

# EXPERIMENTAL INVESTIGATION

Laboratory test # 1/1

## **Direct current machine construction and its preliminary testing**

*Aim of the training* is study of a dc machine construction, marking of its windings leads, installing the brushes on the neutral and factors affecting the voltage generated between the armature terminals.

### ***Work program:***

1. Study of a dc machine construction and familiarization with data of rating plate.
2. Marking the dc machine windings leads.
3. Installing the machine brushes on the neutral.
4. Test run of a dc generator.
5. The report execution.

### ***The work procedure***

#### ***Stage 1 Study of dc machine construction and familiarization with data of rating plate***

Studying dc machines construction pay attention to the following pieces and details:

- the yoke;
- the main poles, their cores and pole shoes;
- interpoles (commutating poles)
- the armature core with teeth and slots on its surface;
- laminations used for assembling armature core, main poles and interpoles; possible cases of main poles or their shoes and interpoles made of solid steel;
- mounting poles to the yoke;
- the coils of shunt, series and separately excited field windings;
- the shaft and shaft extension;
- bearings;
- the armature winding;
- the commutator, its segments and commutator segments insulation;
- the coils of commutating (or interpole) winding;
- the brushes, brush holders, studs, brush yoke;

- the compensating winding;
- ventilators;
- the end shields;
- terminal box and board;
- the eyebolts.

Enter the rating plate data of the machine to be tested into Table 1 and calculate the data indicated in the right side of the table.

Table 1

Ratings of machine under test

Type and serial number	Manufacturer's data				Calculated data			
	$P_r$	$U_r$	$I_r$	$n_r$	$P$	$I_f$	$\eta_r$	$M_r$

The data of Table 1 relate to the machine operation as a motor.  $P_r$  = the rated power on the shaft,  $P$  = the power adsorbed from the mains under full load.

Stage 2 Marking the dc machine windings leads

In laboratory marking the machine leads taken to the test bench terminal board (Fig. 1) is made by two following methods (Fig. 2):

- by assessment degree of an incandescent lamp filament fluorescence (Fig. 2)
- by interpretation of an electromagnetic voltmeter readings.

The marks inscribed at the windings terminals (Ukrainian version) are given in Fig.3.

To recognize the armature winding among the windings with small resistance check which of them has connection to the commutator.

The results of windings type determination fill in Table 2.

Table 2

Results of windings type determination

Winding leads	Degree of lamp fluorescence	Voltmeter reading	Type of winding
1-1			
2-2			
3-3			

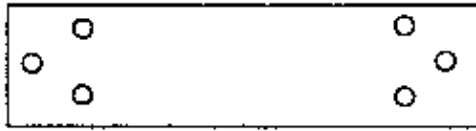


Figure 1 Dc machine terminal plate

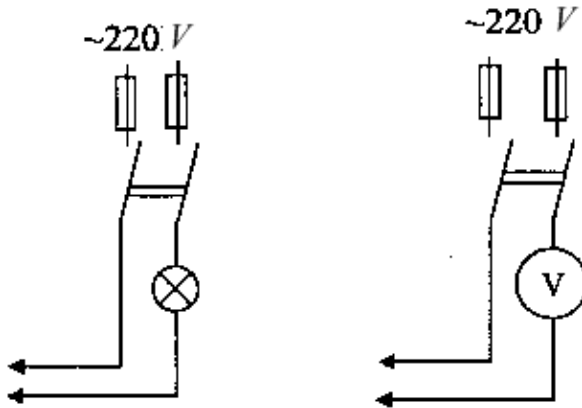


Figure 2 Connection of incandescent lamp and voltmeter for windings terminals determination

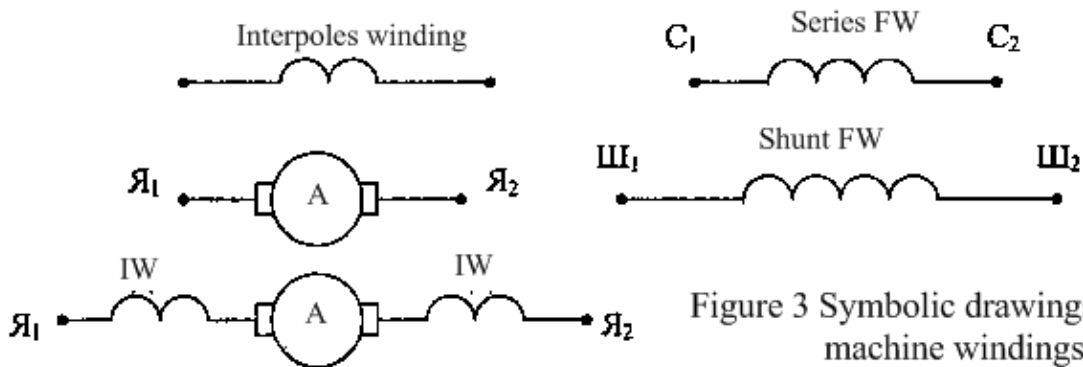


Figure 3 Symbolic drawings of dc machine windings

### Stage 3 Installing the machine brushes on the neutral

Assemble the circuit (Fig. 4). As the indicator, a milliammeter or millivoltmeter with moving coil or galvanometer may be used.

Loose the mount of the brush yoke and install the brushes approximately against centers of the poles.

Determine the instrument pointer deflection at turning the circuit on. Changing the brush yoke position try for the deflection decrease to zero under repeat of the circuit turning on. Change of the pointer deflection sign under turning on the circuit means that the direction of the brushes shifting must be changed to opposite.

Mark the brush yoke position in which the zero deflection is obtained.

After zero deflection is obtained, check that the field winding is de-energized and turn the armature for a small angle. Repeat determination of the brushes position in which zero pointer deflection takes place. If the new brushes position giving zero instrument deflection is different, repeat the experiment one

more time after turning the armature into the same direction for the same small angle. As neutral position of the brushes the middle position of the three obtained is accepted. Fix the brush yoke in this neutral position.

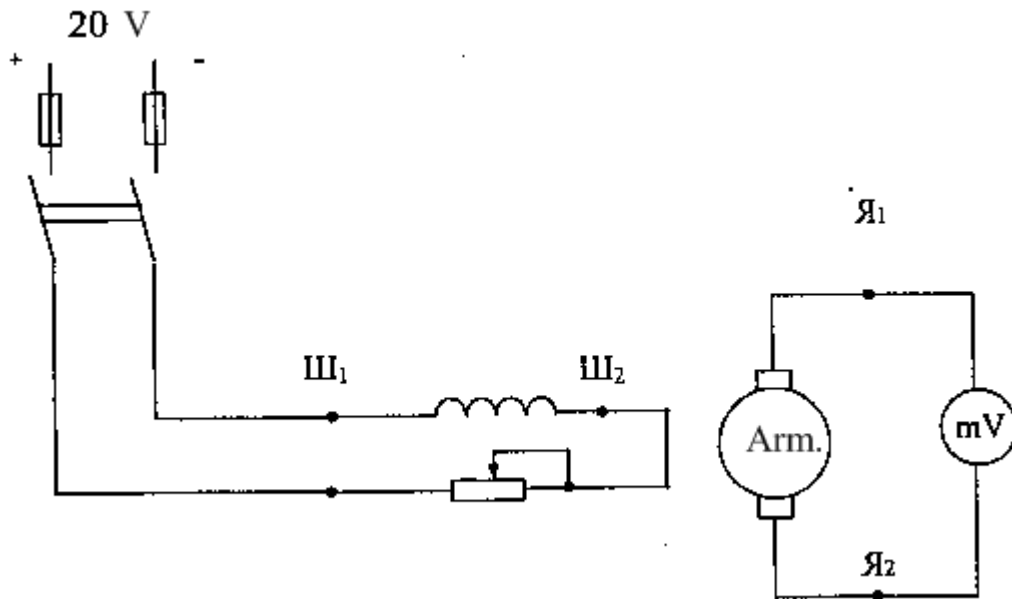


Figure 4 Dc machine neutral determination

#### Stage 4 Test run of a dc generator

Assemble the circuits for testing the separately excited dc generator (Fig. 5). In the driving motor capacity an induction cage motor is used.

Set up maximum resistance in the field circuit. Under the switch  $S1$  and  $S2$  turned off start the driving motor. Turning on the switch  $S2$ , measure the voltage  $U_{0rem}$  across armature terminals of unexcited generator. This voltage is usually in the range of (2 ... 4) % of the rated voltage.

Turn on the switch  $S1$  to energize the field winding.

Increasing the generator field current  $I_f$  by variation of the resistance, increase the voltage  $U_0$  across the armature terminals to its rated value  $U_r$ . Then decrease the voltage by means of the field current reduction. Increase and decrease of the voltage induced in the armature under the field current increase and decrease take place because the voltage is directly proportional to the field magnetic flux which is a function of the field current.

Switch off the driving motor not turning off the field current, and observe that, while the armature speed is gradually reducing to zero, the voltage on the generator terminals is reducing to zero in the same manner. This is explained by the fact that the voltage induced in the armature is directly proportional to the armature rotational speed.

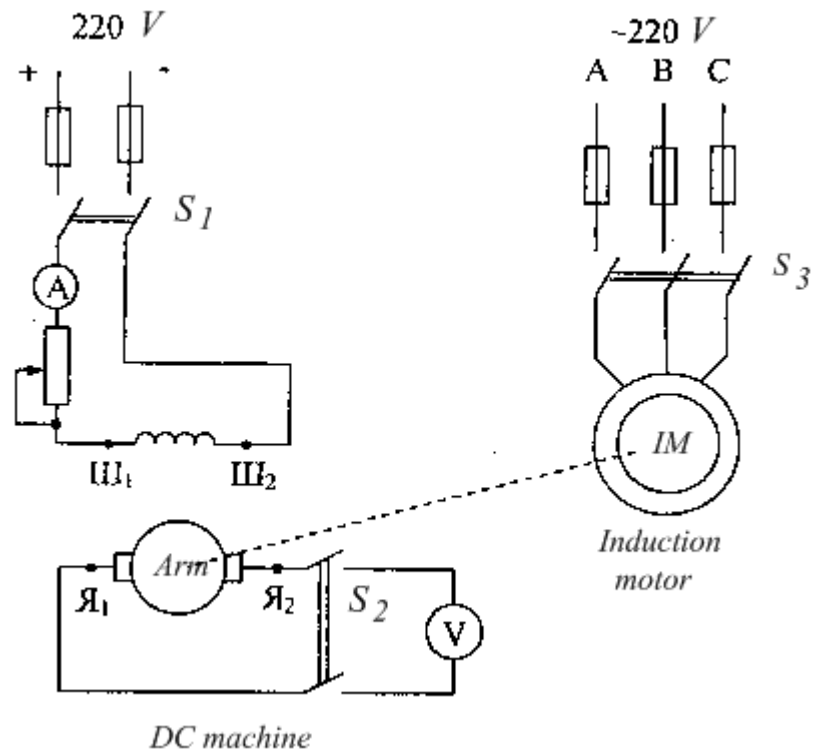


Figure 5 Test run of dc generator under no-load

### Stage 5 The report execution

The report on the test should include:

1. The title of the test and its aim.
2. The list of work stages.
3. Results of the stages performance:
  - on stage 1: the list of a dc machine pieces, completed Table 1;
  - on stage 2: Figures 1, 2 and 3; completed Table 2;
  - on stage 3: Figure 4 and explanation of the method of the brushes installation on the neutral,
  - on stage 4: Figure 5 and the observed dependence of the armature voltage on the field current and on the armature rotation speed.

