Development of the load cycle of the starter battery

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Abstract. During the operation of the starter battery in vehicle, its parameters may decrease, which leads to interruptions in the operation of some items, for example, a starter. To prevent the occurrence of battery failures and simplify the process of eliminating them, you need to know how its parameters change during operation. Standardized testing is required to assess the state of the battery in various states. There are currently no standardized load cycles for batteries. The aim of the article is to develop such a cycle that will allow us to evaluate the technical condition of the battery in various loading modes and draw a conclusion about its performance. An experimentally established change in the parameters of both a workable battery, and with several simulated faults. Further research will be aimed at compiling a dataset for the system for automatically diagnosing starter batteries on board a vehicle.

1. Introduction
Despite the high reliability, the technical condition of the units, systems, components, and parts of vehicles under operating conditions is changing, and failures periodically occur. The main share of passenger vehicle failures is accounted for by an internal combustion engine (23%), as well as electrical and electronic equipment (32%).

A significant proportion of electrical equipment failures is explained by an ever-expanding range of products, an increase in their technical complexity and is consistent with data from other researchers [1, 2, 3]. According to the actual information, electrical components account for an average of 34% of vehicle failures. The electrical equipment of automobiles accounts for from 17% to 25% of all failures, and their elimination accounts for up to 30% of the time spent.

Thus, electrical equipment is the second largest source of failures, with most of the failures occurring in the power supply system, including a starter battery and an alternator.

In Russia, the estimated service life of the starter battery is 2.7 years, which is less than the warranty, equal to 4 years, or 90 thousand kilometers. Moreover, battery life can be significantly reduced due to improper battery operation. Also, some battery failures contribute to this, the list and frequency of occurrence of which is shown in Fig. 1. [4, 5, 6, 7].

In service enterprises, the number of customer complaints with complaints about rechargeable batteries has increased (especially if the date of sale significantly exceeds the date of manufacture of the automobile). Since automobile’s manufacturers usually give a guarantee on the battery from the date of sale, all the costs associated with replacing the battery are borne by the service company [8, 9, 10].
The occurrence of malfunctions is accompanied by a change in the parameters of the battery, such as discharge current and voltage. The purpose of this work is to establish the nature of the dependence of changes in these parameters on the loading mode during the occurrence and development of characteristic failures of starter batteries [11, 12, 13].

2. Load mode
Getting the initial data is possible by testing at a certain load of the starter battery. The load cycle of the starter battery is an established sequence of tests characterized by a given load value and its exposure time [14, 15, 16].

The developed load cycle should consider the specifics of the electrical equipment of the automobile and will fundamentally differ from those presented earlier. Modern rechargeable batteries are designed in such a way that even with a failed automotive alternator to supply electricity to all regular consumers at the same time. Therefore, testing should be carried out both during normal operation and in the highest load conditions [17, 18].

Often, to test the battery’s performance, it is discharged for some time with a current of 25 A to a final voltage at the battery terminals of 10.5 V. This operating mode is used to assess the backup battery capacity. The largest load for the battery is the engine starting mode, in which the discharge current can reach 500 A or more. An intermediate mode may be checking the battery with a battery load plug, providing a load within 180-250 A. It is in these modes that it is supposed to test the starter battery [19].

At this stage of the study, it is not known which of the tests will best identify problems with the battery. Therefore, in the future, the load cycle obtained in the course of this work may be modified. The general electrical diagram of the load cycle is shown in Fig. 2.

The developed load cycle consists of four test modes: connection to a starter motor braked with a hydraulic measuring gauge (force measuring device based on the use of a gauge); connection to a loading plug; connection to a starter motor operating in idle mode; connection to a nichrome spiral with a reference load of 25 A.

The duration of the first loading mode should not exceed 5 s, the current strength is 500-600 A. On a vehicle, such a current strength can be achieved only at an extremely low ambient temperature (less than minus 30° Celsius) due to an increase in the viscosity of engine oil.
During a normal battery check with a battery load plug, the load time is 5 s, however, for the developed cycle, it is increased to 10 s.

