Registration of the diagnostic signals of the starting system for selected faults

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Abstract. The article is devoted to issues related to the test systems of the starting circuit. The article develops the model and simulation of the wear and tear of starter sleeves by changing the size of the starter armature gap. The analysis of the impact of the starter sleeves condition on the device’s power curve was conducted in the Matlab Simulink program. For the model developed in the Matlab Simulink program, resulting from operational wear as a function of the car's course, a method of power characterisation for failure verification was proposed.

1. Introduction
The starter's diagnostics include technical condition assessment, technical suitability forecasting and analysis in generated damage causes.

The importance of diagnostics in the operation of starters results from the following functions [4-5]:
- decision-making – determination of technical efficiency;
- prognostication – anticipation at the time of proper functioning;
- prevention – planning the required technical inspection of the starter.

The starting system of the internal combustion engine consists of [1-2, 10]: electric starter, battery and wires. The starter consists of an electric motor, an electromagnetic switch, a shaft with a guide, a planetary gear mechanism and a one-way clutch. It works in difficult operating conditions and as a result is subject to various types of damage, which include: short circuit, break, oxidation, wear and cracks. The technical condition of the starting system is affected by the tightening torque of the wires, the state of charge of the battery and operational wear [9]. Typical symptoms of the starter's malfunction include: no rotation of the starter rotor, no engagement with the ring of the flywheel of the internal combustion engine and excessive noise generated by the coupling mechanism. The diagnostic parameters of the starting system include the intensity of the current consumed by the starter and the values of voltage drops on individual elements of the starting system: battery terminals, starter current contacts, the cable connecting the starter with the battery and electrical connection with the vehicle mass.

The article is devoted to issues related to the test systems of the starting circuit. Today's test systems are associated with the analysis of defects that have a direct impact on driving safety and occur mainly in the subsystems of the chassis and bodywork [3, 11]. In the case of the starting system, the operation process due to natural wear and tear or damage is not monitored or tested in diagnostic and repair stations. The decision to test a vehicle’s starting system is made by the user based on the symptoms of damage observed during the operation. In accordance with the requirements of OBD (on-board diagnostics) II an important issue is continuous supervision of any electrical system in vehicles from the early stages of damage, the appearance of damage symptoms and confirmation of the failure symptom [6-8]. Following the rules and procedures of the OBD system there is a requirement for ongoing diagnostics and repair as well as continuous monitoring and signalling of a
damage by the MIL (malfunction indicator lamp), informing of the occurrence of damage. The stands designed by the author allow to define the power characteristics on the basis of registration of electrical and mechanical parameters. The author’s four measurement systems have been extended by the possibility of recording magnetic field distribution in the studied starters.

The registered parameters include the voltage at the starter, the current consumed by the starter, and the starter’s rotation speed and torque. On the basis of these values the electrical and mechanical power of the starter are determined. To register the distribution of magnetic flux, Hall sensors were used. The operation study includes an analysis of damaged starters, on the basis of which a reliability model of starter redundancy was developed, with a subdivision into mechanical and electrical parts.

2. Simulation tests in the Matlab Simulink programme

The article develops the model and simulation of the wear and tear of starter sleeves by changing the size of the starter armature gap. The analysis of the impact of the starter sleeves condition on the device’s power curve was conducted in the Matlab Simulink program. The starter model was developed on the basis of the theory of electrical machines of motor vehicles.

A block diagram of a Matlab Simulink simulation of damage is shown in Figure 1. In order to perform the simulation, the following data were entered: mechanical and electrical rated power, rated voltage, the rotational speed of the starter motor at rated power, battery capacity, resistance of the cables connecting the starter with the battery, rated current, efficiency, number of rotor slots, number of active rods of the rotor winding, length and diameter of the rotor packet, outer and inner diameter of the body of the starter, length of the body, number of pole pairs, dimensions of the pole pieces, current value of the wrap of the rotor, conductivity and thickness of copper, and voltage drop across the brushes.

The variable value is the armature gap value (a) and voltage drop across the brushes (ΔU_{SZ}). The output values include: electric power and mechanical starter circuit current, voltage at the starter, power drawn by the starter, current wrap of the rotor, magnetic induction in the armature gap, electromagnetic torque of the starter.