### ***Methodical guideline***

#### To stage 1

For a dc motor:

- the rated power  $P_r$  is mechanical power on the shaft  $P_2$  supplied by the motor under full load;

- the power  $P$  is electrical power absorbed from the mains depending on the motor load. Under full load it equals the product  $P = U_r I_r$  where  $U_r$  **and**  $I_r$  = the motor rated voltage and current accordingly;
- the rated field current is in the range of 1 ... 5 % of  $I_r$ ;
- the rated motor efficiency in per cent is  $\eta_r = \frac{P_r}{P} \mathbf{100}$  where  $P$  is determined under the motor full load;
- the rated torque is the torque produced by the motor on its shaft under full load:

$$M_r = \frac{P_r}{\Omega_r} = \frac{P_r 30}{\pi n_r} = \frac{P_r 9.55}{n_r}, Nm$$

where  $P_r$  is measured in  $W$ ;  $\Omega_r$  = the rated armature angular speed measured in  $rad/s$ ;  $n_r$  = the rated rotational frequency measured in  $rpm$ .

*For a dc generator:*

- the rated power  $P_r$  is the electrical power  $P$  supplied by the generator to the mains under full load and equal  $P_r = U_r I_r$ ;
- the power on the shaft  $P_2$  is mechanical power absorbed by the machine from a driving engine depending on the generator load;
- the rated field current is in the range of 1 ... 5 % of the rated current  $I_r$  as for motors;
- the rated generator efficiency  $\eta_r = \frac{P_r}{P_2} \mathbf{100}$  where  $P_2$  is determined under the generator full load;
- produced by the generator retarding electromagnetic torque on its shaft, equal to the torque applied to the shaft by a driving engine, equals under full load:

$$M_2 = \frac{P_2}{\Omega_r} = \frac{P_r}{\eta_r \Omega_r} = \frac{P_r 30}{\eta_r \pi n_r} = \frac{P_r 9.55}{\eta_r n_r}, Nm$$

where  $P_2$  is determined under the generator full load.

### To stage 2

The armature winding is usually connected with interpole and compensating windings in series inside a machine. Therefore the machine inner armature circuit between terminals  $\mathcal{A}_1$  and  $\mathcal{A}_2$  includes these three windings.

In the laboratory work, experimental determination of terminals belonging to the winding is made using source of alternating voltage having frequency  $f = 50 Hz$ . At the windings type determination take into account that the tested dc machine has small resistance of the armature circuit and series field windings (a fraction or units of  $\Omega$ ) and, under 50 Hz, reactance of 1.5 ... 1.8  $k\Omega$ ; shunt field winding has much greater resistance (not less than 100  $\Omega$ ) and reactance (about 10

...  $12\text{ k}\Omega$ ). The voltmeter has internal resistance about  $10 \dots 15\text{ k}\Omega$ , resistance of a heated incandescent lamp absorbing power  $100\text{ W}$  at voltage  $220\text{ V}$  is  $484\text{ Ohm}$ .

To recognize the armature winding among the windings with small resistance check which of them has connection to the commutator.

### To stage 3

When the armature does not rotate and the field winding circuit is turned on or off the field magnetic flux produced by main poles from zero to a steady-state value or vice versa. Using the Lenz's Law we come to conclusion that, under the brushes installed on the neutral, the voltage pulse induced in the armature during the time when the flux varies (transformed voltage) is compensated within each armature winding parallel path, and the instrument pointer deflection equals zero (Fig. 6).

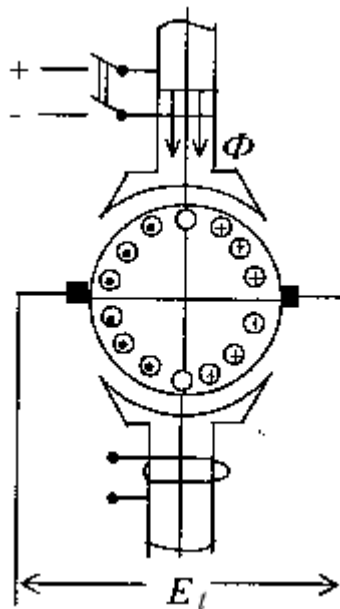


Figure 6 Voltage transformed in armature at flux increase

If the brushes are shifted relative to the neutral the voltage within the parallel paths is not completely compensated, and the instrument pointer deviates while the pulse action. Direction of deviation is different at different directions of the brushes shifting.

### To stage 4

The voltage across the armature terminals under the armature rotation is determined by the equation:

$$U_0 = E_0 = c_0 \Phi \Omega$$

where  $E_0$  = the voltage induced in a parallel path of the armature winding by the machine main magnetic field due to the armature rotation,  $c_0$  = constant for each given machine coefficient,  $\Phi$  = the main magnetic flux passing in the air gap through the surface of a pole pitch,  $\Omega$  = the angular armature speed. It is seen that the voltage is directly proportional to the magnetic flux and is directly proportional to the armature speed.

The magnetic flux depends on the field current and varies with it according the hysteresis loop similar to the curve of ferromagnetic material hysteresis loop. Therefore, changing the field current causes change of the armature voltage in accordance with the machine magnetization curve.

If the machine magnetic circuit was previously magnetized (for example this takes place if the machine operated before), some remanent magnetic flux exists in it when the field current is brought to zero. On this reason, in rotating armature small voltage is induced in absence of the field current being the reason of small voltage  $U_{0rem}$  across the armature terminals when the field current  $I_f = 0$ .

### ***Test questions***

1. Name the pieces of a dc machine.
2. Explain a dc machine construction.
3. Explain the principles of the voltage in the rotating armature winding and the dc machine electromagnetic torque formation.
4. By what features the type of a dc machine winding may be recognized?
5. What is the no-load dc machine neutral?
6. Why the instrument pointer in Fig. 4 gives zero deflection if the brushes are installed on the neutral?
7. Where the interpoles are located inside the machine and what is their destination?
8. What polarity of the interpoles should be provided in the machine operating as a motor and as a generator?
9. Is the polarity of interpoles changed automatically when the machine transfer from motor to generator mode of operation and vice versa under the same direction of rotation? Explain the answer.
10. On what reason the generator armature voltage does not equal zero under  $I_f = 0$ ?
11. How does the armature voltage vary at increase and decrease the field current?
12. How does the armature voltage vary at increase and decrease the armature rotational speed?
13. Is the armature voltage under given constant value of the field current expected to change at the dc generator loading?



# EXPERIMENTAL INVESTIGATION

Laboratory test # 1/2

## INVESTIGATION OF DC GENERATORS

*Aim of the training* is experimental determination of the generators characteristics with separate, shunt and compound excitation.

### ***Work program:***

1. Acquaintance with the dc machine ratings.
2. Investigation of the separately excited dc generator.
3. Investigation of the shunt dc generator.
4. Investigation of the compound dc generator.
5. Analysis and comparison of generators with different excitation properties.
6. The report execution.

### ***The work procedure***

#### Stage 1 Acquaintance with the dc machine ratings.

Enter the generator nameplate data into Table 1.

Table 1

Ratings of DC machine to be tested

Type	Intended application	$P_r$	$U_r$	$I_r$	$n_r$	$\eta_r$
		$kW$	$V$	$A$	$rpm$	$\%$

Pay attention to the intended application of the machine to be tested as a generator and take into account invertibility of electric machines, i.e. possibility of use the same machine either as generator or as motor.

#### Stage 2 Investigation of the separately excited dc generator

Be sure that the test bench have been deenergized and assemble the circuits for testing the separately excited dc generator (Fig. 1).

Put all the switches into turn off position. Set up maximum resistance of the generator field circuit.

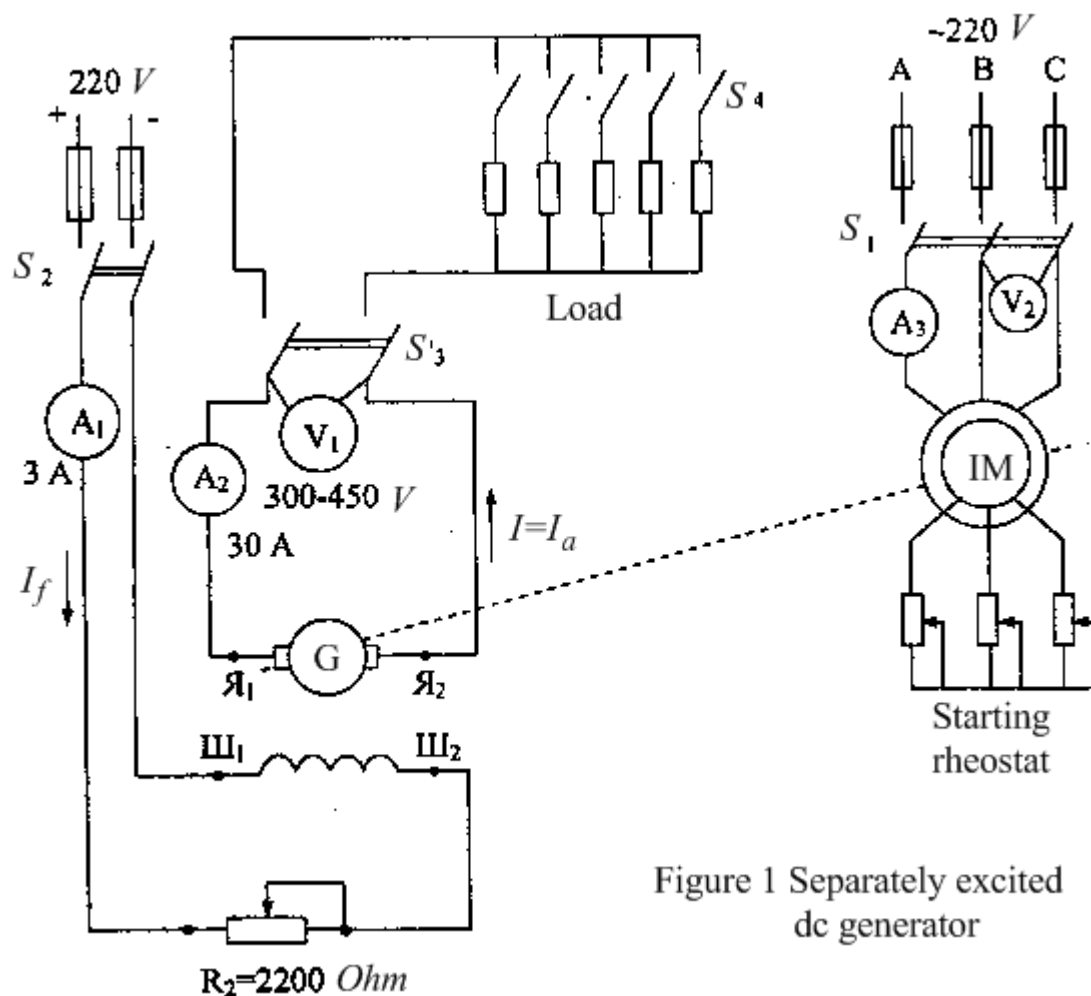


Figure 1 Separately excited dc generator

After checking the circuits by an instructor, start the driving wound-rotor induction motor. Energize the field winding and convince yourself in proper generator performance at no-load and under load.

