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Diagnostics of automobile starters by the parameter of current consumption

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Diagnostics of automobile starters by the parameter of current consumption

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Abstract. The urgency of the problem of diagnosing automobile starters is caused by the high complexity of existing diagnostic methods that require removing the starter from the engine. The occurrence and development of malfunctions of starters are caused by a change in the current consumed at the time of starting the internal combustion engine. The value of the starter current consumption was experimentally determined using current-measuring pliers for a group of vehicles with different mileage. It has been established that the current consumed by workable starters decreases monotonically with an increase in operating time, not reaching the maximum permissible value determined by the method of tolerance boundaries. The current consumption of starters with malfunctions is much less than the allowable value, allowing you to use this parameter to determine the technical condition. To assess the service life of automotive starters, the degree of working capacity was used, due to the difference between the current and limit values of the diagnostic parameter. The practical significance of the research is to determine the residual life of automobile starters. Further research will be aimed at establishing the dependence of the current consumption on the ambient temperature and forming recommendations for diagnosing automotive starters.

1. Introduction

Anautomobile starter, which serves to create the initial (starting) frequency of rotation of an internal combustion engine (ICE), is a fairly reliable device, the service life of which is comparable to the service life of an automobile.However, during the operation of the starters, sooner or later, malfunctions arise, often leading to their failures.Failure of automobile starters leads to impossibility of movement, which leads to remove of automobiles from the line (route) and economic damage.Therefore, there is a need to timely determine the technical condition of automotive starters without removing them from the engine.

As part of automobile starters, it is customary to distinguish: an electric motor that serves to communicate torque to the flywheel of the internal combustion engine; a drive mechanism that engages the gear with the flywheel and the traction relay, which, firstly, transmitting force to the starter drive mechanism and secondly, connecting the electric motor to the battery.

The main malfunctions of automobile starters, according to [1, 2, 3, 4, 5, 6] include faults in the armature winding (gap or closure) –10%, slipping of the freewheel – 10%, coking of the starter drive mechanism – 12%, wear of the bearings of the plain bearings, wear or damage to the motor brushes and compression springs – 11%, wear of the buffer and return springs – 6%, failures of the integrated planetary gear – 9%, damage to the teeth of the drive gear – 7%, malfunction of the traction relays – 18% and others – 17%.

To assess the technical condition of automotive starters, a large number of diagnostic methods have been developed that differ measured parameters, the measurement principle, the method of determination, the means used and etc.An analysis of publications and patents on the methodology for diagnosing automotive starters revealed the following diagnostic parameters measured during engine starting: voltage drop [7], vibration acceleration [8], rotation frequency of electric motor [9], and current consumption [10]. However, in most publications, despite the relevance of methods for determining the technical condition, there is fuzzy logic [11], neural networks are used [12]; Markov models [13], linearized vectors [14], which requires the installation of additional sensors [15,16] (accelerometers, Hall sensors, rotational speed sensors) and impedes the diagnosis process in the conditions of service enterprises. In this case, the main diagnostic parameter of the automobile starter, reflecting the change in ambient temperature, the parameters of the internal combustion engine (number of cylinders, displacement, viscosity of the engine oil), the degree of charge of the starter battery and the technical condition of the starter itself (most mechanical and electrical failures) is the current consumption.

2. The mathematical model of the diagnostic parameter

From the theory of electrical machines it is known

$$I_a = \frac{U - C_e \cdot \Phi \cdot n}{r_a} \quad , \tag{1}$$

where I_a – current consumption, A; U – voltage of the power source (starter battery), V; C_e – constructive constant of electric motor; Φ – magnetic flux, Wb; n – rotation frequency of electric motor rotor, 1/min; r_a – electric resistance of the anchor circuit of an electric motor, Ohm.

The voltage of the starter battery during operation varies within wide limits, and it is not possible to achieve a constant voltage during the experiment.Therefore, given the direct proportionality between current and voltage, the experimentally obtained values will lead to a voltage value corresponding to 75% of the battery charge (U = 12.45 V).In this case, the electrical resistance of the anchor circuit reflects the technical condition of the starter electric motor.

