EXPERIMENTAL STAND FOR INVESTIGATION OF DC ALTERNATOR

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Abstract

Innovation in engineering education is essential to improve the quality and competencies of the future engineering workforce. To improve the quality of education, engineering faculties must keep pace with dynamic changes in engineering science and practice. Only in this way, the graduating students will be competitive on the labour market and will be able to quickly develop as specialists in new and promising areas. This article demonstrates the possibilities of improving the quality of teaching in the discipline of "Electrical Engineering" by applying appropriate scientific and research approaches in the educational practice of students of engineering majors. For this purpose, a stand for the study of a direct current alternator has been developed, which allows a detailed study of the structure and the physical processes taking place in the electrical power supply system of each car. The developed test stand has capabilities for remote control over the Internet, which makes it suitable for remote training of students even in the conditions of a pandemic. For the good assimilation of the educational material, a methodology has been created for conducting experiments to study the characteristics of a direct current alternator in different operating modes. In this way, students will be able to learn what are the components of the electrical system for powering a car, when the alternator is used and when the battery is used to power the electrical consumers, what the energy generated by the alternator depends on and under what conditions it starts charging the battery. The proposed learning approach has been evaluated by a survey conducted among engineering students. The survey shows a higher interest and motivation on the part of the students in the Electrical Engineering course because they have already understood the possible applications of what they learned through direct contact with the complex professional environment.

Keywords: Engineering education, DC alternator, Experimental Stand.

1 INTRODUCTION

In recent years, the new technologies, introduced in engineering education, are crucial for improving the educational process and maintaining a high interest of students in engineering majors [Stoyanova, Stoyanova-Petrova, Mileva, Dobreva, 2021, pp. 5653-5656].

However, societal needs and profound changes in industry in the 21st century require new technical competencies and knowledge to address engineering challenges. In order to adapt to new technologies, students studying engineering, in addition to good technical training, must have a broader view of the emergence of innovations in industry [Innovations in Engineering Education, pp. 4-28]. Therefore, the emphasis in engineering education should be directed towards more student work in teaching laboratories and more research work on practical projects.

The closer connection of students with the problems in modern engineering practice and scientific research will be an incentive for achieving higher educational goals, increasing the quality of the educational process, and not only the achievement of individual educational goals based on quantitative indicators [Innovations in

Engineering Education, pp. 4-28].

This article demonstrates the possibilities of improving the quality of education in the discipline "Electrical Engineering" through the application of scientific research approaches in the educational practice of engineering students. For this purpose, a DC alternator research setup has been developed that has capabilities for remote control, configuration and parameter measurement over the Internet, making it suitable for both distance and face-to-face training. A methodology has been developed for the experimental study of the working characteristics of a direct current alternator, which will help the students to understand the physical processes during the performance of the laboratory tasks. In this way, students will be able to develop the necessary technical competences related to the device and operation of the electrical system of the car's power supply and will be able to solve problems in this area.

2 MAIN COMPONENTS OF THE EXPERIMENTAL SETUP

2.1.1 Principle of Operation and Design of a Direct Current Alternator

Fig.1 presents the design of a modern car alternator. It is used to convert mechanical energy into electrical energy. The alternator works as follows: when the rotor turns, a magnetic field is created which induces a magnetic flux in the stationary winding of the stator. The magnetic flux from the stator creates an alternating electromotive voltage. A diode rectifier is used to convert the alternating voltage generated by the alternator into the direct voltage required to power the electrical systems in the vehicle. Most often, the voltage regulator is built into the alternator and is used to control the output within certain limits. The voltage regulator supplies a voltage to the rotor's excitation coil, resulting in the voltage creating the primary magnetic flux. The mechanical energy is supplied to the belt pulley located at one end of the rotor. The rotation of the rotor is carried out by the track belt, transmitting the torque from the crankshaft of the engine to the alternator [https://engineeringlearn.com/alternator-definition-types-working-principle-parts-uses-components-symptoms-of-bad-alternator].