By adjustment the value of the generator field current *measure the no-load characteristic* of the generator  $U_0 = f(I_f)$  at  $I = I_a = 0$  and  $n = const$  entering the data of measurement into Table 2. At this, take into account that initial point of the characteristic must be determined under the field current value  $I_f = 0$ , measurement of its ascending branch is made till reaching the no-load armature voltage  $U_0 = (1.20 \dots 1.25)U_r$ , the last point of the descending branch is measured at  $I_f = 0$  as at measurement of the first point of the ascending branch. Variation the value of the field current at measurement of the ascending branch should be made only by means of its increase and of the descending branch only by means of its decrease.

Table 2

Measured data of no-load characteristic

Branch	Point #	$I_f, A$	$U_0, V$
ascending	1	0	
	2		
	3		
	4		
	5		
	6		
	7		
descending	8		
	9		
	10		
	11		
	12		
	13		
	14	0	

Measure the *voltage regulation characteristic*  $U = f(I)$  at  $I_f = \text{const}$  and  $n = \text{const}$  of the generator. The obtained data enter Table 3. The first point is determined at  $I = 0$ , the field current should be set up so that no-load voltage is  $U_r$ . Increasing the load current stepwise measure next points taking care that the armature current would not exceed its rated value and the ammeters readings would not went out of their ranges of measurement. In the course of the characteristic measurement the field current must not be varied. Increasing the load current stepwise measure next points taking care that the armature current would not exceed its rated value and the ammeters readings would not went out of their ranges of measurement.

Table 3

Measured data of voltage regulation characteristics

Point #	Separate excitation		Shunt excitation		Compound excitation	
	$U, V$	$I, A$	$U, V$	$I, A$	$U, V$	$I, A$
1						
2						
3						
4						
5						
6						
7						

Measure the excitation characteristic  $I_f = f(I_a)$  at  $U = U_r = \text{const}$ ,  $n = \text{const}$  of the generator. It is necessary to determine both the ascending and descending branches of the characteristic. Readings of the instruments are entered into Table 4. Measurements begin from the load current value  $I = I_a = 0$  (no-load) after setting up no-load armature voltage  $U = U_r$ . The last point of the descending branch is measured at  $I = I_a = 0$  as at measurement of the first point of the ascending branch. In the course of measurement, the voltage must be restored to the value  $U = U_r$  after each stepwise change of the load current. Variation the value of the field current at measurement of the ascending branch should be made only by means of it increase and of the descending branch only by means of it decrease.

Table 4

Measured data of excitation characteristics ( $U = U_r = \dots V$ )

Branch	Point #	Separate excitation		Shunt excitation		Compound excitation	
		$I_f, A$	$I_a, A$	$I_f, A$	$I_a, A$	$I_f, A$	$I_a, A$
ascending	1		0		0		0
	2						
	3						
	4						
	5						
	6						
	7						
descending	8						
	9						
	10						
	11						
	12						
	13						
	14		0		0		0

After all the measurements are over switch off the driving motor and wait till the machines rotation will cease.

Plot the characteristics using the data of Tables 2, 3 and 4.

### Stage 3 Investigation of the shunt dc generator

Being sure that the test bench has been deenergized and the rotation ceased, make correction of the generator circuit (Fig.1) so that the circuit of shunt generator shown in Fig. 2 is obtained.

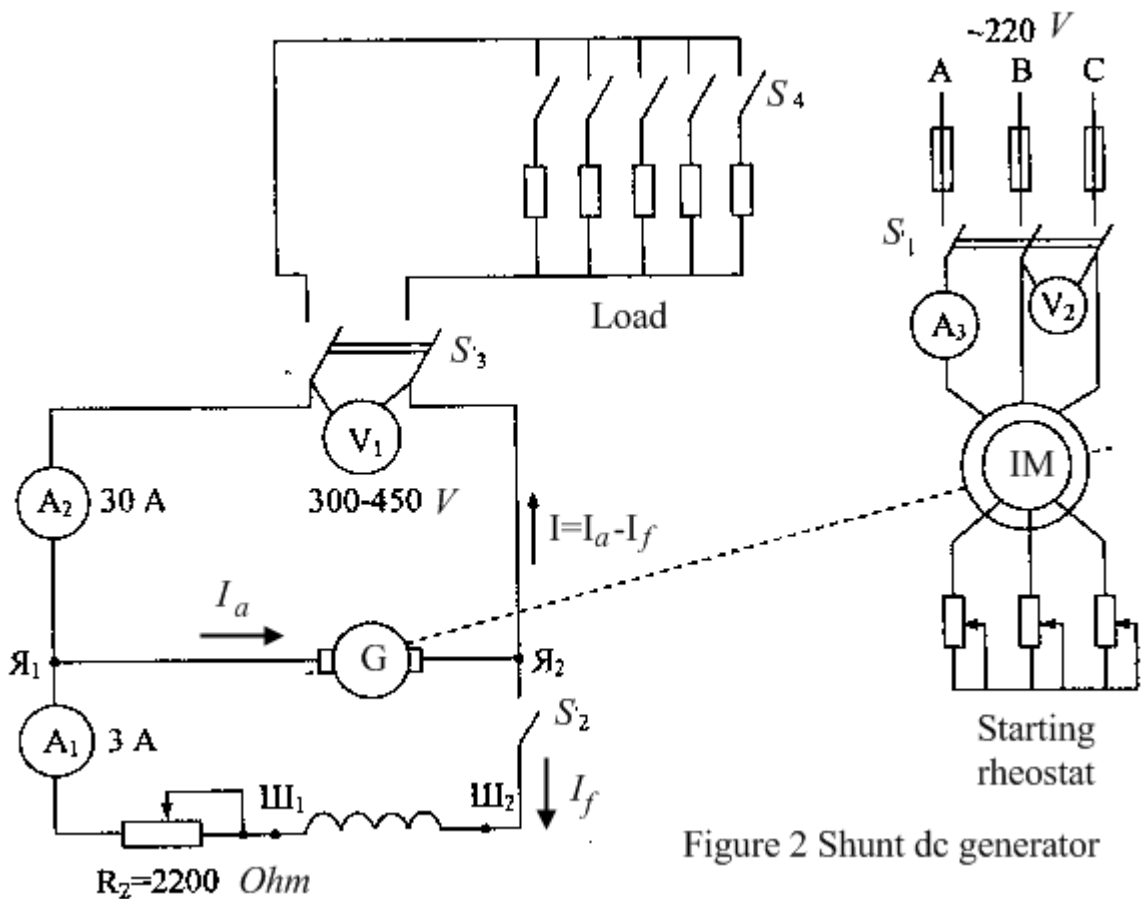


Figure 2 Shunt dc generator

Put all the switches into turn off position. Set up maximum resistance of the generator field circuit.

After checking the circuits by an instructor, start the driving wound-rotor induction motor.

Turn on the switch  $S_2$  and try for the generator to become excited reducing the field winding circuit resistance and watching the voltmeter  $V_1$  pointer deflection.

If the attempt is unsuccessful, switch off the driving motor, wait for rotation cease, deenergize the test bench and interchange the field winding terminals. Then become sure that all the switches are in turn off position and resistance of the generator field circuit is set up maximum. After that, start the driving motor again and repeat the procedure of making the generator excited.

After the generator excitation, begin the characteristics measurement.

First, measure the voltage regulation characteristic  $U = f(I)$  at  $R_f = const$  and  $n = const$  in the same order as for the separately excited generator. Here  $R_f$  is the field winding circuit resistance. The measured data enter into the proper place of Table 3.

Next the excitation characteristic is measured. Order of measurement is the same as for the separately excited generator. The measured data enter into the proper place of Table 4.

After all the measurements are over switch off the driving motor and wait till the machines rotation will cease.

Plot the measured characteristics of the shunt generator in the charts that suitable characteristics of the separately excited generator have been plotted.

Stage 4 Investigation of the compound dc generator

Being sure that the test bench has been deenergized and the rotation ceased, make correction of the generator circuit (Fig. 2) so that the circuit of compound generator shown in Fig. 3 is obtained. At this connection of the shunt field winding remain the same as in the shunt generator to provide the generator self-excitation.

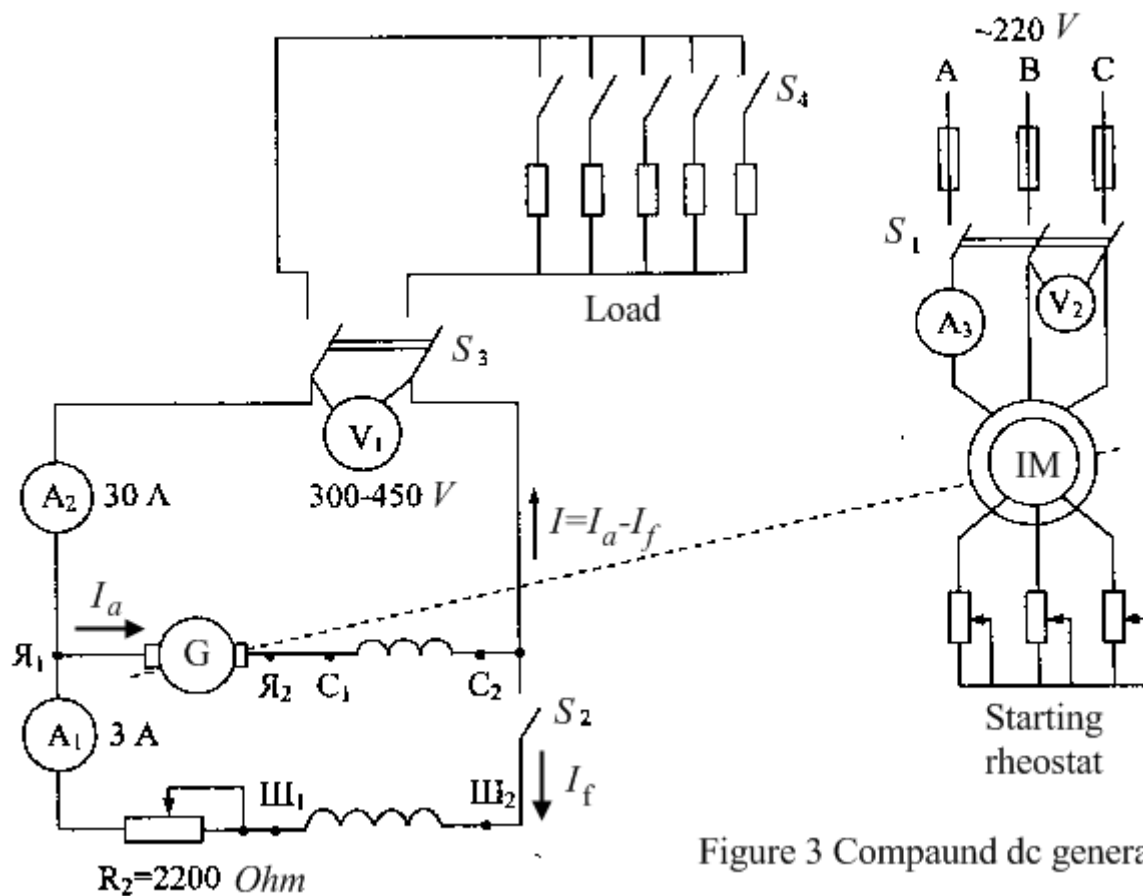


Figure 3 Compaund dc generator

Put all the switches into turn off position. Set up maximum resistance of the generator field circuit.

