EM-4 (*English*)

Ministry of Education and Science of Ukraine
Dnipro University of Technology

Electrical Engineering Department

Ivanov O.B., Tsyplenkov D.V.

COLLECTION OF METHODICAL MATERIALS for laboratory work on discipline "Electric Machines" (section "Induction machines") for students studying specialty 141 “Energy, Electrical Engineering and Electromechanics”

Dnipro
2021

EM-4 (*English*)

Ministry of Education and Science of Ukraine
Dnipro University of Technology

Electrical Engineering Department

Ivanov O.B., Tsyplenkov D.V.

COLLECTION OF METHODICAL MATERIALS for laboratory work on discipline "Electric Machines" (section "Induction machines") for students studying specialty 141 “Energy, Electrical Engineering and Electromechanics”

Dnipro
2021

Recommended for publication by the educational and methodical department (protocol № from the proposal of the scientific-methodical commission on the specialty 141 "Energy, electrical engineering and electromechanics" (protocol № 21/22-01 from 30.08.21)

Collection of methodical materials for laboratory work on discipline "Electric machines" (section "Induction machines") for students studying specialty 141 “Energy, Electrical Engineering and Electromechanics” / O.B. Ivanov, D.V. Tsyplenkov; Dnipro University of Technology – D.: DniproTech, 2021. – 40 p.

Authors:

Ivanov Oleksiy – Professor of Electrical Engineering
Tsyplenkov Dmytro – Head of the Electrical Engineering Department, Associate Professor

Methodical instructions are intended for laboratory work in the discipline of Electrical Machines (section "Induction machines") students studying in specialty141 – Energy, Electrical Engineering and Electromechanics.

© Ivanov O., Tsyplenkov D. 2021.
© Dnipro University of Technology, 2021

LABORATORY TEST # 3/1

STUDY OF INDUCTION MOTORS CONSTRUCTION AND PRINCIPLE

Aim of the training is study of induction motors construction and experimental investigation conditions of obtaining circular rotating magnetic field and electromagnetic torque.

Work program

1. Study of construction of wound rotor and cage induction motors.
2. Observation of the phenomenon of rotating magnetic field.
3. Familiarization with ratings of induction motors.
4. Determination of a motor phase winding terminals.
5. Marking of an induction motor terminals and connection it to supply network.

The work procedure

Attention! *Any change of the circuit connections must be made after it deenergizing, i.e., at the switches turned off and the fuses at the bench supply panel removed.*

Stage 1. *Study of induction motors construction*

Using available in the laboratory specimens of disassembled and complete wound rotor and cage induction motors and their parts, study the machines construction. At this, pay attention to:

- construction of stator and rotor magnetic cores assembled from electrical steel sheets, shape of the sheets and methods of their insulation.
- shape of the stator and rotor slots of cage and wound rotor machines
- construction of single layer and two-layer windings.
- connection of the wound rotor winding to slip rings, construction of brushes and bush holders.
- construction of the motors frame at different degree of protection.
- ways of motors installation in horizontal or vertical position and for its transportation.
- fixation of the motor shaft in bearings, shaft extension.
- terminal box.
- rating plate.
- possibility of motor connection to networks with different lint-to-line voltage.

Stage 2. *Observation of the phenomenon of rotating magnetic field*

Familiarize with available installations for demonstration of formation magnetic field in AC electric machines.

Provide conditions and observe phenomena of magnetic field produced by windings of three phase system:

- pulsating magnetic fields produced by current of each winding of the three-phase system.
- circular rotating field produced by three phase winding fed with a symmetrical three phase currents.
- way of the rotating magnetic field reversing.
- obtaining an elliptic rotating magnetic field at two phase windings energizing.
- manifestation of the action of rotating components of a pulsating magnetic field.

Stage 3. *Familiarization with ratings of induction motors*

Fill in the rated values of the induction motor to be tested to the Table 1.1. Pay attention that line-to-line voltage and line current are given in the motor nameplate.

Table 1.1

Ratings of induction motor

Nameplate data							Extra ratings					
U_{1lr}	I_{1lr}	P_r	n_r	η_r	$\cos\varphi$	f_{1r}	$2p$	n_1	s_r	Ω_r	M_{2r}	P_{1r}
V	A	W	rpm	%	–	Hz	–	rpm		$\frac{\text{rad}}{\text{s}}$	Nm	W

Determine and enter the table extra rating data: number of poles of the motor rotating magnetic field $2p$; synchronous angular speed Ω_1; rotational frequency n_1; rated slip s_r; rated torque on the motor shaft M_{2r}; power consumed by the motor under rated conditions P_{1r}.

Stage 4. *Determination of phase winding terminals*

Before determination pairs of stator winding terminals of cage induction motor, connect available six winding leads to the screw terminals on the temporary panel in arbitrary order. Determination of winding terminals is explained by Fig. 1.1. After finding them, connect the leads to terminals on the panel as shown in the figure.

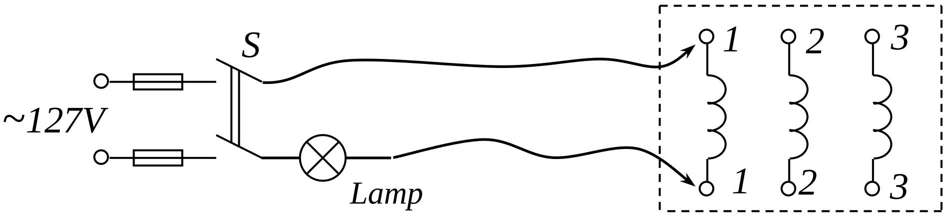

Figure 1.1 – Determination pairs of winding terminals

Stage 5. *Marking the stator phase winding terminals*

Proper marking of the phase winding terminals provides their connection in star and in delta at which circular rotating magnetic field is obtained.

The machine terminals marking is performed with the help of circuit shown in Fig. 1.2.

When start lead of one phase and start lead of another phase (or end lead of one phase and end lead of another phase) of two of three phases are connected, the voltmeter connected across the third phase gives zero reading.

If start lead of one phase and end lead of another phase are connected, the voltmeter gives reading different of zero.

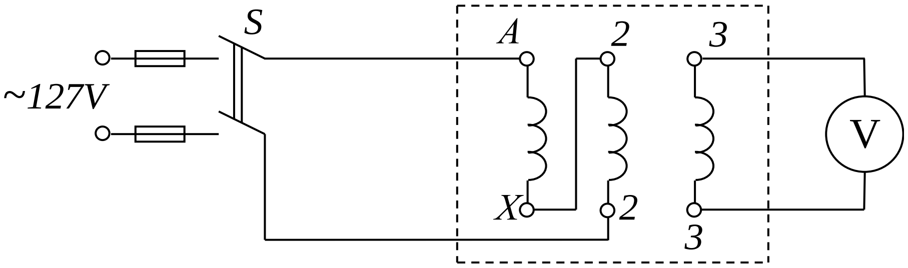

Figure 1.2 – Marking the winding terminals

Stage 6. *Connection induction motor to supply network*

Arrange connection the winding leads to panel terminals in order shown in Fig. 1.3.

Proceeding from the supply network line-to-line voltage and the machine rated voltage, select the way of the stator winding connection (Y or Δ).

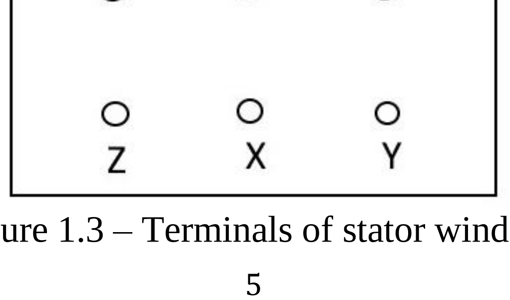

Figure 1.3 – Terminals of stator winding

Connect the machine to the network according to Fig. 1.4, *a*, and perform a test start of the unloaded motor.

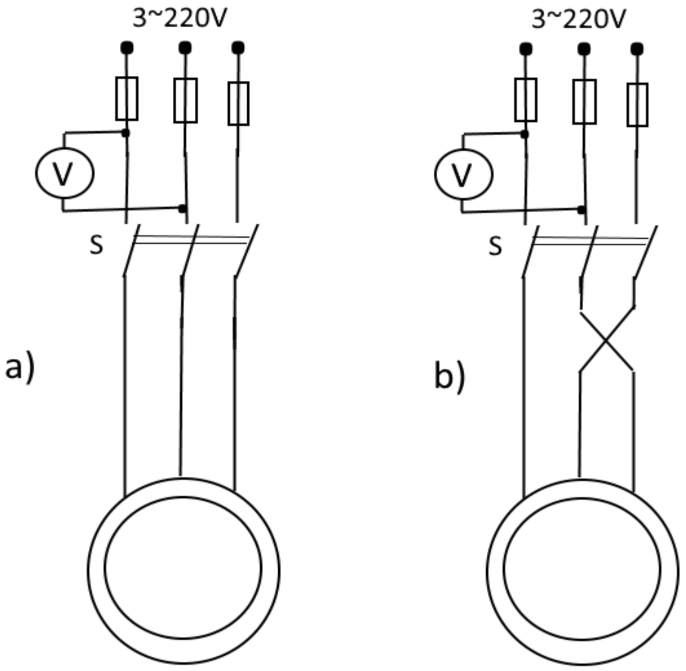

Figure 1.4 – Connection the motor to three-phase circuit

The motor rotation with speed practically equal to its synchronous speed with little operating noise confirms correctness the terminals marking.

Switch off the motor and notice the direction of the shaft rotation. Then interchange the ends of any two wires connecting switch S with the motor (Fig. 1.4, *b*) to change sequence of phases of three-phase voltage system applied to the motor.

Start the motor again. The rotation will be in the opposite direction to the previous, that is, the motor is reversed.

***Stage 7**. The report execution*

The report must contain:

1. The work title, its aim and program
2. The motor ratings and extra ratings data entered the Table 1.1 and calculations needed for the extra ratings data determination
3. Circuit for determination phase winding leads Fig. 1.1)
4. Circuit for marking the machine terminals (Fig. 1.2)
5. Arrangement the terminals in the motor connection box (Fig. 1.3)
6. Circuits for the motor connection to the network for both directions of rotation (Fig. 1.4 *a*, *b*).

Methodical guidelines

To stage 2

There are installations for observation phenomena of pulsating and rotating magnetic fields. The first unit is a three-phase symmetrical coil system on the axis of which the ferromagnetic arrow able to rotate is located (Fig. 1.5). The coils of the system can be fed either separately by one with single-phase current or being connected in Y - with three-phase current system. It is also possible to feed two of the coils with two-phase current system.

One coil fed by alternating current produces pulsating magnetic field, and the arrow takes a position coinciding with the coil axis (Fig. 1.5, *a*). Feeding coils in turn, three positions of arrow at the angle of 120°are observed.

