

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
Zaporozhye National Technical University

METHODICAL INSTRUCTIONS

for performing laboratory works
at discipline "Electric machines"
Synchronous machines. DC machines
for students specialty 141
«Electrical and Power Engineering»
daily form of education

2016

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INTRODUCTION

Methodical instructions to laboratory works on discipline "Electrical machines" contains works by such major sections, as the construction of synchronous motors and DC motors, principles of their work, start-up SM, testing of electrical machines at idling and short-circuit modes, including SG into parallel work, etc.

Laboratory works are carried out according to the program of the course "Electrical machines". They reinforce knowledge students; help to acquire the skills for control and testing synchronous motors and DC motors.

When performing laboratory works at electrical machines, students must:

- execute the internal rules in the laboratory;
- execute practice safety requirements in the laboratory of electrical machines.

The purpose of laboratory works – provide the help to students in the assimilation and strengthening of theoretical knowledge, acquisition of practical skills work on connecting, start-up and testing electrical machines.

On the first introductory lesson, teachers spend for students instructions in issues of safety and labor protection, acquaint them with the schedule of laboratory work.

For successful implementation of laboratory work students need:

- learn the purpose of the work, its content, the order of execution on the laboratory booth;
- prepare the necessary schemes and tables;
- learn the appropriate sections of the recommended literature;
- have an interview with the head, who leads laboratory works, submit a report on previously carried out work and obtain permission for the following works;
- at performance of works students must strictly observe the safety regulations and labor protection.

At the end of holding experiments, student must show lecture the results and put in order their workplace.

According to obtained research data each student makes out a report

on laboratory work and protects it.

Checking the report and interviews were conducted with each student individually. During the conversation, student must answer the questions of theoretical and practical character in the volume of work performed, as well as to know the circuit and test methods. In case of unsatisfactory answers to questions, untidy the report is executed its inconsistency with program requirements and USDD laboratory work does not count. The report must renew and laboratory work must be protected outside the grid schedules for the next laboratory works.

When protecting of laboratory work lecturer puts differentiated assessment, which taken into account for module control affix per semester.

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1 LABORATORY WORK № 1-S

STUDYING CONSTRUCTION AND OPERATION SYNCHRONOUS MACHINE

1.1 Purpose of the work

Learn the basic constructive elements with salient poles and not salient poles synchronous machines; demonstrate operation synchronous generator.

1.2 The working order of performance

1.2.1 Learn the device and appointment single elements of construction salient poles and not salient poles synchronous machines by using stands, posters, models, slides.

1.2.2 Write nameplate data of synchronous generator given on the data plate, determine their nature.

1.2.3 Get acquainted with designation of clamps stator and rotor windings, with the help of megohmmeter test the integrity of phase windings, compare the designation of stator and rotor windings with the same designations in induction machines.

1.2.4 Determine number of poles, structure, method of cooling, type of bearings, shape of stator grooves, method of excitation synchronous generator.

1.2.5 Perform sketches of the main parts and construction elements of synchronous generator:

- a) stator;
- b) rotor;
- c) rotor pole;
- d) a stamped stator plate packet;
- d) sections of stator and rotor windings;
- e) terminal box;
- g) brush apparatus and the node of contact rings electrical pathway of rotor winding.

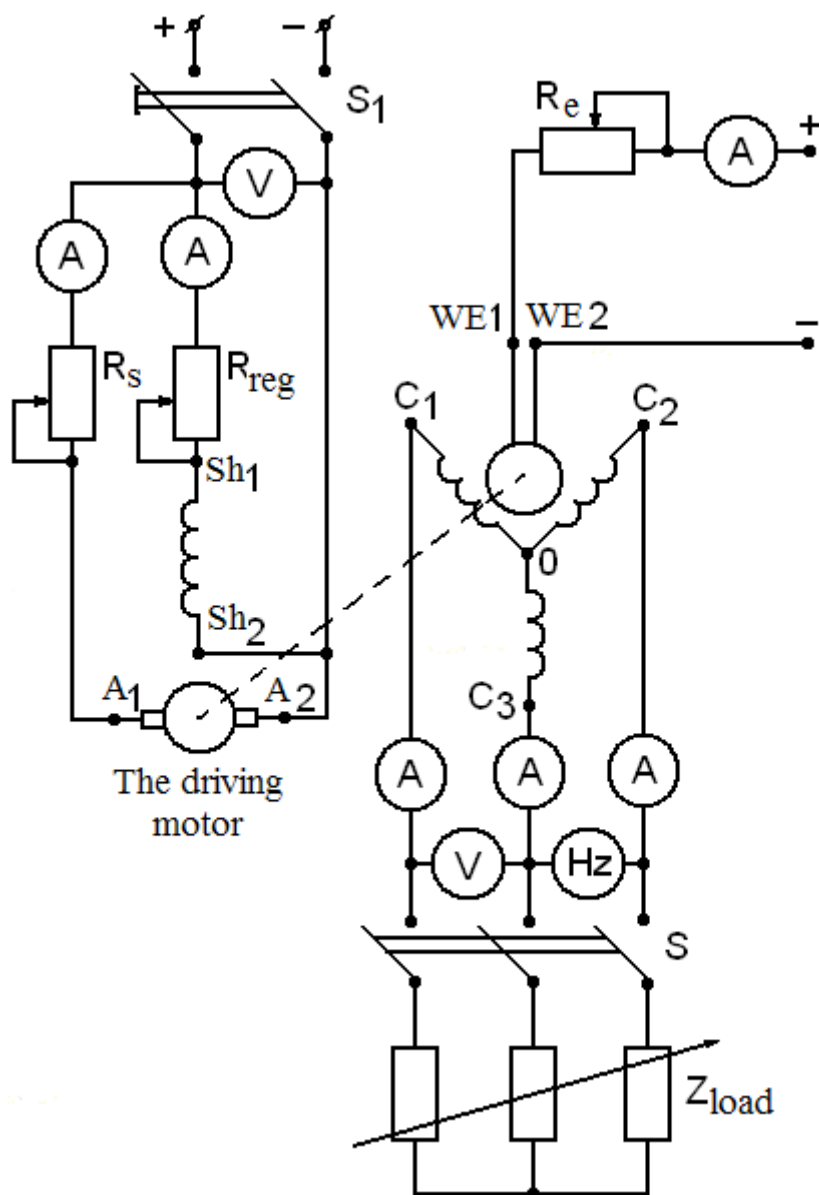


Figure 1.1 - Scheme of synchronous generator

1.2.6 Get acquainted with the work of three-phase synchronous machine in generator mode:

- a) examine the appointment of synchronous machine in block with power transformer;
- b) get acquainted with the scheme in Fig. 1.1.
- c) examine the principle of work SG;
- d) carry out the launching of generator via a DC drive motor;
- e) excitate generator;
- e) loading SG to the rated load;
- g) stop the machine.

1.3 Instructions for preparation of the report and protection laboratory work

1.3.1 The report should contain:

- a) the data nameplate;
- b) sketches of the main nodes and elements synchronous machine construction;
- c) sheme of switching synchronous generator.

1.3. 2 Questions for self-preparation

- 1 The principle of work synchronous machine.
- 2 Operating modes of synchronous machine (generator, motor).
- 3 Construction of salient-pole synchronous machines.
- 4 Construction of not salient-pole synchronous machines.
- 5 Differences in a constructive execution of turbogenerator and hydrogenerator rotors.
- 6 Appointment of short-circuited winding in synchronous machine rotor.
- 7 Why is the diameter of powerful turbogenerators rotor with different nominal powers has approximately the same value: 1000-1200 mm.
- 8 Why is rotor of turbogenerator massive and rotor of asynchronous machine laminated?
- 9 Why is hydrogenerator has a larger radial dimension, and turbogenerator - a larger size along the axis at a relatively small other overall dimensions?
- 10 Ways of excitation synchronous machines.

- 11 Possible number of contact rings synchronous generator. On what indicates the number of contact rings?
- 12 The construction of hydrogenerators umbrella type.
- 13 The construction hydrogenerators suspended type.
- 14 The capsule generator design.
- 15 The principle of work synchronous generator with self-excited.
- 16 Ways of cooling synchronous generators.

2 LABORATORY WORK № 2-S

TESTING THREE-PHASE SYNCHRONOUS GENERATOR

2.1 Purpose of the work

2.1.1 Remove the main characteristics of three-phase synchronous generator.

2.1.2 Studying the properties of three-phase synchronous generator according to its specifications.

2.2 The working order of performance

2.2.1 Determine type and purpose of machine in the block. Write data from nameplate. To familiarize with features of synchronous machine construction.