After checking the circuits by an instructor, start the driving wound-rotor induction motor.

Adjust the regulating resistor in the shunt field winding circuit to set the no-load voltage  $U_0 = U_r$ . After that, measure the voltage regulation characteristic  $U = f(I)$  at  $R_f = const$  and  $n = const$  in the same order as for the separately excited and shunt generators. Here  $R_f$  is the shunt field circuit resistance. The measured data enter into the proper place of Table 3.

Next, measure the excitation characteristic. For that, before measurement set the shunt field winding circuit resistance at which the armature voltage under no load equals to its rated value. Measuring the characteristic adjust the shunt field current so that the output voltage under any load equals its rated value. Order of measurement is the same as for the separately and shunt excited generator. The measured data enter into the proper place of Table 4.

After all the measurements are over switch off the driving motor and wait till the machines rotation will cease.

Plot the measured characteristics of the compound generator in the charts that suitable characteristics of the separately and shunt excited generators have been plotted.

### Stage 5 Analysis and comparison of generators with different excitation properties

Using the obtained experimental data, determine the following quantities:

1. With the help of no-load characteristic find the machine magnetic circuit saturation factor at  $U_0 = U_r$ . The saturation factor is found with the help of the center line between ascending and descending branches of the no-load characteristic (Fig. 4) as

$$k_{\mu} = \frac{F_f}{F_{\delta}} = \frac{AC}{AB}.$$

2. By the voltage regulation characteristics find the voltage regulation at full load for the generators with separate, shunt and compound excitation in per cent as

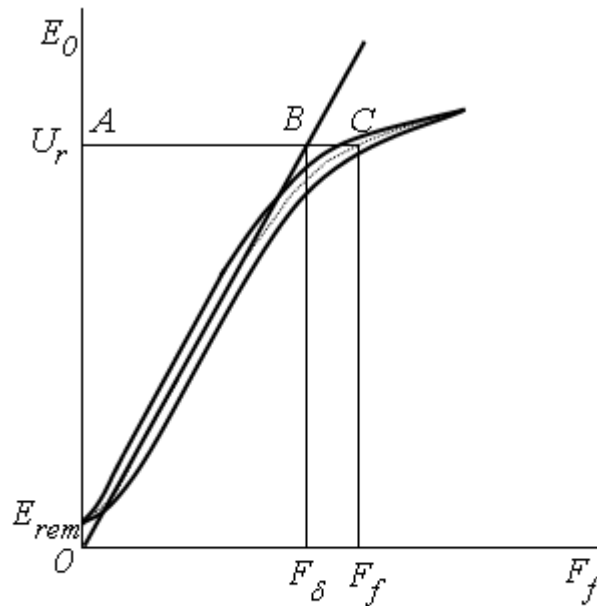
$$\Delta u_r = \frac{U_0 - U_r}{U_r} \mathbf{100 \%}.$$

Compare the obtained values for different methods of excitation and explain difference between them. Define whether the field windings of the compound generator are connected in accordance or opposite to each other.

3. By center lines of the excitation characteristics find the field current regulation in % as

$$\Delta i_r = \frac{I_{fr} - I_{fo}}{I_{fr}} \mathbf{100 \%}.$$

Compare the obtained values for different methods of excitation and explain difference between them.



**Figure 4 Determination of saturation factor using no-load characteristic of dc machine**

### ***Drawing up the report***

The prepared report must include:

1. The number and title of the test and its aim.
2. The work program.
3. The dc machine nameplate data (Table 1).
4. For the separately excited dc generator:
  - circuit diagram (Fig. 1), experimental data of the no-load characteristic (Table 2) and the no-load characteristic chart;
  - experimental data of the voltage regulation characteristic (Table 3) and the voltage regulation characteristic chart;
  - experimental data of the excitation characteristic (Table 4) and the excitation characteristic chart.
5. For the shunt excited dc generator:
  - circuit diagram (Fig. 2), experimental data of the voltage regulation characteristic (Table 3) and the voltage regulation characteristic chart plotted in the same coordinate system that suitable characteristic of the separately excited generator have been plotted;
  - experimental data of the excitation characteristic (Table 4) and the excitation characteristic chart plotted in the same coordinate system that suitable characteristic of the separately excited generator have been plotted.
6. For the compound excited dc generator:



- circuit diagram (Fig. 3), experimental data of the voltage regulation characteristic (Table 4) and the voltage regulation characteristic chart plotted in the same coordinate system that suitable characteristics of the separately and shunt excited generators have been plotted;
  - experimental data of the excitation characteristic (Table 4) and the excitation characteristic chart plotted in the same coordinate system that suitable characteristic of the separately and shunt excited generators have been plotted.
7. Calculations of the machine saturation factor, and also of the voltage regulation and the field current regulation at full load for the generators with separate, shunt and compound excitation. Be prepared to explain the obtained results.

### *Methodical guideline*

1. Dc generators are divided for separate-excited and self-excited generators. The last group includes generators which do not require separate dc power source to feed the field winding or windings. To the group of generators with self-excitation belong generators with shunt, series and compound excitation.

In this laboratory test two types of generators with self-excitation are investigated – shunt and compound generators.

2. Appearance and maintaining the voltage across the armature terminals at no- load under load in self-excited dc generators require fulfillment definite requirements. These requirements for a generator with shunt excitation are:

- Availability of the remanent magnetic flux at  $I_f = 0$ , caused by magnetic hysteresis of the ferromagnetic material used in the machine magnetic circuit.
- Concordant action of the field mmf and the remanent magnetic flux.
- Total field winding circuit resistance must be less than some it value called critical field winding circuit resistance. At the critical total field winding circuit resistance the machine is on the boundary of excitation.

For a generator with compound excitation having the shunt winding with prevailing above the series winding mmf the requirements to be carried out for the machine excitation are the same as for a shunt generator.

3. In most cases saturation factor of dc machines is over the range of 1.2 ... 1.35. Less values indicate to a machine underuse. In this case, not considerable increase of the field mmf (and the field winding) brings appropriate growth of the machine rated power. The greater values of the saturation factor indicate that possibilities of better use of the machine are practically exhausted, the machine is oversaturated, the field mmf was increased unreasonably that had required

significant increase of the machine dimensions and cost not almost giving gain in the machine power.

4. In the separately excited generators two reasons stipulate the terminal voltage reduction at the machine loading:

- the voltage drop on the armature inner circuit resistance;
- decrease of the magnetic flux due to demagnetizing effect of the quadrature-axis armature reaction.

5. In the shunt generator the voltage decrease under load is greater than in the separately excited generator because in it there is additional reason decreasing the voltage at loading: reducing the armature voltage causes decrease of the field current ( $R_f = const$ ) and, hence, the magnetic flux.

6. In the compound generator the shunt and series field windings may be connected so that their action will be or consonant or opposite to each other.

In the first case the voltage at loading or decreases in less degree than in the shunt generator or even increases due to magnetizing effect of the series field winding depending on ratio of the field windings magnetomotive forces.

In the second case the terminal voltage of the compound generator decreases in greater degree than in the shunt generator because of the series field winding demagnetizing effect.

### ***Test questions***

1. How to explain variation of the voltage across the armature at the load change in generators with separate, shunt and compound excitation?

2. On what reason the dc generator no-load characteristic is ambiguous? On what reasons does the magnetic flux under no-load depend?

3. What is the remanent magnetic flux? On what reason the armature voltage does not equal to zero when the machine is not excited ( $I_f = 0$ )?

4. On what reasons does the field current value needed to maintain constant voltage across the armature terminals depend? In what of the generators the field current needed for maintaining the armature voltage at the same level is the least and the largest if the no-load voltage in all the cases is equal?

5. Explain on what reasons may the shunt and the compound generators remain not excited at closing the circuit of the shunt field winding?

# EXPERIMENTAL INVESTIGATION

## Laboratory test # 1/3

### Investigation of dc motors with shunt and compound excitation

***Aim of the training*** is study of working properties of dc motors under shunt and compound excitation.

#### ***Work program:***

1. Acquaintance with the machine ratings.
2. Investigation of the shunt motor under basic circuit connection.
3. Investigation of the shunt motor under additional resistance in series to the armature.
4. Investigation of the compound motor.
5. Analysis and comparison of the obtained motor characteristics.
6. The report execution.

#### ***The work procedure***

##### Stage 1 Acquaintance with the machine ratings

Enter the generator nameplate data into Table 1.

Table 1

Ratings of DC machines

Machine function at test execution	Application assigned by manufacturer	$P_r$	$U_r$	$I_r$	$n_r$	$\eta_r$
		$kW$	$V$	$A$	$rpm$	$\%$
Motor to be tested						
Loading generator						

Pay attention to application assigned for the machines by the manufacturer and take into account invertibility of electric machines, i.e. possibility of use the same machine either as motor or as generator.

##### Stage 2 Investigation of the shunt motor under basic circuit connection

Being sure that the test bench is deenergized assemble the circuits of the shunt motor to be tested and the loading generator (Fig. 1). Pay attention that the positive terminal of the supply dc grid should be connected to terminal «Л 1» of the starting device and the negative grid terminal to starting device terminal «Л 2».