When all three coils are energized with three-phase current system, the rotating magnetic field is produced, and the arrow rotates in the direction of the coil currents phase sequence (Fig. 1.5, *b*). Direction of rotation can be changed by changing the currents phase sequence. As three-phase current system is balanced, amplitude of the fundamental harmonic of rotating magnetic field flux density is constant and its vector describes a circle. Rotating magnetic field at symmetry of coil and current systems is the circular rotating magnetic field.

Rotation of the arrow can also be observed at two-phase feeding of two coils (Fig. 1.5, *c*). In such a case elliptic rotating magnetic field is obtained because of asymmetry of two-phase systems of coils and currents, the arrow rotation is uneven.

Pulsating magnetic field can be represented as sum of two magnetic fields rotating in opposite directions. If short-term pulse of external force is applied to the arrow in the case of single-phase winding feeding and due to that it begins rotation in the direction of the applied force, this rotation will continue under action of the field component rotating into that direction. So, in magnetic field of a single-phase winding, any desirable direction of the rotor rotation can be obtained (Fig. 1.5, *a*).

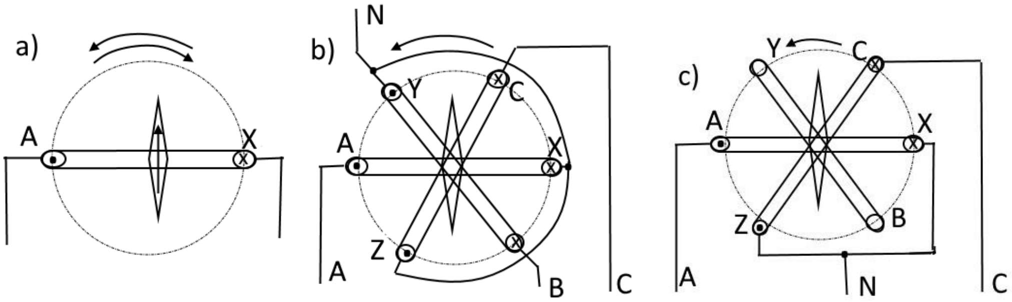

Figure 1.5 – Model for observation pulsating and rotating magnetic fields

The next demonstration unit is the stator of an induction motor with means for observation effect of rotation the magnetic field created by three-phase current system of an induction motor stator winding, and rotation of squirrel cage model placed inside the stator bore.

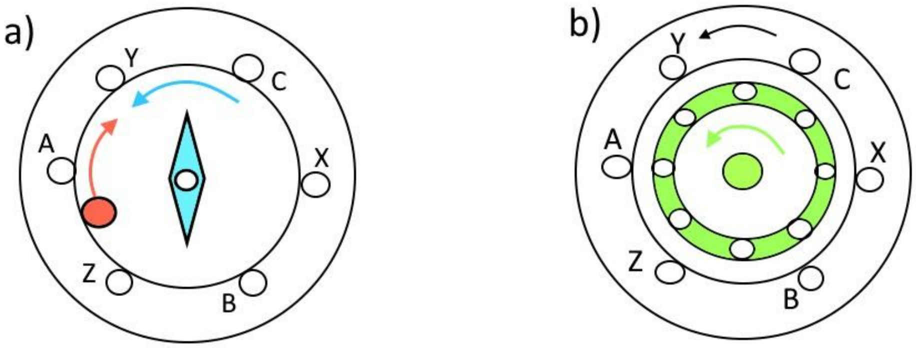

Figure 1.6 – Unit for observation effect of rotating magnetic field in induction machine

To stage 3

The synchronous rotational frequency n_1 is equal to the nearest greater value to the rated motor rotational frequency of the values obtained by calculation with expression

$$n_1 = \frac{60 f_1}{p},$$

where pole pairs number p is consequently taken equal to 1, 2, 3, 4, ….

Poles number $2p$ is equal to the value suitable the found rotational frequency n_1.

The rated rotor angular speed

$$\Omega_r = \frac{\pi n_r}{30}.$$

The rated motor torque

$$M_{2r} = \frac{P_r}{\Omega_r}.$$

The motor slip under full load

$$s_r = \frac{n_1 - n_r}{n_1}.$$

The active power consumed by the stator winding under full load

$$P_{1r} = \sqrt{3} U_{1lr} I_{1lr} \cos\varphi = \frac{P_r}{\eta},$$

where P_r – is the rated motor power, i.e., mechanical power on the motor shaft under rated load, U_{1lr} is the rated line-to-line voltage, I_{1lr} is the rated line current.

To stage 5

The principle of terminals marking is explained by Fig. 1.7.

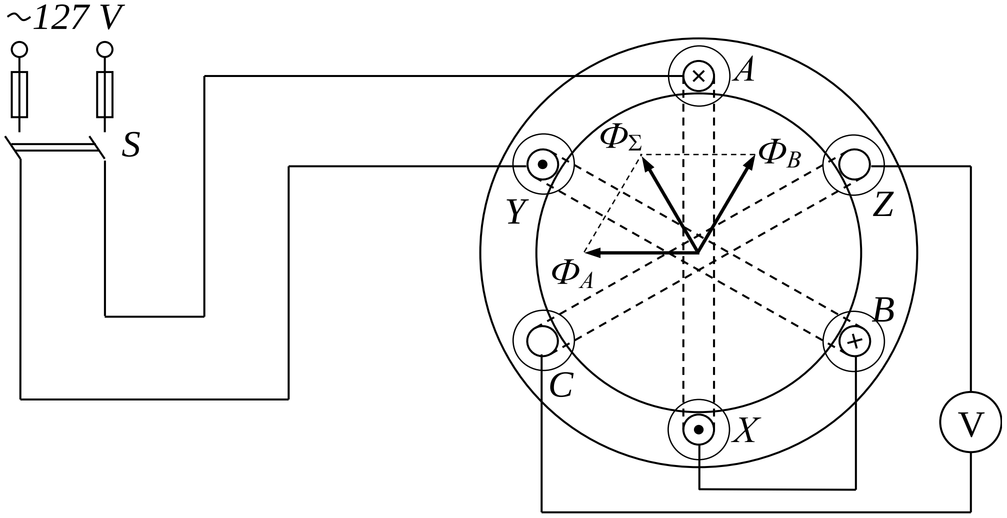

Figure 1.7 – To determination the start and end leads of phase windings

If connection is made between start or between end terminals of two phases, the axis of the resulting pulsating magnetic field is in the plane of the third phase winding which flux linkage equals zero in this case, and voltage is not induced in it.

If connection is made between start terminal of one phase and end terminal of another phase, the axis of the pulsating magnetic field is at right angle to the plane of the third phase winding which flux linkage is maximum in such a case, and voltage is induced in it.

Test questions

1. What for are the ferromagnetic cores of induction motors assembled from steel laminations?
2. Explain, why fed-in-windings are not used in cases when they are made with a rectangular wire.
3. For what reason are the windings of ac machines made distributed?
4. Explain construction of cage rotor windings.
5. What function is performed by the slip rings of induction wound rotor machine?
6. What is the electric machine degree of protection?
7. What for is the shaft extension needed?
8. What for are terminals arranged with shift of start and end of each a phase according to Fig. 1.3?
9. Why is it necessary to mark a machine winding terminals?
10. How can a three-phase induction motor be reversed?
11. How is connection of a stator winding with six leads brought to the terminal box of three-phase induction motor selected?

12. How can the rated slip of induction motor be found based on the machine ratings?
13. What is difference in determination efficiency of electric motors and generators?
14. How can difference in direction of magnetic field rotation and direction of movement of a steel ball on inner stator surface be explained?

LABORATORY TEST # 3/2

INVESTIGATION OF THREE-PHASE INDUCTION MOTOR USING DATA OF NO-LOAD AND SHORT-CIRCUIT TESTS

Aim of the training is study of a wound rotor induction motor performance using experimental data of no-load and short-circuit.

Work program

1. Study of the motor construction.
2. Measurement of the phase stator windings resistance.
3. Carrying out the no-load test.
4. Carrying out the short-circuit test.
5. Plotting the motor equivalent circuit
6. Plotting simplified circle diagram.
7. Determination of data and plotting the motor operating characteristics and speed-torque curve.
8. Analysis of experimentally obtained induction motor characteristics.
9. The report execution.

The work procedure

Stage 1 Study of the motor construction

Study construction of the motor that is a subject to testing.

Fill the motor nameplate data in the Table 2.1.

Table 2.1

Motor manufacturer data

Motor type	Stator winding connection	U_{1r}	I_{1r}	P_r	n_r	η_r	$\cos\varphi_r$	I_{2r}	U_{2r}
-	-	V	A	kW	rpm	%	-	A	V

Stage 2. *Measurement of the stator phase windings resistance*

Measurement of the stator windings resistance is performed at direct current by method of ammeter and voltmeter according to the circuit shown in Fig. 1. The circuit should be checked by the instructor.

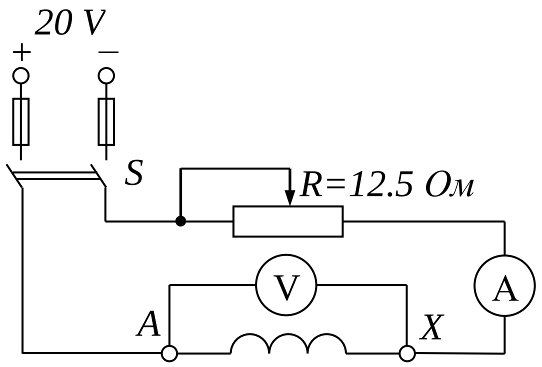

Figure 2.1 – Measurement of phase stator windings resistance

Determination of the resistance is fulfilled based on measurements at three different current values made separately for each of three phases.

The result of phase resistance determination must be found as average value of all the results obtained at every of the measurements. It should be reduced to the windings working temperature of 75° C. The measurement and calculation results are to be filled in Table 2.2.

Table 2.2

Data of measurement and calculation of stator phase winding resistance

Winding phase	Measured			Calculated		
	U	I	t_{amb}	R_{1ph}	R_1	$R_{1,75^\circ}$
	V	A	°C	Ohm	Ohm	Ohm
A-X						
B-Y						
C-Z						

Denotation in the table:

t_{amb} = the ambient temperature while the measurements

R_{1ph} = resistance of each the phase

R_1 = average phase resistance calculated on the basis of the measurements

R_{175° = the phase average resistance reduced to the working temperature.

Stage 3. *Carrying out the no-load test*

Connect the circuit according to Fig. 2.2 after selection of the needed values of the current transformer ratios and the resistance of additional series resistors in the wattmeter voltage circuit basing on the instruments circuit limitations.

