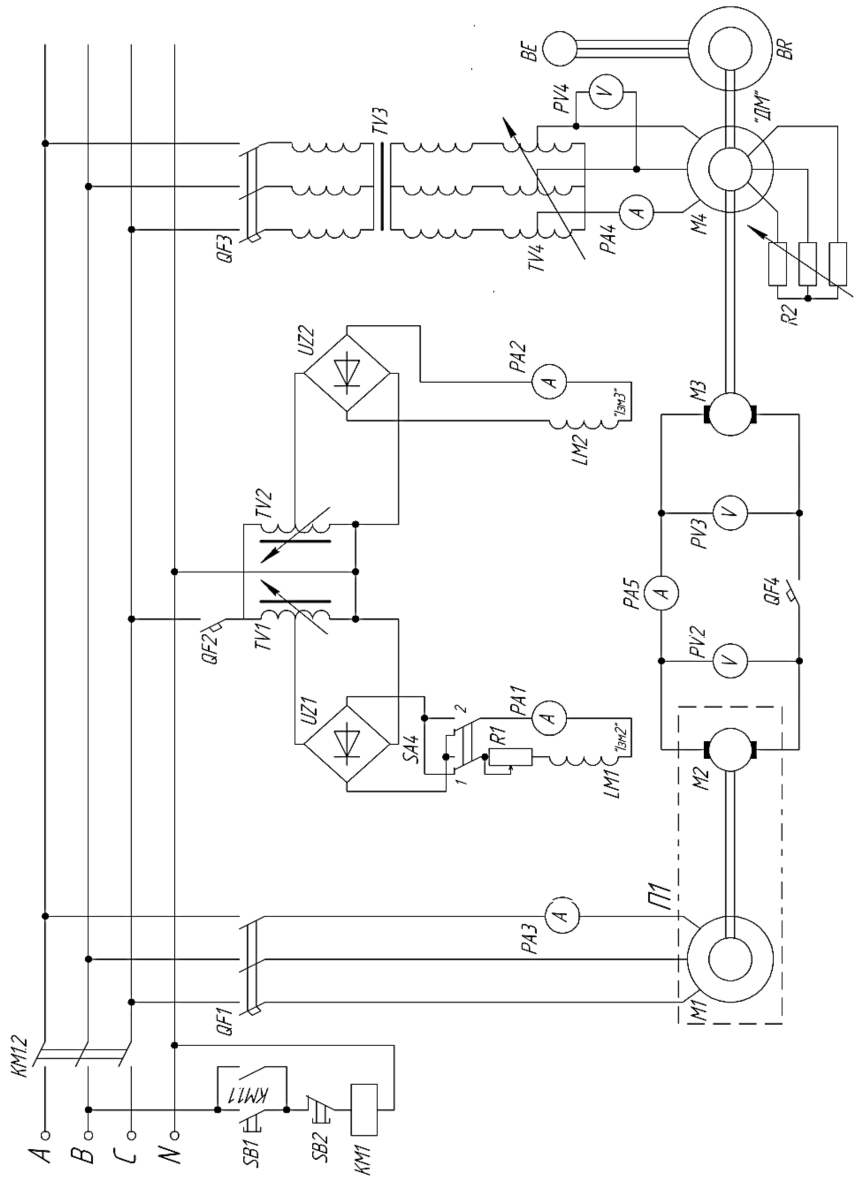


Figure 3.4

3.3 Description of the laboratory installation

The circuit is represented in figure 3.3 (and also on the panel of the stand). The object of investigations is the induction three-phase motor with a phase rotor (a designation ДМ on the circuit scheme – the investigation motor) which nominal parameters are represented in table 3.1.

Resistor R2 in a circuit of a rotor of IM is used as starting or regulating dependent on an operating mode

Table 3.1 − The nominal parameters of the electric motors used in the laboratory stand

Name and designation	Type	Nominal Data			
		Voltage, V	Power, kW	Current, A	Revolution frequency, rev/min
Investigating motor M4	АК-51/6	380	1.7	5.0	880
Loading generator M3	Л32	230	1.0	5.7	1000
Generator M2	ПН-85	230	6.8	28.5	1460
Motor MI	А5I-4	380	4.5	16.3	1440

Investigated motor is mechanically connected with generator M3, which is direct current motor of independent excitation. Using as a load the direct current motor M3 for IM, it is possible to realize braking and generator regimes on IM motor. For measurement of a revolution frequency of IM tachometric device is used, which consists of the sensor (three-phase synchronous tacho-generator BR with magnetoelectric excitation and receiver BR installed on the panel board of the stand). For definition of speed of IM (rev/min) it is necessary to multiply obtained value on BR by 25. Loading generator M3 is switched on according to the circuit generator-motor with direct current motor of independent excitation M2. Last one is rotated practically with constant speed by means of power-driven motor M1 (induction, three-phase with a short-circuited rotor).

Converter P consisting of motor M1 and generator M2, is intended for supplying of loading generator M3 with a direct current.

After turning on button SB1 ("Switch on") voltage supplies the stand. After switching QF3 the source voltage supplies transformer TV3, and investigated motor through autotransformer TV4. Switch QF4 is intended for turning on of an armature circuit of generators M2, M3 on parallel operation. Excitation windings of direct-current generators M2, M3 are supplied from an alternating current network through rectifiers UZ1 and UZ2, and in a circuit of generators M2, M3 before the rectifier autotransformers TV1, TV2 are installed, which allow to control an excitation voltage of generators M2, M3 over a wide range. Switch SA1 is intended for changing of direction of a magnetic flux of generator M2. Circuits of excitation of generators M2, M3 are switched on by switch QF2. Converter P is started by switch QF1.