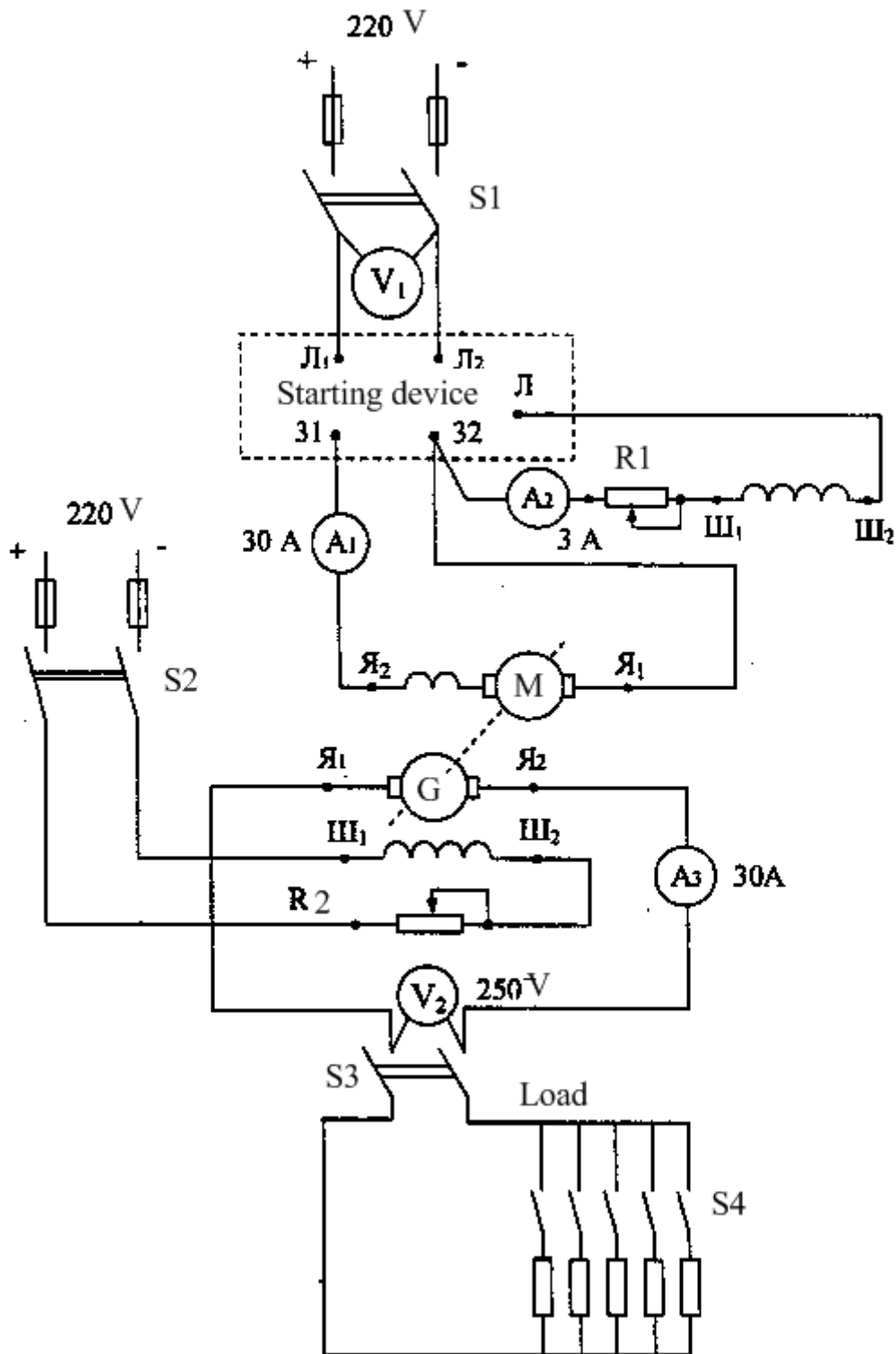


Figure 1 Basic circuit for testing shunt motor

For measurement voltages and currents instruments with moving coil are used, therefore, their connection providing proper direction of current flow inside the instruments is necessary. As the generator voltage polarity is not known before the test, proper connection of instruments V2 and A3 may be finally defined after the motor start. If change of their connection is needed, it is done only after the motor turn off, its full stop and the test bench deenergizing.

After checking the circuits by an instructor prepare them for the motor starting. For that check that all the switches are in turn off positions, the regulating rheostat in the motor field circuit is set to zero resistance, and regulating rheostat in the generator field circuit is set to maximum resistance. Energize the test bench by installation of the fuses to their socket contacts. Turn on switch S1 and start the motor pushing the “Start” button. Turn on switch S2 and check deflection of voltmeter V2. If correction of instruments V2 and A3 connection is not needed, continue the experiment.

! Pay attention that the motor shunt field winding circuit must not be disconnected while the motor operation as it causes the motor overturn or stop depending on load on its shaft. In both cases the armature current increases inadmissibly.

First, determination of the speed-current curve (electromechanical characteristic)  $n = f(I_a)$  under  $U = U_r = const$  and  $I_f = const$  is carried out.

Loading the motor is made by loading the generator with the loading rheostat. First point of the curve is determined under no-load at not excited generator (switch s2 is turned off). For determination the following curve points, turn on switch S2 and set up the voltage of the generator equal its rated value with the help of rheostat R2. This value of the generator voltage has to be maintained during the further experiment. The motor field current is not changed at the time of experiment.

The measured data enter into Table 2.

Table 2

Data for plotting speed-current curves

Point	Shunt excitation			Shunt excitation with additional resistance in series to armature			Compound excitation		
	U, V	I <sub>a</sub> , A	n, rpm	U, V	I <sub>a</sub> , A	n, rpm	U, V	I <sub>a</sub> , A	n, rpm
1									
2									
3									
4									
5									
6									
7									

Then, the speed-field current curve of the motor under no-load  $n = f(I_f)$  under  $U = U_r = const$  is determined. The switches S2, S3, S4 must be turned off. The first point is determined at maximum field current value (rheostat in the motor field circuit is set up to zero resistance). The following points are determined lowering the motor field current. Allowable maximum speed of the motor is 1500 rpm. Experiment is completed when this value of the speed is obtained.

The measured data enter into Table 3.

Table 3

Data for plotting speed-field current curves

Point	Shunt excitation				Compound excitation			
	$U, V$	$I_a, A$	$I_f, A$	$n, rpm$	$U, V$	$I_a, A$	$I_f, A$	$n, rpm$
1								
2								
3								
4								
5								
6								
7								

Using data of Tables 2 and 3 plot the speed-current and speed-field current curves for the tested shunt motor under basic circuit connection.

*Stage 3 Investigation of the shunt motor under additional resistance in series to the armature*

! Before making connections for obtaining the circuit of Fig. 2, be sure that the test bench is deenergized and rotation the machines is completely stopped.

Difference between the test bench circuit used in this test (Fig. 2) and the circuit of the previous test (Fig. 1) consists only in availability of additional resistor  $R_{add}$  connected in series to the motor armature. Therefore, complete disassembling the previous circuit is not necessary. To obtain the circuit given in Fig. 2 it is enough to disconnect the motor armature circuit represented in Fig. 1 between terminals “Я1” and “32” and connect to this place a rheostat with resistance of 0.8 ... 1.0 Ohm and designed for currents up to 30 ... 40 A.

Before starting the motor turn off all the switches, set the regulating rheostat in the motor field circuit to zero resistance and regulating rheostat in the generator field circuit to maximum resistance.

Start the motor and make experimental determination of the speed-current curve in the order described above in the instruction to Stage 2.

The measured data enter into Table 2.

Plot the speed-current current curve for the tested shunt motor under additional resistance in series to the armature in the same coordinate axes that were used for such a curve of the shunt motor under basic circuit connection.

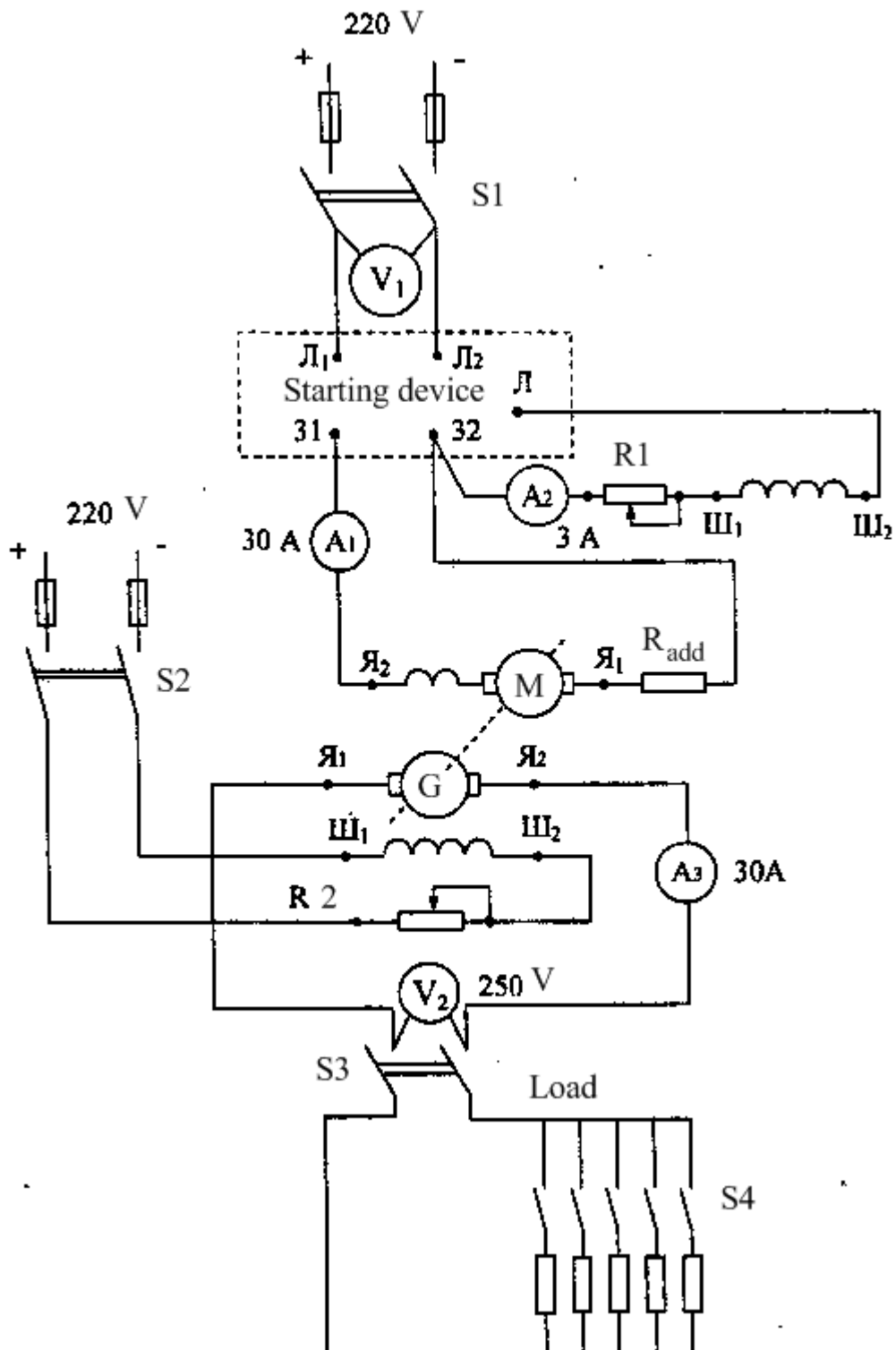


Figure2 Testing shunt motor under additional resistance in series to armature

Stage 3 Investigation of the compound motor

! Before making connections for obtaining the circuit of Fig. 3, be sure that the test bench is deenergized and rotation the machines is completely stopped.