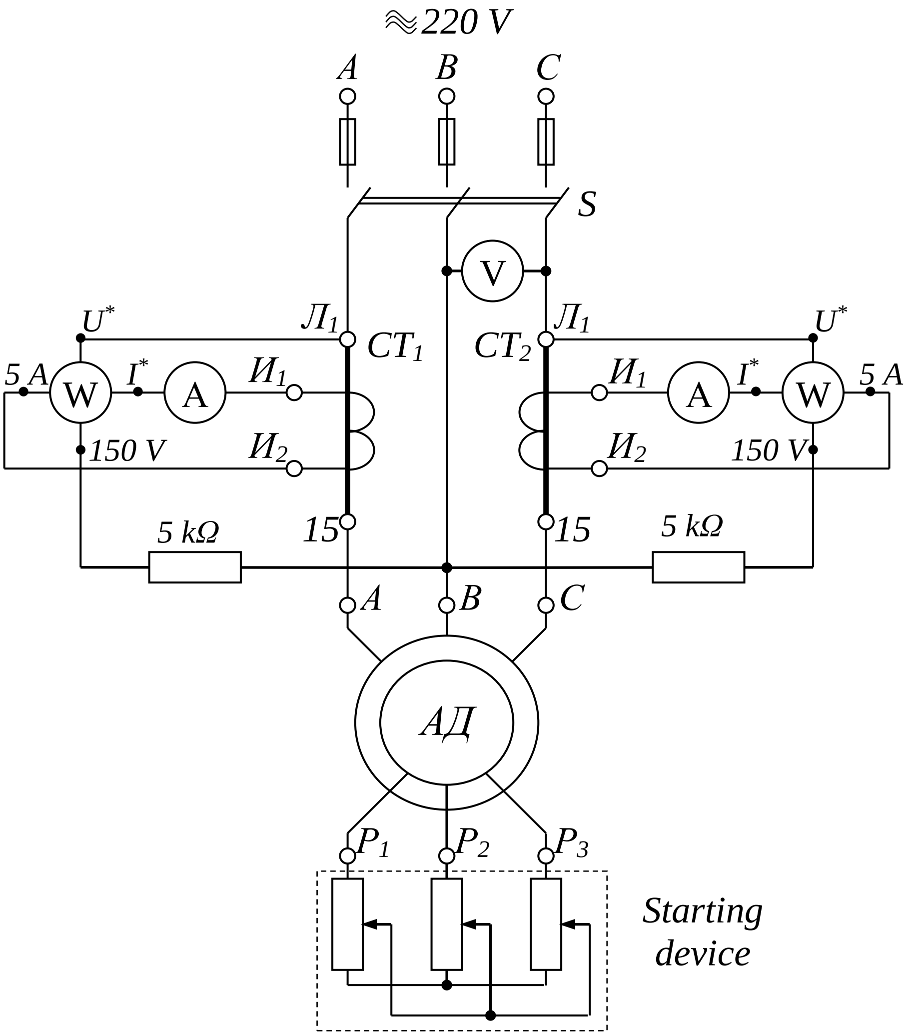

Figure 2.2 – Motor circuit at no-load test

Connection of the stator winding (Y or Δ) is selected basing on the rated voltage values given in the nameplate data.

The no-load test is performed at the motor running without any load on its shaft. In this case the motor slip is almost zero, and its speed is practically equals the motor synchronous speed.

Determine the instruments scale division values and fill them in Table 2.3.

Table 2.3

Instruments scale division values

C_V	C_A	C_W
V/div	A/div	W/div

After checking the circuit by the instructor, start the motor and take readings of the instruments. Before starting, the rheostat in rotor circuit should be put in and should be gradually put out to zero while starting. The rheostat handle must not be remained at intermediate position.

After filling the instruments readings in Table 2.4, switch the circuit off and calculate phase voltage and current, losses and parameters of the no-load condition filling them in the same Table.

Table 2.4

Data of no-load test

Measured					Calculated							
$U_{1,l-l}$	I_{A0}	I_{C0}	P_{w10}	P_{w20}	U_{10}	I_{10}	P_0	Δp_c	Δp_{mech}	Z_m	R_m	X_m
V	A	A	W	W	V	I	W	W	W	Ω	Ω	Ω

The quantities denotation:

U_{10} = the stator phase voltage under no-load

$I_{10} = \frac{I_{A0}+I_{C0}}{2}$ is the stator phase current under no-load

$P_0 = P_{w10} + P_{w20}$ is active power consumed under no-load. Should be determined with account of the summand signs

Δp_c = the motor magnetic loss under rated voltage

Δp_{mech} = mechanical loss

Z_m, R_m, X_m = the motor no-load parameters.

Stage 4. *Carrying out the short-circuit test*

Attention! *The short circuit test must be carried out under reduced voltage at which the stator current does not exceed its rated value.*

Connect the circuit according to Fig. 2.3. Select the needed value of the current transformers ratio. Line-to-line voltage supplying the stator winding under the test does not exceed 70 V. Therefore, if the voltage limit of the wattmeter is not less than this value, the additional series resistor in the wattmeter circuit is not necessary. Determine the instruments scale values and fill them into Table 2.5.

Table 2.5

Instruments scale division values

C_V	C_A	C_W
V/div	A/div	W/div

After checking the circuit connection by the instructor, ascertain that the mains supply voltage is zero, block the rotor, switch the circuit on, whereupon increase the supply voltage till the stator current becomes equal or some less the rated value.

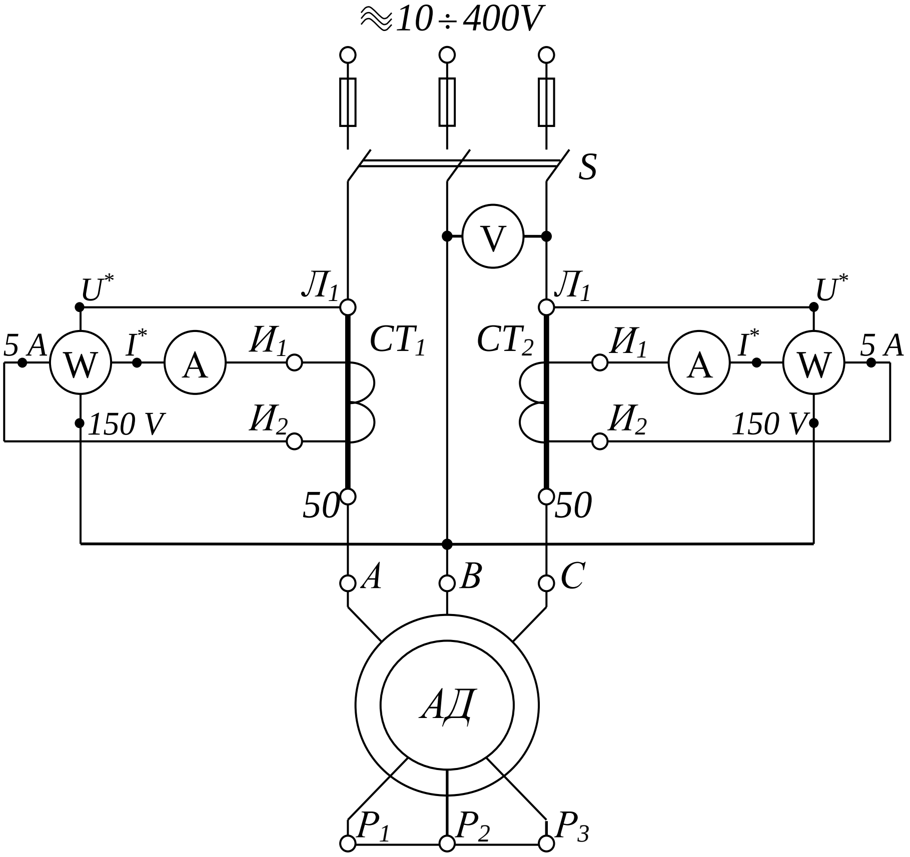

Figure 2.3 – Motor circuit at short-circuit test

Take the instruments readings and fill them in the Table 2.6. Switch off the circuit.

Table 2.6

Data of short-circuit test

Measured					Calculated						
$U_{sc,l-l}$	I_{scA}	I_{scC}	P_{1sc}	P_{2sc}	U_{sc}	I_{sc}	P_{sc}	R_{sc}	R_{sc75}	$R'_{2,75}$	X_{sc}
V	A	A	W	W	V	A	W	Ω	Ω	Ω	Ω

Using the data of measurement, calculate values of the stator phase voltage and current U_{sc} and I_{sc}, active power P_{sc} consumed by the motor under short-circuit condition as the sum of the wattmeter readings with account of their signs, the equivalent motor resistance and reactance R_{sc} and X_{sc} under condition of short-circuit (with rotor blocked) test, resistance R_{cs75} related (reduced) to the working temperature of 75℃ , and the rotor phase resistance referred to the stator (primary) phase winding and reduced to the working temperature $R'_{2,75}$.

Stage 5. *Plotting the motor equivalent circuit*

Draw the simplified motor equivalent Γ-circuit, indicating parameters obtained at no-load and short-circuit tests.

Stage 6. *Plotting motor simplified circle diagram*

It is recommended to use for plotting the circle diagram a chart-paper sheet of A4 size.

After definition of the current scale factor, plot the motor simplified circle diagram marking on it the lines of electromagnetic, useful output and input power P_{em},P_2 and P_1 respectively, the line of the motor electromagnetic torque M, the scales of motor power factor $\cos\varphi$, slip s and efficiency η.

Stage 7. *Determination of data and plotting the motor operating characteristics and speed-torque curve*

Find values of the scale factors m_P and m_M for determination power and electromagnetic torque by the circle diagram.

Using the circle diagram, determine values of the motor consumed input power P_1, stator current I_1, electromagnetic torque M, slip s, rotor rotational frequency n, efficiency η and power factor $\cos\varphi$ at specified values of the motor useful power on the shaft P_2. It is recommended to assume the shaft power values for determination the values of quantities needed to plot the operating characteristics equal to $P_{2*} = 0, 0.25, 0.5, 0.75, 1.0, 1.25$ relative units.

The found quantities values, needed for plotting the motor operating characteristics fill in Table 2.7.

Table 2.7

Data for plotting induction motor operating characteristics obtained from circle diagram

Point	P_2			P_1		I_1		M		s	n	η	$\cos\varphi$
	m_P= … kW/mm					m_I= … A/mm		m_M= … Nm/mm		-	rpm	%	-
	Rel. unit	mm	kW	mm	kW	mm	A	mm	Nm				
1	0												
2	0.25												
3	0.50												
4	0.75												
5	1.00												
6	1.25												

Plot the operating characteristics of the induction motor $M = f(P_2)$, $n = f(P_2)$, $s = f(P_2)$, $I_1 = f(P_2)$, $P_1 = f(P_2)$, $\cos\varphi = f(P_2)$, $\eta = (P_2)$ by the data of Table 2.6 using one mutual system of coordinate axes.