The duration of the third loading mode should not exceed 30 s to avoid overheating of the starter motor. For the developed cycle, we limit ourselves to 15 s.

Finally, the duration of the last loading mode is selected in the range of 2.5-3 minutes.

To determine the nature of the change in voltage and current of the battery during loading, a Testo 760-2 digital multimeter and Testo 770-2 clamp meter were used.

Fig. 3 shows the dependences of the discharge current and voltage of a workable fully charged battery.

**Figure 2.** Scheme of experiments.

**Figure 3.** Change in discharge current and voltage of a working fully charged battery.
Analyzing the data of Fig. 3, one can notice that in the first loading mode the discharge current was 560-580 A, the voltage was about 7 V; in the second mode: 140-180 A and 10.6-11.0 V; in the third: 52-56 A and 11.8 V; in the fourth: 25-27 A and 12.4 V.

To justify the choice of a specific loading mode, it is necessary to test the starter battery with characteristic failures and determine the most informative one. In the work, the nature of the change in the discharge current and battery voltage for deep discharge, oxidation of terminals and short circuit in one of the batteries was experimentally established. Before each step, the battery is fully charged again.

The battery was discharged to a final voltage of 12.0, 11.5, and 11.0 V (deep discharge simulation), and for each case, the nature of the change in the parameters of the battery in each of the load cycle modes was also determined. The studies' results are shown in Fig. 4.

![Figure 4](image_url)

**Figure 4.** Changing the parameters of the battery when simulating a deep discharge.

From fig. 4 it follows that the first and second loading modes are the most informative to a deep discharge.

At the second stage, a resistor with a resistance of 0.025, 0.05, and 0.1 Ohm was connected in series with the battery (modeling the oxidation of the terminals) [20]. The experimental results are presented in Fig. 5.

A comparison of Fig. 4 and 5 shows that the second loading mode is the most informative on the example of two faults. The first loading mode failed, since the starter operates in the “machine-gun effect” mode, that is, the gear enters and disengages continuously. The third loading mode is also not informative since a decrease in current is accompanied by an increase in voltage.

At the third stage, a resistor with a resistance of 0.025, 0.05, and 0.1 Ohms was connected in parallel with one of the extreme batteries of the battery (simulation of a short circuit in one of the batteries). The experimental results are presented in Fig. 6.
Figure 5. Changing the parameters of the battery when modeling the oxidation of the pole terminal.

Figure 6. Changing the parameters of the battery when simulating a short circuit in one of the batteries.
Analysis of the data in Fig. 6 showed that all four loading modes are sensitive to faults. Thus, not all the selected load cycle modes are sensitive to battery failures. According to the results of the experiment, the second loading mode (battery load plug) has the greatest sensitivity. Further research will be devoted to the study of changes in battery parameters when modeling faults such as a lagging battery, an open circuit in the battery, sulfation and a decrease in residual capacity.

3. Conclusions
The operability of the car depends on the serviceability of the battery. According to statistics, about 15% of all failures of cars with an internal combustion engine are due to the battery. The ability to assess the technical condition of the starter battery on board the vehicle will significantly increase the reliability of the vehicle.

To identify a malfunction on board the vehicle, you need to know how the parameters of the starter battery change when a malfunction occurs. For this, a load cycle was developed, which is an established sequence of tests characterized by a reference value of the load and its exposure time. The developed load cycle consists of four test modes: current 500-600 A with a duration of 5 s; current strength 180-250 A, duration 10 s; a current of 50-60 A for a duration of 15 s and a current of 25 A for a duration of 2.5 minutes. The nature of the change in the discharge current and voltage of a workable fully charged battery, which will serve as a standard for detecting failures, has been experimentally established. Changes in the discharge current and voltage during the simulation of such battery failures as deep discharge, oxidation of the pole terminals and short circuit in one of the batteries are determined.

Further researches will be oriented to the physical simulation of other faults and compilation of data array for the system of automatic diagnostics of starter batteries.