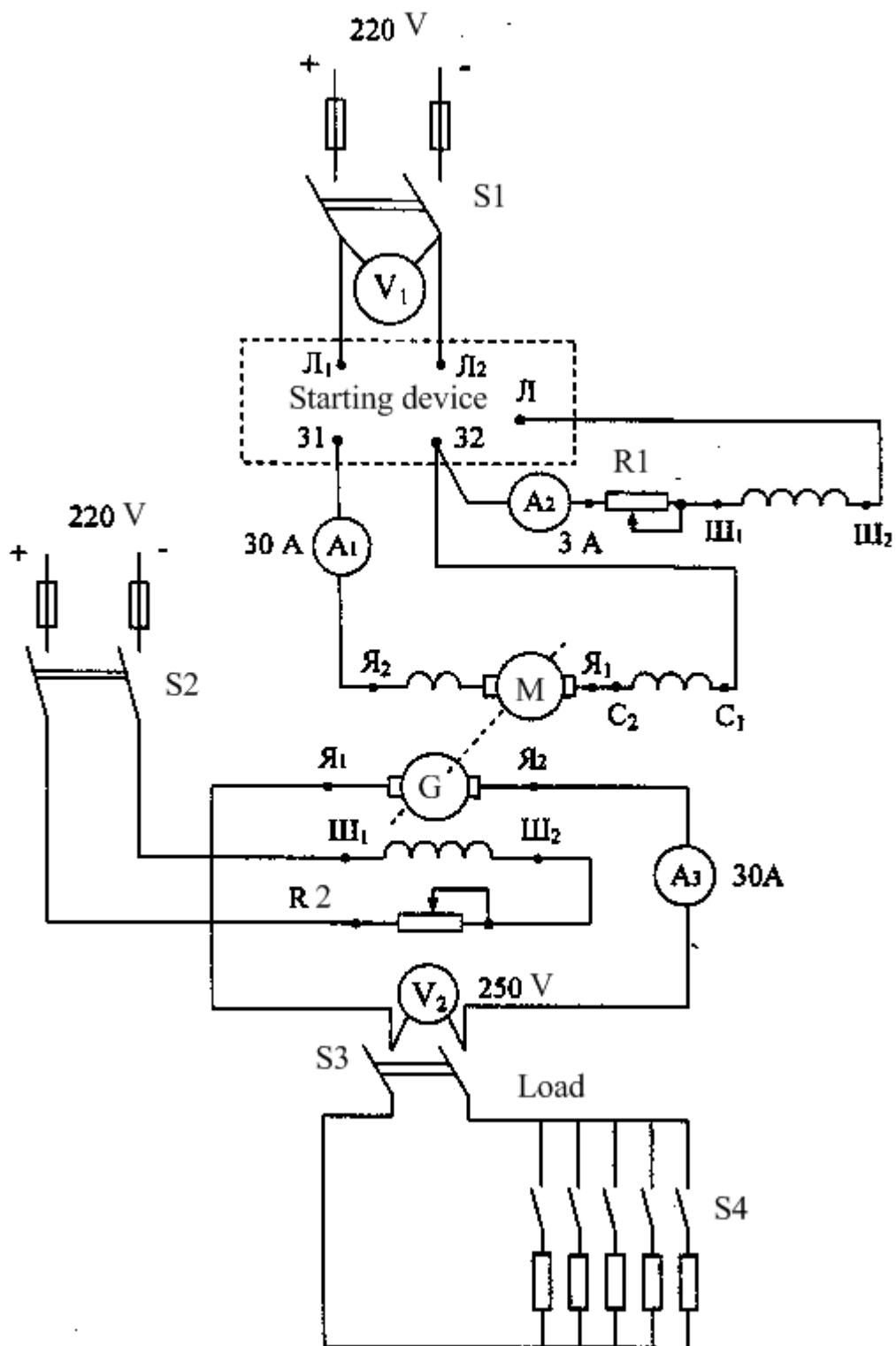


Figure 3 Testing of compound motor



Difference of the test bench circuit used in this test (Fig. 3) and the circuit of the previous test (Fig. 2) consists in absence of additional resistor  $R_{add}$  connected in series to the motor armature and availability the series field winding connected in series with the armature. Therefore, complete disassembling the previous circuit is not necessary. To obtain the circuit given in Fig. 3 it is enough to disconnect the additional resistor  $R_{add}$  (Fig. 2) and connect instead of it the series field winding (terminals “C1” and “C2”).

Before starting the motor turn off all the switches, set the regulating rheostat in the motor field circuit to zero resistance and regulating rheostat in the generator field circuit to maximum resistance. It is recommended to connect the field windings terminals as it is shown in Fig. 3 to provide their concordant action (if no error is made at the terminals marking). In the case of their counter-action, speed-torque curve becomes rising that causes the motor unstable operation.

Start the motor and check the field windings connection by observation whether the motor speed decreases under load in greater degree as of the shunt motor under basic connection. If not it is necessary to switch off the motor, deenergise the test bench and, after full motor stop, to interchange the series winding terminals “C1” and “C2” connection. In the case of the loaded motor unstable operation, that is manifested in it overturning, the switch S1 must be immediately turned off (or the starting device button “Stop” pushed). After that the test bench must be deenergized, and after the machines full stop the series field winding terminals connection interchanged.

After the field windings proper connection is provided, restart the motor and make experimental determination of the speed-current curve in the order described above in the instruction to Stage 2.

The measured data enter into Table 2.

Make experimental determination of the compound motor speed-field current curve in the order described above in the instruction to Stage 2.

The measured data enter into Table 3.

Plot the speed-current current curve and speed-field current curve for the tested compound motor in the same coordinate axes that were used for such curves of the shunt motor.

#### Stage 4 Analysis and comparison of the obtained motor characteristics

Find the motor speed regulation under shunt excitation at basic circuit connection and at additional resistance inserted into the armature circuit, and under compound excitation by the expression:

$$\Delta n_r = \frac{n_0 - n_r}{n_0} 100 \%$$

where  $n_0$  and  $n_r$  = values of the motor rotational frequency under no-load and full (rated) load.

Compare the obtained values of the motor speed regulation and explain difference between them.

### Stage 5 The report execution

The report should include:

1. The title of the test and its aim.
2. The machines nameplate data (Table. 1).
3. Circuits of the test bench for the cases of the motor shunt excitation at basic conditions (Fig. 1), shunt excitation with additional resistance in series to the armature (Fig. 2) and compound excitation (Fig. 3).
4. Experimentally obtained data (Tables 1 and 2)
5. Plots of speed-current and speed-field current curves according to the data of Tables 1 and 2.
6. Calculation the speed regulation for the three cases.

### **Methodical guideline**

*At start shunt and compound dc motors* with rated voltage applied the starting current is restricted to accepted value by means of additional starting resistor (starting rheostat) connected in series to the armature for the starting period. The resistor may have one or several steps shorted step-by-step as the motor accelerates. In the laboratory the starting devises for dc motors include the starting resistors which are connected between terminals “J11” and “31”. To the end of starting the resistance is derived from the circuit.

*General equation of the dc motor speed-current characteristic is*

$$\Omega = \frac{U - R_{ac}I_a}{c_0\Phi} \quad \text{or} \quad \mathbf{n} = \frac{U - R_{ac}I_a}{c_e\Phi}$$

where  $U$  = the mains circuit,  $I_a$  = the armature current,  $R_{ac} = R_a + R_{add}$  = the armature circuit resistance,  $\Phi$  - the magnetic flux passing through the pole pitch,  $c_0 = pN/(2\pi a)$  and  $c_e = pN/(60a)$  = constant coefficients,  $p$  = the number of pole pairs,  $N$  = the number of the armature winding effective conductors,  $a$  = the number of the armature parallel paths pairs.

The magnetic flux depends in different ways on the load according to the method of excitation.

*At shunt excitation* neglecting the armature reaction the flux may, to a first approximation, be accepted constant. Then the motor speed equals

$$\Omega = \Omega_0 - \frac{R_{ac}}{c_0 \Phi} I_a$$

where  $\Omega_0 = \frac{U}{c_0 \Phi}$  = the speed under ideal no-load conditions,  $\Phi = \Phi_0$  = the flux under ideal no-load.

Neglecting the armature reaction, the speed-current curve of a shunt motor is an inclined straight line, crossing the speed axis in the point  $\Omega_0$ . Its inclination depends on the additional resistance inserted to the armature circuit. At  $R_{add} = 0$  this is a slightly inclined (rigid) line. The greater  $R_{add}$  is, the more is the speed-current characteristic inclination. At  $\Omega = 0$  the armature current (short circuit current) equals  $I_a = U/R_{ac}$ .

Factually the armature reaction in some degree demagnetizes the machine at it loading, and the speed curve deflects upward from the straight line as the load increases.

*The speed-current curve of a compound dc motor* is more inclined and has larger upward deflection from a straight line than a shunt motor because increase of the armature current causes increase of the magnetic flux. The curve crosses the speed axis at the speed  $\Omega_0 = \frac{U}{c_0 \Phi_0}$ .

*Speed-field current curves* of unloaded shunt and compound motors are practically identical. Without taking into account the magnetic circuit saturation the flux is roughly directly proportional to the field current:  $\Phi \cong k_i I_f$  where  $k_i$  is the proportionality constant. The speed-field current curve equation may be written as

$$\Omega \cong \Omega_0 \cong \frac{U}{c_0 k_i I_f}$$

and the curve is close to hyperbola. The field current reduction brings the speed increase which should be restricted because of danger of mechanical damage of the motor and the commutation conditions worsening.

*Consider consequences of the operating motor shunt field circuit disconnection.* Proceeding from the last idealized equation, it is seen that at the shunt motor field circuit disconnection ( $I_f = 0$ ) the no-load speed tends to infinity. At the same time, the motor torque at  $\Omega = 0$  (torque of the motor short-circuit) decreases considerably. In Fig. 4 line 1 is the speed-torque curve for the case of closed field circuit, line 2 – the same after the field circuit disconnection. Lines 3 and 4 represent the load torque and the inherent motor braking torque respectively.