By the circle diagram, find data for plotting the motor *rotational frequency-torque curve* and fill them in Table 2.8.

Table 2.8

Data for plotting rotational frequency-torque curve

Point	M		s	n	Notes
	m_M= … Nm/mm		-	rpm	
	mm	Nm			
1					No-load condition
2					
3					
4					
5					Full load
6					
7					
8					Critical point (s_m, M_m)
9					
10					
11					Short-circuit condition (s=0)

Data for the first six lines of Table 2.8 are to be taken from Table 2.7. Using data of Table 2.8, plot the motor rotational frequency-torque curve $n = f(M)$.

Stage 8. *Analysis of experimentally obtained induction motor characteristics*

Analysis of the data, obtained experimentally with the help of the circle diagram which has been plotted by the data obtained from the motor no-load and rotor-blocked tests, is performed by comparison them with the motor rated values given in the nameplate data (see Table 2.9).

Table 2.9

Comparison of motor nameplate and experimentally obtained data

Quantity	Unit of measurement	Rated value by nameplate	Experimentally obtained value	Deviation in %

Deviations of experimental data are found as difference between the experimentally obtained and nameplate values in per cent of the nameplate values. If deviation magnitude of experimental value exceeds 10%, the value experimentally obtained at the study conditions must be considered as unsatisfactory.

Stage 9. *The report execution*

The report must contain:

1. The work title, its aim and program.
2. The motor nameplate data (Table 2.1).
3. Test circuits (Fig. 2.1, 2.2, 2.3).
4. Experimental and calculated data (Tables 2.2, 2.3, 2.4, 2.5, 2.6, 2.7, 2.8).
5. The motor equivalent circuit.
6. The machine circle diagram.
7. Plots of operating characteristics and rotational frequency-torque curve.
8. Comparison of motor nameplate and experimentally obtained data (Table 2.9).

Methodical guideline

To stage 2

Reducing of the rotor phase winding resistance to normal working temperature is made by the expression:

$$R_{1,75^\circ} = R_1[1 + \alpha_R(75 - t_{amb})]$$

where α_R is the temperature coefficient of resistance. For copper conductors:

$$\alpha_R = 0.0043\ \frac{1}{℃}\,.$$

To stage 3

The stator phase current under no-load test I_{10} is equal to average value of phase currents defined by the measured line currents I_{A0} and I_{C0} with account with the stator winding connection.

The active power consumed by the machine under no-load operation is determined as $P_0 = P_{w10} + P_{w20} > 0$ where P_{w10} and P_{w20} are the wattmeter readings.

The amount of the magnetic and mechanical losses is found as

$$\Delta \mathrm{p}_c + \Delta \mathrm{p}_{mech} = P_0 - 3R_1 I_{10}^2.$$

Magnetic and mechanical losses can roughly be assumed equal. Therefore, we find them as

$$\Delta \mathrm{p}_c = \Delta \mathrm{p}_{mech} = \frac{P_0 - 3R_1 I_{10}^2}{2} \, .$$

The motor no-load parameters are calculated by the expressions:

$$Z_m = \frac{U_{10}}{I_{10}} \, , \; R_m = \frac{P_0 - \Delta \mathrm{p}_{mech}}{3 I_{10}^2} \, , \; \mathrm{X}_m = \sqrt{Z_m^2 - R_m^2} \, .$$

The power factor at no-load is equal to

$$\cos \varphi_0 = \frac{P_0}{3 U_{10} I_{10}} \, .$$

To stage 4

To find short-circuit current and power values under sort-circuit condition at the rated voltage use the expressions

$$I_{scr} = I_{sc} \frac{U_{1r}}{U_{sc}} \, , \;\; P_{scr} = P_{sc} \left(\frac{U_{1r}}{U_{sc}}\right)^2 \, .$$

The power factor under short-circuit is

$$\cos \varphi_{sc} = \frac{P_{sc}}{3 U_{sc} I_{sc}} \, .$$

Short-circuit parameters:

$$Z_{sc} = \frac{U_{sc}}{I_{sc}} \, ; \;\; R_{sc,75^{\circ}} = R_{sc}[1 + \alpha_R (75 - t_{amb})] \, ; \;\; \mathrm{X}_{sc} = \sqrt{Z_{sc}^2 - R_{sc,75}^2} \, ,$$

where $R_{sc} = \frac{P_{sc}}{3 I_{10}^2}$ is short-circuit resistance under the test conditions at the ambient temperature t_{amb} .

The rotor phase resistance referred to the stator side and reduced to the normal working temperature:

$$R'_{2,75} = R_{s,75^{\circ}} - R_{1,75^{\circ}} \, .$$

The stator phase leakage reactance and the rotor phase leakage reactance referred to the stator side:

$$X_1 \cong X_2' \cong \frac{X_{sc}}{2}.$$

To stage 5

The motor simplified equivalent Γ-circuit is sown in Figure 2.4. This circuit is used for construction of the simplified circle diagram. Write down the values of the motor parameters obtained in stages 2, 3, 4 on the equivalent circuit plot.

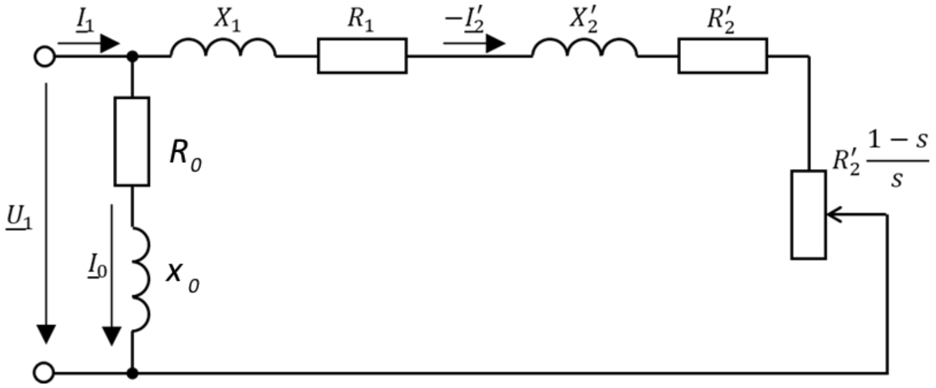

Figure 2.4 – Simplified equivalent Γ-circuit of the induction machine

To stage 6

It is recommended to use a chart-paper sheet of A4 size for plotting the circle diagram (Fig. 2.5).

The diagram construction is made in the following order:

1) Cartesian rectangular coordinates axes are plotted. The stator phase rated voltage vector U_{1r} is overlaid on the ordinate axis being plotted in an arbitrary scale.
2) Choose the current scale m_I, A/mm, of integral value so that the length of the vector I_{sr} be in the bounds of 200 … 300 mm.
3) Plot the no-load point H laying off the segments representing scaled active and reactive no-load current components: segment OH_1 representing the reactive component $I_{10react}$ is laid out by the abscissa axis, segment H_1H representing the active component I_{10act} is laid off parallel to the vector U_{1r}. The segment OH represents the vector I_{10}.
4) Plot the short-circuit point K laying off the segments representing scaled active and reactive short-circuit current components: segment OK_1 representing the reactive component $I_{scr,react}$ is laid out by the abscissa axis,

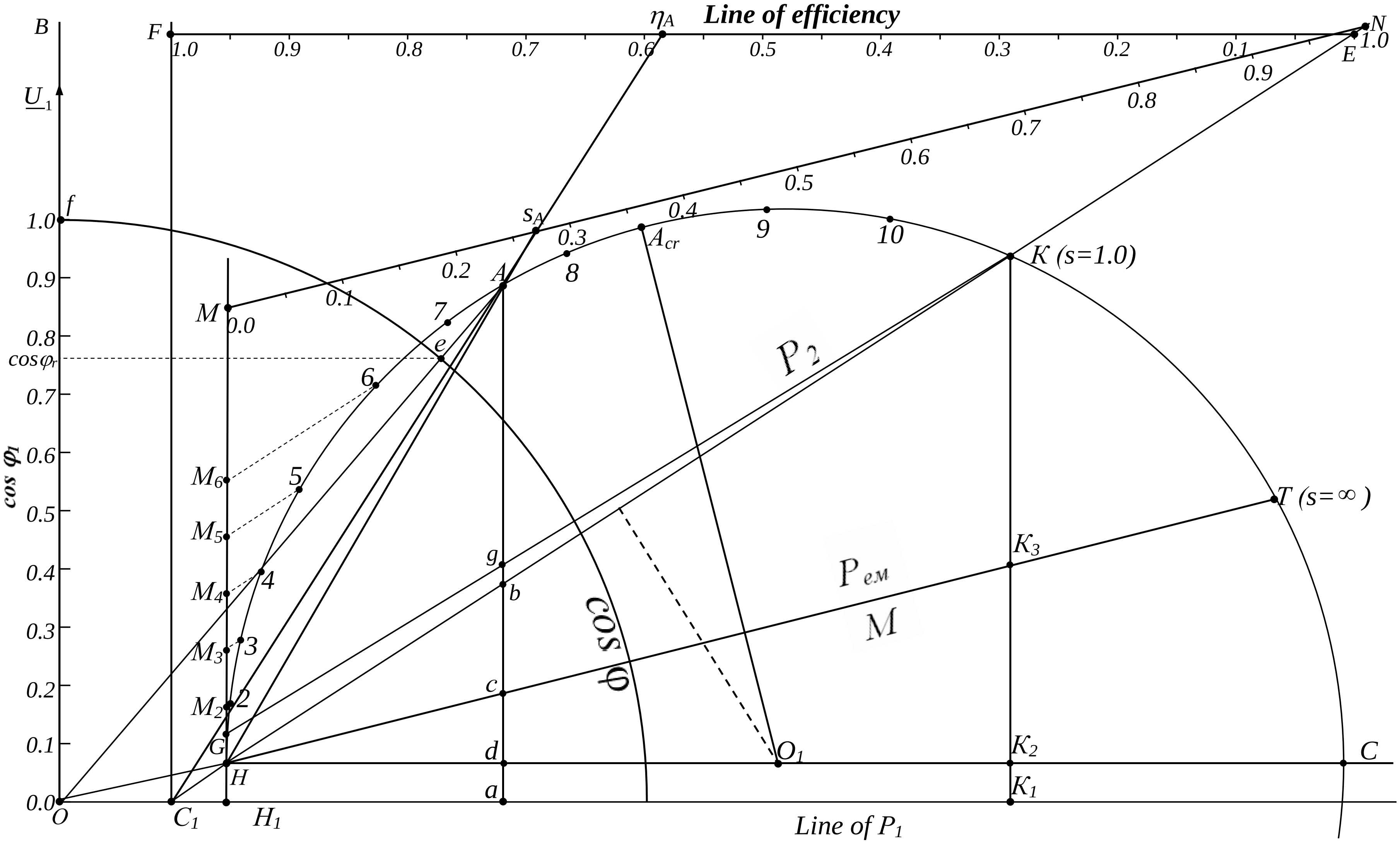

Figure 2.5 – Circle diagram of asynchronous machine

segment K_1K representing the active component $I_{scr,act}$ is laid off parallel to the vector U_{1r}. The segment OK represents the vector I_{scr}.