3.4 Preparation for the work

The student should be prepared for laboratory work in advance. For this purpose it is necessary to study a theoretical material according to given questions, to study an order of work, to make preparation of report.

Before the beginning of performance of laboratory work the student submits to the teacher the report and answers questions. The unprepared student is not admitted to performance of laboratory work, and works it off in given order.

3.5 Order of the work execution

3.5.1 Before the work begins it is necessary to check the initial conditions of elements of installation: switch SA1 should be installed in a position "I", other switches are disconnected. Rheostat R1 in an excitation circuit of generator M2 is inserted. Handles of autotransformers TV1, TV2, TV3 are installed in a zero position. The starting rheostat of investigated motor R2 is brought out.

3.5.2 Turning on of the stand is made as following.

Button SB1 "Switch on" supplies stand. For starting of IM it is necessary to switch on switch QF3. With autotransformer TV4 increase a supply voltage of the motor to the value given by the teacher = (140...160)V.

Start power-driven motor M1 of converter P, with switching on of switch QF1. Motor M1 remains switched on till the end of all experiences.

The position "I" of switch SA1 coordinates polarity of voltage of generators M2, M3, so at achievement of equality of U1 = U2 it is possible to switch on switch QF4 which switches on armature circuits of generators on parallel operation.

After turning on QF4 the circuit scheme is prepared for work.

As the electromechanical characteristic of IM represents a curve which passes from limits of a generator regime into limits of motor regime and then braking (reversing), it is better to start taking characteristics from generator regime, and then to pass accordingly into motor and braking.

During experiments it is necessary to pay attention that in transient regimes (starting, excitation current change etc.) dynamic moment is observed which influences on indications of many devices of the circuit scheme. Therefore, before taking these indications, it is necessary to wait for approach of the steady regime and to edit values of $I_{ВМ3}$, $U_{ДМ}$.

3.5.3 To set induction motor to operation as generator in parallel with a network, it is necessary to rotate rotor with a speed, higher than synchronous (for induction motors with a phase rotor the rotational speed should not exceed synchronous more than on 20... 30 %). From passport data it follows that synchronous rotation frequency of IM is 1000 rev/min.

Increasing the exciting current of generator M2, speed of IM is set to a maximum limiting value, and then, reducing it to synchronous, execute 3-6 measurements, the data of measurements and results of calculations are tabulated in table 3.2. Point of synchronous speed for which at decrease of exciting current it is necessary to install a rotational speed 1000 rev/min. Thus it is necessary to remember that these experiments is necessary to execute at $I_{ЗМ3}$=const and $U_{ДМ}$=const.

Table 3.2 – Measurement and calculation data for determination of electromechanical and mechanical characteristics of induction motor in different regimes

№	Measurement data				Calculating data					Regime of operation
	$U_4=U_{IM}$, V	I_4, A	I_5, A	n, rpm	I_0, A	ω, s^{-1}	Mn, N·m	I, A	M,N·m	

3.5.4 At operation of the investigating motor in a generator regime motor M3 worked as the generator, M2 − as the motor. At decrease of current I_{3M2} speed of motor M3 and speed of the investigating motor of IM decreases too.

Transition of IM from a generator regime in motor (and motor M3 vice versa, from motor into generator) passes a point of synchronous speed without any switchings in the circuit design.

The further decrease of a current I_{3M2} will result accordingly and in the further decrease of speed of IM which works already in a motor regime.

It is necessary to note that at transition from a generator regime of IM into motor through a point of synchronous speed the stator current has the least value ($I_{4\min}$).

It is necessary to remember that for definition of the maximum moment in this regime, it is necessary to take the data carefully near the critical speed zone. For this purpose half of all measurements executes on one quarter of a control range of speed from a generating regime. Critical speed achievement should be fixed according to indications of devices. On this speed the IM operation is unstable and thus there is an appreciable oscillation of an arrow of ampermeter RA4 in a circuit of the stator of ДМ.

The point with coordinates { $\omega = 0$; $I_{3M2} = 0$ } will be a characteristic of finishing point in motor regime. Thus autotransformer TV1 is withdrawed. If at completely withdrawed autotransformer TV1 the motor IM was not stopped, then it is necessary to switch SA1 in generator M2 circuit into position "II" (the direction of exciting current M2 thus changes) and to raise an exciting current I_{3M2} until the motor stop.

3.5.5 opposite direction. In this experiment an external counter-torque for IM is formed by loading generator M3.

This experiment is continuation of the previous one. If in the end of the previous experience the ДМ rotor stopped at switched on SA1 (position "I") for realization of a regime of reverse it is necessary to switch SA1 into position "II" and to increase exciting current.

As current increases (opposite polarity in comparison with a current I_{3M2} in a motor regime) a rotor of IM under the influence of motor M2 will be rotated against a direction of rotation of a field of the stator with increasing of the speed, the maximum speed in the opposite direction also should not exceed synchronous more than on 25... 30 %. Within the limits of a regime of reverse (from null till the given speed) it is possible to execute 5-6 measurements, the data of measurements and design data tabulate in table 3.2.

All presented experiences were executed for definition of natural characteristics ($R_2 = 0$) at lower voltage of a source. Rheostat characteristics of IM decrease at input in a rotor circuit of additional resistance (starting rheostat R_2). At this experiment it is enough to use only motor regime, for this it is necessary to switch ДМ from a reverse to motor regime (again to reduce a current to null. Lowering thus speed of system to a minimum, to switch SA1 in a rule "And", to switch the tachometer toggle actuator, to inject autotransformer TV1 and to raise speed to synchronous).