After the field winding disconnection the flux reduces to small remanent flux  $\Phi_{rem}$  being roughly 30 ... 50 times less as the rated flux.

If the motor before the field circuit disconnection works under load (point *a* in Fig. 4), its torque immediately after the field circuit disconnection will be defined by point *b* of line 2 at the same speed  $\Omega_1$ . The speed will *begin* to decrease

till the motor will stop, at this the working point will move from  $d$  to  $c$  by arrow  $N$ . In the transient the armature current tends to the value  $I_a = U/R_a \gg I_{ar}$ .

If the motor before the field circuit disconnection works under no-load condition (point  $d$  in Fig. 4), its torque immediately after the field circuit disconnection will be defined by point  $e$  of line 2 at the same speed  $\Omega_0$ . The speed will *begin* to increase tending usually to  $\geq(3 \dots 5) \Omega_0$ , at this the working point will move from  $e$  by arrow  $K$ . In the transient the armature current tends to the value  $I_a = U - (0.05 \dots 0.1) \Phi_r \Omega_0 / R_a \gg I_{ar}$ .

As it is seen the armature current at the field winding disconnection reaches inadmissible values. Therefore machine in such a case must be switched off.

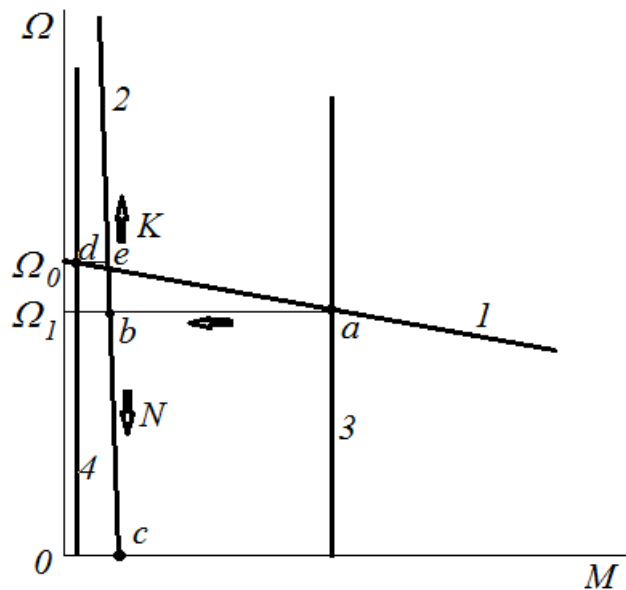


Figure 4 Consequences of shunt motor field circuit disconnection

As the tested compound motor has not strongly expressed series field winding the consequences of the shunt field winding disconnection for it are approximately the same that for the shunt motor.

### ***Test questions***

1. What is the starting resistor destination?
2. How is the starting resistance varied in the course of the motor start? How may it be observed in the starting period?
3. How does the armature reaction affect the motor characteristic?
4. How may concordant or counter field windings of a compound motor action be revealed?
5. What are consequences of the shunt field winding circuit disconnection under the motor operation?
6. Why do protection devices or switches which may disconnect the circuit not included into the shunt field path?

7. In what bounds of the slip is the induction motor operation at constant torque on the shaft stable?
8. Is there difference of the motor behavior after breaking the shunt field circuit under no-load and under load?
9. Explain difference of the motor speed regulation values at different methods of excitation?
10. Explain why and how the motor speed varies when the field current of the motor is changed.

# EXPERIMENTAL INVESTIGATION

Laboratory test # 1/4

## Investigation of dc motors with series excitation

*Aim of the training* is study of working properties of series dc motors.

### *Work program:*

1. Acquaintance with the machine ratings.
2. Calculation of loading torque values.
3. Investigation of the series motor under basic conditions.
4. Investigation of the series motor at the field winding shunted with a resistance.
5. Investigation of the series motor at the armature shunted with a resistance.
6. Analysis and comparison of the obtained motor characteristics.
7. The report execution.

### *The work procedure*

#### Stage 1 Acquaintance with the machine ratings

Enter the generator nameplate data into Table 1.

Table 1

Ratings of DC machines

Date from rating plate				Calculated	
$P_r$	$U_r$	$I_r$	$n_r$	$M_r$	$\eta_r$
$kW$	$V$	$A$	$rpm$	$N\cdot m$	$\%$

#### Stage 2 Calculation of loading torque values

The motor is loaded with electromagnetic disc brake like used in Laboratory test # 3/2. The loading torque is adjusted by means of variation the current in the brake excitation coil. Reading the loading torque is made with the help of a pointer placed on the axis of the braking device provided with the balancing weight.

In the course of the motor characteristics determination it is necessary to set different values of the load torque in the range of  $(0.25 \dots 1.25M_r)$ . Pay attention that operation of a series motor without load is not permissible as it causes it overrunning. It is recommended to set in the experiments the torque equal approximately  $(1.25, 1.0, 0.75, 0.5, 0.25) M_r$ .

Using the data of the rating plate calculate the rated motor torque on the shaft and the indicated torque values to be used at the motor loading.

In the Table 2 actually set in the course of the characteristic determination torque values should be entered.

Stage 3 Investigation of the series motor under basic conditions

The circuit of test bench is given in Fig.1.

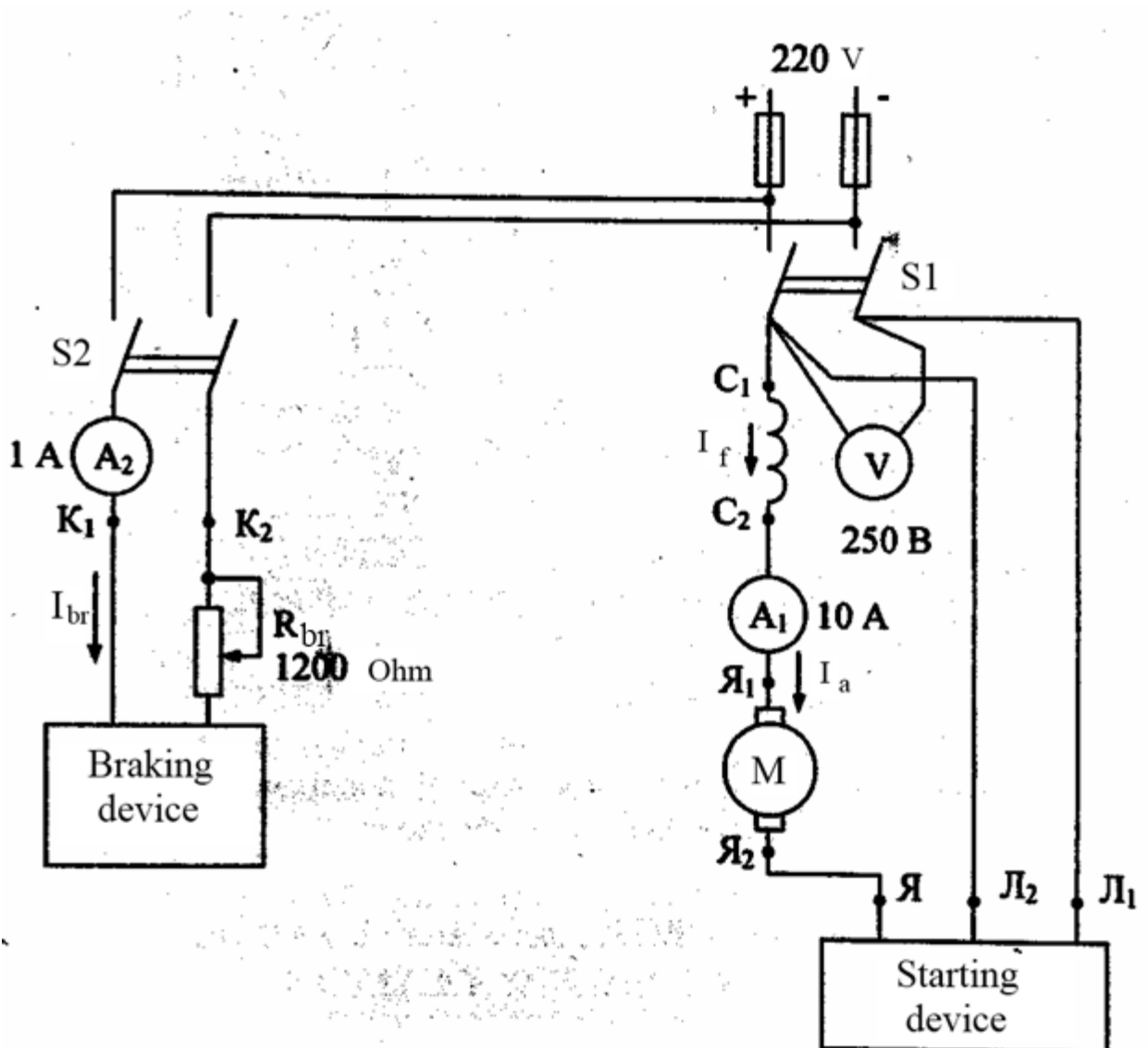


Figure 1 Motor test under basic circuit connection

Before the test bench energizing the switches S1 and S2 must be turned off. Being sure of that energize the test bench installing the fuses.

To prepare the circuit to the motor start, turn on the switch S2 and set the brake excitation current equal about 0.3 A that provides the torque after the motor start not less  $0.25M_r$ .

Turn on the switch S1 and start the motor with the help of the starting device.

Determine experimental data under the load torque values equal approximately the calculated previously beginning from  $1.25M_r$  and reducing the load step by step till minimally permissible value about  $0.25M_r$ .

The obtained data enter into Table 2.

Table 2

Experimental and calculated data

Motor circuit	Measured data					Calculated			
	$M_2, Nm$	$U, V$	$I_a, A$	$n, rpm$	$I_{sh}, A$	$P, W$	$P_2, W$	$\eta, \%$	$I_f, A$
Basic					-				
					-				
					-				
					-				
					-				
Field shunted									
Armature shunted									
	0								

*Stage 4 Investigation of the series motor at the field winding shunted with a resistance*

The circuit of test bench is given in Fig.2.

Before the test bench energizing the switches S1 and S2 must be turned off. Being sure of that energize the test bench installing the fuses.

To prepare the circuit to the motor start, turn on the switch S2 and set the brake excitation current equal about 0.3 A that provides the torque after the motor start not less  $0.25M_r$ .

Turn on the switch S1 and start the motor with the help of the starting device.



Determine experimental data under the load torque values equal approximately the calculated previously beginning from  $1.25M_r$  and reducing the load step by step till minimally permissible value about  $0.25M_r$ .

The obtained data enter into the proper place of Table 2.

