Instrumental monitoring of the load of the automotive alternator during the movement of the vehicle

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Abstract. The charge balance of the vehicle indicates whether the starter battery is being charged while the vehicle is running. For normal operation of the power supply system, the charge balance must remain positive, preventing progressive discharge of the battery. A decisive influence on the balance of electricity is provided by the current output of the alternator, which depends on the rotor speed. The maximum current output of the alternator is described by a current-speed characteristic depending on the technical condition of the alternator. In the process of vehicle movement, the rotor speed and alternator current strength vary over a wide range determined experimentally. The ratio of these parameters is the alternator efficiency coefficient, which can be used to assess the technical condition of the automotive alternator. The productivity of the vehicle’s charge balance is objectively evaluated by the alternator load factor. Further research will be aimed at identifying changes in the charge balance of the vehicle in the event of a malfunction of the automotive alternator and starter battery.

1. Introduction
Improving the design of vehicles leads to a steady increase in the number and installed capacity of electricity consumers. Over the past 15 years, the capacity of consumers has increased 4 times and continues to increase. Electricity is used for the operation of the power plant, transmission and chassis; workflow automation; creating comfortable conditions for the driver and passengers, as well as ensuring traffic safety [1].

The development of electronic devices responsible for traffic safety, the prospect of which is fully autonomous vehicles, requires stricter requirements for the uninterrupted supply of electricity. Despite the emergence of new devices that ensure the generation and storage of electricity onboard vehicles (fuel cells, ionistors), the most popular are batteries and automotive alternators.

The main source of current is considered to be an automotive alternator, which supplies electricity to consumers included in the on-board network of the vehicle and charges the battery. Attempts to provide the vehicle with redundant power supplies cannot be considered successful since several responsible consumers (electric power steering, active suspension and others) can completely exhaust them in just a few minutes.

Thus, the alternator is a key element ensuring the power supply of vehicles, the safety of the driver and passengers, the safety of cargo, etc.

When the engine is running, the alternator generates current, which is usually enough depending on the voltage parameters in the on-board network (depending on the alternator speed and connected consumers), to provide consumers and charge the battery [2]. If the current consumption in the on-board network is higher than the alternator current (for example, when the engine is idling), the battery is
discharged. The highest energy consumption is characterized by starting the engine at low air temperature.

A decisive influence on the balance of electricity, along with the battery itself, is provided by the current efficiency of the alternator, as well as the power of consumers. The current output of the alternator depends on the speed. At an idle speed of the engine \( n \), the alternator can give only a part of its rated current at the normal gear ratio (crankshaft – alternator) from 1:2 to 1:3. The rated current is given as determined at an alternator speed of 6,000 rpm \([3, 4]\).

The driving profile as an input parameter for calculating the balance of electricity is displayed using the relatively high-speed mode of engine operation. The curve indicates how often a certain engine speed is reached and exceeded.

A vehicle while driving in urban conditions with intensive work of transport before and at the end of the working day has a higher proportion of engine speed at idle caused by a frequent stop at traffic lights and due to the high traffic intensity.

### 2. Determination of the current output of an automotive alternator

The current-speed characteristic is the dependence of the current of the alternator \( I_a \) supplied to the load power on the rotational speed \( n \) of the rotor. The characteristic is removed provided that the entire alternator current is supplied to the load and the voltage is constant (figure 1).

To build a current-speed characteristic, the formula is used:

\[
I_a = I_{a\text{max}} \cdot (1 - e^{\frac{n_0 - n_a}{\tau}})
\]

where \( I_a \) - alternator current, A; \( I_{a\text{max}} \) - maximum alternator current, A; \( n_0 \) - frequency of rotation of the rotor of the beginning of the recoil, rpm; \( n_a \) - current rotor speed, rpm; \( \tau \) is the time constant of the exponent approximating the curve of the current-velocity characteristic.

We used the formula:

\[
\tau = \frac{n_0 - n_p}{\ln (1 - \frac{I_a}{I_{a\text{max}}})}
\]

where \( n_p \) is the estimated rotor speed, rpm; \( I_p \) - rated alternator current, A.

![Figure 1. Current-speed characteristic of the automotive alternator](image-url)
The change in the factor $k_e$ in the frequency range of the automotive alternator is shown in Figure 1. The alternator has the greatest efficiency in the zone of medium rotational speeds (1500-2500 rpm), which is consistent with the data of researchers [5, 6].