Under directions of the teacher install magnitude of voltage a source of the investigated motor; inject rheostat R2 into circuit of a rotor of ДМ, thus magnitude resistance is defined by the teacher; in limits of motor ДМ regime (decrease of speed from synchronism to null) execute 5-6 measurements, (the obtained data and results of calculations bring in table 3.2), value R2 takes place in the column of the table "operating mode").

For construction of these characteristics it is necessary to submit a rotational speed fixed by a tachometer in a system of units of SI:

$$\omega = \frac{2 \cdot \pi \cdot n}{60},$$

where n − a rotational speed, rev/min.

Neglecting motor saturation, it is possible to consider that at the set sliding (angular speed of a rotor) the stator current is proportional to voltage, therefore

$$I = I_4 \cdot \frac{U_{ДМном}}{U_{ДМ}},$$

where I − a stator current at rated voltage ($U_{ДМn}$ = 380), A; I_4 − the current of the stator gained in experience at a lower voltage, $U_{ДМn} = U_{4}$.

To build speed-torque characteristics, it is necessary to count the M moment on the ДМ shaft at supply rated voltage = 380 V. Moment of the motor is fixed by an armature current of loading generator M3 in the steady regime. The electromagnetic moment of generator M3, Nm:

$$M_{el} = C_1 \cdot \Phi \cdot I_5,$$

where C_1 − a coefficient of proportionality which depends on an exciting current; I_5 − generator M3 armature current, A; magnitude C_1 is defined from the empirical data resulted in table 3.3. Where the factor C_1 is set for some values of an exciting current of loading generator M3.

Table 3.3 – Value of coefficient C_1 of loading generator

I_{3M2}, A	0,5	0,6	0,7
C_1, N·m/A	–	1,77	–

The moment on the shaft of the investigated motor of ДМ is equal to the moment created by generator M3:

$$M_{ДМ} = M_{ЕЛ1} + M_n$$

where M_n - the moment of losses caused by mechanical losses and an iron loss of loading generator M3, and also mechanical losses in IM, Nm.

The right part of this equation represents an algebraic sum, therefore when loading generator M3 works in motor regime, it compensates losses in the assembly. It is observed at a generating regime of the investigated motor of ДМ and at its reverse:

$$|M_{ДМ}| = |M_{ЕЛ1}| - |M_n|$$

At motor regime of ДМ generator M3 works in a generator regime, hence losses in the assembly are compensated by the investigated motor of ДМ, therefore in this case the moment it is possible to count by formula:

$$|M_{ДМ}| = |M_{ЕЛ1}| + |M_n|$$

For a finding the so-called curve of losses:

$$\omega = f(I_0),$$

where I_0 – generator M3 armature current at the switched off of investigated motor of ДМ. In table 3.4 dependence of a current on speed is represented.

Table 3.4 – Dependence of velocity ω from armature current I_0 of loading generator M3

ω, c^{-1}	0	10,5	31,4	42,0	52	63	84	105	126	147	768
I_0, A	0,35	0,5	0,63	0,7	0,72	0,75	0,8	0,9	0,93	0,98	1,0

Knowing this dependence, it is easy to calculate the moment of losses, Nm:

$$M_{EL} = C_1 \cdot \Phi \cdot I_5$$

where C_1 - is defined from table 3.3 according to an exciting current, Nm/A; I_0 – from table 3.4 on speed ω, which is taken from table current 3.2.

Thus, a formula for defining of a moment $M_{ДМ}$ (Nm) on the shaft of the investigated motor of ДМ at supply voltage reduction when the ДМ works in motor regime:

$$M_{ДМ} = C_1 \cdot (I_5 + I_0).$$

In a generating regime and reverse:

$$M_{ДМ} = C_1 \cdot (I_5 - I_0).$$

The moment which is developed by an induction motor is proportional to a square of supply voltage, therefore for definition of the moment of the motor at an undervoltage it is necessary to execute the moment inventory, proceeding from the moment at an undervoltage, Nm:

$$M = M_{ДМ} \cdot \left(\frac{U_{nom}}{U_{ДМ}}\right)^2,$$

where M − the ДМ moment at rated voltage; $M_{дм}$ − the ДМ moment at an undervoltage which undertakes from table 3.2.

3.6 Control questions

3.7.1 Explain the work of laboratory installation in general and features of work of its separate elements.

3.7.2 Explain according to the circuit design, realization of each mode.

3.7.3 What is the sense of electromechanical and mechanical characteristics, their interconnection and difference.

3.7.4 Result graphs of natural and rheostat characteristics.

3.7.5 Equivalent circuits of an induction motor.

3.7.6 Structure of induction motors with a phase and short-circuited rotor, a principle of their work.

3.7.7 How to count the natural characteristic by passport data.

3.7.8 Write the speed-torque characteristic equation of induction motor.

3.7.9 Find on a speed-torque characteristic its characteristic points.

3.7.10 Why induction motor characteristics were taken at undervoltage, instead of nominal voltage.

3.7.11 Why in all experiences the performance of conditions $I_{ЗМЗ}$=const and $U_{ДМ}$=const.

3.7.12 What is a sense of a regime of a reverse braking for induction motors.

3.7.13 What are the features of a regime of regenerative braking for induction motors.

3.7.14 Ways of speed regulation of induction motors which are possible on conditions of the experiences.

3.7.15 Advantages and disadvatages of the drive with an induction motor compare with the the direct-current motor.

3.7.16 Name brunches of industry where induction motors are used.

4 LABORATORY WORK №5

Speed regulation and control circuit of the multispeed induction motor

The purpose of the laboratory work: to study physical processes and features of regulation of angular velocity of the induction motor by switching of number of poles; circuit of automatic control of starting, braking and reverse of the dual-speed induction motor.