Magnetic flux in starters equipped with permanent magnets is a constant value. The rotation frequency at the time of starting the internal combustion engine is determined by the equality of the moments from the starter to the flywheel$M_{st}$and force resistance to rotationM_{crank}.

$$M_{st} = C_M \cdot \Phi \cdot I_a \cdot i_r \cdot \eta_r, \tag{2}$$

where C_M – constructive constant of electric motor; i_r, η_r – gear ratio and efficiency of the gear transmissionof starter-flywheel of the internal combustion engine.

$$M_{crank} = (\alpha + \beta \cdot n \cdot i_r \cdot \eta_r) \cdot \sqrt{\nu} \cdot V_h \ , \tag{3}$$

where α, β – constants determined by the type of engine (gasoline / diesel) and the number of cylinders; ν – kinematic viscosity of engine oil, m^2/s; V_h – working volume of cylinders of an internal combustion engine, m^3.

From the expression (3) it follows that the variable is the viscosity of the engine oil, which continuously changes during operation. Therefore, for the purity of the experiment, the automobiles were selected with the same volume and number of cylinders of the internal combustion engine and the same type of engine oil with the SAE 10W30 index. As well, measurements were made at the same ambient temperature.

Then a generalized mathematical model of current consumption can be represented

$$I_a = f(U, V_h, \nu, r_a) = f(U, t, L), \quad (4)$$

where t – ambient temperature, °C; L – automobile mileage, km.

In expression (4), the temperature indirectly takes into account the change in the viscosity of the engine oil and the forces of resistance to rolling, and the operating time (automobile mileage) – a change in the technical condition of the starter, in particular, a change in the electrical resistance of the anchor chain.

3. Experimental research

The experiment was conducted on cars of the LADA family with different mileage, equipped with starters with a power of 1 kW and starter batteries with a nominal capacity of 55 Ah at an ambient temperature of 0 to minus 5 °C.The connection electric circuit of the measuring devices is shown in figure 1.

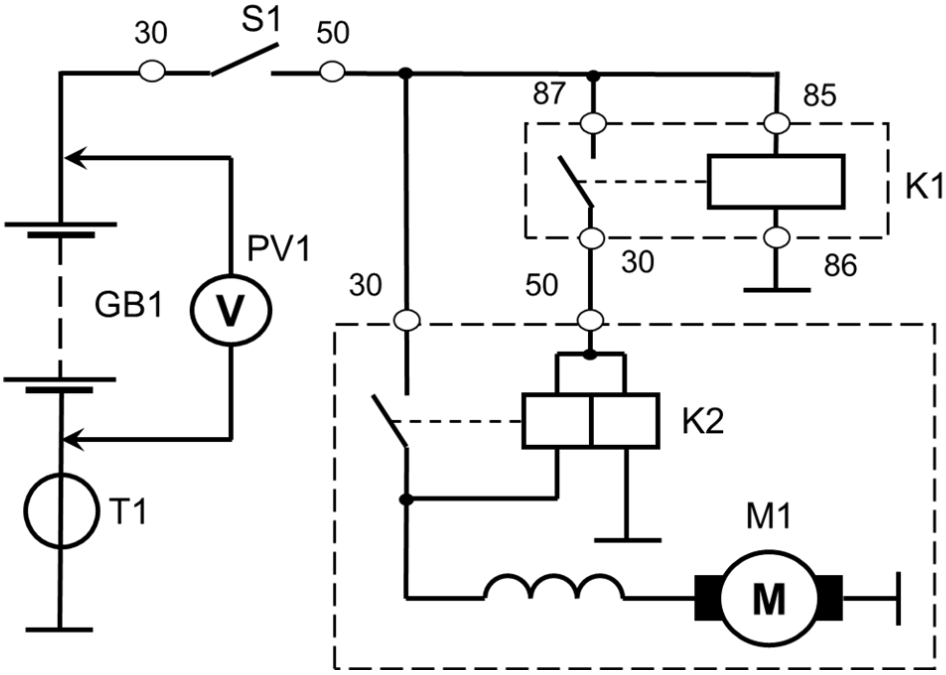

Figure 1. The electrical circuit used during the experiment to connect measuring devices: GB1 – starter battery; K1 – starter relay; K2 – traction relay of starter; M1 – electric motor of starter; PV1 – digital multimeter; T1 – current-measuring pliers Testo 770-2; S1 – ignition switch.

The sequence of the experiment is as follows: the car was kept on the street until the engine and other parts reached the ambient temperature and the battery voltage stabilized; the vehicle's mileage according and the ambient temperature were recorded; a digital multimeter was connected to the pole terminals of the battery and the battery voltage was measured; current-measuring pliers Testo 770-2 in the "INRUSH" mode were connected to the power wire connecting the negative terminal of the battery with the "mass" of the car; the internal combustion engine was started and the value of the starting current was recorded.