2.2.2 Assemble the DC scheme for testing synchronous generator with a drive motor as shown in Fig. 2.1

2.2.3 With the help of drive motor set in rotation rotor of synchronous generator up to the rated speed (rated frequency). Excite generator to the nominal voltage.

2.2.4 Take readings for idling characteristic SG $E_{ID} = f(I_e)$, when $I_0 = 0$; $f = 50 \text{ Hz}$; $n_{nom} = const$

At removal ID characteristic current change so as to receive voltage at generator terminals in the range from minimum to nominal voltage increased by (10-20)%. Perform 5-8 measurements, thus it is necessary to perform the measurement in the case of nominal voltage U_{nom} .

Measurement data and calculated data recorded in the table 2.1.

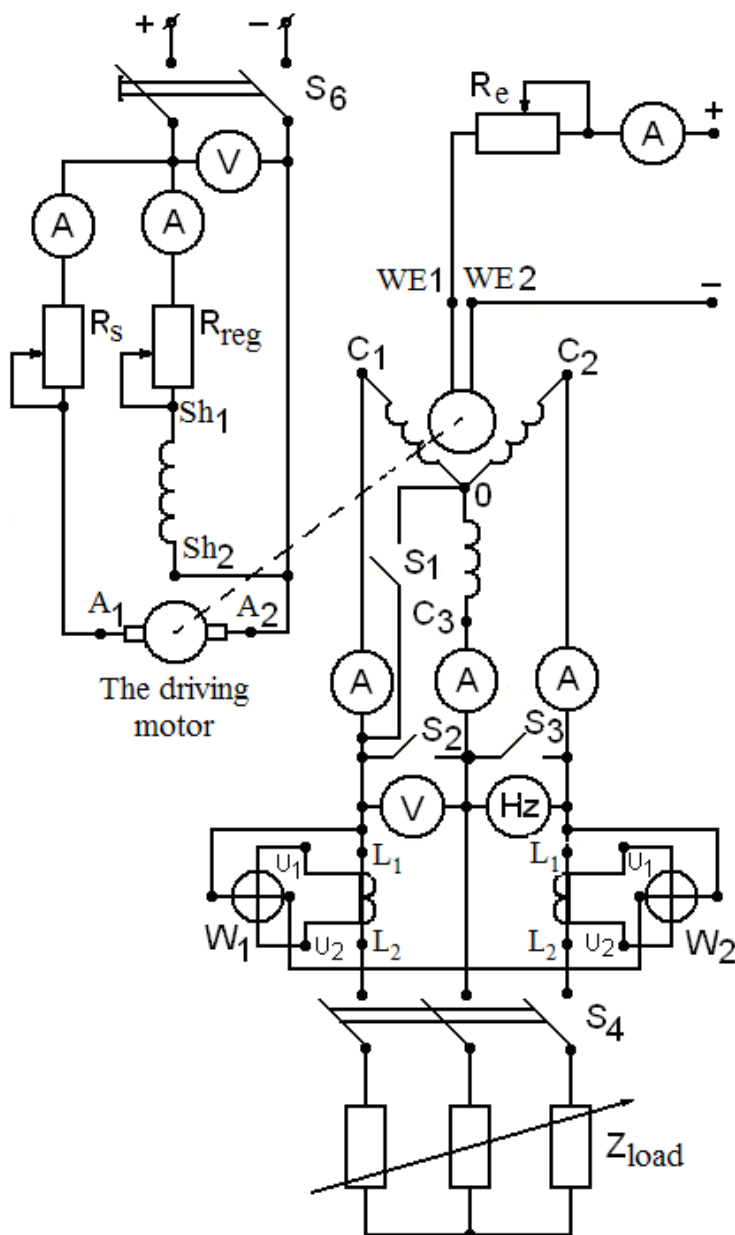


Figure 2.1 - Scheme for testing synchronous generator

Table 2.1 - Data measurement and calculation data of testing synchronous generator at idling mode

№	Measurement data				Calculated data	
	I_e , A	E_{ID} , V	f , Hz	n rev /min	I_{e*} , r.u.	E_{ID*} , r.u.

For nominal voltage check symmetry of voltage between phases. Depict the ID characteristics of testing generator and normalized (Table 2.2) in the same coordinate system. Compare them and make conclusions.

ID characteristics of testing generator should not differ from normative more than $\pm 5\%$.

Table 2.2 - Normalized ID characteristics synchronous generators

I_{e*}	0.2	0.5	1.0	1.5	2.0	2.5	Notes
E_{ID*}	0.2	0.58	1.0	1.21	1.33	1.4	Turbogenerator
E_{ID*}	0.2	0.53	1.0	1.23	1.3	-	Hydrogenerator

2.2.5 Take readings for external characteristic $U = f(I_a)$ when $\cos\varphi = 1.0$, $\cos\varphi = 0.8$.

At removal of external characteristics for increasing mode of voltage, as a source mode accept a nominal load generator mode: U_{nom} ; I_{nom} ; $I_{e,nom}$, then at $I_{e,nom} = \text{const}$ and $n_{nom} = \text{const}$ reduce the load to zero and perform 5-8 measurements for purely resistive and resistive-inductive ($\cos\varphi = 1.0$, $\cos\varphi = 0.8$) load.

Measurement data and calculated data recorded in the table 2.3.

Table 2.3 - Data measurement and calculation data for determination external characteristic of synchronous generator

№	Measurement data							Calculated data				
	U , V	I_a , A	I_e , A	α , div	f , Hz	$\cos\varphi$ -	n , rev /min	S , VA	P , W	$\cos\varphi$ -	U^* , r.u.	I_a^* , r.u.

According to data table 2.3 build external characteristic in relative units.

By the external characteristic determine the percentage exceeding of voltage remaining after the dropping of the load, with the proviso that

$$n = n_{nom} = const; I_e = I_{e.nom} = const$$

$$\Delta U\% = \frac{U_{ID} - U_{nom}}{U_{nom}} \cdot 100\%,$$

where U_{nom} , U_{ID} - respectively, the nominal voltage at rated load and generator voltage at ID.

Percentage exceeding ΔU voltage should be no more than 50%.

2.2.5 Take readings for regulation characteristics $I_e = f(I_a)$ when $U_{nom} = U = const$, $n = n_{nom} = const$ in the case of a resistive load.

The load current is changed within the $(0.2 \dots 1.25) \cdot I_{nom}$, perform 5-8 measurements, at the same time it is necessary to perform measurement in the case of nominal current I_{nom} .

Measurement data and calculated data recorded in the table. 2.4.

Table 2.4 - Data measurement and calculation data for determination regulation characteristic of synchronous generator

№	Measurement data						Calculated data				
	U , V	I_a , A	I_e , A	α , div	f , Hz	$\cos \varphi$ -	S , VA	P , W	$\cos \varphi$ -	I_{e*} , r.u.	I_{a*} , r.u.

According to data table 2.4 build the regulation characteristic in relative units.

By the regulation characteristic determine the amount of change excitation current which is the ratio of excitation current at nominal mode to idling current

$$\Delta I_e = \frac{I_{e.nom*}}{I_{ID*}}.$$

In tables 2.1, 2.3 - 2.4 adopted the following notation:

I_e - excitation current, A;

E_{ID} – idling EMF of generator, V;

f - the stator current frequency, Hz;

n - synchronous speed (rotor frequency), rev/min;

I_a - phase stator current, A;

U - line voltage stator, V;

S - full generator power, VA;

$$S = \sqrt{3} \cdot U \cdot I ,$$

α_1, α_2 – indications of wattmeter, divisions;

P - active generator power, W;

$$P = (\alpha_1 \pm \alpha_2) \cdot C_W \cdot C_{TT} ,$$

C_W - constant wattmeter, W/div;

C_{TT} - current transformer ratios, $C_{TT} = 3$;

$\cos \varphi$ - the power factor;

$$\cos \phi = \frac{P}{S} .$$

2.3 Instructions for preparation of the report and protection laboratory work

2.3.1 The report should contain:

- a) scheme, tables with measured data and calculated values, calculated formulas;
- b) graphics with an explanation of changes dependencies;
- c) the determination of percentage increasing of voltage at the load and the change of excitation current at a nominal mode;
- g) brief information and analysis by obtained results and characteristics, conclusions of investigated synchronous generator.