4.1 General theory

Value of synchronous velocity of electric motors at given frequency of a power supply voltage is defined by polarity of the system, and angular velocity of an induction motor is defined from expression:

$$\omega = \omega_0 \cdot (1 - s) = \frac{2 \cdot \pi f_1}{p} \cdot (1 - s) \qquad (4.1)$$

where ω_0– synchronous velocity, s^{-1};

s – sliding, r.u.;

f_1 – frequency of the power source, Hz;

p – number of pairs of poles.

From the formula (4.1) follows that is possible to control angular velocity of the induction motor by changing quantity of pairs of poles, if the network frequency is stable and sliding changes slightly. As the quantity of pairs of poles can be only integer, regulating of angular velocity is stepped. This way is used for induction motors with a short-circuited rotor where it is enough to change only quantity of poles of a winding of the stator. And in a rotor corresponding quantity of poles will be installed automatically, as the rotor winding represents "the squirrel cage" – property of polysynchronism.

Switching of number of poles of the stator usually carried out:

– the stator has two or more three-phase windings on the different quantities of poles, and velocity is changed by turning on one or another winding;

– carry out one three-phase winding on the stator, and velocity is controlled by current varying in certain sections of each phase winding according to chosen connection schemes.

Deficiency of the first way is a deterioration of size and weight of motor parameters.

Multispeed motors combine both named ways of switchings of poles of the stator.

On figure 4.1 circuit diagrams for change of quantity of pairs of poles are represented with relationship 2:1 for following joints of halfwindings: consistent in series (a) with quantity of poles 2p = 4; directed in series (b) with 2p = 2; parallel (c) with 2p = 2.

There are various circuit designs of switching of three-phase windings of the stator, the most expedient represented in figure 4.2. The single quantity of poles is marked by 1, double by 2.

At transition from greater number of poles to less angle of the phase zones of pole windings changes the magnitude from 60 el.deg. to 120 el.deg that leads to phase sequence change on the opposite. Proceeding from it, at switching from one number of poles to another for the purpose of not changing the direction of rotation, it is necessary to change priority of phases into inverse. Represented in figure 4.2 circuit designs are characterized by various values of power and moment.

From the theory of electric machines it is known that for induction motor value of electric power will be converted in mechanical, it is defined by expression:

$$P = m \cdot E^{'}2 \cdot I^{'}2 \cdot \cos\varphi_2 \, 2\text{x} \qquad (4.2)$$

де m – quantity of phases;

$E\`2$ – – a total EMF of a winding of a rotor;

$I\`2$ – total current of a rotor;

$\cos\varphi_2$ – power factor of a rotor.

Schemes of switching of windings of the stator:

- Scheme Δ (Y) / YY (Δ) for regulating at M = const; Scheme Y/(Δ) for regulating at P = const;
- Scheme Y / YY for regulating at M = const; Scheme Y(Δ)/Y(Δ) for regulating at P = const.