5) Plot the straight line HC parallel to the abscissa axis.
6) Draw the current circle. For that, plot the straight line HK and find the point dividing the segment HK in half. Restore the perpendicular from that point. The point $O_1$of its intersection with the line HC is the current circle center. Its radius equals the length of the segment O_1H. The obtained circle is the locus of the stator phase current vector end at different values of the machine slip occurring at different values of the shaft torque in steady mode of operation.

Assume that at some load the stator current end is in point A. The segment OA represents the stator current vector I_1 which value is equal to $I_1 = OA \cdot m_I$, A. The referred value of the rotor phase current is $I_2' = HA \cdot m_I$.

Different points of the current circle meet different values of the motor load P_2 and, consequently, of slip s. The no-load point *H* meets the slip $s = 0$, the short-circuit point *K* – the slip $s = 1$. The circle section between *H* and *K* represents the complete set of conditions while the machine operates as a motor ($0 < s < 1$).

The point *T* meets the conditions of the machine operation at infinite speed: $n = -\infty$ ($s = -\infty$) in generator condition and $n = +\infty$ ($s = +\infty$) in condition of electromagnetic brake. The circle section between *K* and *T* represents the complete set of conditions while the machine operates as electromagnetic brake ($1 < s < +\infty$). The part of the circle between the points *H* and *T* meets conditions of generator ($0 > s > -\infty$).

To find position of the point *T*, it is necessary to divide the segment *KK*$_2$ of the vertical line passing through the point *K* in the ratio

$$\frac{K_3K_2}{KK_2} = \frac{R_{1,75}}{R_{sc,75}}.$$

Finding from this ratio length of the segment K_3K_2 we determine position of the point *K*$_3$. Drawing the line HK$_3$ till it crossing to the circle find the point *T*.

With the help of the circle diagram the data needed for plotting the induction motor operating characteristics and the speed-torque curve may be obtained.

There are some special lines in the diagram having special names:

- The line of consumed power P_1- the straight line H_1K_1
- The line of electromagnetic power P_{em} and the electromagnetic torque – the straight line *HT*
- The line of mechanical power P_{mech} - the line *HK*
- The line of output mechanical power on the shaft P_2 - the line *GK*. The segment *HG* is scale representation of the sum of mechanical and additional losses. The additional losses to a first approach may be neglected.

The electric active power consumed by the motor, the mechanical power on the shaft and electromagnetic power equal:

$$P_1 = Aa \cdot m_P, \quad P_2 = Ag \cdot m_P, \; P_{em} = Ac \cdot m_P$$

where $m_P = 3U_{1r} m_I 10^{-3}$, kW/mm is the power scale factor.

Length of the segment HG equals $HG = \Delta p_{mech}/m_P$ where m_P is defined in *stage 2*.

The electromagnetic torque is equal to

$$M = Ac \cdot m_M$$

where $m_M = \frac{m_P}{\Omega_1} = \frac{m_P 10^3 p}{2\pi f_1}$ Nm/mm is the electromagnetic torque scale factor.

The critical condition of the motor operation at which the electromagnetic torque is maximum (the appropriate slip value is called the critical slip and is denoted as s_{cr}) meets the point A_{cr} of the circle. This point is found as tangent point of the line, parallel to the line of electromagnetic torque *HT*, to the circle.

The motor efficiency is defined as

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

It is convenient to determine it with the help of the efficiency scale which is constructed in the following way. The straight line *KH* is prolonged to both sides. It crosses the abscises axis in the point C_1. The perpendicular C_1F to the abscises axis is restored from the point C_1. Above the current circle the line *FE* parallel to the abscises axis is drawn so that the segment could be divided into 10 equal parts. The segment *FE* is the scale of the motor efficiency which zero mark is point *E*, and the unity mark – is point *F*. The scale may be divided with some step, for example, with the step of 0.1. To determine the efficiency value, it is necessary to draw the straight line through the points C_1 and the working point (*A*) and to read the efficiency value η_A.

For determination of the slip for any motor operating condition, the scale of slip may be used. This scale is built as follows. The perpendicular to the abscises axis is held through the point *H*. Above the current circle, the line *MN* parallel to the electromagnetic power line *HT* is drawn so that the segment *MN* could be conveniently divided in 10 equal parts. This segment is the slip scale, it is marked as shown in Fig. 2.5. If the working point on the current circle is given (for example, the point *A*), the slip value may be determined by this scale. For that, the line *HA* is drawn till it crosses the slip scale. The crossing point determines the sought-for value of the slip.

The motor power factor may be found from the circle diagram as follows. Put the line segment *Of* on the ordinate axis and put the scale on it in the bounds between 0 and 1.0 with the step of 0.1 and designate the obtained marks with the numerical values. The segment serves as the scale of $\cos\varphi$. Draw a quarter of a circumference by radius *Of in* the first quarter of the coordinate plane. The obtained circumference ark is the line of $\cos\varphi$. Connect the coordinate origin *O* and the working point *A* on the circle diagram with the straight line and find the point e of the line OA intersection with the line of $\cos\varphi$. Find the point e projection on the scale of $\cos\varphi$ and make the scale reading of $\cos\varphi$ value.

To stage 7

As it was said above, the operating characteristics of the induction motor $M = f(P_2),\ n = f(P_2),\ s = f(P_2),\ I_1 = f(P_2),\ P_1 = f(P_2), \cos\varphi = f(P_2),\ \eta = f(P_2)$ by the data of Table 7 using one mutual system of coordinate axes. The scale factors for these quantities are chosen so that the plots fill the coordinate plane sufficiently and scale readings may be easily made. Approximate form of graphics is shown in Fig. 2.6.

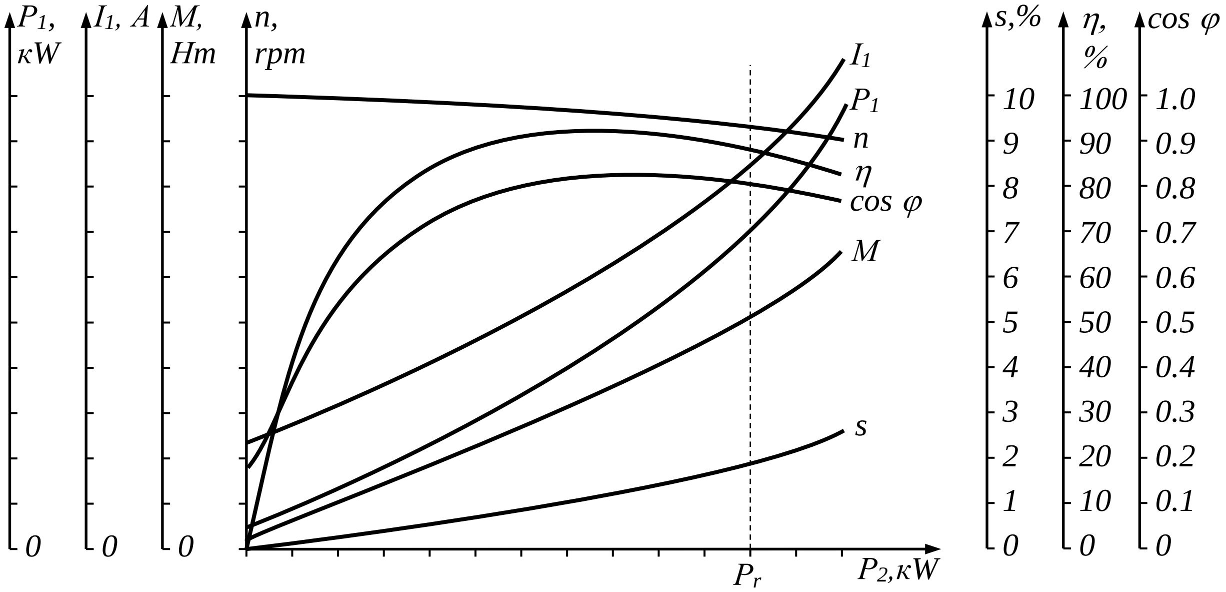

Figure 2.6 – Operating characteristics of an induction motor (approximate form)

Using the data of Table 8, plot the rotational frequency-torque curve of the motor. An approximate form of the curve is shown in Fig. 2.7.

Test questions

1. What is the aim of the induction motor testing under no-load and short-circuit conditions?
2. What are the required conditions for carrying out the motor no-load test?
3. What are the required conditions for carrying out the motor short circuit test?
4. How to recalculate the data of short-circuit test for the rated voltage?
5. Why is the no-load current of an induction motor relatively large in comparison with power transformer?

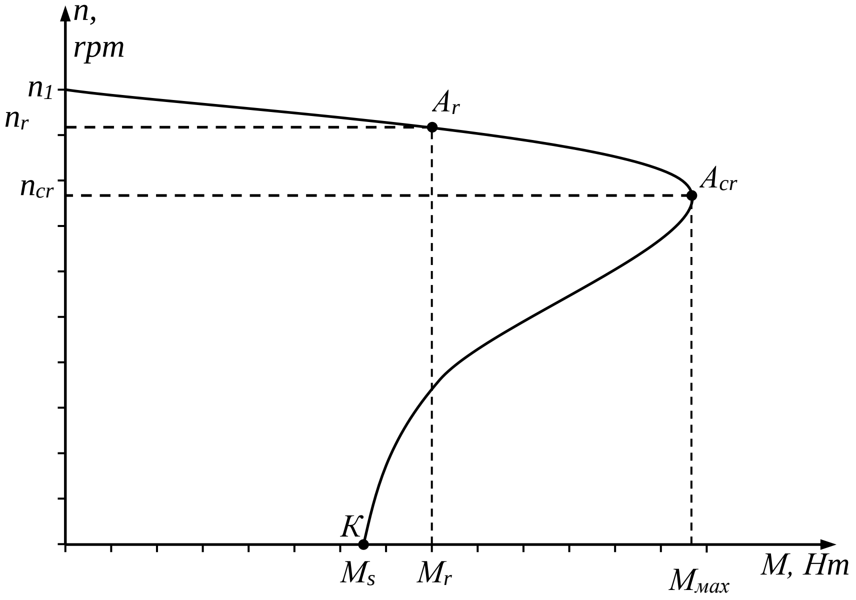

Figure 2.7 – Rotational frequency-torque curve of induction motor (approximate form)

6. Explain the order of the current circle construction and stator and rotor current determination with its help.
7. How to build the lines of the consumed, electromagnetic, mechanical and shaft power and how to find these quantities with the help of the circle diagram?
8. How to find a value of electromagnetic torque with the help of the circle diagram?
9. How to find the motor slip and efficiency with the help of the circle diagram?
10. How to find the maximum electromagnetic torque using the circle diagram?
11. What sections of the circle diagram do relate to the motor, generator, and electromagnetic brake operating conditions?
12. What is the critical slip of an induction motor?
13. What are the values that the slip takes in different operating conditions?