2.3.2 Questions for self-preparation

- 1 What is RSC of synchronous generator?
- 2 How to determine the change of voltage in synchronous generator under load changes?
- 3 Is it possible to get absolutely rigid external characteristic of synchronous generator?
- 4 How will be changed the voltage of synchronous generator at inclusion it at the capacitive load?
- 5 Why idling characteristic is nonlinear and short circuit characteristic is a linear relationship?
- 6 What is the anchor reaction of synchronous generator and how does it affect on its work?
- 7 When anchor reaction longitudinal, transverse, magnetizing, demagnetizing?

3 LABORATORY WORK № 3-S

PARALLEL WORK OF SYNCHRONOUS GENERATORS WITH POWERFUL NETWORK

3.1 Purpose of the work

To learn methods of including synchronous generator into parallel work with a powerful network; the possibility of synchronous generator give away active or reactive energy (power) at parallel work with the network; remove and examine the characteristics of synchronous generator into parallel work with the network.

3.2 Brief theoretical information

There are two methods for including synchronous generators into parallel work with the network: by accurate and coarse synchronization.

3.2.1 Conditions for inclusion of synchronous generator into parallel work with the network by accurate synchronization:

- a) EMF of included generator E_G must be equal to the voltage of network U_C ;
- b) generator frequency f_G must be equal to the network frequency f_C ;
- c) the sequence of phase rotation of generator and network must be the same;
- g) vector EMF of generator E_G and vector of network U_C should be in antiphase.

3.2.2 The inclusion of a synchronous generator into parallel work with the network by accurate synchronization method.

Just before inclusion of a synchronous generator into parallel work with the network it is necessary to verify the conditions for inclusion.

Equality of EMF generator and mains voltage check by voltmeter, equality of frequencies - by cymometer. Phase sequence checked by phase tester, the shift angle between vectors EMF of generator and mains voltage – with the help of lamp synchroscope.

When precise execution of these conditions was made it is possible to include synchronous generator into parallel work with a powerful network.

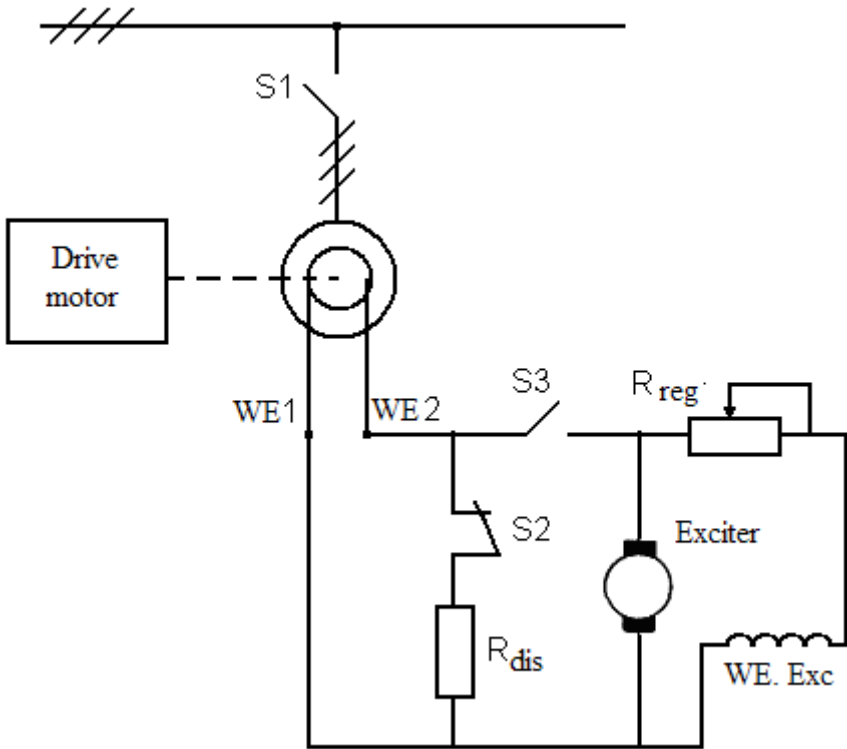


Figure 3.1 – Principal scheme of inclusion synchronous generator into parallel work with network by self-synchronization method

The disadvantages of accurate synchronization method of including are: scheme complexity, duration of the process and complexity of its automation.

3.2.3 Inclusion of synchronous generator into parallel work with the network by self-synchronization method.

Currently, this method has enough wide circulation. Its essence is as follows. The winding excitation is shorted to discharge resistor, and rotor is driven in rotation. When rotor speed is close to synchronous, stator winding of not excited generator is connected to a common joint ties (at mains voltage). Upon reaching the subsynchronous rotor speed, at rotor winding supplied direct voltage and included discharge resistor.

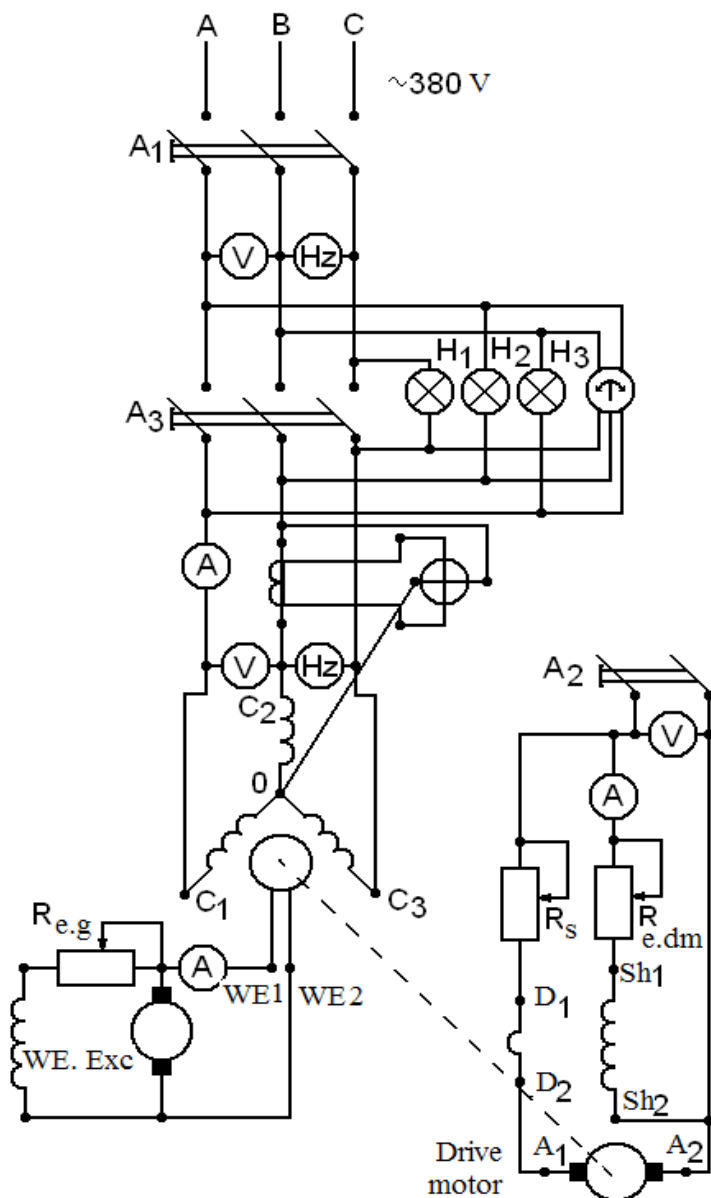


Figure 3.2 - Scheme of inclusion synchronous generator into parallel work with network by accurate synchronization method

Due to interaction of the magnetic fields stator and winding excitation, rotor starts to rotate synchronously with stator magnetic field (pulled into the synchronism).

Inclusion of synchronous generator with open excitation circuit is not permitted, as thus is induced in the winding excitation significant EMF which can cause breakdown of insulation.

The disadvantages of self-synchronization method include significant fluctuations of current at the time of inclusion.

The sequence of operations at including generator according to the scheme (Fig. 3.1) is shown in table 3.1.

Table 3.1 - The sequence of operations at including synchronous generator into parallel work by self-synchronization method

Mode	Operation	Position of switches		
		S1	S2	S3
Preparatory	Excitation winding of SG included at discharge resistor	switched off	switched	switched
Launching	Rotor of SG is driven by a prime motor	switched	switched	switched
Previous synchronization	Stator winding of SG is connected to the busbars	switched	switched	switched off
Synchronization	Excitation winding of SG connected to exciter	switched	switched	switched
Work	Switch off discharge resistor	switched	switched off	switched

3.3 The experimental part of the laboratory work

Determine the type and appointment of machines in aggregates.

