Getting external load characteristics of the axle-box generator

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Abstract. This article addresses the problem of supplying freight railcars. It is about the axle-box generator. The generator uses to power the on-board electronics. The design feature consists in the fact that the generator is installed to the generator's axle-box and, as a result, it has increased requirements for the weight and size indications. The generator was designed with an external rotor due to the limited space, since the rotor acts as an inductor. The inductor is made of permanent magnets. The stator is made of laminated electrical steel in the six-pointed star form. The winding is made of copper conductor with a cross-sectional area of 0.2 mm². Characteristics are presented in the form of waveforms and graphs. During the experiment, a number of oscillograms were taken and harmonics were counted. Voltage were also measured at different loads and rotation speeds. The obtained power at an average speed of 30 km/h was 4 W, and at a speed of 80 km/h it was 6.3 W. The method for determining the parameters of the anchor chain equivalent circuit is given.

1. Introduction
This article explores the autonomous power source of a freight wagons [1, 2]. Different equipment is installed on the cars, the equipment has the follow functions: geolocation determination, monitoring the wagons state parameters etc. But since there is no on-board network on freight cars, there is a problem with the electric power supply [3, 4, 5]. It’s very difficult to provide power to the cars from the locomotive centrally as the trains are often reformed, which entails high operating costs. With such a design, there is an accident possibility due to the human factor. This reduces the system reliability. This problem can be solved by using the generators directly located on the freight wagons [6, 7, 8]. There are many other power electric sources, but in this article we will focus on the axle-box generator of electromechanical action [9, 10, 11]. Its main function is to supply the wagon with uninterrupted electric power during its moving to ensure the smooth operation of the on-board electronics. To determine the basic parameters of the generator magnetic system, mathematical modelling was previously performed [12, 13, 14].

2. Generator construction
The generator consists of an inductor with permanent neodymium magnets and an anchor made in the a six-pointed star form (figure 1). The stator acts as an anchor, and a rotor - as an inductor (figure 2) [15, 16, 17]. The stator and the rotor are rigidly and coaxially connected relative to each other. The inductor is made of a steel cylindrical shape core, in which the electro erosive installation cuts grooves for permanent neodymium magnets with a minimum gap [19]. The size of the magnets is 10x10x10 mm. Magnets are installed in these grooves in two rows.
The anchor is made of laminated electrical steel with a thickness of 0.5 mm to reduce the remagnetization loss [20, 21, 22]. The winding is made of varnished copper conductor with a cross-sectional area of 0.2 mm². The windings have a serial connection, so the currents summarized and there was maximum efficiency at the output. The winding resistance is 16 ohms. In our variation, the generator has one phase and it’s constructed with an external rotor, since in order to obtain the highest EMF it is necessary to place more magnets in a limited space [23, 24, 25]. The rotor is attached to the shaft in the axle box using bolted joints. In turn the stator is attached to the fixed parts of the car carriage and to the rotor through the bearing. This generator design allows to withstand shock loads during the movement of the composition. Through the inspection cover wires leaded to the external transducer. Transducer is installed on sprung masses.

3. Experimental circuit description

The experimental setup is made in full size and is driven by a three-phase asynchronous drive with frequency control (figure 3). The drive is connected to the generator coaxially by means of a soft rubber coupling. The drive and the generator are installed on a light frame. This makes it easy to transfer the installation. As a load, we used the resistors set of \( R1=8.2, R2=16, R3=33.4, R4=48.8 \) and \( R5=88.8 \) Ohm.

The experiment used the following equipment

- Teslometer Aktakom ATE-8702
- Digital photo tachometer Aktakom ATT-6000
- Multimeter-oscilloscope Aktakom ADS-2029
- Asynchronous motor AIR63B4, Power: 0.37 kW.
- Frequency converter YASKAWA Varispeed F7: 2.2 kW
4. The experiment course

For characteristics obtaining the frequency converter was used to change the asynchronous drive speed. And using an oscilloscope, we took the waveform data in the graphs and tables form, as well as the voltage at the load, using a voltmeter. The data were taken at composition speeds from 8 to 80 km/h in 8 km/h increments. For the experiment, kilometres per hour were converted to rotations per minute. Speed rotations were controlled with a tachometer. For more complete information, the magnetic induction of a single neodymium permanent magnet was also measured.