4. The results of the research

The dependence of the current consumption of automotive starters on operating time (car's mileage) is shown in figure 2.It was found that the current consumption of starters decreases monotonically with increasing operating time, with a high probability forming a linear trend line.The current consumption of automotive starters with malfunctions are much less than the permissible values, allowing you to use this parameter to determine the technical condition.

The process of starting internal combustion engines with faulty starters was characterized either by an increase in start time, or by an unsuccessful attempt to start and the occurrence of uncharacteristic noise.

The scatter in the current consumption of automotive starters with malfunctions is explained by the difference in the nature of the malfunctions that occur and the stochasticity of the process of their development.

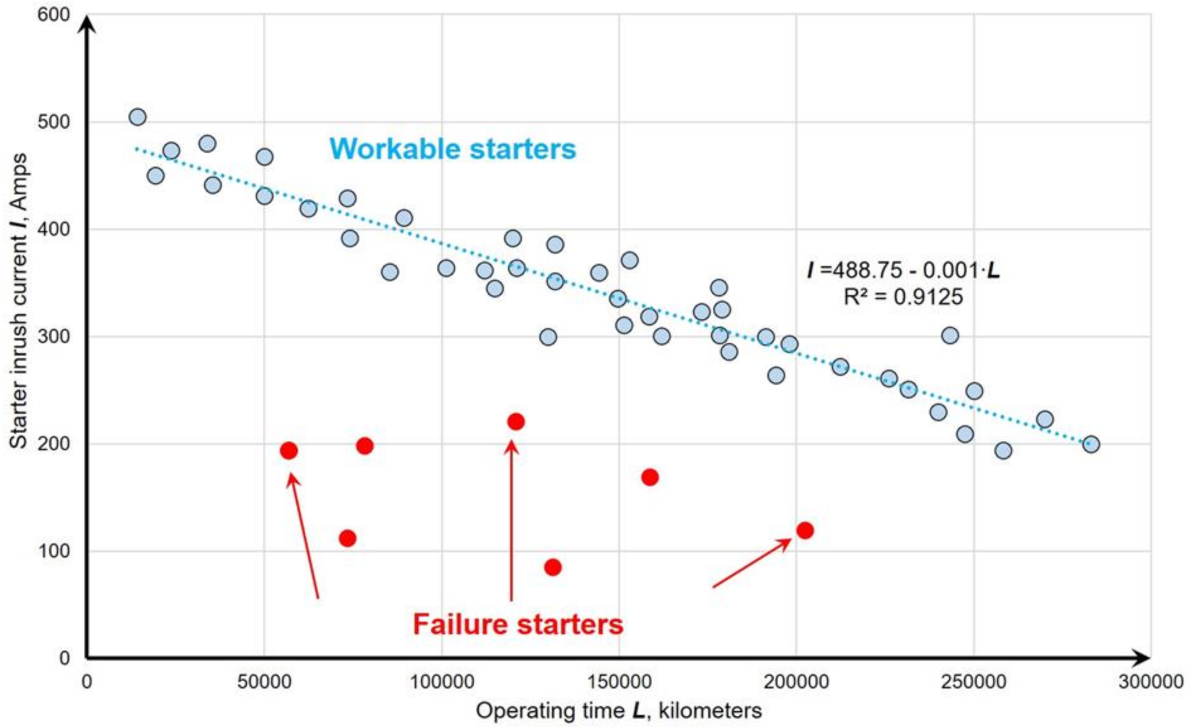

Figure 2. The dependence of the current consumption of automotive starters on operating time (car's mileage).

The determination of the permissible value S_{mp} of the diagnostic parameter is carried out on the basis of the statistical method for distinguishing tolerant boundaries by the formula

$$S_{mp} = \bar{X} + K \cdot \sqrt{s^2} \,, \qquad (5)$$

where $\bar{X}$ and S – sample mean value and variance of the diagnostic parameter; K – coefficient determining tolerance field (tolerance factor).

Since the current consumption is a one-way diagnostic parameter, limited from below, the coefficient K is taken equal 1 if the parameter is directly related to traffic safety, and K is taken equal 1.7 if not related to traffic safety.

Substituting the values we obtain the permissible value of the starting current.

$$S_{mp} = 339.63 - 1.0 \cdot 79.7 = 260\ A.$$

Since a trend can be highlighted in a random process characterizing a change in a diagnostic parameter, it becomes possible to use the diagnostic results by the proposed method to predict the residual life of automobile starters [8].