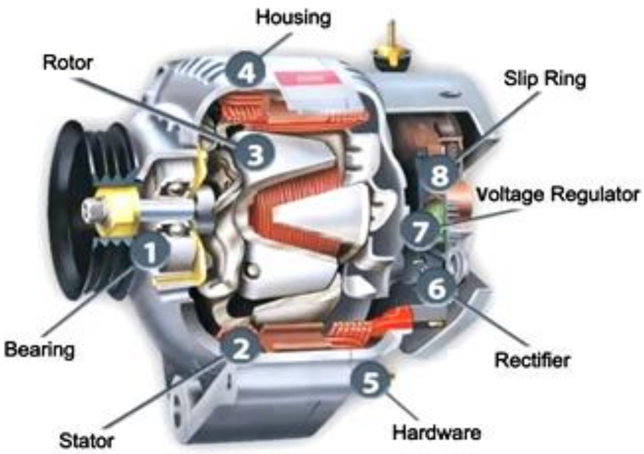

Fig. 1. Alternator components [https://engineeringlearn.com/alternator-definition-types-working-principle-parts-uses-components-symptoms-of-bad-alternator]

Automotive alternators are constructed from aluminium alloy and are characterized by compact dimensions. Aluminium contributes to less magnetization, as the rotor creates a large magnetic field, as well as better dissipation of heat from the housing that is generated during operation. There are vents on the front and back of the alternator housing to help dissipate additional heat [https://engineeringlearn.com/alternator-definition-types-working-principle-parts-uses-components-symptoms-of-bad-alternator].

Fig.2 schematically presents the components of the alternator. The stator houses the three windings, the diode rectifier and the voltage regulator. The excitation winding of the alternator is located on the rotor and is controlled by the control unit via the voltage regulator.

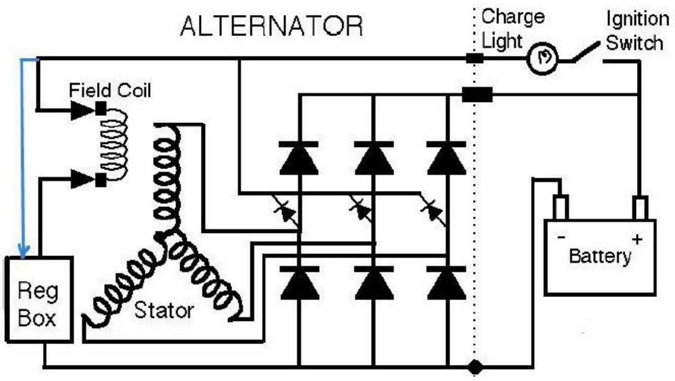

Fig. 2. Wiring diagram of the main components of the alternator [Borysiak, Moore, Sklar, Lamb, Dunn, p.15]

2.1.2 Design and principle of operation of a collector electric motor

A collector electric motor is an electrical device that converts electrical energy into mechanical energy. The construction and main components of the collector electric motor are shown in fig.3.

In this design, at least one winding is connected to the rotor collector. This structural element is used to switch the windings and as a sensor allowing to determine the position of the armature (rotor).

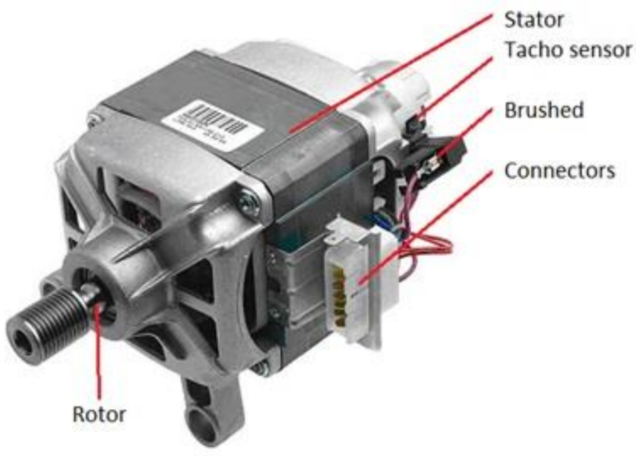

Fig. 3. Collector electric motor [https://www.instructables.com/Washing-Machine-Motor-Wiring-Diagram/]

The other main elements of the collector electric motor are shown in fig. 4.

