1. Introduction

There is a problem in the use of electric motors in modern practice of operation of switch electric drives of railway automation [1, 2]. There is a situation where the lifetime guaranteed use of electric drives reaches the end, or even runs out for a large number of units, but despite these they continue to be used in the future, which mainly causes an increase in load on the engine and shorten its life.

In this matter, it is necessary to develop a theoretical basis for determining the possibility of extending the life of such electric drives and scientifically substantiate them in order to grant or prohibit in each case the authorization for further operation of each individual switch electric drive.

The aim of this research is determination of the nature of the load on the engine when it applied in the electric drive with long term of operation.

2. Methods

The operating factors of switch electric motors are influenced by the following factors: stability of the power source, nature and value of load, environmental conditions, own design features [3–5]. The magnitude of the load on the engine is determined by the mass of the tongue that must be transferred to change the direction of the rail track. In this case, the nature of the load on the engine is determined by the reducer, which converts the rotational motion of the engine into a translational movement of the damper rack. Transmission mechanism of electric drives (Fig. 1) consists of four cascades. The rotational motion of the motor shaft is converted into a translational movement of the damper rack by four gear pairs, the parameters of which are given in Table 1 [6, 7].

Fig. 1. General view of the transmission mechanism of the drive: 1 – turn limiter; 2 – damper rack; 3 – wall of oil bath; 4 – main gear shaft; 5 – shim of the main shaft; 6 – radial cut-out on the projecting cylindrical part; 7 – output gear shaft of the reducer; 8 – back cover of the reducer; 9 – spacer ring; 10 – shim; 11 – casing of the reducer; 12 – gear wheel; 13 – splines; 14 – frictionless bearing; 15 – friction casing; 16 – steel bushing; 17 – movable disks; 18 – spline; 19 – steel bushing; 20 – three disc springs; 21 – shim; 22 – nut; 23 – screw; 24 – splines; 25 – safety shim; 26 – springs; 27 – input gear shaft of the reducer; 28 – front cover of the reducer; 29 – gear wheel; 30 – gear wheel; 31 – shim main shaft; 32 – trapezoidal projection; 33 – projection; 34 – detent
Table 1

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Cascade number</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
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<tr>
<td>Number of teeth:</td>
<td></td>
</tr>
<tr>
<td>gear</td>
<td>14</td>
</tr>
<tr>
<td>wheel</td>
<td>68</td>
</tr>
<tr>
<td>damper rack</td>
<td>–</td>
</tr>
<tr>
<td>module</td>
<td>1.5</td>
</tr>
<tr>
<td>Cascade number</td>
<td>4.86</td>
</tr>
<tr>
<td>Total Transmission Number</td>
<td>70,5</td>
</tr>
</tbody>
</table>

Fig. 2. Connection of engine and working machine

As the value of the coefficient of elasticity increases, the mechanical part becomes more rigid and the deformation decreases. And as its value approaches infinity, the motion transmitted from engine to the working machine does not twist and the mechanical part of the drive can be considered as a single mass system (Fig. 3) [9–13].

Fig. 3. Equivalent single-mass system

The moment of inertia of the working machine is reduced to the motor shaft. The speeds of the engine and the working machine are the same. But in cases where the stiffness factor is small and the deformation becomes significant, there can be several such masses connected by the shafts.

Analysis of multi-mass systems is extremely complex, so all the masses are usually reduced to two: an engine with its own moment of inertia and a working machine separated by elastic moment and its own moment of inertia. Such a mechanical structure is a two-mass system (Fig. 4) [7, 10].

If the gears connecting the engine and the working machine are not solid shafts, planetary gears or ropes, but are represented by a reducer to change the speed of rotation, then the mechanical connection by means of gears requires consideration of the effect of the gap on the dynamics of the two-mass mechanical system. Let’s consider the equation of a two-mass system under this condition.