LABORATORY TEST # 3/3

INVESTIGATION OF INDUCTION MOTOR WORKING PROPERTIES USING METHOD OF DIRECT LOADING

Aim of the training is study of technique of electric machines operating characteristics determination by their direct loading for assessment of induction machines working properties.

Work program

1. Study the test bench.
2. Calculation of the loading torque.
3. Running of the test, experimental data processing and plotting the operating characteristics.
4. The report execution.

The work procedure

Stage 1. *Study the test bench*

The test bench for testing a cage induction motor is fed by a three-phase power supply line and provides starting the motor, measurement the current by alternate connection the ammeter in the line conductors *A* and *C*, measurement the power consumed by the motor with application the two-wattmeter method using one wattmeter alternately connected into the three-phase circuit, formation the adjustable braking torque on the motor shaft by means of electromagnetic brake, and measurement the motor rotational frequency. Study the test bench diagrammatic view (Fig. 1) and its arrangement.

Fill the induction motor to be tested nameplate data in the Table 3.1.

Table 3.1

The induction motor nameplate data

Motor type	Stator winding connection	Rated power P_r	Rated line voltage U_{1lr}	Rated line current I_{1lr}	Rated frequency f_{1r}	Rated rotor rotational frequency n_r	Rated efficiency η_r	Rated power factor $\cos\varphi_r$
-	-	kW	V	A	Hz	rpm	%	-

Stage 2*. Calculation of the loading torque*

It is recommended to apply to the motor shaft in turn the braking torque from the range:

$$M_b = (1.20;\ 1.00;\ 0.75;\ 0.5;\ 0.25;\ 0)M_r$$

where M_r is the rated torque of the tested induction motor.

The rated torque of the induction motor is found using its nameplate data as

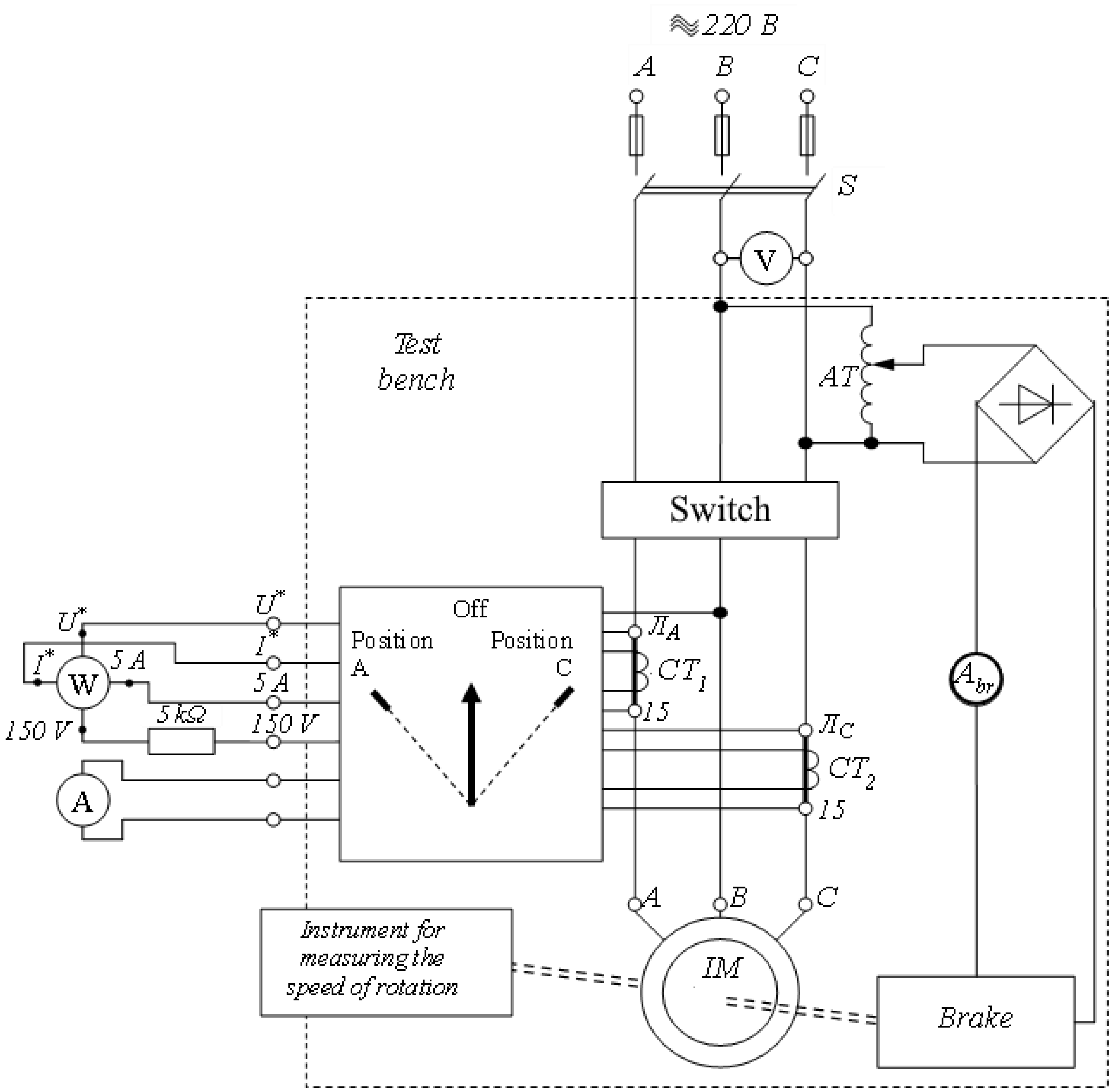

Figure 3.1 – Test bench diagrammatic view

$$M_r = \frac{30P_r10^3}{\pi n_r}, \text{ Nm}$$

where the values of P_r in kW and n_r in rpm are taken from Table 3.1.

The found values of the braking torque write down in Table 3.2 (see Stage 3).

Stage 3. *Running of the test, experimental data processing and plotting the operating characteristics*

Attention!!! Be careful with the brake disk. The disc is accessible though some measures for contact protection are provided. *Avoid touching the steel brake disc! It is* *dangerous!* While running the test, the disk rotates with high speed. During the motor operation and for a long enough time after the test, the disk temperature exceeds 100℃.

During test, the desirable braking torque value is established by adjustment of the current flowing through the electromagnetic brake field coil with the help of adjustable autotransformer AT (Fig. 3.1).

The wattmeter current circuit and ammeter are connected through the current transformers which transformation ratio equal to 3. In the wattmeter voltage circuit, the additional resistor may be available. That must be taken into consideration at the instruments scale division values determination.

Connect the circuit according to Fig. 3.1. Set the minimum current through the brake coil and start the motor. After the start, set the braking torque equal to $M_b = 1.20M_r$ and fill the quantities reading into first line of Table 3.2. Measurement of currents and the wattmeter readings is made at two positions of the interchanging switch of the measurement unit.

Then, setting in turn other braking torque M_b values calculated in *Stage 2*, read the instruments, and fill the values of torque and the instruments readings in the next lines of Table 3.2.

Table 3.2

Measured and calculated data for plotting operating characteristics

Point number	Measured							Calculated					
	M	n	U_{1l}	I_A	I_C	$P_{pos.A}$	$P_{pos.C}$	P_2	I_{1l}	P_1	η	$\cos\varphi$	s
	Nm	rpm	V	A	A	W	W	W	A	W	%	-	-
1													
2													
3													
4													
5													
6													

Calculate the quantities indicated in the right side of the table.

Using data of Table 3.2 plot the induction motor operating characteristics $P_1 = f(P_2)$, $I_{1l} = f(P_2)$, $M = f(P_2)$, $n = f(P_2)$, $\eta = f(P_2)$, $\cos\varphi = f(P_2)$ and $s = f(P_2)$ where P_1 is electric power consumed by the motor from the supply network, I_{1l} is the stator line current, M is the motor torque on shaft, n is the shaft rotational frequency, η is the efficiency, $\cos\varphi$ is the power factor, s is the slip and P_2 is useful mechanical power on the shaft. For plotting characteristics, use one mutual coordinate axes system.

Stage 4. *The report execution*

The report on the test should include:

1. The title of the test and its aim
2. The motor nameplate data (Table. 3.1)

3. Calculation the loading torque values
4. Measured and calculated data for plotting operating characteristics (Table 3.2)
5. Calculation the data under full load included in Table 3.2
6. The induction motor operating characteristics plotted in mutual coordinate axes.

Methodical guideline

To stage 1

Loading the motor is made with the help of electromagnetic brake. The brake has pivoted field system having its own shaft. The field coils situated on the poles having forked shoes. The field coils are connected to the output terminals of the rectifier fed from the autotransformer with adjustable transformation ratio. The brake field current is controlled by turning the autotransformer knob. This causes variation of the alternating voltage impressed to the rectifier input that brings in turn the direct current flowing through the brake field coils variation.

The solid steel disc is fixed on the induction motor shaft and rotates with it. The disc periphery enters the space between the brake pole shoe faces and, therefore, cuts the magnetic flux during rotation. The eddy currents occur. Interaction of the eddy currents with the field flux causes electromagnetic torque, tending to turn the braking system in the direction of the motor rotation. Eccentrically fixed weight is attached to the brake field system. When electromagnetic torque turns the field system, the weight counter-torque appears. As the counter-torque increases with the angle of turn, the rotating and braking torques become balanced after the field systems takes a certain position due to its turning under action of the rotating torque. After the field system takes the position of equilibrium, the value of the torque may be counted on the scale of the braking device with an arrow attached to the moving field system of the brake.

The torque enthralling the brake moving field system equals braking torque for the motor as it is transmitted to the induction motor shaft through the braking disc. At the motor rotation with a steady-state speed, the braking and electromagnetic torques acting on the shaft are counterbalanced, and the value of the braking torque read on the scale of the braking device equals the torque developed by the motor on its shaft.