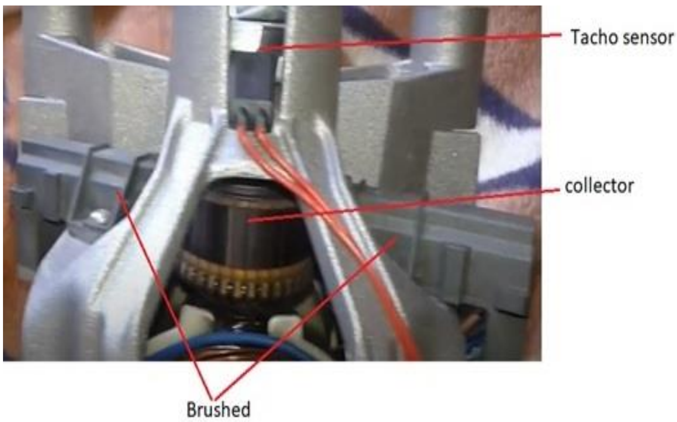

Fig. 4. The location of the collector, the location of the brush holders and the position of the sensor for measuring revolutions

The collector is part of the rotor and is connected to the windings located on the rotor. Usually, the collector is made of copper, on the two opposite ends of which there are graphite brushes. They are in continuous

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contact with the collector and serve to transfer the voltage to the rotor. The tacho sensor is located at the end of the rotor. Through it, the feedback is carried out, through which the revolutions of rotation are mainly monitored.

3 DC ALTERNATOR RESEARCH STAND

The developed stand consists of a direct current alternator, a collector electric motor, a wireless unit for controlling the speed of the electric motor, an elastic coupling connecting the two shafts, as well as devices for measuring current and voltage.

The individual components of the stand are shown in fig. 5.

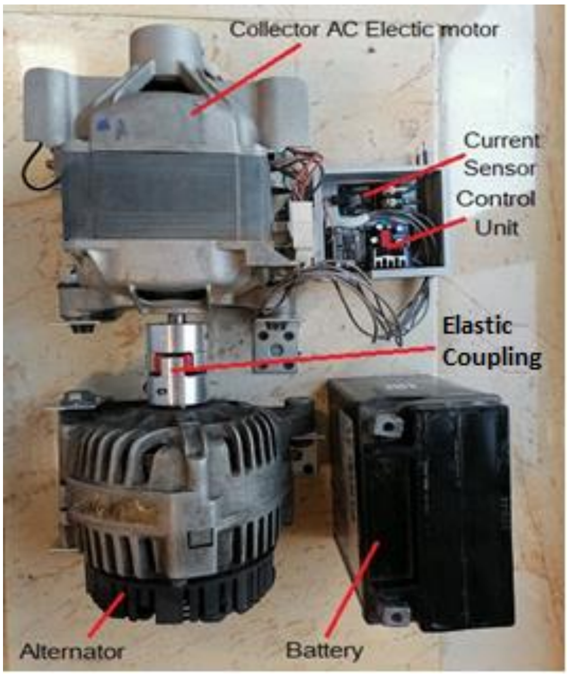


Fig. 5. Constituent components of the stand

The electrical diagram of the DC alternator test stand is shown in Fig. 6a and 6b.

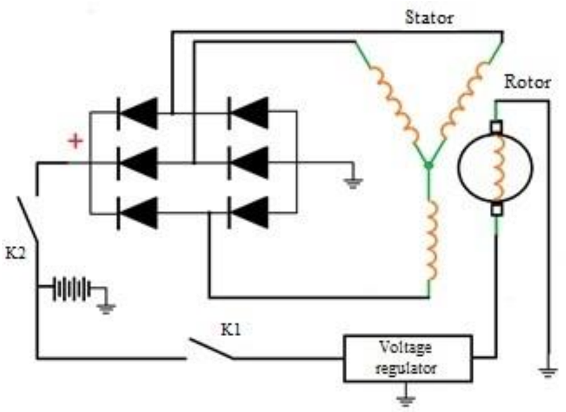


Fig. 6a. Alternator wiring diagram

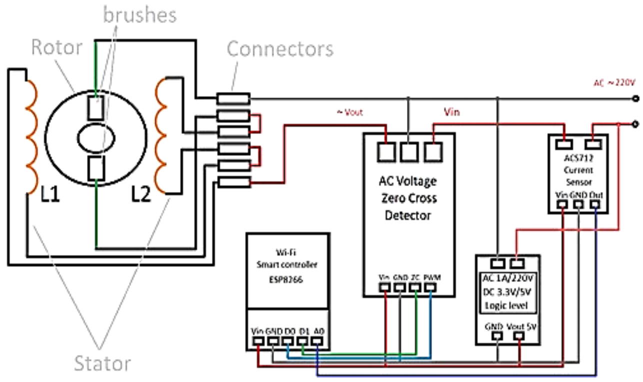


Fig. 6b. Electric motor connection diagram

The collector electric motor is connected to the alternator by a flexible connection, which is used to drive the alternator to the required revolutions.