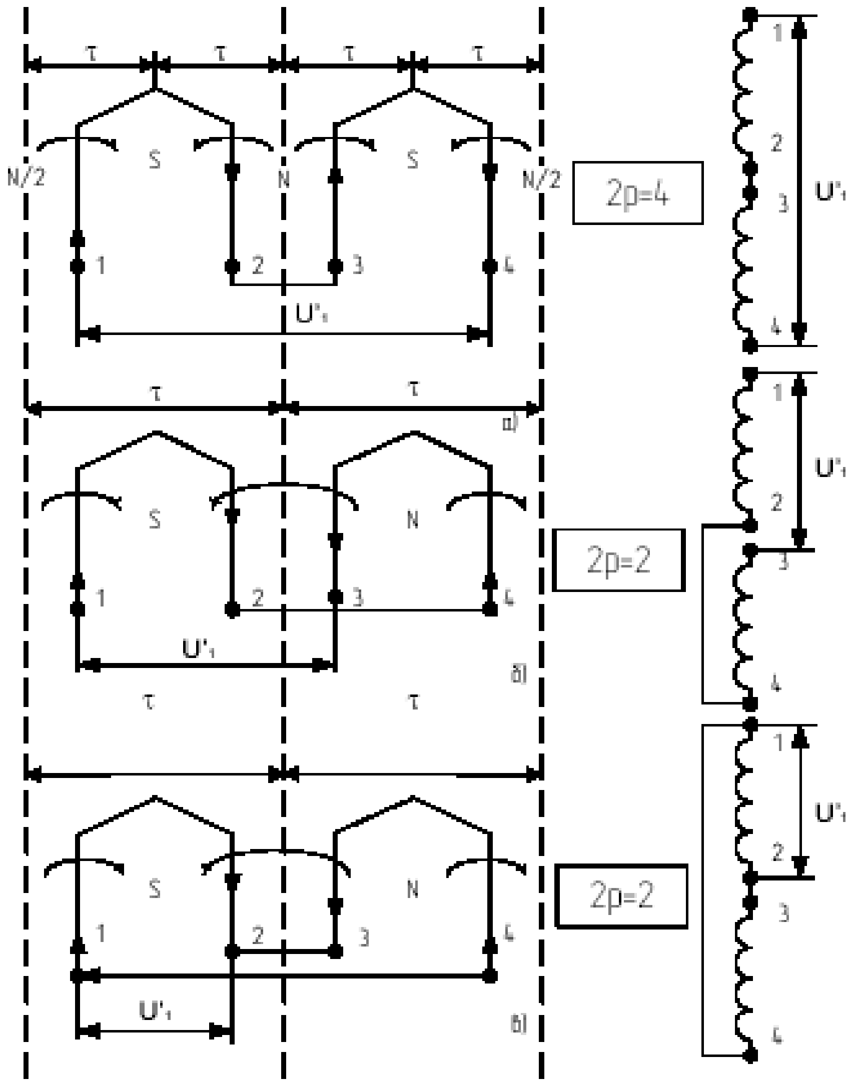


Figure 4.1 – Connection of half-windings

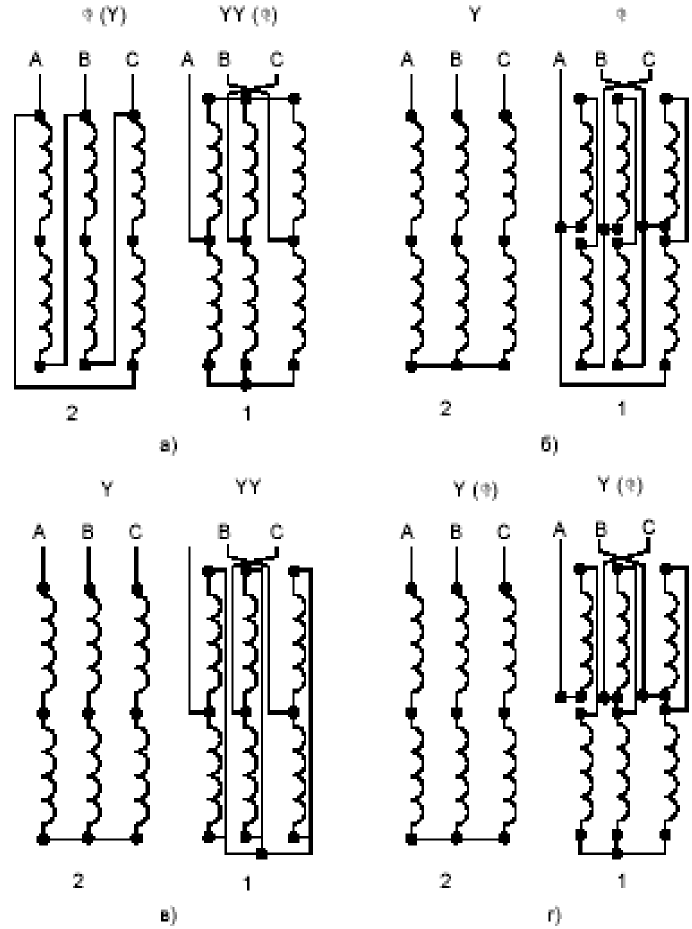


Figure 4.2 – Scheme of the switching of the stator windings

Expression can be written down approximately:

$$P = C \cdot U_{1ph} \cdot I_{1ph},$$

де $C = m \cdot \cos\varphi_2$;

U_{1ph} – phase voltage;

I_{1ph}– phase current of the stator.

As we see, the schemes of switchings represented in figure 4.2, a,c allows to regulate velocity at constant moment (mechanical characteristics in figure 4.3, a). Schemes of switchings in figure 4.2, b, d allows to regulate velocity at constant power (mechanical characteristics in figure 4.3, b).

4.2 Program of the work

5.2.1 Study main ways of regulation of velocity of multispeed induction motors, execute report with nominal data of the motor, the circuit of installation, tables 4.2, 4.3.

5.2.2 Study the laboratory installation, write down motor nominal data in table 4.2.

5.2.3 Execute experiments, write down results of measurements in table 4.3.

5.2.4 Make conclusions of the work.

4.3 Description of the laboratory installation

The installation scheme is shown in figure 4.4. Object of researches is a dual-speed induction motor. Circuit of main motor current is equipped by automatic switch QF1 and thermal relays KK1, KK2 which provide protection of the motor from overloads and short circuits.

Table 4.1 − Power and moment at various circuit of winding switchings

Switching circuit	Designation of polarity	Connection circuit	Voltage ration	Current ration	Power	Moment	Conditions of speed regulation
Figure 5.2, a	2	Δ	$U_{1ph}=U_{1l}$	$I_{1ph}=I_{1l}/\sqrt{3}$	P	M	M=const (figure 4.3, a)
	1	YY	$U_{1ph}=U_{1l}/\sqrt{3}$	$2I_{1ph}=2I_{1l}$	2P	M	
Figure 5.2, b	2	Y	$U_{1ph}=U_{1l}/\sqrt{3}$	$I_{1ph}=I_{1l}$	P	2M	P=const (figure 4.3, b)
	1		$U_{1ph}=U_{1l}$	$I_{1ph}=I_{1l}/\sqrt{3}$	P	M	
Figure 5.2, c	2	Y	$U_{1ph}=U_{1l}/\sqrt{3}$	$I_{1ph}=I_{1l}$	P	M	M=const (figure 4.3, a)
	1	YY	$U_{1ph}=U_{1l}/\sqrt{3}$	$2I_{1ph}=2I_{1l}$	2P	M	
Figure 5.2, d	2	Y	$U_{1ph}=U_{1l}/\sqrt{3}$	$I_{1ph}=I_{1l}$	P	2M	P=const (figure 4.3, b)
	1	Y	$U_{1ph}=U_{1l}/\sqrt{3}$	$I_{1ph}=I_{1l}$	P	M	

Switching on of the installation is carried out by pressing button SB1 ("Switch on"). Then a winding of contactor КМ1 is energized and contacts are closed: power contacts in a three-phase network of the AC voltage 380V and regulation contacts, which shunting the button SB1 and set contactor KM1 winding on a self-supply.