Record data from nameplate of machines, starting and adjusting devices, measuring instruments.

Check assembled scheme shown in Fig. 3.2.

Prepare a scheme to work: switch on consistently an automats, enter the starting rheostat. With the help of lamp synchroscope and resistors ensure about performance all conditions of accurate synchronization. When

the rotation of the fire on synchronoscopes is low, include synchronous generator into parallel work with the network.

Load the synchronous generator by active and reactive loads.

The active load shall be increased by increasing the torque of prime motor by increasing the angle of rotor emission θ . Reactive load is carried out by changing excitation current (by changing magnetic flux in synchronous generator). Changes in the active load control by wattmeter, reactive - by ammeter in the generator rotor circuit.

Take readings for *U-imaginative* curves of synchronous generator $I = f(I_e)$; for values active loads $(0; 0.1; 0.2) \cdot P_{nom}$.

Perform measurements for each of the *U-imaginative* characteristics of synchronous generator.

Table 3.2 - Results of removing the *U-imaginative* characteristics of synchronous generator

№	Load P , kW	Measurement data			Calculated data			
		U , V	I , A	I_e , A	$\cos \varphi$	S , VA	I_a , A	I_r , A

Calculation full power of synchronous generator, VA

$$S = \sqrt{3} \cdot U \cdot I$$

where I - phase stator current, A;

U - line voltage stator B;

the active component of stator current, A;

$$I_a = I \cdot \cos \varphi$$

the reactive component of stator current, A;

$$I_p = I \cdot \sin \varphi$$

power coefficient

$$\cos \phi = \frac{P}{S}.$$

3.4 Instructions for preparation of the report and protection laboratory work

3.4.1 The report should contain:

a) scheme, tables with measured data and calculated values, calculated

formulas;

- b) U - *imaginative* characteristics of SG with an explanation of their simplified vector diagrams;
- c) a brief description of performed work.

3.4.2 Questions for self-preparation.

- 1 What are the conditions for inclusion synchronous generator into parallel work by accurate synchronization method.
- 2 What causes necessity of parallel work synchronous generators?
- 3 Characterize the ways of including synchronous generators into parallel work.
- 4 Give the formula of electromagnetic power synchronous generator and draw its angular characteristic.
- 5 How to load synchronous generator by active and reactive power?
- 6 How to convert synchronous generator in the mode synchronous motor or synchronous compensator?
- 7 Draw a U - *imaginative* characteristic of synchronous motor.
- 8 Physical essence angle of rotor emission. As it varies with loading SG, working at parallel with the network?

4 LABORATORY WORK 1-DC

STUDYING OF THE STRUCTURE DC MACHINE

4.1 Purpose of the work

Study the structure of individual elements (nodes) DC machine and machine in assembly; the principle of the machine work in generator regime and in regime of engine; the demonstrate of the machine work in different modes; measure the resistance of windings and insulation of windings machine.

4.2 The working order of performance

4.2.1 Study of the structure and the principle of machine work:

- a) examine structure and appointment of single elements of DC machines and machine in assembly;
- b) consider the structure and principle of the machines during watching of training film;
- c) write data from panel factory machines and understand their essence.

4.2.2 Determine and record parameters of the machine indicating the numbers:

- a) of main poles $2p$;
- b) of additional poles $2pa$;
- c) of brushes on one brush finger;
- d) of brush fingers;
- e) of collector plates that overlapped by brush.

4.2.3 Make a sketch of the main parts and elements of machines with an indication of their size:

- a) of the stator (longitudinal and cross incisions);
- b) of the anchor (longitudinal and transverse incisions, sector of teeth);
- c) of main pole;
- d) of additional pole;
- d) of anchor sections ;
- e) of the collector (longitudinal and cross incisions);
- g) of brush machine.

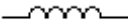
Indicate the name and purpose of machine elements.

4.2.4 Draw down scheme of connection of coils main poles between themselves; connect the coils main poles to the source of DC and identify the polarity of major poles using a compass or magnetic needle.

4.2.5 Using index of voltage to determine the clamps winding machine and mark their letters and indices according to Table 4.1.

4.2.6 Draw down a schematic diagram of connection winding anchor with windings of additional and main poles.

Table 4.1 - Marking of the windings of DC machines

Name winding	Marking findings		Pictogram
	Start	End	
Winding parallel or independent excitation (shunt-wound)	SW1	SW2	
The winding anchor	A1	A2	
The winding additional poles	AP1	AP2	
Sequential excitation winding (seriyesna)	S1	S2	
The compensation winding	C1	C2	

4.2.7 The demonstration of the generator work DC Independent excitation:

a) get acquainted with the appointment of machines in the unit and with assembled scheme; to assimilate purpose apparatus and devices in the scheme;

b) learn the principle of the generator;

a) start the generator;

d) excite the generator;

e) load generator until the rated load;

f) learn the control methods of generator voltage and loading.

4.2.8 Demonstration of a DC motor with parallel excitation:

a) get acquainted with the appointment of machines in the unit and with collected scheme;

b) understand the purpose devices and devices in the scheme;

- c) learn the principle of the engine;
- d) start the engine;
- d) load engine until to nominal load;
- e) understand methods speed control of anchor motor.

4.3 Instructions for preparation of the report and protection laboratory work

4.3.1 Content of the report.

Report on laboratory work must contain materials specified in paragraphs 4.2.1 - 4.2.6 and conclusion.

4.3.2. Questions for self-preparation.

- 1 Principle of the generator.
- 2 Principle of the engine.
- 3 Appointment of main poles.
- 4 Appointment of additional poles.
- 5 Appointment of winding anchor .
- 6 Features EMF that induced in anchor winding DC machine (DCM).
- 7 Appointment of collector and brushes in the DCM.
- 8 How to determine the direction of the EMF in conductors armature winding machine when operating in generator mode or motor mode if given the polarity of the main poles and the direction of rotation anchor?
- 9 How to determine the direction of rotation of the anchor DC machine at work in motor mode, if given the polarity of the main poles and the direction of the current in conductors of anchor winding?
- 10 How is controlling the voltage of the generator?
- 11 How is controlling the speed of rotation anchor motor?
- 12 Why does the yoke (frame) make from solid metal, and poles and anchor make from sheet steel (laminated) in DC machines?

5 LABORATORY WORK 2-DC

TEST OF DC GENERATOR WITH INDEPENDENT AND PARALLEL EXCITATION

5.1 Purpose of the work

Study the design features of the machine DC; rated data indicated on the nameplate of the machine; physical processes and properties of a DC generator by taking off idling characteristics, external characteristics, regulating characteristics and make their analysis; by the results of tests to evaluate the analyzed generator.

5.2 The working order of performance

5.2.1 Write down data from factory panel of testing generator, drive engine and design features of the proven machine: the numbers of main and additional poles, the type of performance (open, protected), a method of cooling (natural, self venting, independent ventilation), type of bearings.

5.2.2 By using voltmeter to test marking of terminals windings on factory panel of the generator . Draw in report the location of terminals on the panel machine and their designations

5.2.3 According to nominal data of generator and test scheme choose measuring devices for characterization: idling $U_I = f(I_E)$, external $U = f(I_A)$, regulating $I_E = f(I_A)$.

5.3 The order of lab performance when tested DC generator with independent excitation

5.3.1 Collect scheme of generator DC with independent excitation (Fig. 5.1) for characterization: idling $U_I = f(I_E)$, external $U = f(I_A)$, regulating $I_E = f(I_A)$.

5.3.2 Before switching scheme of engine under voltage to set a starting rheostat knob in the circuit of anchor engine in the position "Start" (wherein the resistance of starting rheostat is fully introduced), engine of adjusting rheostat in the excitation engine circuit is a position in which the resistance rheostat equal zero.

5.3.3 Make a trial start of the engine. According to the standard the starting current should not exceed $2I_{nom}$. Excite and load the generator ; make sure that the arrows devices in scheme of the motor and the generator have deviated in normal position. Otherwise, turn off the engine, wait for it to complete cessation and make a change polarity of connection devices.

5.3.4 Install brushes in geometric neutral position by method of the largest voltage at idle . In this time the anchor generator to lead in rotation with nominal rotation frequency and to excite the generator to about $(0.5 \dots 0.8) U_{nom}$. Then brushes with the brush crossmember to move in the direction of rotation of the anchor generator or against rotation and to set to a position where voltmeter involved in anchor generator's clamps ,will show the greatest voltage. This position is the position of the brushes on the geometric neutral. Fasten the brush crossmember in this provision..