The collector motor control module circuit board is shown in fig. 7.

Fig. 7. Collector motor control module [https://robotdyn.com/ac-dimmer-controller-1channel-ac-esp8266.html]: 1) AC Dmmer 8A with RC filter; 2) AC Zero-cross detector; 3) WI-FI microcontroller ESP8266; 4) Flash memory 32MB (4MB); 5) AC-DC isolated power supply V_{DC} = 3.3V (650mA); 6) Pinout 10 I/O header; 7) Buttons: Prog, Reset; 8) LED dimming indicate

The control module is an intelligent control for managing the power of alternating current circuits and has a maximum permissible load of up to 1.7kW at a current of up to 8A. It consists of a phase control module (zero-cross detector), a wireless WI-FI module ESP8266 with a built-in microcontroller that can be used for remote control via the Internet, and an AC-DC rectifier circuit from ~220V to VDC = 3.3V to power the microcontroller [https://robotdyn.com/ac-dimmer-controller-1channel-ac-esp8266.html].

The collector electric motor is controlled via the MQTT (Message Queuing Telemetry Transport) protocol using the WI-FI module ESP8266 [Ganguly and Chatterjee, 2020, pp. 1-5], [Kodali, Mahesh, 2016, pp. 404-408]. The ESP8266 communicates constantly with the zero-cross detector and knows when the phase crosses the so-called zero moment. In this way, the output voltage can be controlled by unblocking a symmetric thyristor (triac) for a certain time, which is set by PWM, which allows smooth regulation of the power supplied to the electric motor [https://www.kaper.com/electronics/wifi-240v-ac-led-dimmer-speech-controlled/].

An ACS712 current sensor is connected to the control board. The ACS712 sensor measures the current consumed by the collector electric motor in different operating modes. It has the ability to measure both AC and DC current up to 30A [https://www.sparkfun.com/datasheets/BreakoutBoards/0712.pdf].

A virtual dashboard is used to send commands to the stand remotely via the Internet by the website of Adafruit IO HTTP API [https://io.adafruit.com/api/docs/mqtt.html#adafruit-io-mqtt-api], [Sayed, Hussain, Gastli, Benammar, 2019, pp. 1405-1422]. The virtual panel has tools for smooth regulation of the electric motor revolutions by percentage setting of the power, showing the alternating current flowing through the collector electric motor.

The stand can be controlled from a mobile device or a computer, regardless of the operating system, simultaneously by two users. The virtual dashboard is equipped with a reset button in case the communication between the ESP8266 module and the WEB page of the virtual dashboard breaks.

4 EXPERIMENTS AND ANALYSIS OF THE RESULTS

The developed stand was used in the training of engineering students to enrich their knowledge and competences in the field of "Electrical Engineering".

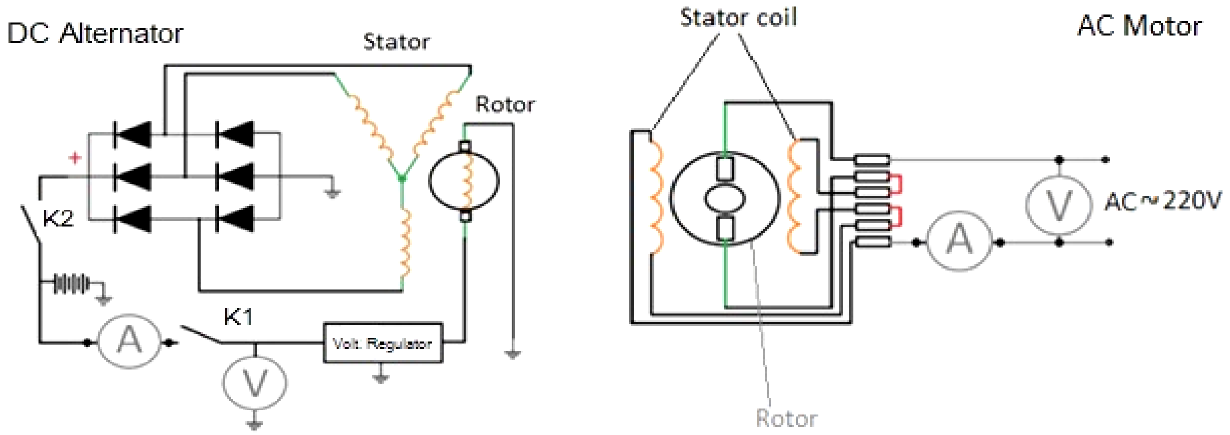
In order to achieve high educational results, a laboratory exercise with performance tasks was created, fully focused on engineering practice.