Choosing of regime of motor operation is carried out by pressing buttons SB6 ("Low speed") or SB7 ("High speed"). Thus, contactor KM4 winding (or КМ5) is energized and КМ6 provides turning on of windings of the motor according to schemes correspondingly "Δ" or "YY" and mutual blocking, and energizing of contactor КМ7 and with its help preparation of the circuit for the further work.

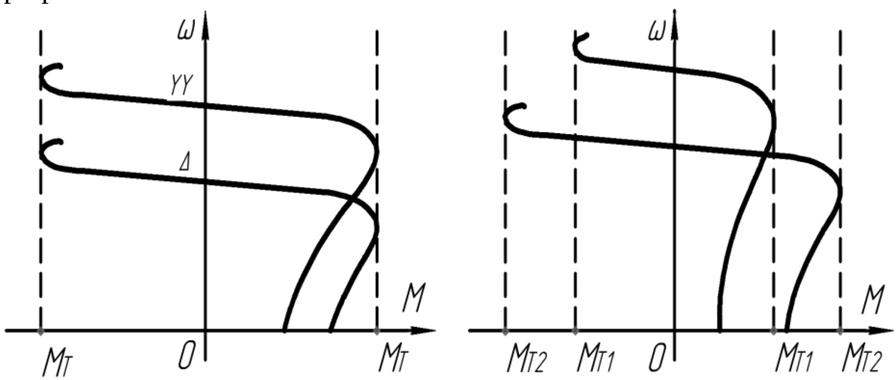


Figure 4.3 – Mechanical characteristics

Table 4.2 – Motor passport data

№	Denomination	Units	Nominal data
1	Type	–	
2	Power	kW	
3	Number of phases	–	
4	Voltage	V	
5	Current	A	
6	Revolution speed	rev/min	
7	$\cos\varphi$	–	
8	Mass	kg	

Choice of a direction of rotation of a rotor and engine is carried out by pressing button SB4 ("Forward") or SB5 ("Back"). Thus windings of contactors KM2 or KM3 are energized and provide feeding of direct voltage and reverse and also mutual blocking.

The circuit is equipped by diagonal lamps which give information of regime of operation of motor, and measuring devices. Switching-off of the motor from a network and dynamic braking is carried out by pressing button SB3 ("Switch off").

Table 4.3 − Measurement data

Denomination	Units	Small speed	Large speed
Speed	rev/min		
Voltage U_1	V		
Steady stator current	A		
Maximum stator current at plugging	A		
Voltage U_2	V		
Maximum current at dynamic braking	A		

In a DC circuit there is also automatic switch QF2, which protects from short circuit. Contact KT1 time relay KT1 in a corresponding time interval feeds contactor KM9, with the help of which contactor KM8 is disconnected and the engine is switched off from a DC network.

The circuit allows the transition from Low speed to High, and also plugging and reverse without stopping of the motor by pressing of button SB3 ("Stop").

Installation switching-off is carried out by pressing button SB2 ("Switch off"). Contactor KM1 is disconnected and installation is disconnected from an AC network.