When assessing the residual life of automotive starters, we proceed from the following

$$R_S = S_i / S_{max}, \quad (6)$$

where R_S – residual life of an automobile starter; S_{max} – limit value of the diagnostic parameter, A; S_i – current value of the diagnostic parameter, A.

Figure 3 shows a graphical representation of the change in the residual life of automotive starters during operation.

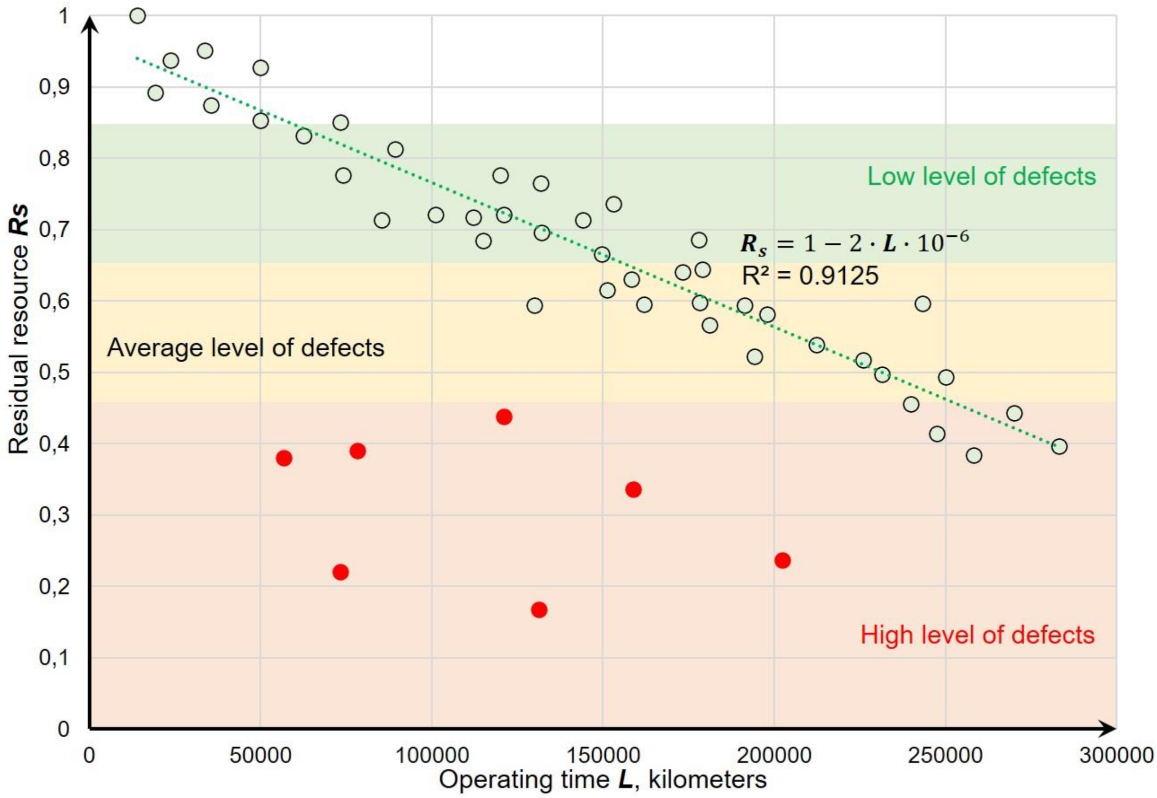

Figure 3. Change in residual life of starter with increasing on operating time (car's mileage).

5. Conclusions

The urgency of the problem of diagnosing automobile starters is caused by the high complexity of existing diagnostic methods that require removing the starter from the engine.The occurrence and development of malfunctions of automobile starters causes a change in the current consumed at the time of starting the internal combustion engine.The value of the starter current consumption was experimentally determined using current-measuring pliers for a group of vehicles with different mileage.It was established that the current consumed of starters decreases monotonically with an increase in operating time, without reaching the maximum permissible value determined by the method of tolerance boundaries. The current consumption of starters with malfunctions is much less than the allowable value, which allows you to use this parameter to determine the technical condition. To assess the service life of automotive starters, the degree of working capacity was used, due to the ratio of the current consumption to the limit value of this diagnostic parameter. Further research will be aimed at establishing the dependence of the current consumption on the ambient temperature and the formation of recommendations for diagnosing automotive starters.

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