Fig. 4. Equivalent dual-mass system with elastic coupling

Mechanical coupling with gears requires taking into account the effect of the gap on the dynamics of the two-mass mechanical system. The presence of a gap makes the dependence \( M_{el} = f(\phi) \) nonlinear. To account for this nonlinearity, it is necessary to consider the effect of the gap on the gear case example (Fig. 5).

At the beginning of the rotor movement of the engine, the working machine remains stationary through the gap. The elastic moment at this \( M_{el} = 0 \). After passing a gap, the working machine starts to rotate. An elastic moment appears. The dependence \( M_{el} = f(\phi) \) has the form of nonlinearity of type “insensitivity” (Fig. 6).

Fig. 5. Gear of mechanical transmission

The gap size \( \delta_1 \) and \( \delta_2 \) depends on the starting position of the transmission. Usually accepted \( \delta_1 = \delta_2 = \delta/2 \), where \( \delta = l_1 - l_2 \), which is relevant for the transmission mechanism of the switch electric drive, because during all time of operation it works the same number of times in the forward and reverse directions. In this case, the deterioration of both gears on both sides appears simultaneously. The magnitudes of \( \delta_1 \) and \( \delta_2 \) are affected by the time and intensity of operation.

A block diagram of a two-mass gap-based system is shown in the Fig. 7.

Fig. 7. Structural diagram of a two-mass system with the gap

The system of differential equations of a two-mass mechanical system with the gap has the following form [6]:

\[
\begin{align*}
J_1 \frac{d\omega_1}{dt} &= M_{ex} - M_{el}; \\
J_2 \frac{d\omega_2}{dt} &= M_{el} - M_{out}; \\
\frac{d\Delta\phi}{dt} &= \omega_1 - \omega_2; \\
M_{el} &= \begin{cases} 
0, & |\Delta\phi| < \frac{\delta}{2}; \\
c_{12} \left( \Delta\phi - \frac{\delta}{2} \right), & \Delta\phi \geq \frac{\delta}{2}; \\
c_{12} \left( \Delta\phi + \frac{\delta}{2} \right), & \Delta\phi \leq -\frac{\delta}{2}
\end{cases}
\end{align*}
\] (1)
where \( I_1 \) – moment of inertia of the engine, \( I_2 \) – load moment of inertia, \( \omega_1 \) – angular speed of the motor shaft rotation, \( \omega_2 \) – angular speed of the load rotation, \( M_{en} \) – moment on the motor shaft, \( M_{ld} \) – elasticity moment, \( M_{d} \) – load resistance moment, \( c_{12} \) – coefficient of elasticity, \( \Delta \varphi \) – load moment of inertia.

3. Results

Rotation transmission system that takes into account the gap and a system that does not account for it have a fundamental difference.

From the obtained values it becomes known that the increased gap in the mechanical transmission leads to the appearance of a pulsating load (Fig. 8), at a time when such a pulsation is minimal in the absence of a gap (Fig. 9).

![Fig. 8. The angular velocities of the first and second masses with the gaps of the mechanical transmission](image)

It should also be noted that the experiments were performed for the reduced two-mass system, and since the reducer has four stages of transmission, the effort will be even more unstable.

4. Discussion and conclusions

It is important to note that as the operating time increases, the gap in the mechanical transmission increases as the deterioration of the gears increases. With the increase of the gaps, the instability of the load on the shaft of the electric motor also increases. This leads to an increase in electricity consumption, while its nature takes on a pulsating appearance. The engine starts operating in the mode of additional load, which leads to a shortening of its life. It should be also taken into account that the electrical network is an unstable power source, and therefore the operation of the engine is further complicated, which leads to an increase in its wear.

Thus, the effect of the gaps in the mechanical transmission on the operation of the switch motor is established. On the basis of the established dependence in carrying out additional studies, it is possible to determine the regularity between the increase in the gap and the life of the electric motors. In addition, the measurement of the gaps will allow timely fixation of their increase and by extrapolation to predict the achievement of their critical values and perform timely replacement of equipment.

References