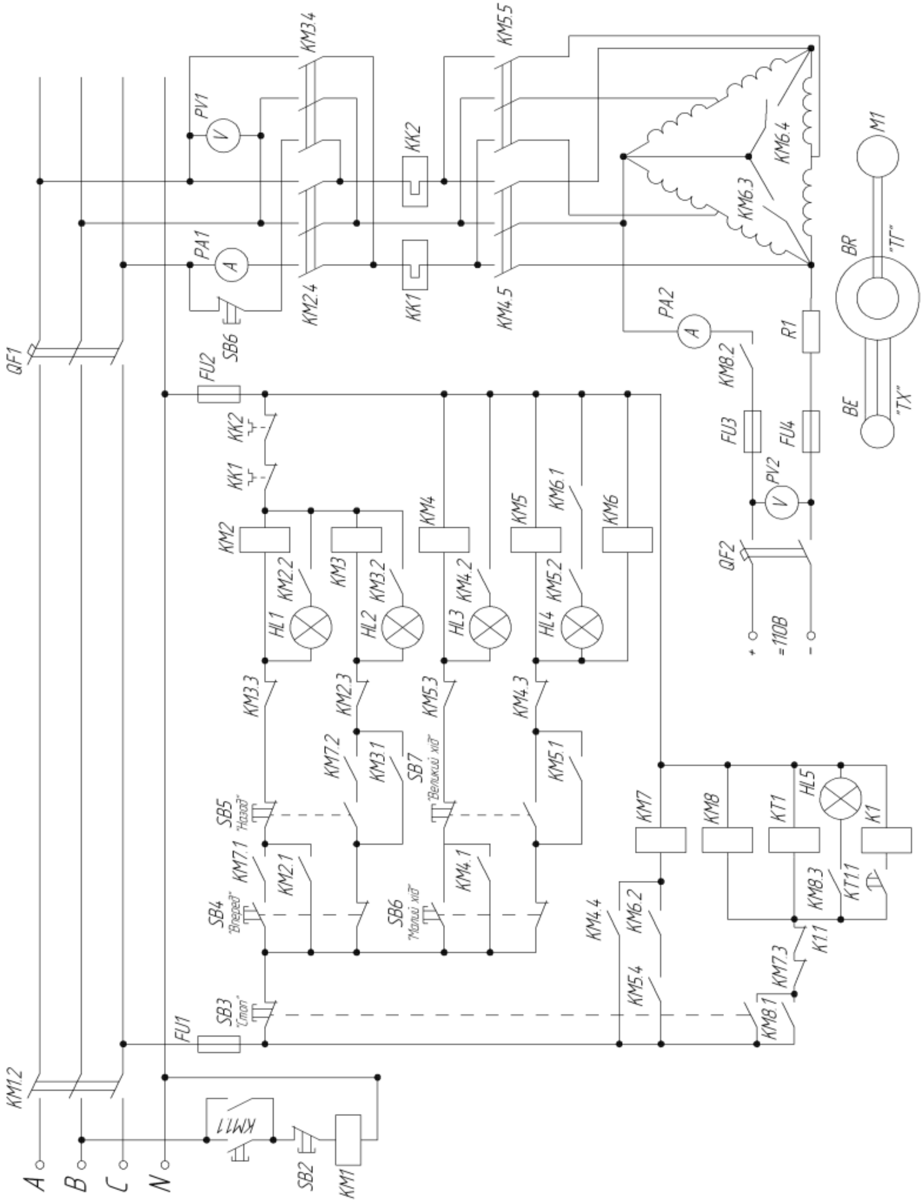


Figure 4.4 – Circuit of the laboratory installation

4.4 Order of the laboratory work execution

Work should be carried out in a following order:

- obtain the permission of the teacher;
- switch on the installation by pressing button SB2 ("Switch on")
- switch on automatic switches QF1 and QF2;
- choose the circuit of connection of stator windings of the engine on Δ by pressing the button SB6 ("Low speed");
- start the motor by pressing of button SB4 ("Forward"), write down indications of devices PV1 and PA1;
- carry out plugging and reverse of the engine by pressing the button SB4 ("Forward"), write down the maximum value of a current of device PA1;
- execute switching on and dynamic braking of the motor by pressing button SB3 ("Stop"), write down the values of devices PV2 and PA1;
- disconnect switches QF1 and QF2, switch off installation by pressing button SB2 ("Switch off").

4.5 Content of the report

The report should contain the work name, the circuit of installation, passport data of the investigated motor, the table of experimental data, conclusions of the work.

4.6 Control questions

4.6.1 How does preparation of the circuit for work is provided at Low (High) speed.

4.6.2 How does forward-back work of motor is carried out, work of scheme at dynamic braking and stop of motor.

4.6.3 How does protection of the scheme against overloads and short circuits is carried out.

4.6.4 How does electric blocking and a self-feeding of contactors are provided in the circuit.

4.6.5 Advantages and disadvantages of regulation of velocity by switching of number of poles.

4.6.6 Difference of regulation of velocity by switching of number of poles in the induction motor with phase and short-circuited rotors.

4.6.7 Features of electric braking of multihigh-speed induction motors.

4.6.8 Where multihigh-speed the induction motors are used, [4].

5 LABORATORY WORK № 6

The control scheme of reversal of the electric drive with short-circuited induction motor

The purpose of the laboratory work: to study principles of reversal of electric drives with induction motors; to study relay-contact circuit of manual and automatic control of the reversal of the electric drive with induction motor with the short-circuited rotor.

5.1 General theory

Most electric drives demands change in direction of rotation (or linear movement), for example at work of a drive gear of shifting of various tube cleanings, a drive gear of feeders of machine tools, a drive gear of load-lifting elevating gears and others. Sometimes mechanical reversal or cranks are used. But electric reverse by change of magnitude on the moment which electric motor expands is used. For d.c. engines reverse is more often carried out by changing the direction of a current by means of change of polarity of voltage across the winding of an armature. Induction motors are reversed by means of change of directions of rotation of a magnetic field of a stator for what it is enough to change priority of phases of power source (at three-phase source it is enough to interchange any of two phases).

In the manual control circuit for this purpose reverse magnetic actuator is used which has two contactors (forward and reverse motion) and two buttons of control, with help of which corresponding contactor windings are fed, power contactors of which switche phases on a stator.

At automatic control with the given cyclic recurrence of the forward and reverse motion it is necessary to control a path (the linear displacement at angle of rotation) or time.

5.2 Program of the work

5.2.1 Study the scheme of laboratory installation and features of work of its separate elements.

5.2.2 Fulfill stand work by all types of control.

5.2.3 Make the analysis of results of research.

5.3 Description of the laboratory installation

At the stand circuit which is represented in figure 5.1, an induction motor with a short-circuited rotor is installed. It is mounted according to kinematic link of a screw-nut which transforms a rotating motion of electric motor into progressive motion of the cart, which emits progressive working body of the industrial gear. In the beginning and in the end of a stroke of the cart finite switches are mounted. The stand allows to carry out both manual and automatic control of a reversal (manual - position "0" of switch SA1; automatic – position "П" and position "В" of switch SA1). The main control apparatus is the reverse magnetic actuator consisting from contactors KM1 (forward action) and KM2 (reverse action). Besides, intermediate relays KH1, KH2, time relays KT1, KT2, final switches SQ1, SQ2 and control buttons are installed. The stand is connected to three-phase network voltage 380 V also it is provided with the automatic switch QF, protecting installation from overloads and short circuits. In figure 5.2 the mechanical characteristic of induction motor at forward and reverse rotation are represented.

Segments AB and A`B` correspond to change of rotation from forward to reverse and engine regime in transition to regime of plugging at reactive static moment.

5.4 Preparation for the work

The student should be prepared for the laboratory in advance. For this purpose it is necessary to learn theoretical course in correspondence with the questions, to study an order of the work, to make report headlines.

5.5 Order of the work execution

5.5.1 Check up an initial condition of the scheme: switch QF is switched off, switch SA in a position "O". To switch on a power supply by pressing button "Switch on".