The simulations produced the starter power curves for the sleeves’ wear and tear corresponding to the armature gap of 0.5 mm, 1 mm and 1.5 mm. A summary of the power characteristics of the R76 starter for selected armature gap values is shown in Figure 2. A corresponding summary of the power characteristics of the R76 starter for a selected voltage drop across the brush values is shown in Figure 3.
Figure 1. Matlab Simulink program for R76 starter

Figure 2. Characteristics of the R76 starter power for selected armature gap values

Figure 3. Characteristics of the R76 starter power for selected voltage drop across the brushes
The size of the armature gap affects the power developed by the starter and the short-circuit current. For the armature slot of 0.5 mm the starter has reached the power of 580 W and the short-circuit current of 410 A. Increasing the gap to 1 mm reduced the starter power by 100 W, and the short-circuit current by 50 A. The introduction into the model of an air gap of 1.5 mm results in reducing the power to 390 W. At this size of the gap the short-circuit current is 300 A.

3. Experimental tests

For the model developed in the Matlab Simulink program, resulting from operational wear as a function of the car’s course, a method of power characterisation for failure verification was proposed. On the basis of the model a prepared verification was performed at test stand TSR-76 (Fig. 4) of the characteristics of an efficient starter (Fig. 5) and selected starter damages. The test stand consists of the following: battery – 1, tested starter – 2, analogue recorder – 3 and a laptop – 4. The test stand includes the tested R76 starter, which has been specially prepared by placing the Hall sensor in the yoke gap. Mechanical load of starter on the test stand is realized by motorbike braking system. The measurements were made including starter idling, followed by the process of braking to a stop.

The stand allows to measure the following values:

- current I [A];
- voltage [V];
- magnetic induction B [T];
- rotational speed n [rev/min].

The following failures in the start system were simulated on the test stand:

- open-circuit between the excitation winding and the positive brushes (Fig. 6),
- open-circuit in armature winding (Fig. 7),
- used sleeve (Fig. 8).

![Figure 4. TSR-76 test stand for starter R76 testing](image)

![Figure 5. Characteristics of the efficient starter: 1 – rotational speed, 2 – magnetic induction, 3 – battery voltage, 4 – current](image)
Figure 6. Characteristics of a starter with an open-circuit between the excitation winding and the positive brushes: 1 – rotational speed, 2 – magnetic induction, 3 – battery voltage, 4 – current

Figure 7. Characteristics of a starter with an open-circuit in armature winding: 1 – rotational speed, 2 – magnetic induction, 3 – battery voltage, 4 – current

Figure 8. Characteristics of a starter with a used sleeve: 1 – rotational speed, 2 – magnetic induction, 3 – battery voltage, 4 – current

On the basis of the recorded values, electric power (Fig. 9) was set for damages in the form of the used sleeve of the starter’s rotor disc and the efficient starter. The simulated state of the used sleeve of the R76 starter results in decrease of electrical power by about 10%. The purpose of the carried out
simulation tests is to work out diagnostic standards for stand tests of starters with the use of computers.

![Figure 9. Characteristics of the electric power for an efficient starter (1) and starter with a used sleeve (2)](image)

4. Summary
On the basis of the carried out calculations and simulation tests, it has been found that the shapes of power characteristics are comparable to the catalogue ones. It has been noticed that for the R76 starter the maximum of electric power at the used sleeve decreased by 60 W in relation to the catalogue state.

Previous studies conducted at the laboratory of electrical engineering and automotive electronics confirmed the possibility of forecasting the state of the reliability of starters on the basis of operational symptoms and information on the number of starts made.

The simulated damages in the form of an operationally used sleeve of the rotor disc, open-circuit between the excitation winding and increased resistance of the positive clamp cable affect the change in the size of particular areas which can be used as parameters for predicting operational wear and recognising the type of damage.

Based on the experimental simulation studies performed, a significant influence was confirmed of the type of damage on the power characteristics.

The author is conducting further research of the magnetic field in order to implement diagnostic methods at the car production stage.

The developed method of reasoning about the state of operational wear or damage to the starter by using the Matlab Simulink software and simulation of selected damage can be used to extend the on-board diagnostics (OBD).

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