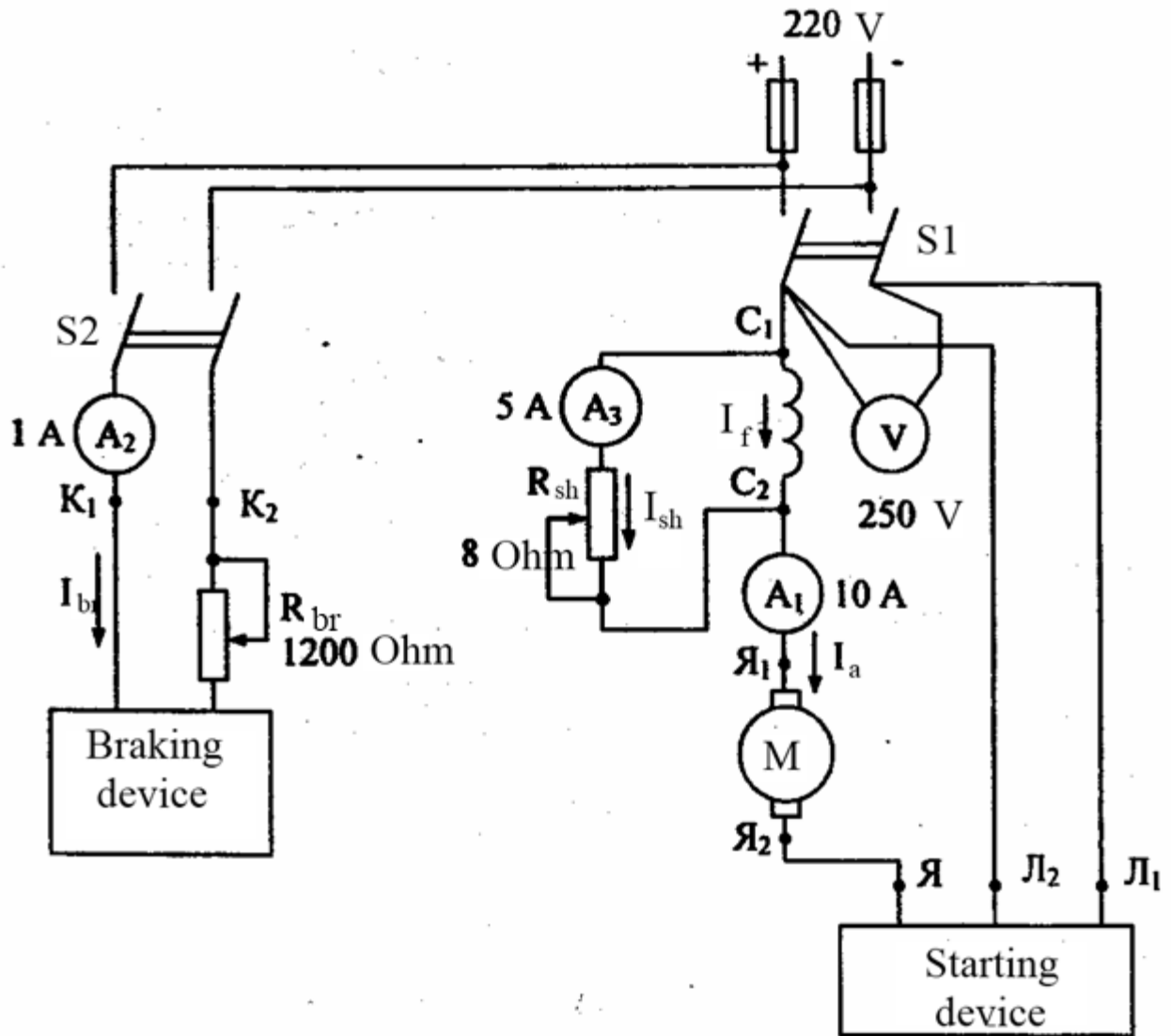


Figure 2 Motor test under field shunting

*Stage 5 Investigation of the series motor at the armature shunted with a resistance*

The circuit of test bench is given in Fig.3.

The motor with shunted armature has finite no-load rotating frequency. If the current through shunting resistor is commensurable with the current through armature, there is no danger of the unloaded motor overrun.

Turn on the switch S1 and start the motor with the help of the starting device.

Determine experimental data under the load torque values equal approximately the calculated previously beginning from  $1.25M_r$  and reducing the load step by step till zero.

The obtained data enter into the proper place of Table 2.

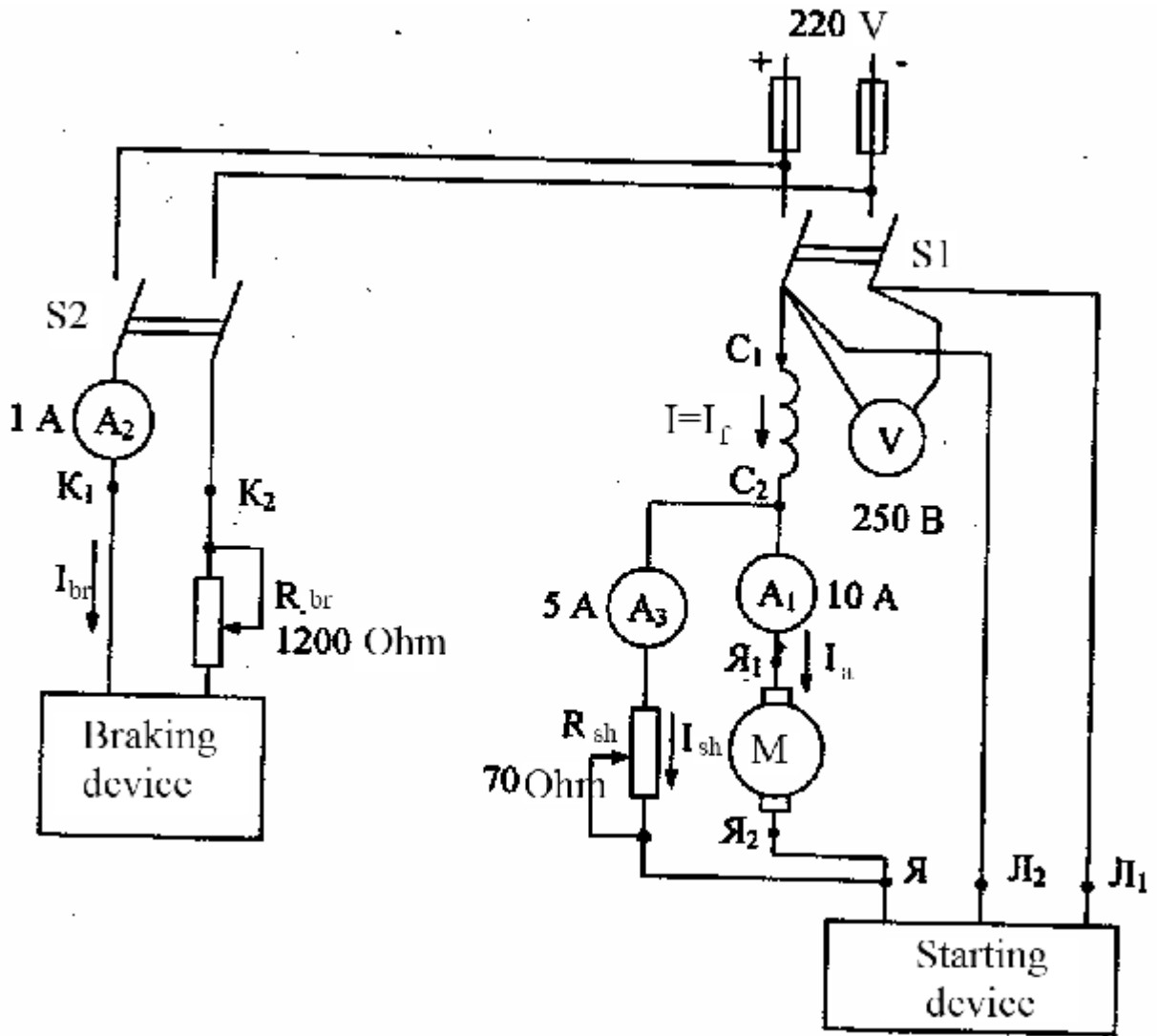


Figure 2 Motor test under armature shunting

*Stage 6 Analysis and comparison of the obtained motor characteristics*

Plot performance characteristics of the series motor representing dependences of the rotational frequency  $n$ , torque on shaft  $M_2$ , absorbed electric power  $P$ , and efficiency  $\eta$  on the mechanical power  $P_2$  given to the load. It is required that the performance characteristics were drawn in three graphs, separately for the basic conditions, for the case of field shunting and the armature

shunting. Compare curves presented in these three graphs, pay attention to features of the characteristics at different connections of the series motor.

Plot in one graph the motor torque-speed curves for the three cases of circuit connection. Compare the curves and pay attention to difference between them.

Explain the obtained results.

### Stage 5 *The report execution*

The report should include:

4. The title of the test and its aim.
5. The machine nameplate data (Table. 1).
6. Circuits of the test bench for the cases of basic conditions (Fig. 1), field shunting (Fig. 2) and armature shunting (Fig. 3).
7. Experimentally obtained data (Tables 2)
8. Graphs of the motor performance characteristics and the torque-speed curves.

### *Methodical guideline*

At the armature current not exceeding the rated value the magnetic flux produced by the field winding is roughly directly proportional to the current, and equation of the torque-speed curve under basic circuit connection and under shunting the field winding is:

$$\Omega = \frac{U}{\sqrt{c_0 k_\Phi} \sqrt{M}} - \frac{R_{ta}}{c_0 k_\Phi}$$

where  $U$  = mains voltage,  $R_{ta}$  = total resistance of the armature circuit,  $c_0$  and  $k_\Phi$  = constant coefficients,  $\Omega$  = the armature angular speed,  $M$  = the electromagnetic torque. The curve resembles hyperbola and does not crosses the speed axis. When the load torque tends to zero, the motor speed tends to infinity and the machine overruns. To avoid overrunning the load torque should be not less than  $(0.2 \dots 0.25)M_r$ .

Under shunting the armature the magnetic flux of the unloaded series motor ( $M = 0$ ,  $I_a = 0$ ) has finite value  $\Phi_0$  corresponding to the field current equal  $I_{sha}$ . The no-load speed is in this case finite. At  $I_{sha}$  commensurable with the rated armature current, unloading the motor does not cause it overrun.

### *Test questions*

1. How to find the rated torque on shaft using the motor ratings?
2. What losses cause difference between the motor absorbed and output power?
3. Under what conditions the performance characteristics of the motor have been determined at it testing?
4. Is it possible to transfer a series dc motor into generator operating mode at its connection to the mains?
5. Under what conditions does overrun of a series motor may occur?
6. How and on what reason does a series motor speed at shunting the field winding under constant loading torque increase?
7. How and on what reason does a series motor speed at shunting the armature under constant loading torque decrease?
8. Explain why a series motor does not overrun at shunting the armature?
9. Does the coefficient  $c_0$  have the same value in the cases of basic circuit connection and shunting the field winding?
10. In what of the investigated cases and on what reasons does the motor efficiency is smallest and maximal?