To stage 3

Calculation of the quantities needed for plotting the induction motor operating characteristics is made by the following expressions:

$$I_{1l} = \frac{I_A + I_C}{2}, \ \ A;$$

$$P_2 = M\frac{\pi n}{30} = 0.105Mn, W;\ P_1 = P_{pos.A} + P_{pos.C}, W;$$

$$\eta = \frac{P_2}{P_1}100, \%;\ \cos\varphi = \frac{P_1}{\sqrt{3}U_{1l}I_{1l}};\ \ s = \frac{n_1 - n}{n_1}$$

where n_1 is the motor synchronous rotational speed found as the next to the rated speed value taken from the synchronous rotational speed series determined for the motor rated frequency.

Test questions

1. What kind of dependence may be called an operating characteristic of electric motor?
2. What losses do affect the efficiency of an induction motor?
3. How does the rotor core loss depend on the induction machine slip?
4. Is the dependence of the torque on motor shaft the linear function of the useful power?
5. What is a motor efficiency under no-load operation? Explain the answer.
6. What is the motor power factor value at no-load? Explain.
7. In what range of the slip is the induction motor operation at constant torque stable?
8. What does happen if the torque of induction motor load exceeds the motor maximum torque?
9. What range of the load torque is considered as normal operating range of an induction motor?
10. Why are general purpose induction motors designed so that their rated slip value does not exceed a few per cent?

LABORATORY TEST # 3/4

INVESTIGATION OF STARTING METHODS OF CAGE INDUCTION MOTORS

Aim of the training is to study and investigate the starting methods used for squirrel-cage induction motors.

Work program

1. Familiarization with the motor nameplate data.
2. Investigation of starting the cage induction motor by connecting directly across the feeding line.
3. Investigation of the cage induction motor Y-Δ starting.
4. Investigation of the induction motor starting with use of an autotransformer.

5. Comparison of the investigated starting methods.
6. Execution of the report.

The work procedure

Stage 1. *Familiarization with the motor nameplate data*

Read nameplate data of the motor to be tested and fill them into the Table 4.1.

Table 4.1

Nameplate data of the tested induction motor

Motor type	Stator winding connection	Rated power P_r	Rated line voltage U_{1lr}	Rated line current I_{1lr}	Rated frequency f_{1r}	Rated rotor rotational frequency n_r	Rated efficiency η_r	Rated power factor $\cos\varphi_r$
-	-	kW	V	A	Hz	rpm	%	-

Stage 2. *Investigation of starting the cage induction motor by connecting directly across the feeding line*

Select the stator connection under the line-to-line voltage of the available feeding line.

Proceeding from the possible range of the motor starting current ratio at connection under the rated voltage equal to $\frac{I_{1lst(dir)},}{I_{1lr}} = 4 \dots 7$, find the possible bounds of the starting line current at starting by direct connection on the rated voltage.

Select the automatic switch, ammeter, voltmeter, and fuses for starting the motor by direct connection across the line on the rated voltage (Fig. 4.1). Connect the circuit.

Carry out the motor test staring without blocking the rotor paying attention to the starting current inrush.

After that, determine the current at the initial instant of the motor started executing the investigation in the following order:

- block the rotor by means of the bandbrake
- turn on the switch S and read the values of the stator current and voltage.

To avoid the motor overheating, **release the brake not later than in 3 *s*** giving the rotor an opportunity of turning without load. **During the time when the rotor is blocked, it is necessary to meter the instruments readings that must be done simultaneously by ammeter and voltmeter after calming their pointers fluctuation around the equilibrium positions that requires 1-2 s.** Fill the instruments readings in Table 4.2.

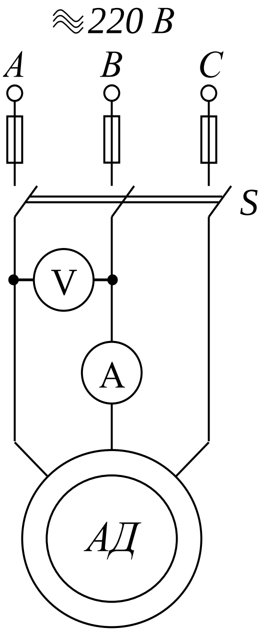

Figure 4.1 Direct starting squirrel-cage induction motor under rated voltage

Table 4.2

Results of induction motor investigation at direct starting

Measurement		Calculations	
$U_{1l(dir)}$	$I_{1l\,st(dir)}$	$I_{1l\,st\,r(dir)} = \\ = I_{1l\,st(dir)} \dfrac{U_{1lr}}{U_{1l(dir)}}$	$k_{I(dir)} = \\ = \dfrac{I_{1l\,st\,r(dir)}}{I_{1lr}}$
V	A	A	-

As the voltage $U_{1l(dir)}$ under the test may occur not equal the rated value, the starting current at the rated motor voltage is determined by means of expression:

$$I_{1l\,st\,r(dir)} = I_{1l\,st(dir)} \frac{U_{1lr}}{U_{1l(dir)}}.$$

Find the starting current ratio under starting by direct connection to the rated voltage:

$$k_{I(dir)} = \frac{I_{1l\,st\,r(dir)}}{I_{1lr}}$$

Stage 3. *Investigation of the cage induction motor Y-Δ starting*

The method is applicable if the stator winding is normally connected in Δ under the available network voltage (compare the inscription on the panel of network terminals and the motor nameplate data).

Select the automatic switches, ammeters, voltmeters, and fuses for starting the motor by switching connections from Y to Δ (Fig. 4.2). Connect the circuit.

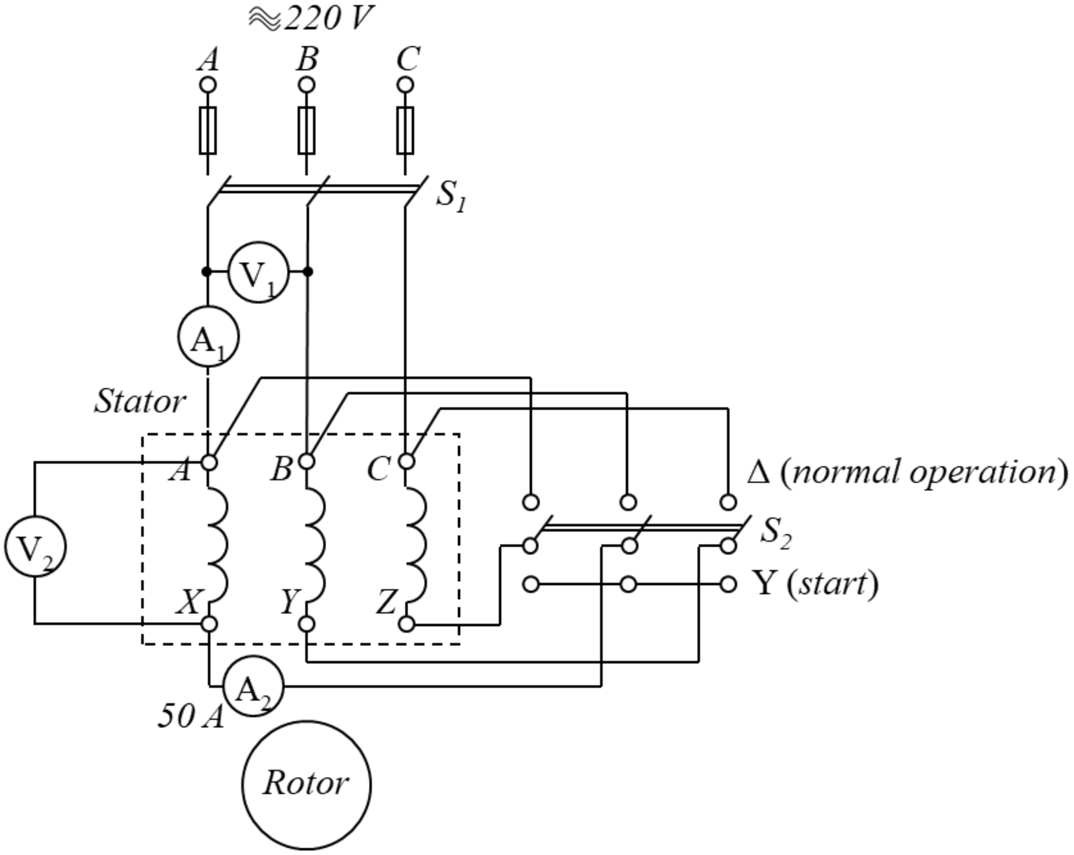

Figure 4.2 Starting the motor by switching connections from *Y* to *Δ*

Carry out the motor test staring without blocking the rotor, switching it first in Y and after acceleration changing the connection to Δ. Pay attention to the current inrushes at the beginning of starting and at changeover to Δ, and notice that acceleration of the motor is in this case is slower than at direct starting.

After putting the switch S_2 into position "Y" and blocking the rotor by means of the bandbrake, turn on the motor with switch S_1, read simultaneously the instruments and turn off switch S_1. Duration of ON state should be no longer than 3 s. Fill the instruments readings in Table 4.3.

Table 4.3

Results of induction motor investigation at starting by switching connections from Y to Δ (initial stage at connection in *Y*)

Measurement			Calculations		
$U_{1l(Y)}$	$U_{1(Y)}$	$I_{1l\,st(Y)} = I_{1st(Y)}$	$I_{1l\,st\,r(Y)}$	$k_{I(Y)} = \frac{I_{1l\,st\,r(Y)}}{I_{1l\,st\,r(dir)}}$	$\frac{M_{st(Y)}}{M_{st(dir)}}$
V	V	A	A	-	–

Pay attention that while starting at connection of the stator winding in Y unlike the case of connection in Δ the line voltage $U_{1l(Y)}$ and phase voltage $U_{1(Y)}$ are unequal whereas the line and phase starting currents $I_{1l\,st(Y)}$ and $I_{1st(Y)}$ are equal.

Calculate and fill in Table 4.3 also values of the quantities related to the initial stage of starting (Y-connection):

- The starting line current under the rated line voltage

$$I_{1l\,st\,r(Y)} = I_{1l\,st\,(Y)} \frac{U_{1l\,r}}{U_{1l(Y)}}.$$

- The starting current ratio at *Y*-connection and direct starting

$$k_{I(Y)} = \frac{I_{1l\,st\,r(Y)}}{I_{1l\,st\,r(dir)}}$$

- The ratio of starting torques at *Y*-connection and direct connection under rated voltage

$$M_{st\,r(Y)}/M_{st\,r(dir)} = (U_{1\,r(Y)}/U_{1r(dir)})^2 = \frac{1}{3}.$$

Stage 4. *Investigation of the induction motor starting with use of autotransformer*

As autotransformer, the three-phase transformer studied at previous laboratory classes is used. Its connection is shown in Fig. 4.3. Transformation ratio of the autotransformer equals

$$n_A = \frac{U_{AX}+U_{ax}}{U_{ax}} = \frac{220+133}{133} = 2.65.$$

Select the automatic switches, ammeters, voltmeters, and fuses for starting the motor with use of autotransformer (Fig. 4.3). Connect the circuit.