5. Results

During the experiment, it was determined the generator produces a voltage that varies sinusoidal. To analyze the harmonic composition of the generator output voltage, the data was digitized with a sampling period of 0.8e-7 sec. The data obtained were processed using the fast Fourier transform. As a result, harmonic voltage components were determined.

From the graphs of the harmonics can be seen that the third harmonic stands out (figures 4 - 9). The generator produces a voltage of 5.7, 8.75, 12.1 V at 144, 248.5 and 474 rpm respectively. When the generator rotation speed changes, the output voltage frequency also changes at 18.2, 22.4 and 35.5 Hz respectively. During the experiment, the magnetic induction of the permanent magnets’ field was measured. The average value was 437 mT. Generator power with an average design speed of 30 km/h was 4 W.
Figure 4. Oscillogram of the output voltage at an angular speed of 144 rpm.

Figure 5. Spectrogram of the output voltage at an angular speed of 144 rpm.

Figure 6. Oscillogram of the output voltage at an angular speed of 248.5 rpm.

Figure 7. Spectrogram of the output voltage at an angular speed of 248.5 rpm.

Figure 8. Oscillogram of the output voltage at an angular speed of 474 rpm.

Figure 9. Spectrogram of the output voltage at an angular speed of 474 rpm.

Inductor angular rotation speed:
where $N_{\text{meas}}$ – measured generator speed, $\min^{-1}$.

Then the calculated linear speed of the composition ($\text{km/h}$) is determined as:

$$V = \frac{R_w}{2} \cdot \frac{3600}{\pi N_{\text{meas}} R_w} = \frac{3.6 \pi N_{\text{meas}}}{60}$$

(2)

where $R_w$ – car wheel radius.

During the experiment, dependence graphs of the voltage on the design speed of $U=f(V)$, and the power on the design speed $P=f(V)$ were also obtained (figures 10-11). The value of the useful power was determined by calculation:

$$P_U = \frac{U^2}{R_{Load}}$$

(4)

where $R_{Load}$ - load resistance.

According to the obtained data during the experiment, you can determine the inductance of the armature in the steady state operation. To do this, you can use the simplified equivalent circuit of the anchor chain (figure 12).

The voltage drop effective value of generator armature circuit determines by the load current known value:

$$U_{R_g} = I R_{g}$$

(5)
where $R_G$ – active resistance of generator windings.

For anchor chain according to the second Kirchhoff law:

$$
U_{X_G} + U_{\text{load}} + U_{R_G} = E_G
$$

(6)

where $U_{X_G}$ – reactive component of voltage drop;

$E_G$ – EMF generator. Let us assume that it is numerically equal to the no-load voltage.

Voltage drop across the reactance determines by the measured voltage value at idle

$$
U_{X_G} = \sqrt{E_G^2 - (U_{\text{load}} + U_{R_G})^2}
$$

(7)

Inductive resistance of the armature winding:

$$
X_G = \frac{U_{X_G}}{I}
$$

(8)

The armature inductance is determined as (9):

$$
L_{qi} = \frac{X_G}{2\pi f}
$$

(9)

6. The results discussion

During the experiment, it was found that the dependence of power on speed is almost linear. These values allow to optimally match the load. It is also necessary to select the battery charge unit configuration so the output has the maximum power. The experiment showed that this generator is suitable for installation on freight cars of railway composition. The power produced by the generator is enough to power the on-board electronics when the speed changes in a wide range. The graphs show that at speeds not exceeding 50 km/h, the most effective load will be the resistance of 33.4 Ohms, and over 48.8 Ohms. This is due to the fact that the winding resistance varies with the speed changing. Therefore, the design should take into account how fast the composition moves with during the long time and select the appropriate load. Oscillograms and spectrograms of the output voltage show the harmonic distortion’s permissible level, which does not exceed 5%.

7. Conclusion

The experiment results showed this generator is capable of delivering 4 W at an average estimated speed of 30 km/h, and at a speed of 83 km/h, output power was 11.4 W. This generator design does not allow to obtain a high output power to supply the passenger cars. But it is quite enough to supply the batteries to power the electronic diagnostic systems for freight cars.

During the generator rotation speed changing, the voltage and frequency change too. Therefore, the battery charge unit must rectify and stabilize the voltage. Thus, this generator copes with the task and can provide electrical power to electronic components installed on freight cars.

Using the above method, it is also possible to determine the parameters of the anchor chain replacement circuit, which is often required when conducting numerical experiments and simulations.

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