It was proved in [1, 7] that the occurrence of a fault even at an early stage of development leads to a decrease in the current strength of the alternator (decrease in the current-speed characteristic of the alternator) (Figure 2). Therefore, the value $k_e$ can be used to assess the technical condition of the automotive alternator [8–11].

\[ k_e = \frac{l_a}{n_a}. \]  

(3)

Figure 2. Effect of fault on the current-speed characteristic of the alternator

3. Results of experimental studies

A current shunt with a nominal value of 100 A was used to measure the alternator current during the movement of the vehicle. The current was recorded using the CEM DT-171V DC data logger. This device allows you to record in the DC voltage values in the range from 0 to 30 V with up to 32,000 values stored in memory. The connection diagram of the datalogger to the alternator is shown in Figure 3.

In addition to the amperage, during the experiment, the monitoring of the crankshaft speed of the internal combustion engine was carried out. To determine the current speed values, a standard crankshaft position sensor was used, the values of which were displayed on the laptop computer screen via the DLC3 (OBD-II) connector using the ELM327-WiFi adapter (software: OBD Fusion) (figure 3).

The load cycle was carried out on a Hyundai Getz car equipped with an alternator with a maximum current of 90 A.

Figure 4 shows the results of changing the speed of the internal combustion engine during the movement of the vehicle. The average speed was $n_{average} = 1762 \text{ rpm}$.

The current strength of the alternator during the movement of the vehicle (Figure 5) does not remain constant since it depends on the speed of the crankshaft of the internal combustion engine, as well as the number and power of consumers involved. The average current strength was 27.8 A, but there were times with low (7 A) and high (47 A) load on the alternator.
A1 – an electronic control unit for an internal combustion engine,  
A2 – a diagnostic scanner ELM 327 Wi-fi,  
A3 – a laptop computer,  
B1 – a position sensor for the crankshaft of an internal combustion engine,  
B2 – a vehicle speed sensor,  
G1 – an automotive alternator,  
GB1 – a battery,  
HL1 – control lamp,  
pV1 – data logger,  
R1-Rn – consumers involved,  
RS1 – current shunt (100 A),  
S1-Sn – switches, switches and consumer control buttons,  
S – ignition switch,  
T1 – clamp meter,  
X1 – diagnostic connector DLC3.

Figure 3. Electrical diagram of the test

Figure 4. Change in crankshaft speed

4. Alternator load determination
The loading of the alternator can be called the ratio of the current strength of consumers at the current time to the potential capabilities of the alternator for a given speed:

$$Z_a = \frac{I_{al}}{I_{a \max}(n_i)}$$  \hspace{1cm} (4)

where $I_{al}$ is the current value of the alternator current, $A; I_{a \max}(n_i)$ - current strength of the alternator according to the current-speed characteristic for the current value of the rotor speed of the alternator, $A$.  

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The change in load factor during alternator operation is shown in Figure 6.

Figure 5. Alternator current change

Figure 6. Change in the load factor of the automotive alternator

The average load factor of the automotive alternator was $Z_a = 0.387$, the maximum load factor reached $Z_{a,max} = 0.93$, which is explained by the combination of low rotor speed and high power consumption. Thus, the load factor more objectively evaluates the charge balance of the vehicle, since the battery discharge is possible even with the regular operation of the vehicle.

Further research will be aimed at identifying changes in the charge balance of the vehicle in the event of a fault of the automotive alternator and starter battery [12, 13].
5. Conclusion
The charge balance of the vehicle indicates whether the starter battery is being charged while the vehicle is running. For normal operation of the power supply system, the charge balance must remain positive, preventing progressive discharge of the battery. A decisive influence on the balance of electricity is provided by the current output of the alternator, which depends on the rotor speed.

The maximum current output of the alternator is described by a current-speed characteristic depending on the technical condition of the alternator. In the process of vehicle movement, the rotor speed and alternator current strength vary over a wide range determined experimentally. The ratio of these parameters is the alternator efficiency coefficient, which can be used to assess the technical condition of the automotive alternator.

The productivity of the vehicle’s charge balance is objectively evaluated by the alternator load factor. Further research will be aimed at identifying changes in the charge balance of the vehicle in the event of a malfunction of the automotive alternator and starter battery.

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