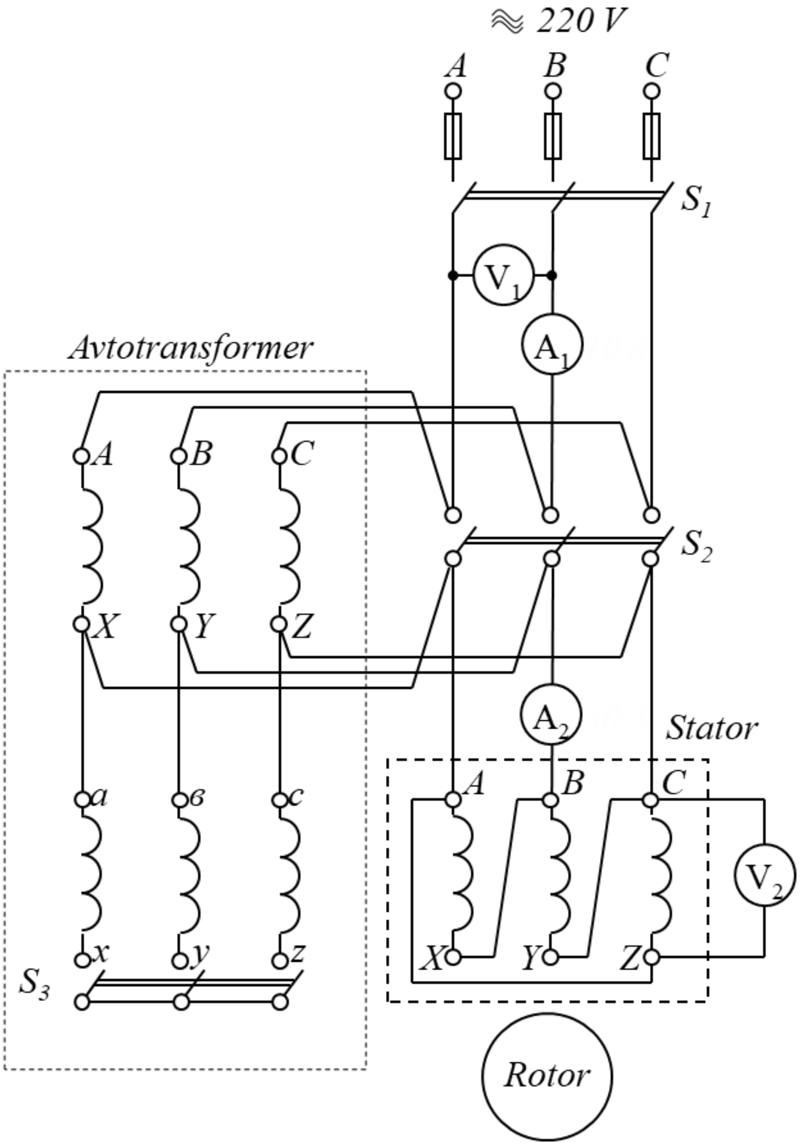

Figure 4.3 Cage induction motor starting with use of autotransformer

Set the switches to the initial state to start the motor: the switches S_1 and S_2 – into position "off", the switch S_3 – into position "on". Then put the fuses and carry out the motor test staring without blocking the rotor in the following sequence:

- *Turn on* the switch S_1. The voltage is impressed across the motor terminals being reduced by the autotransformer.
- After the motor acceleration to the steady speed, *turn off* the switch S_3 *then immediately turn on* the switch S_2.

Pay attention that the motor accelerates not as fast as at use two other methods that is explained by greater reduction the voltage on the motor terminals, that depends on the transformation ratio, and more considerable decrease of the starting torque. The current inrush at the beginning of start is smaller in this case on the reason of more essential voltage reduction under the given transformation ratio of the step-down autotransformer.

After testing the circuit, turn the motor off by means of the switch S_1 and then restore the initial state of the switches as described above.

Block the rotor and turn on the switch S_1. Read all the instruments simultaneously and turn off the motor in 3…5 *s*. Fill the instrument readings in Table 4.4.

Table 4.4

Results of induction motor investigation at starting with use of autotransformer

Measurement				Calculation			
$U_{1l(AT)}$	$U_{2l(AT)}$	$I_{1lst(AT)}$	$I_{2lst(AT)}$	$I_{1l\,st\,r(AT)}$	$I_{2l\,st\,r(AT)}$	$k_{I(AT)}=\frac{I_{1l\,st\,r(AT)}}{I_{1l\,st\,r(dir),}}$	$\frac{M_{st(AT)}}{M_{st(dir)}}$
V	*V*	*A*	*A*	*A*	*A*		–

Denotations used in Table 4.4:

- $U_{1l(AT)}$ – line voltage on the primary side of the autotransformer (line network voltage)
- $U_{2l(AT)}$ is the line voltage on the secondary side of the autotransformer (line voltage across the motor terminals)
- $I_{1l\,st(AT)}$ is the starting line current in the network at testing
- $I_{2l\,st(AT)}$ is the starting line current in the motor circuit at testing
- $I_{1l\,st\,r(AT)}$ is the starting line current in the network under the rated voltage
- $I_{2l\,st\,r(AT)}$ is the starting line current in the motor circuit under the rated network voltage
- $k_{I(AT)}=\frac{I_{1l\,st\,r(AT)}}{I_{1l\,st\,r(dir),}}$ is the ratio of the starting current at use of an autotransformer to the starting current at direct motor connection to the rated voltage
- $\frac{M_{st(AT)}}{M_{st(dir)}}$ is the ratio of starting torques at autotransformer and at direct starting.

Stage 5. *Comparison of the investigated starting methods*

Analyze the data obtained at use of different methods for starting the squirrel-cage induction motor (Tables 4.1…4.4) and make conclusions about their validity and also on advantages and disadvantages of these methods.

Stage 6. *The report execution*

The report should include:

1. The title of the test and its aim
2. The motor nameplate data (Table. 4.1)
3. Circuit diagrams (Fig. 4.1, 4.2 and 4.3) for starting the motor using different methods, and results of measurement and calculation (Tables 4.2, 4.3 and 4.4)

4. Conclusions based on analysis of results obtained at testing the induction motor direct starting under rated voltage and starting under reduced voltage.

Methodical guideline

To stage 2

Three-phase cage induction motor at direct connection to the network with the rated voltage draws comparatively great starting currents (to 4 … 7 times as the rated current). The starting motor torque is in this case about 1.1 … 1.4 of the rated motor torque and provides start when the external braking torque does not exceed that value. The direct start is acceptable if the network voltage regulation caused by the starting currents relatively the rated value is not greater than 10%.

Otherwise, measures preventing considerable voltage decrease must be taken. These measures may relate to a power line or to the methods of the motor starting.

Possible ways of starting may be use of methods providing start at reduced voltage, such as starting with switching the motor stator winding being initially connected in Y with subsequent transfer to Δ-connection or starting with use a step-down autotransformer.

To stages 3 and 4

Starting induction motor with use Y-Δ connections is applicable under condition if the motor at the given network voltage must be normally connected in Δ and start and ends leads of all the phases are brought into the motor terminal box. This method reduces the starting currents by three times. At this, reduction of the starting torque is also by three times. Therefore, this method may be applied when the loading torque is small enough, usually not more than 30% of the motor rated torque. In high voltage motors this method causes commutation overvoltage arising at shifting the stator winding connection.

Reduction of starting current at use of step-down autotransformers depends on the transformation ratio. The starting current decreases by n_A^2 times. The same is decrease of the starting torque. The start may be successfully carried out if the motor load is appropriately decreased. Selection of the autotransformer ratio depends on the motor starting conditions.

Test questions

1. On what cage induction motor parameters does the starting current depend?
2. How can be explained that starting current inrush of squirrel cage motor at considerably exceeds direct start the motor rated current?
3. Does the starting current inrush depend on the motor load on the shaft?
4. How can it be explained that at start under Y-connection the current inrush decreases by three times?

5. How can it be explained that at start under Y-connection the induction motor starting torque decreases by three times?
6. Why do the supply network current inrush and the motor starting torque are reduced by n_A^2 times at starting by means of autotransformer?
7. How is the speed-torque curve of the squirrel-cage induction motor changed at use of the methods based on decrease of the impressed voltage at the motor starting?

REFERENCES

1. Півняк Г.Г., Довгань В.П., ШкрабецьФ.П. Електричні машини: Навчальний посібник. – Дніпропетровськ: Національний гірничий університет, 2003. – 327 с.
2. Ivanov, O.B., Shkrabets, F.P., Zawilak, Jan. (2011). "Electrical generators driven by renewable energy systems", Wroclaw University of Technology, Wroclaw – 169 p.
3. Бєлікова Л.Я., Шевченко В.П. Електричні машини: Навчальний посібник. – Одеса: Наука і техніка, 2012. – 480 с.
4. Яцун Я.А. Електричні машини: Підручник. – Львів: Видавництво Львівської політехніки, 2011. – 464 с.
5. Брускин Д.Э. и др. Электрические машины и микромашины: Учеб. для электротехн. спец. вузов/ Д.Э. Брускин, А.Е. Зорохович, В.С. Хвостов. – 3-е изд., перераб. и доп. – М.: Высш.шк., 1990. – 528 с.
6. Радин В.И. и др. Электрические машины: Асинхронные машины: Учеб. для студ. электромех. спец вузов/Радин В.И., Брускин Д.Э., Зорохович А.Е.; Под ред. И.П. Копылова. –М.: Высш шк., 1988. –328 с.: ил.;
7. Иванов-Смоленский А.В. Электрические машины: Учебник для вузов. – М.: Энергия, 1980. – 928 с.
8. Вольдек А.И. Электрические машины. Учебник для студентов высш. техн. учебн. заведений. Изд. 3-е, перераб. и доп. Л.: Энергия, 1978. – 832 с.
9. Электротехнический справочник /Под общ. ред. В.Г. Герасимова, П.Г. Грудинского, Л.А. Жукова и др. – М.: Энергоатомиздат.-Т.1, 1980. –520 с.; Т.2, 1981. – 640 с.

CONTENTS

LABORATORY TEST # 3/1

LABORATORY TEST # 3/2

LABORATORY TEST # 3/3

LABORATORY TEST # 3/4

Упорядники:
Іванов Олексій Борисович
Ципленков Дмитро Володимирович

МЕТОДИЧНІ ВКАЗІВКИ
до виконання лабораторних робіт
з дисципліни „ЕЛЕКТРИЧНІ МАШИНИ”
(Розділ "Асинхронні машини")
для студентів спеціальності
141 – Електроенергетика, електротехніка та електромеханіка
(на англ. мові)