References
[1] Li Y (2014). Automotive electrical control system fault diagnosis based on weight-direct determined neural network. pp. 671-676. 10.2495/ISME20140881.
[2] Hashemi A & Pisu P (2011). Adaptive threshold-based fault detection and isolation for automotive electrical systems. Proceedings of the World Congress on Intelligent Control and Automation (WCICA). 10.1109/WCICA.2011.5970668.
[3] Kodali A, Zhang Y, Sankavaram C, Pattipati K & Salman M (2013). Fault Diagnosis in the Automotive Electric Power Generation and Storage System (EPGS). Mechatronics, IEEE/ASME Transactions on. 18. pp. 1809-1818.
[4] Hu X, Zhang K, Liu K, Lin X, Dey S & Onori S (2020). Advanced Fault Diagnosis for Lithium-Ion Battery Systems. 10.36227/techrxiv.11777448.
[5] Hammad N (2010). Vehicle valve regulated lead acid battery modeling and fault diagnosis. 10.4271/2010-01-0028.
[6] Garche J, Karden E, Moseley P T, & Rand D A J (2017). Lead-Acid Batteries for Future Automobiles (Elsevier) p 706, ISBN 0444637036.
[7] Brik K & Ammar F (2008). The Fault tree analysis of the lead acid battery’s degradation. Journal of Electrical Systems. 4.
[8] Catherino H, Feres F & Trinidad F (2004). Sulfation in lead–acid batteries. Journal of Power Sources. 129, 113-120. 10.1016/j.jpowsour.2003.11.003.
[9] Demirici O, Demirici B & Taskin S (2019). Battery Cell Measurement and Fault Diagnosis System for Detection of Problem in Automotive Batteries. Pamukkale University Journal of Engineering Sciences. 25. pp. 546-552. 10.5505/pajes.2019.98105.
[10] Yahmadi R, Brik K & Ammar F (2016). Failures analysis and improvement lifetime of lead acid battery in different applications. Proceedings of Engineering & Technology (PET). pp. 148-154.
[11] Kim S T, Jeongbin L, Kim U & Shin C B (2013). Modeling of the lifetime prediction of a 12-V automotive lead-acid battery. Journal of Energy Engineering. 22.
10.5855/ENERGY.2013.22.4.338.

[12] López J, Navarro R, Gallego J M, Parres F & Ferrándiz, S (2009). Failure analysis of automotive battery parts. Engineering Failure Analysis - ENG FAIL ANAL. 16. pp. 2217-2223. 10.1016/j.engfailanal.2009.03.004.

[13] Ruetschi P (2004). Aging mechanisms and service life of lead-acid batteries. Journal of Power Sources, Vol. 127, Issue: 1-2. pp. 33-44.

[14] Cugnet M, Laruelle S, Grugueon S, Sahut B, Sabatier J, Tarascon J-M & Oustaloup A (2009). A Mathematical Model for the Simulation of New and Aged Automotive Lead-Acid Batteries. Journal of The Electrochemical Society. 156. A974-A985. 10.1149/1.3224868.

[15] Hammad N (2011). Automotive Battery Modelling and Management. Journal of Engineering Science and Technology Review. 4. pp. 140-145. 10.25103/jestr.042.05.

[16] Mürken M, Kübel D, Thanheiser A & Gratzfeld P (2018). Analysis of automotive lead-acid batteries exchange rate on the base of field data acquisition. 10.1109/ESARS-ITEC.2018.8607507.

[17] Shin K-K & Salman M (2010). Evidence Theory Based Automotive Battery Health Monitoring. SAE International Journal of Passenger Cars - Electronic and Electrical Systems. 3. pp. 10-16. 10.4271/2010-01-0251.

[18] Khare N & Govil R (2008). Modeling automotive battery diagnostics. Power Electronics Technology. 34. pp. 36-41.

[19] Richter G (1993). Improvement of bench life-tests for automotive batteries. Journal of Power Sources. 42. pp. 231-236. 10.1016/0378-7753(93)80151-E.

[20] Puzakov A (2019) Physical modeling of failures of the automotive alternator. IOP Conf. Series: Materials Science and Engineering. 643. 10.1088/1757-899X/643/1/012019