4.1.1 Experiments for the Study of a Direct Current Alternator

Fig. 8a and 8b show the schematics and the necessary measuring devices that the students use in the first task to investigate the load on the collector electric motor and the alternator when the battery begins to charge.

In this task, the switches K1 and K2 (in Fig. 8a) are closed and an excitation current of 80 mA and an excitation voltage of 12 V are applied to the excitation coil of the alternator continuously.

In performing this experimental study, the students measured the following parameters: the load on the collector electric motor P_{load} (W), the current through the electric motor I_{ac_motor} (A), the constant current at the output of the alternator $I_{dc\_out\_alternator}$ (A) and the constant voltage at the output of the alternator, $U_{dc\_out\_alternator}$ (V).



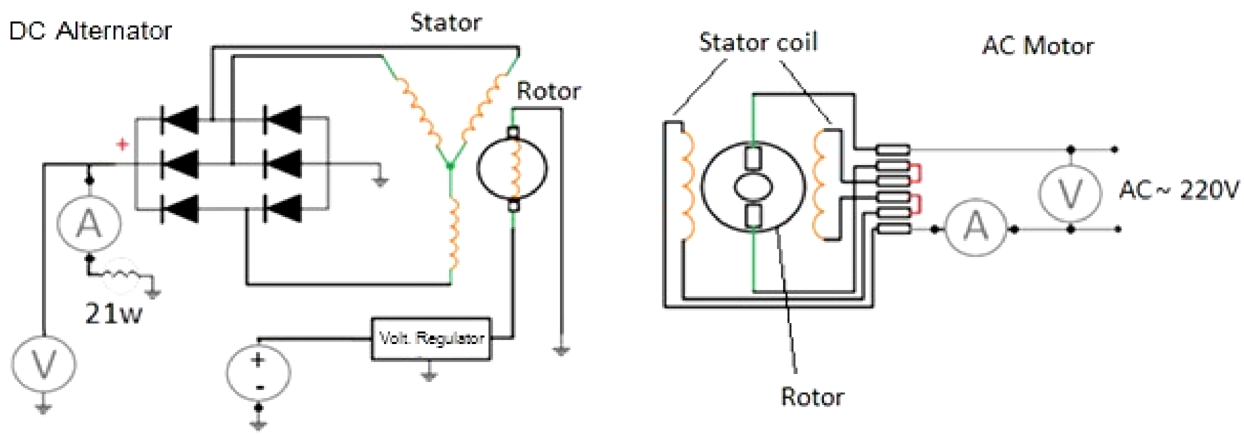
a) Alternator parameter measurement scheme

b) Scheme for measuring the parameters of the collector electric motor

Fig. 8. Experimental setup for the first task

Fig. 9a and 9b show the schemes needed by the students in the performance of the second task for researching the output voltage $U_{dc\_out\_alternator}$ and the load current $I_{dc\_out\_alternator}$ generated by the alternator when its revolutions change.

In the second task, the experimental study is carried out when a constant current I_{dc_alt} of 40 mA is supplied to the excitation coil of the alternator.



a) Scheme for measuring the parameters of the alternator when changing its revolutions and adding a load

b) The scheme of the collector electric motor remains unchanged

Fig. 9. Experimental setup for the second task

A load (light bulb) with power P_{bulb} = 21W is connected to the output of the alternator (in Fig. 9a).

In this test, the alternator speed is varied from 200 to 2200 RPM.

The revolutions can be measured through a virtual dashboard when the stand is used remotely or through a

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non-contact laser revolution meter for convenience when students are present in the teaching laboratory.