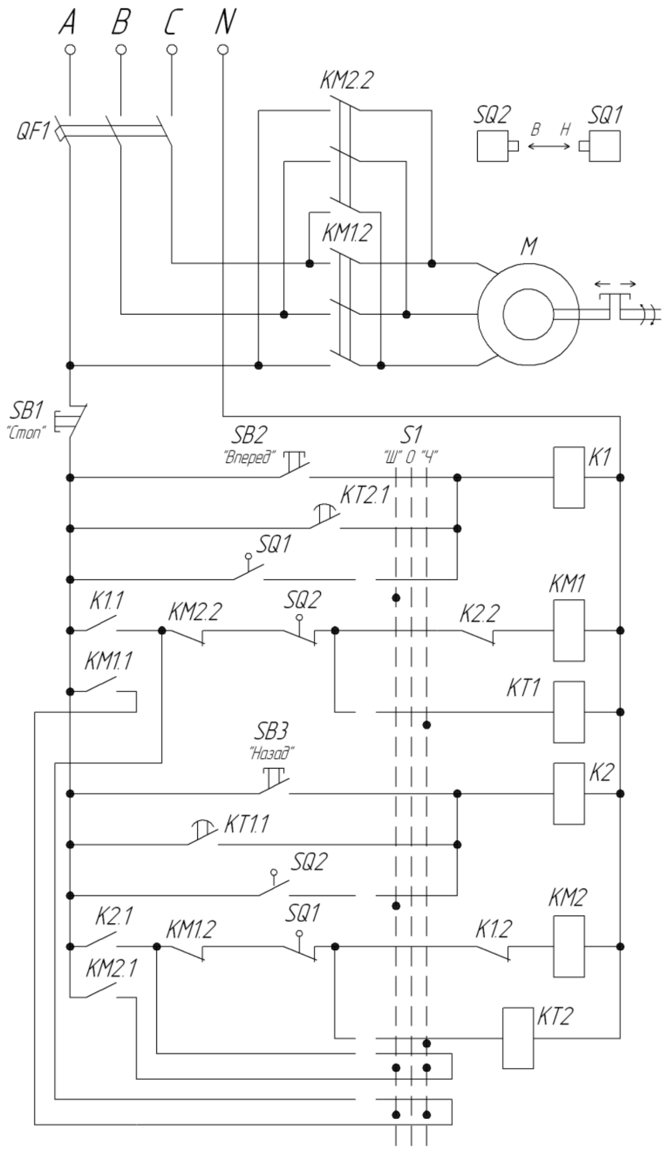


Figure 5.1 – The circuit of the laboratory installation.

5.5.2 For switching the circuit into a manual control mode at position of the switch SA1 "O" switch on automatic switch QF. In case of pressing, for example, button SB2 ("Forward") the winding of intermediate relay KH1 is fed, closing contacts of which provides a feeding the winding of contactor КM1, and, accordingly, closing of power contact of contactor КM1.

The engine starts to rotate in a direction "Forward". At this time disconnecting relay contact KH1 opens circuit of a winding of contactor КM2 for prevention of casual simultaneous closing of contactors КM1 and КM2. Pressing button SB3 ("Reverse") the circuit works similarly, but intermediate relay KH2 and contactor КM2 are used.

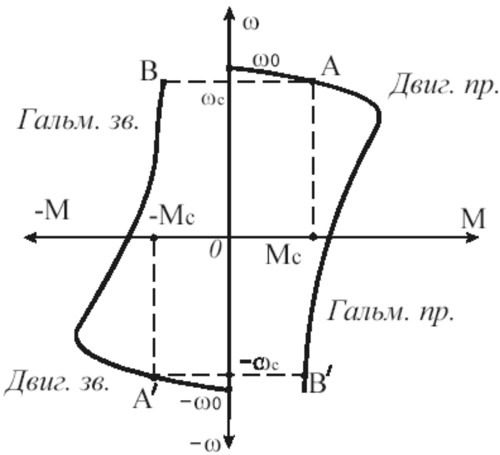


Figure 5.2 − Mechanical characteristics of IM in the drive and breaking modes.

For switching into control mode as time function it is necessary to set the switch SA1 into position "B". In this case at switching on of a winding of contactor КM1 or КТ2 simultaneously windings of the time relay correspondingly КM1 or КТ2 will be switched on, and time of motor operation in the adjusted direction will be defined by endurance time, set on a corresponding time relay. With a passing of this time the closing relay contact of time works. For example, with switching on winding of contactor КM1 winding of time relay КТ1 is fed after established on it time interval the relay closing relay contact КТ1 to feed the coil of the intermediate relay КН2. The opening contact of this relay disconnects contactor КМ1, and closing – switches on КМ2. Operation time of it will be defined by endurance of time, established on timer КТ2 and other.

For switching scheme into control mode in function of path, switch SA1 must be in position "П". At this time relays КТ1 and КТ2 are removed, and the final switches SQ1 and SQ2 are involved. In this case, for example, at work of contactor КМ1 the cart will move forward till the moment of operation of final switch SQ2.

Thus, there will be a reverse. The cart, moving back, reaches final switch SQ1, its operation (similarly SQ2) leads to a reverse and movements in the opposite direction.

Attention! Before work on stand in the mode of automatic control in functions of time by means of a manual control you should establish the cart in the position for which movement of a cart forward or reverse would provide period of operation of motor, set on time relay КТ1 and КТ2.

5.6 Content of the report

The report should contain: the stand circuit, the graph of the mechanical characteristics, the short analysis and conclusions on work.

5.7 Control questions

5.7.1 Main point of manual and automatic controls.

5.7.2 In functions of which quantities it is possible to carry out the automatic control of electric motor.

5.7.3 Functions and features of elements of the considered circuit.

5.7.4 How the interlock of contact is executed in the reverse magnetic actuator.

5.7.5 How the automatic interlock circuit of contactors is executed.

5.7.6 How the circuit works at a manual control.

5.7.7 How the circuit works at automatic control in function of time.