5.3.5 Remove of idling characteristic:

$$U_I = f(I_E) \text{ at } I_A = 0; n = const = n_{nom}.$$

In this time the breaker of load circuit must be turned off, the generator anchor must be to rotate by drive motor and to rotate at nominal speed.

The first point of the characteristics to calculate with turned off automatic machine (contact-breaker) excitation circuit, i.e at $I_E = 0$ If the voltage at the terminals of the armature of the generator is not zero in this time, it means that the main poles have residual magnetic flux. Enable automatic machine (contact-breaker) excitation circuit and remove characterization, gradually increasing excitation current to the value at which $U_I = (1.2 \dots 1.3)U_{nom}$. Thus to do 5 - 8 measurements. These measurements and calculations add to the table. 5.1

Table 5.1 - Measurement data and calculated data of idling characteristic with independent excitation

№	Measurement data			Calculated data		
	U'_I , V	I_E , A	n , rev/min	U_I , V	U_{*I} r.u.	I_{*E} , r.u.

When filling out Table 5.1 in the case of deviation rotation frequency of generator anchor n from rated frequency n_{nom} the measured voltage of idling U'_I recalculate into voltage of idling U_I at rated rotation frequency anchor according to the formula

$$U_I = U'_I \cdot n_{nom} / n$$

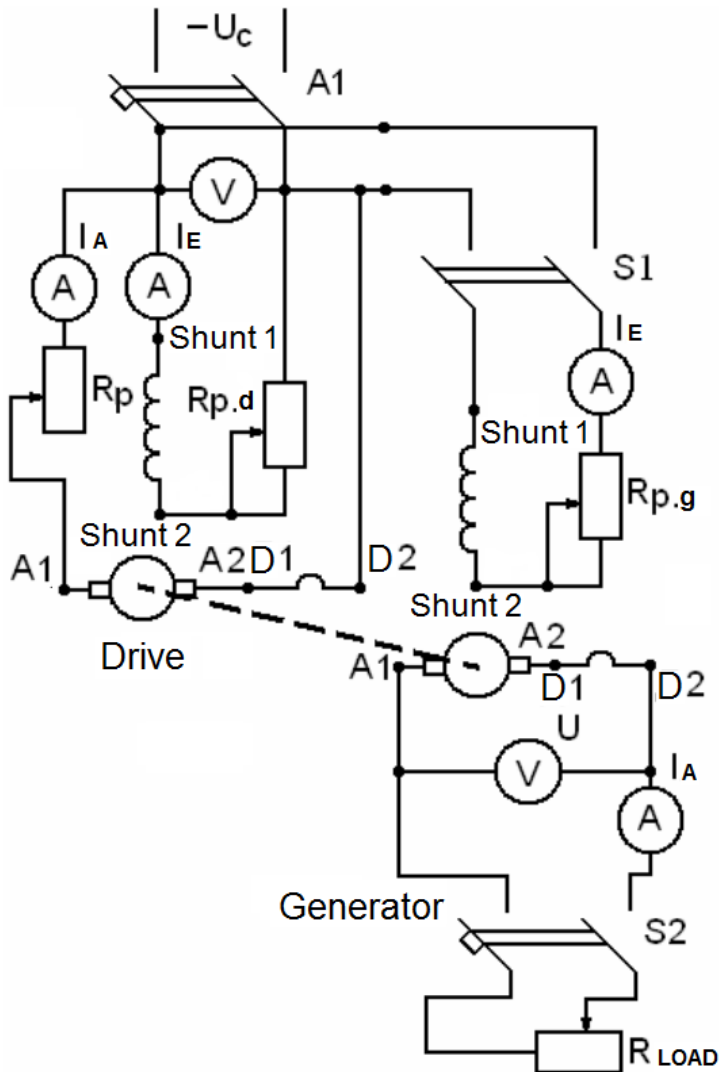


Figure 5.1 - Diagram of a DC generator independent excitation with electric drive (DC motor)

Table. 5.1 is contain the following notation:

$U_{*I} = U_I / U_{nom}$ - voltage generator at idle, r.u.;

$I_{*E} = I_E / I_{EInom}$ - current excitation, r.u.,

where I_{EInom} - current excitation at $U_I = U_{nom}$.

Build of idling characteristic in relative units using calculated data from table. 5.1

$$U_{*X} = f(I_{*3}).$$

On this characteristic to determine the rated voltage $U_{*I} = 1$ and corresponding the excitation current I_{EInom} for this voltage. Explain the variation of idling characteristics $U_{*I} = f(I_{*E})$, using the formula EMF of generator anchor

$$E_A = Ce \cdot n \cdot F.$$

Make analyze of type for idling characteristic (for parts of the curve). Identify and evaluate the coefficient of saturation of the magnetic circuit generator

$$K_{SAT} = F_{*I} / F_{*\delta} = I_{*EInom} / I_{*E\delta},$$

where F_{*I} - MMF at $U_{*I} = 1$;

$F_{*\delta}$ - MMF air gap at $U_{*X} = 1$;

I_{*EInom} - current excitation corresponding of F_{*I} ;

$I_{*E\delta}$ - current excitation corresponding of $F_{*\delta}$.

In machines of conventional performance $K_{SAT} = 1.1 \dots 1.35$.

5.3.6 Remove of external characteristic:

$$U = f(I_A) \text{ npu } I_E = \text{const}; n = \text{const} = n_{nom}.$$

Removing of external characteristic to make according to the scheme (Figure 5.1) with the contact-breaker of load which turned on. Anchor generator to rotate before the rated speed, increase the load before the rated current $I_A = I_{nom}$ at nominal voltage $U = U_{nom}$; the resulting current of excitation take a nominal. If at the rated current of the anchor generator the nominal voltage can not be obtained, then the actual voltage at rated current to accept as the output voltage. Then change the resistance of loading resistors so that the load current has changed approximately through $0.25I_{nom}$ in the range $(0 \dots 1.25)I_{nom}$. These measurements and calculations add in the Table 5.2. Thus to do 5 - 8 measurements.

Table 5.2 - Measurement data and calculated data of the external characteristic with independent excitation

№	Measurement data				Calculated data	
	U , V	I_A , A	I_E , A	n , rev/min	U^* r.u.	I_{*A} , r.u.

Table 5.2 is contain the following notation:

$U_* = U / U_{nom}$ - voltage, r.u.;

$I_{*A} = I_A / I_{nom}$ - loading current (anchor), r.u.

Construct external characteristic in relative units. Show nominal data U_{*nom} and I_{*nom} on the characteristic. Determine the increase in voltage at reset of rated load

$$\Delta U_{\%} = (U_I - U_{nom}) / U_{nom} \cdot 100 ,$$

where D is generally in the range of (8 -3)%. Explain the principle of variation characteristics using the equations of equilibrium EMF anchor.

5.3.7 Remove of regulating characteristic:

$$I_E = f(I_A) \text{ at } U = const = U_{nom}; n = const = n_{nom}.$$

Removing of regulating characteristic to make according to the scheme (Figure 5.1) with the contact-breaker of load which turned on. Set nominal (or possible) voltage at the terminals of the anchor generator at $I_A = I_{nom}$ and $n = n_{nom}$. Then change the resistance of loading resistors so that the load current has changed approximately through $0.25I_{nom}$ in the range $(0...1.25)I_{nom}$. At the same time regulate the excitation current so that the voltage at the terminals of the armature remains constant. These measurements and calculations add in the Table 5.2. Thus to do 5 - 8 measurements.

Table 5.3 - Measurement data and calculated data of the regulating characteristic with independent excitation

№	Measurement data				Calculated data	
	U , V	I_A , A	I_E , A	n , rev/min	I_{*A} , r.u.	I_{*E} , r.u.

Table 5.3 is contain the following notation:

$I_{*E} = I_E / I_{EInom}$ - current excitation, r.u.,

I_{EInom} - current excitation at idling and $U_I = U_{nom}$.

Construct external characteristic in relative units

$$I_{*E} = f(I_{*A}),$$

which show the rated current anchor $I_{*A} = 1.0$ and the corresponding excitation current I_{*EInom} . Calculate the ratio of the excitation current to the anchor current:

$$I_{Enom\%} = I_{Enom} / I_{nom} \cdot 100 .$$

Determine the degree of excitation current regulation

$$\Delta I_{E\%} = (I_{Enom} - I_{EI}) / I_{EI} \cdot 100 ,$$

where I_{Enom} , I_{EI} - excitation current according to the nominal current anchor and the idling.

Explain the principle of variation characteristics using the equations of EMF anchor.