Fig. 10 shows the experimental setup during the measurement of rotation revolutions by means of a non-contact laser revolution meter.

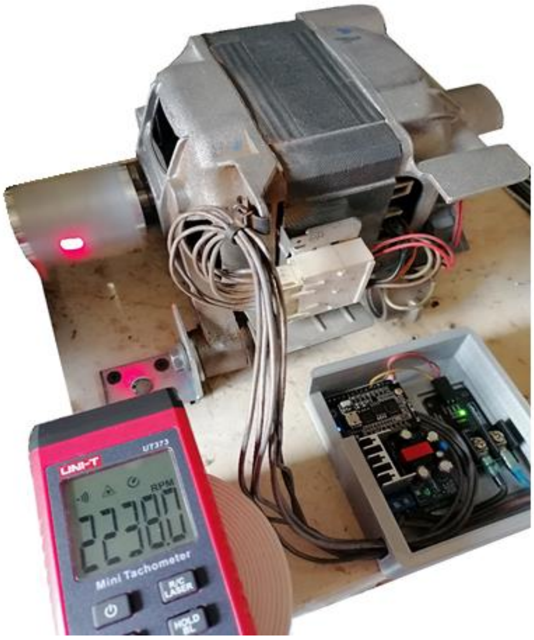

Fig. 10. Laser tachometer for non-contact measurement of revolutions

4.1.2 Experimental data

Table 1 presents the results of the experimental study on the first task.

Table 1. Results of measurements of the first task

№	P_{load} (W)	I_{ac_motor} (A)	U_{ac} (V)	$I_{dc\_out\_alternator}$ (A)	$U_{dc\_out\_alternator}$ (V)	time (min.)
1	200	2	100	2.8	14.4	1
2	180	1.8	100	2.3	14.2	6
3	170	1.7	100	1.9	14.1	12
4	150	1.5	100	1.5	14	18
5	140	1.4	100	0.8	13.9	24

From the data shown in Table 1, it can be seen that when no external consumers are connected, the output current of the alternator $I_{dc\_out\_alternator}$ reaches 2.8 A and is used to charge the battery. At this moment, the alternator output voltage is $U_{dc\_out\_alternator}$ = 14.4 V. This voltage value is set by the alternator voltage regulator. In this case, the highest load of the collector electric motor, P_{load} = 200 W, is also observed.

The results of measurements every 6 minutes show that when the battery is discharged, the current $I_{dc\_out\_alternator}$ and the voltage $U_{dc\_out\_alternator}$ at the output of the alternator start to decrease smoothly. After 24 minutes, current values $I_{dc\_out\_alternator}$ = 0.8 A at voltage $U_{dc\_out\_alternator}$ = 13.9 V are reached.

When the battery is sufficiently charged, a decrease in the collector motor load is observed to P_{load} = 140 W. The voltage of a fully charged battery should be ≥13.7 V.

The results of the experimental research on the second task with the load connected to the output of the alternator are presented in table 2.

The data in Table 2 shows that an increase in the speed of the alternator leads to a smooth increase in the values of the current $I_{dc\_out\_alternator}$ and the voltage $U_{dc\_out\_alternator}$ at the output of the alternator. This pattern is observed until reaching 1500RPM. At these revolutions, the highest value of the current $I_{dc\_out\_alternator}$ = 3.4 A is reached at the output voltage $U_{dc\_out\_alternator}$ = 13.4 V.

At 1600 RPM and 1700 RPM, the $U_{dc\_out\_alternator}$ output voltage is seen to increase to its maximum value of 14.4 V, and the $I_{dc\_out\_alternator}$ output current begins to decrease from 2.8 A to 2.4 A.

From 1800 RPM to 2000 RPM of the alternator, the $U_{dc\_out\_alternator}$ output voltage drops to 14.2 V, but the $I_{dc\_out\_alternator}$ current value drops rapidly from 2.4 A to 1.2 A.

At 2200 RPM of the alternator, the $U_{dc\_out\_alternator}$ output voltage drops further to 13.1 V and the current drops sharply to 0.4 A.

