The Axle Box Generator Efficiency Determination Using A Scalar Frequency Controlled Induction Electric Drive

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Abstract. The article discusses a method for determining the axle box generator efficiency. The generator is installed in the axle box of the freight car. It is driven by a wheels pair. The axle box generator provides power supply to freight car systems: diagnostics, geolocation and telemetry. To determine the efficiency, an indirect method of determining the mechanical power transmitted to the axle box generator is considered. The electromagnetic torque is determined through the induction electric drive model parameters of the generator. The article describes an experimental unit. It consists of a test generator, an induction electric drive, and an open platform frequency converter. The converter control system was created in MexBios Development Studio software. Oscillograms of generator tests are presented.

1. Introduction
The rail freight direction is developing. There is a demand for modern types of monitoring the condition of the car [1, 2]. Control electronics are installed on a freight car for status monitoring. In this regard, it is necessary to ensure the electronics autonomous operation when the train is moving. The electronics power consumption is not large, so the axle box generator can be used. Due to this, electronics is used without the construction of additional wiring between freight cars. In this regard, the system reliability increases. This article discusses the determination of the axle box generator efficiency. For testing, an experimental unit was assembled. It consists of a frequency converter, an induction electric drive and an axle box generator. The article discusses the indirect torque control method to determine the generator efficiency.

The axle box generator is a synchronous machine with permanent magnets [3, 4]. The machine construction includes a rotating inductor and a fixed anchor [5, 6]. There are 6 poles on the stator. To test the generator, a frequency control induction electric drive is used.

2. Mathematical description
The mechanical power on the generator is defined as (1):

\[ P_{IG} = P_{2AM} \]  \hspace{1cm} (1)

where \( P_{IG} \) – is the mechanical power supplied to the generator;
\( P_{2AM} \) – mechanical power generated by the drive motor.

The power generated by the electric motor is defined as (2):

\[ P_{2AM} = \omega_m T_L \]  \hspace{1cm} (2)
where \( \omega_m \) – is the rotor angular velocity;
\( T_L \) – is the load torque by the generator.

The linear train speed is related to the inductor angular velocity of the axle box generator by equation (3):

\[
V = \frac{R_w}{2} \omega
\]

where \( R_w \) – is the freight car wheel radius.

The generator efficiency is defined as (5):

\[
\eta_G = \frac{P_{2G}}{P_{1G}}
\]

where \( P_{2G} \) – is the electric power generated by the generator (6).

\[
P_{2G} = \frac{U_G^2}{R_L}
\]

where \( U_G \) – is the voltage at the output of the generator;
\( R_L \) – generator load resistance.

Taking into account expressions (2), (3), (4), the generator efficiency can be defined as (5):

\[
\eta_G = \frac{R_w U_G^2}{2VR_L T_L}
\]

An analysis of equation (5) shows that it is difficult to determine the load torque \( T_L \).

The load torque can be estimated indirectly through the state variables of the drive motor \([7, 9]\). To do this, the induction motor mathematical description in a fixed coordinate system is used (7):

\[
\begin{align*}
\dot{u}_s\alpha &= R_s i_s\alpha + L_s \frac{di_s\alpha}{dt} + k_n \frac{d\psi_s\alpha}{dt} \\
\dot{u}_s\beta &= R_s i_s\beta + L_s \frac{di_s\beta}{dt} + k_n \frac{d\psi_s\beta}{dt} \\
0 &= -k_n R_s i_s\alpha + \frac{1}{T_s} \psi_s\alpha + \frac{d\psi_s\alpha}{dt} - \frac{R_s L_s}{\sigma} \psi_{s2\alpha} + Z_{r\alpha} \omega_n \psi_{r\alpha} \\
0 &= -k_n R_s i_s\beta + \frac{1}{T_s} \psi_s\beta + \frac{d\psi_s\beta}{dt} - \frac{R_s L_s}{\sigma} \psi_{s2\beta} + Z_{r\beta} \omega_n \psi_{r\beta} \\
M &= \frac{3}{2} p_s k_s (\psi_{s\alpha} i_s\alpha - \psi_{r\alpha} i_s\alpha) \\
\frac{d\omega_n}{dt} &= \frac{M - B \omega_n - T_L}{J}
\end{align*}
\]

where \( u_s\alpha, u_s\beta, i_s\alpha, i_s\beta, \psi_s\alpha, \psi_s\beta \) – are the spatial components of the voltage, current and rotor flux linkage vector;
\( \omega_n \) – is the rotor angular velocity;
\( M \) – is the induction motor electromagnetic torque;
\( B \) – is the friction coefficient.

If the stator current is measured, then system (7) can be converted into the operator form (8):
\[
\begin{align*}
\psi_{sa} &= k_s \left[ \frac{u_{sa} - R_s i_{sa} + L_s' i_{sa}}{p} \right] \\
\psi_{sb} &= k_s \left[ \frac{u_{sb} - R_s i_{sb} - L_s' i_{sb}}{p} \right] \\
M &= \frac{3}{2} Z_p k_s \left( \psi_{sa} i_{sb} - \psi_{sb} i_{sa} \right)
\end{align*}
\] (8)

In steady state operation, the load torque can be calculated as (9):

\[ T_L = M - B\omega_m. \] (9)

3. Hardware

An experimental unit has been created to determine the axle box generator efficiency. An induction electric drive without a mechanical converter was used.

![Figure 1. Experimental unit: 1 – induction motor, 2 – generator, 3 – frequency converter; 4 – speed sensor.](image)

Figure 1 shows a photo of an experimental unit. It consists of an induction motor with a power of 370 W and a synchronous speed of 1500 rpm, an axle box generator with a power of 16 W, a frequency converter with an open platform and a speed sensor.

To develop, simulate and debug the frequency converter control system, Mexbios Development Studio software was used [10]. Figure 2 shows the graphical interface of the created program. It is used to start and evaluate the operation parameters of the induction motor and generator.
Figure 2. Figure 2. Graphic User Interface (GUI).

A digital control system as a structure is a state machine (Figure 3), consisting of several subsystems.

Figure 3. The state machine of the control system.

The «Drivers» subsystem controls the inverter power keys (Figure 3). The «Protect» subsystem is responsible for various types of power unit protection from fault current and voltage values. The «Scalar» and «VoltControl» units are used for scalar control. The «Calc P» formula is a block diagram for calculating the electric motor power load and the load torque (Figure 4) using expressions (2), (7), (8).
Figure 4. Block diagram for determining the electric motor power load and the load torque.

The digital integration block is shown in Figure 5.

Figure 5. Integrator block.

4. Experiment features
In the course of the experiment, a different generator speed was set. It corresponds to certain values of the linear motion speed of the car. It corresponds to certain movement speed values of a freight car. In this case, the torque load and the power load values were determined in an indirect way. The rotation speed was determined by an incremental encoder. The generator output power value and the efficiency were determined by the expression (6).

5. Results
The motor speed change with a stepwise change in the voltage frequency is shown in Figures 6-11.
To assess the load moment determining accuracy in dynamic mode, the oscillograms (Figure 11, 12) additionally shows a linearly increasing load torque curve (T1).

6. Conclusion
The proposed method determines the power consumption of the axle box generator and the load torque. The developed frequency converter control system operates in the speed range of 1:225. In
dynamic operating modes and with sharp fluctuations in speed, the determination error can reach 300%. However, in the steady state operation mode at low loads, the error is not more than 5%. Under real operating conditions, the acceleration during the train movement is small and amounts to 0.3 m/s². The axle box generator efficiency is 68% at a speed of 83 km/h and 51% at a speed of 30 km/h.

7. References

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