5.4 The order of lab performance when tested DC generator with parallel excitation

5.4.1 Collect scheme of generator DC with parallel excitation (Fig. 5.2) for characterization: idling, external and regulating. Rotate anchor generator by the drive motor (DC motor). Check self-excitation conditions of the generator (the presence of residual flow, direction of rotation, etc.).

5.4.2 Remove of idling characteristic:

$$U_I = f(I_E) \text{ at } I_L = 0; n = const = n_{nom}.$$

Remove of characteristic similar to idling characteristic of separate excitation generator. The first measurement make with $I_E=0$ (at the open circuit of excitation). These measurements and calculations write in the Table 5.4.

Table 5.4 - Measurement data and calculated data of characteristic idling with parallel excitation

№	Measurement data			Calculated data		
	$U'_I,$ V	$I_E,$ A	$n,$ rev/min	$U_I,$ V	U_{*I} r.u.	$I_{*E},$ r.u.

Build of idling characteristic in relative units on same figure with idling characteristic of separate excitation generator using calculated data from table 5.4. Show the nominal $U_{*I} = 1$ and $I_{*E} = 1$ on this characteristic.

5.4.3 Remove of external characteristic:

$$U = f(I_A) \text{ at } r_{EC} = \text{const}; n = \text{const} = n_{nom}.$$

where r_{EC} - resistance of excitation circuit.

Remove of characteristic similar to external characteristic of independent excitation generator. These measurements and calculations write in the Table 5.5.

Table 5.5 - Measurement data and calculated data of the external characteristic with parallel excitation

№	Measurement data				Calculated data	
	$U,$ V	$I_A,$ A	$I_E,$ A	$n,$ rev/min	U_* r.u.	$I_{*A},$ r.u.

Build of external characteristic in relative units on same figure with the external characteristic independent excitation generator. Show the nominal data of machins on this characteristic. Identify increasing the voltage $\Delta U\%$ and compare with $\Delta U\%$ of separate excitation generator. Explain the principle of variation characteristics using the equations of equilibrium EMF anchor.

5.4.4 Remove of regulating characteristic:

$$I_E = f(I_A) \text{ at } U = \text{const} = U_{nom}; n = \text{const} = n_{nom}.$$

Remove of characteristic similar to the regulating characteristic of independent excitation generator. These measurements and calculations write in the Table 5.6.

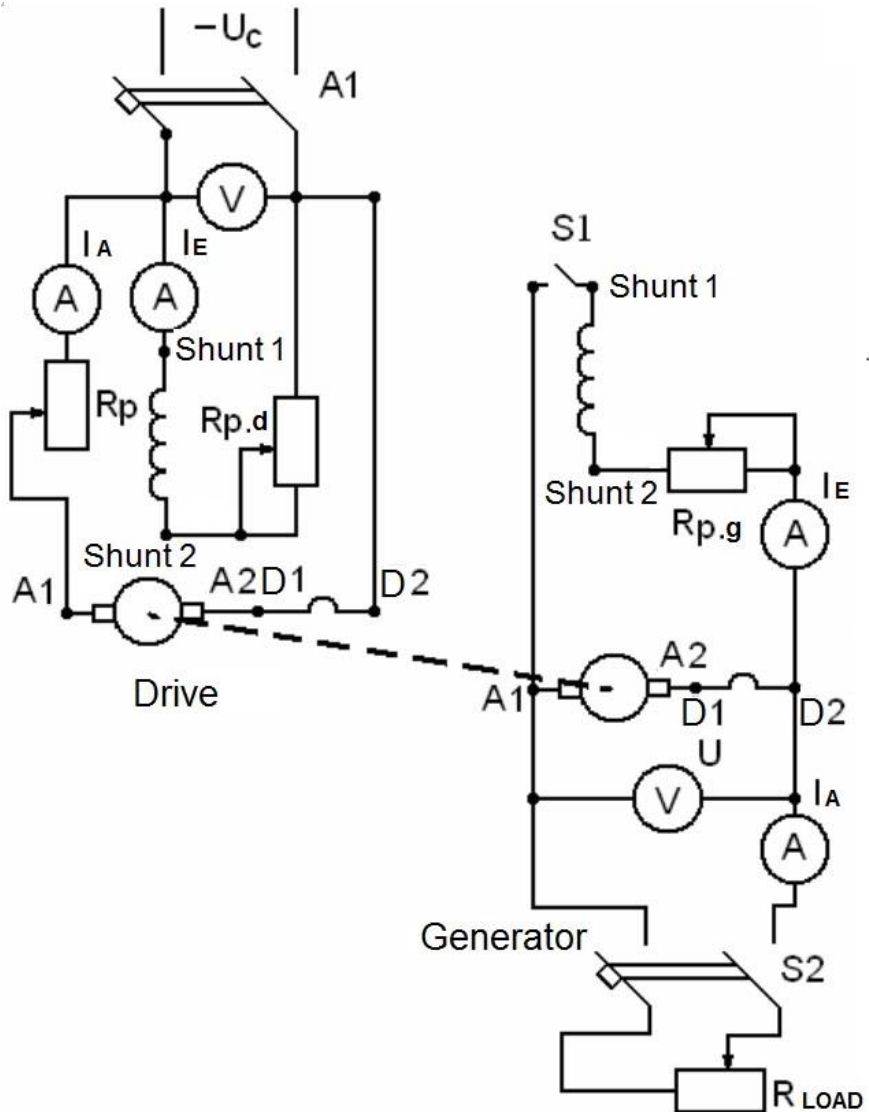


Figure 5.2 - Diagram of a DC generator parallel excitation with electric drive (DC motor)

Table 5.6 - Measurement data and calculated data of the regulating characteristic with parallel excitation

№	Measurement data				Calculated data	
	U , V	I_A , A	I_E , A	n , rev/min	I_{*A} , r.u.	I_{*E} , r.u.

Build of regulating characteristic in relative units on same figure with the regulating characteristic of independent excitation generator. Show the nominal data of machines on this characteristic. Explain the principle of variation characteristics using the equations of EMF anchor.

Calculate the ratio of the excitation current to the rated anchor current:

$$I_{Enom} \% = I_{Enom} / I_{nom} \cdot 100,$$

where I_{Enom} - corresponds to $I = I_{nom}$. Compare $I_{Enom} \%$ with what is recommended in the table 5.7.

Table 5.7 - Recommended values $I_{Enom} \% = f(P_{nom})$

P_{nom} , kW	0,5...20	2...5	5...10	10...20	20...50	50...100
I_{Enom} , %	8...10	7	5	4	3	0.5

To determine the degree of regulation of the excitation current $\Delta I_3 \%$ for parallel excitation. Compare $I_{Enom} \%$ and $\Delta I_E \%$ with the corresponding data obtained with independent excitation.

5.5 Instructions for the preparation of the report and the protection of laboratory work

5.5.1 Make analysis and conclusions of the testing car based on the summary table 5.8 of the basic experimental data and factory panel data of generator. In case of variance data to explain them (outspeak possible causes available variations).

5.5.2 The report should contain:

a) schemes, tables with the measurements and calculation, a brief description of the work performed;

- b) drawn by characteristics in arbitrary units according to the table;
 c) tables, which compares the test data according to the data from factory plate;
 d) the findings about the tested mashin, containing an explanation of the laws change characteristics with the involvement of relevant formulas and explain possible discrepancies data.