Table 2. Results of measurements from the second task

№	Alternator speed (RPM)	$U_{dc\_out\_alternator}$ (V)	$I_{dc\_out\_alternator}$ (A)
1	200	2.3	1
2	400	3	1.2
3	600	3.8	1.32
4	700	7.5	2.2
5	800	8.9	2.65
6	900	9.5	2.8
7	1000	9.8	3
8	1100	10	3.1
9	1200	11	3.1
10	1300	12	3.1
11	1400	12.5	3.2
12	1500	13.4	3.4
13	1600	14.4	2.8
14	1700	14.4	2.6
15	1800	14.2	2.4
16	1900	14.2	1.9
17	2000	14.2	1.2
18	2200	13.1	0.4

From the obtained results, it can be concluded that with an increase in the speed of the alternator, the current and voltage at the output of the alternator proportionally begin to increase, i.e. the alternator begins to generate more electrical energy. In this way, the battery begins to receive more electrical energy for recharging, which makes it charge faster. When the battery is fully charged and the consumer's current consumption is greater than the alternator's current, current is drawn from the battery. This results in a drop in current and voltage at the alternator output. Alternator output voltage may drop to battery voltage level.

4.1.3 Evaluation by students

Pilot laboratory exercises with 4 groups of students from different engineering undergraduate programs have been conducted. The exercises have been followed by a survey among students.

The survey included 10 questions that assess students' satisfaction with the training conducted according to various criteria. For each question, students can assign points from 1 to 10. The final grade is formed by adding up all the points for each of the questions.

The maximum results in the survey is 100 points (indicating complete satisfaction), results below 60 points (indicating complete dissatisfaction) of the students.

The survey results are shown in Figure 11.

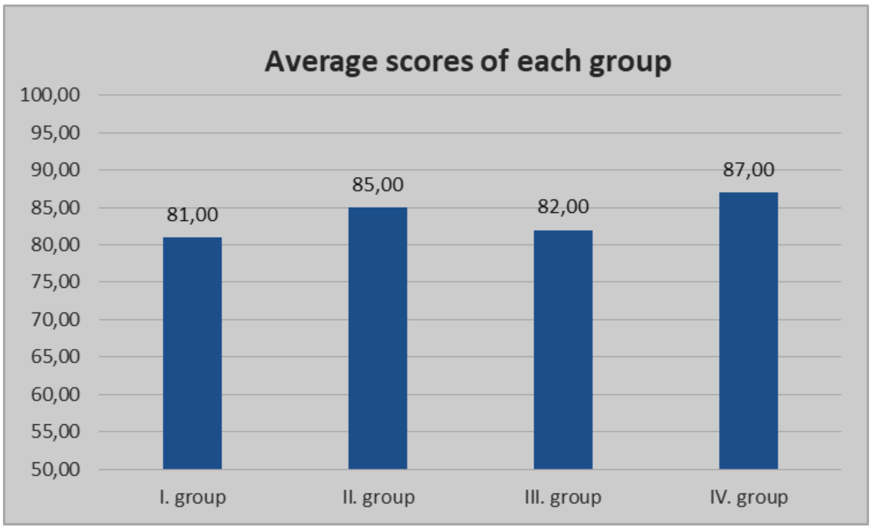

Fig. 11. Average points of each group of students in the survey

The results of the survey show that the students from the different groups highly value the applied approach to conducting laboratory exercises. This shows that the research approach creates the necessary conditions for students to acquire new technical skills through practice.

However, the survey shows that there are students who find it more difficult to adapt to practical work in a laboratory where different measuring instruments and apparatus are used. For this reason, teachers should work more with these students to improve their technical competencies.

5 CONCLUSION

This article demonstrates the possibilities of improving engineering education through a scientific research approach in the laboratory practice of engineering students studying the discipline "Electrical Engineering".

For the good adaptation to the future professional environment, a DC alternator research setup with remote control capabilities was developed.

The experimental research methodology applied allows the students to improve their technical competences by learning:

- The principle of operation and the design of a direct current alternator;

- Connecting the basic components of the alternator;

- The components and operation of the electrical system for the electrical supply of a car:

- The working characteristics of an alternator;

- The relationship between alternator speed and battery charging and discharging conditions in vehicles.

The proposed approach was evaluated with a survey conducted with 4 groups of students from different

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engineering majors. The survey results showed that the proposed approach helps to understand the complex physical relationships in modern automotive electrical power and battery charging/discharging systems.

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