Table 5.8 - Basic experimental data and factory panel data

№	Name value	Marking	Units	Excitation	
				Independent	Parallel
1	Mashin type				
2	Nominal power	P_{nom}	kW		
3	Nominal voltage	U_{nom}	V		
4	Nominal anchor current	I_{nom}	A		
5	Rated speed rotation anchor	N_{nom}	rev/min		
6	Excitation current at idling $U_I = U_{nom}$	I_{EInom}	A		
7	Excitation current, $I_{Enom} \% = I_{Enom} / I_{nom} \cdot 100$	$I_{Enom} \%$	%		
8	Excitation current at the rated current anchor	I_{Enom}	A		
9	Same	$I_{Enom} \%$	%		
10	Factor useful to action	η	%		

5.5.3 Questions for self-preparation.

- 1 What conditions must be met for self-excitation of the DC generator?
- 2 What is device control self-excitation of the generator?
- 3 What factors determine the change in voltage at the terminals of the generator independent and parallel excitations when voltage changing?
- 4 How need to change the excitation current with increasing load generator to the voltage at the terminals remained constant?
- 5 What explains the presence of voltage at the terminals of the generator at open circuit of excitation?
- 6 What are conditions of the generator determined by the characteristic of the idle?
- 7 What is the reaction of the anchor and how it affects the generator characteristics ?
- 8 How does the reaction of the anchor affects on the EMF of generator?
- 9 Why can't remove the characteristic of idle of the reverse branch for the generator parallel excitation ?
- 10 How do you explain the fact that value of the research current short circuit of the generator parallel excitation less than nominal value?
- 11 Why is the rated voltage generator above standard voltage of the consumers?
- 12 The basic conditions for self-excitation and the means of their determination.
- 13 What is the critical resistance of the excitation circuit of the generator?
- 14 Does value critical resistance of the excitation circuit depend on the of the anchor speed rotation?
- 15 How to determine the geometrical and physical generator neutrals by experimentally?
- 16 Why with the increase the load the anchor current increases too?
- 17 How is control the voltage of the generator?
- 18 The DC generator is a inverter?
- 19 Write and analyze the equilibrium equations of EMF anchor.
- 20 What is the nominal change of voltage at load shedding of generator and why it value of parallel excitation generator is more than the generator separate excitation has?
- 21 Why is external characteristic at the agreed start of excitation windings of the generator mixed excitation is formed tougher than if excitation windings are connected in opposition?

6 LABORATORY WORK 3-DC

TESTING OF DC MOTOR

6.1 Purpose of the work

6.1.1 Explore means of starting, speed control of the motor anchor and direction changes.

6.1.2 Build characteristics according to measurements and make analyze of them, to compare measurement data with the data plate of the motor.

6.2 The working order of performance

6.2.1 Determine the destination machine in the unit.

6.2.2 Record the data plate of the motor and load generator. Identify and record the design features of the test engine (number of main and additional poles, a form of performance, the cooling means, the basic elements of the brush unit, the type of bearing). Check terminal markings on the plate with voltmeter or megger.

6.2.3 Choose measuring instrumentation, starting and adjusting devices for removing characteristics:

regulating	$n = f(I_E),$
speed	$n = f(I_A),$
operating	$n, I_A, P_L, M, \eta = f(P_2).$

6.3 The order of lab performance when tested DC motor with parallel excitation

6.3.1 Collect scheme of DC motor with parallel excitation (Fig. 6.1) for characterization: regulating at idling, speed and operating.

6.3.2 Start the motor, and the set starting and adjusting rheostats to the start position. To familiarize with the methods of speed control of the motor anchor and change of direction rotation of the anchor. Load the engine to the nominal value by the loading DC generator.

6.3.3 Determine the position of the brushes on the geometric neutral "by motor".

Load the engine to $I = 0.5I_{nom}$ at excitation current $I_E = I_{Enom}$, measure and record the speed of the anchor. Then stop the engine, make the changes in the scheme for changing the direction of rotating anchor. Perform start-up, load up to 50% and measure the speed anchor. If the speed of the anchor is the same for forward and reverse rotation, the brushes are on the geometric neutral. Otherwise the brush crossmember to move until equality of frequencies.

6.3.4 Remove of regulating characteristic at idling:

$$n = f(I_E) \text{ at } U_C = const = U_{nom}; P_2 = 0.$$

Excitation current of the motor to change from the maximum value ($R_{Ad} = 0$) to the minimum, when the speed of the motor anchor will be no more $1.4 n_{nom}$ (valid for mechanical parameters and conditions for switching the motor). Thus to do 5 - 8 measurements. These measurements and calculations add in the Table 6.1.

Table 6.1 - Measurement data and calculated data of regulating characteristic at idling of engine with parallel excitation

№	Measurement data				Calculated data				
	U , V	I_A , A	I_E , A	n , rev/min	I_{*E} , r.u.	n_* , r.u.	P_E , W	P_{AI} , W	P_I , W

Table 6.1 is contain the following notation:

$I_{*E} = I_E / I_{Enom}$ - excitation current, r.u.,

where I_{Enom} - excitation current at $U = U_{nom}$, $n = n_{nom}$, $P_2 = 0$;

$n_* = n / n_{nom}$ - speed anchor;

$P_E = U \cdot I_E$ - power drive circuit, W;

$P_{AI} = U \cdot I_A$ - power that goes to the motor anchor. Mainly determine by the power of mechanical losses and losses in the steel of anchor at $R_P = 0$, W.

$P_I = P_E + P_{AI}$ - idling power engine, W.

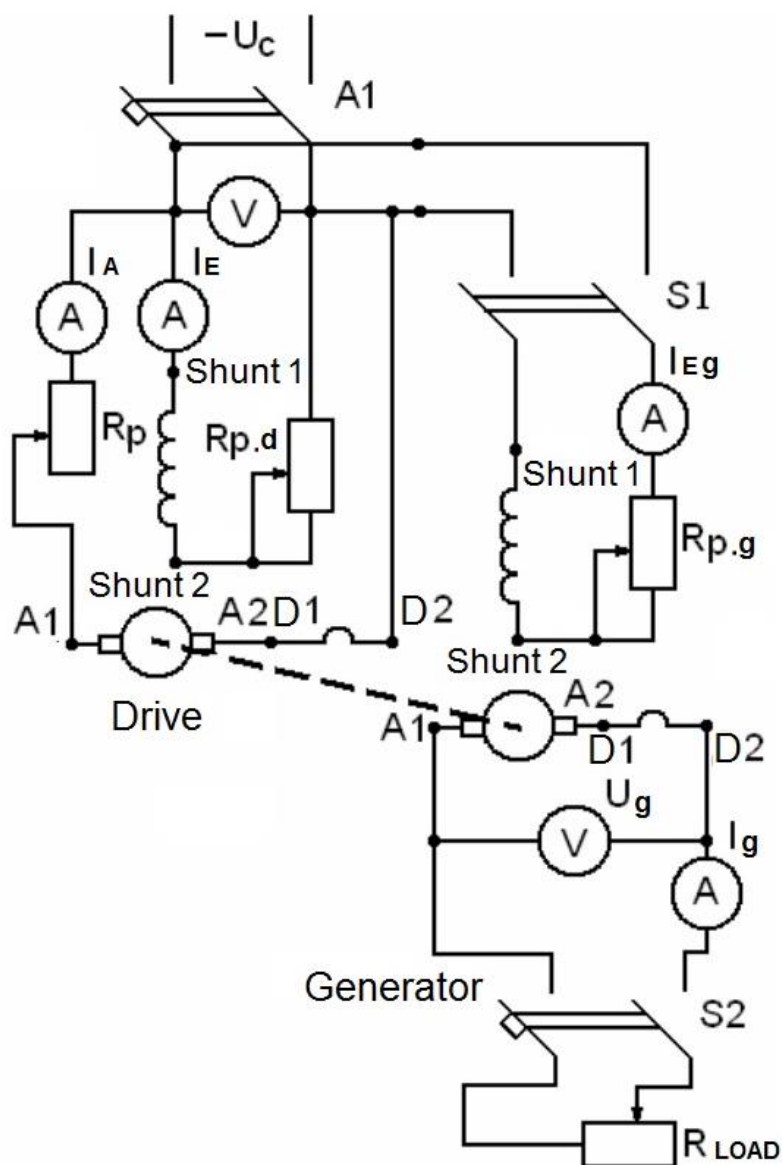


Figure 6.1 - Scheme DC motor with parallel excitation which load by generator DC

Build characteristics according to the calculations from table 6.1 on the one figure to:

regulating $n_* = f(I_{*E})$;

powers at idle $P_E, P_{A1}, P_I = f(I_{*E})$.

Mark the nominal data on the characteristics (data at $I_{*E} = 1$).

6.3.5 Remove of natural speed characteristic of the parallel excitation engine:

$$n = f(I_A) \text{ at } I_E = \text{const} = I_{Enom}; U_C = \text{const} = U_{nom}; R_P = 0.$$

Set starting and adjusting rheostats to the start position and start the motor. lead out starting rheostat. Load engine by generator DC. Set the rated motor field current. To do this, at nominal voltage $U = U_{nom}$ and the motor current $I = I_{nom}$ to set the excitation current of the value at which the speed of the anchor $n = n_{nom}$.

Change the anchor current of the engine from idle current until $1.25I_{nom}$ approximately through $0.25I_{nom}$ without starting rheostat. These measurements and estimates add to the table 6.2.

Table 6.2 - Measurement data and calculated data of natural speed characteristic of engine with parallel excitation

№	Measurement data				Calculated data	
	$U,$ V	$I_A,$ A	$I_E,$ A	$n,$ rev/min	$I_{*A},$ r.u.	$n_*,$ r.u.

From table 6.2 $I_{*A} = I_A / I_{nom}$; $n_* = n / n_{nom}$.

6.3.6 Remove the rheostat characteristic:

$$n = f(I_A) \text{ at } I_E = \text{const} = I_{Enom} = \text{const} = U_{nom}; R_P = \text{const} > 0 (\approx 50\%).$$

Measurement data and calculated data add in table 6.3.

Table 6.3 - Measurement data and calculated data of speed rheostat characteristic at $R_P \approx 50\%$

№	Measurement data				Calculated data	
	$U,$ V	I_A A	I_E A	$n,$ rev/min	$I_{*A},$ r.u.	$n_*,$ r.u.

6.3.7 Remove the artificial speed characteristic:

$$n = f(I_A \text{ at } I_E = 0.8I_{E\text{nom}} \text{ (with a weakened magnetic field)});$$

$$U_C = \text{const} = U_{\text{nom}}; R_P = 0.$$

Measurement data and calculated data add in the table 6.4.

Table 6.4 - Measurement data and calculated data of artificial speed characteristic

№	Measurement data				Calculated data	
	U , V	I_A A	I_E A	n , rev/min	I_{*A} , r.u.	n_* , r.u.

6.3.8 According to Table. 6.2 - 6.4 in one figure draw natural, artificial and rheostat speed characteristics in relative units. mark on the characteristics the rotation speeds corresponding to the nominal current anchor $I_{*A} = 1$, write them in report in relative and absolute units.

Using formulas to explain the variation of speed characteristics.

Determine change of frequency rotation anchor in the transition from idle to mode of rated load ($I_A = I_{\text{nom}}$) for the speed natural characteristic

$$\Delta n_{\%} = \frac{n_I - n_{\text{nom}}}{n_{\text{nom}}} \cdot 100$$

Compare the value obtained $\Delta n_{\%}$ with the usual, which is in the range of 8 - 3% where the value treats to more low-power machines. Specify options affecting on $\Delta n_{\%}$.

Data obtained at this point, and their analysis must be reflected in the conclusions of the report on laboratory work.

6.3.9 Use the method of two identical machines to remove the engine characteristics:

$$\text{working} \quad n, I_A, P_1, M_2, \eta = f(P_2)$$

$$\text{mechanical} \quad n = f(M_2)$$

$$\text{moment} \quad M_2 = f(I_A)$$

$$\text{at } U_C = \text{const} = U_{\text{nom}}; I_E = \text{const} = I_{E\text{nom}}; R_P = 0$$

Method of two identical machines is that the engine loading by generator, which is similar to the engine only works in generating mode.

Therefore 6.3.9 performed if in scheme (Fig. 6.1) use the same machines. When characteristics are removing the anchor current change from the no-load current to $1.25I_{nom}$ approximately through $0.25I_{nom}$.

The measurement data record in table 6.5.

Table 6.5 - Measurement data of mechanical, moment and working characteristics of engine DC

№	Data engine				Data generator		
	U_C , V	I_A , A	I_E , A	n , rev/min	U_G , V	I_G , A	I_{EG} , A

Calculated data add in table 6.6.

Table 6.6 - Calculated data of mechanical, moment and working characteristics of engine DC

P_1 , W	P_G , W	η , r.u.	P_2 , W	M_2 , Nm	n_* , r.u.	I_{*A} , r.u.	P_{*1} , r.u.	P_{*2} , r.u.	M_{*2} , r.u.

Calculated data from table. 6.6 calculated according to the formulas:

$$P_1 = U_C \cdot (I_A + I_E) - \text{power that goes to the engine};$$

$$P_G = U_G \cdot I_G - \text{power that is given by generator};$$

$$\eta = \sqrt{\frac{P_G}{P_1}} - \text{efficiency DC machine, provided that these machines}$$

are the same;

$$P_2 = P_1 \cdot \eta - \text{useful power to the motor shaft};$$

$$M_2 = 9.55 \cdot P_2 / n - \text{moment on the motor shaft, NM};$$

$$M_{*2} = M_2 / M_{2nom} - \text{moment, B.O.};$$

$$n_* = n / n_{nom}; I_{*A} = I_A / I_{nom}; P_{*1} = P_1 / P_{2nom}; P_{*2} = P_2 / P_{2nom},$$

where n_{nom} , I_{nom} , P_{2nom} - data plate of the motor;

M_{2nom} - calculated according to data plate of the motor.

Using table 6.6 on one figure to build working characteristics in

relative units n_* , I_{*A} , P_{*1} , M_{*2} , $\eta = f(P_{*2})$.

Show on this figure the data corresponding to $P_{*2} = 1$. It'll be nominal data in relative units derived from test results. Translate them in absolute units and record in table. 6.7. Draw mechanical characteristic $n_* = f(M_{*2})$ on second figure. Show on the figure n_* , corresponding to $M_{*2} = 1$, translate in absolute units and record in table 6.7.

Build moment characteristic $M_{*2} = f(I_{*A})$ on third figure. Show on the figure M_{*2} , corresponding to $I_{*A} = 1$, translate in absolute units and record in table 6.7.

Explain the variation law of the working, mechanical and moment characteristics using for explain necessary formulas.

If there is a discrepancy in the data shown in table 6.7, it is necessary to explain them (tell possible causes of differences). Analysis of the data table 6.7 with an explanation of the reasons for the differences must be reflected in the findings of laboratory work.

Table 6.7 - Nominal data plate of the DC motor and номінальні nominal data obtained in tests

Parameters	Units	Nominal data		Deviations, %	Comment
		of meas- ure-ments	of plate		
I_{nom}	A				As a result building of working characteristics
n_{nom}	rev/min				
P_{1nom}	kW				
η	r.u.				
M_{2nom}	Nm				
n_{nom}	rev/min				From mechanical characteristics
M_{2nom}	Nm				From momentl characteristics

6.4 Instructions for the preparation of the report and the protection of laboratory work

6.4.1 Make conclusions about the results of the engine DC tests according to the table data and performance by comparison of nominal data with the nameplate data. If there is a discrepancy in the data, it is necessary to explain them.

6.4.2 Report should contain:

- a) schemes, tables with measurements and calculated data;
- б) characteristics indicating the nominal size;
- в) explanation the variation laws of characteristics with using appropriate formulas;
- г) conclusions.

6.4.3 Questions for self-preparation.

- 1 Appointment of starting resistors in circuit anchor of motor.
- 2 Appointment of adjusting rheostat in the field circuit.
- 3 Main methods speed control of engine DC with.
- 4 How to change the direction of rotation of the engine?
- 5 What will happen with the parallel excitation engine at breakage of anchor chain?
- 6 What is meant by performance of the engine?
- 7 What is meant by the regulating characteristics of a DC motor?
- 8 What is meant by speed characteristics of DC motor?
- 9 Which characteristic is called natural?
- 10 What is a artificial characteristic?
- 11 What is the reaction of the anchor, and how it affects engine performance?
- 12 How will change the anchor speed at shear brushes from geometric neutral in the direction of anchor rotation and against it?
- 13 Why it is desirable that the motor brushes are at geometric neutral?
- 14 Why does increase of load on the motor shaft increases the anchor current?
- 15 Why when starting the engine with an increase in the anchor speed the current anchor is reduced?

16 Will change whether the anchor current of motor that operating at constant loading torque on the shaft , if we introduce additional resistance in the armature circuit?

17 How is changing the voltage at the terminals of the motor armature at the start engine?

18 How is classified DC motors?

19 Why motor with sequential excitation can not be run without a load on the shaft?

20 Why is not removing the regulating characteristic for of the engine with sequential excitation?

21 Why sequential excitation motors are used where high starting torque is required?

22 Describe the advantages and disadvantages of mixed excitation motor as compared with other methods of excitation engines.

23 What is a concerted and meeting connection of excitation windings of the mixed excitation motor ? How it affects the operation of the engine and its performance?

24 Compare engines parallel, serial and mixed excitations in their regulatory properties.

25 Describe the types of losses in collector DC machines .

26 Under what conditions is the efficiency of the DC machine is maximized?

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Attachment A

**A sample of the title page
to the report by the laboratory works
MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
Zaporozhye National Technical University**

Department "Electric machines"

The report by the laboratory works

On the theme of: _____

in discipline „ Electric machines ”

Completed: student group _____ electrotechnical faculty

(surname, name, patronymic of student, signature, date)

Adopted: _____

(surname, name, patronymic of the lecturer, signature, date)