THE INFLUENCE OF THE GAPS IN THE MECHANICAL TRANSMISSION OF THE REDUCER OF THE SWITCH ELECTRIC DRIVE

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Abstract: Switch electric drives are one of the most important and responsible components of railway automation, and therefore require the development and implementation of advanced diagnostic systems. Achievement of the goal is possible only through the use of modern mathematical and software tools. There is a problem in the use of electric motors for switch electric drives today. The point is that the nature of the load on the engine is determined by the reducer. Deterioration appears on the reducer during operation. The appearance of gaps between the gears causes the instability of the load on the shaft. Measurements and control of the size of the gaps is not performed. To solve this problem, it is proposed to use linear measurement of the gaps of the gears and further modelling of the reducer. This method will allow to determine the arising load fluctuations by the deviation of the angular velocities of rotation of the drive and driven shafts. The effect of the gaps on the system operation is shown by model in the form of transfer functions of the constituent elements and the system of equations. It will be possible to set limit values for the deterioration of the gears of the reducer by the determination the maximum deviation of shafts angular speeds of rotation in order to take measures in advance for their timely replacement and to keep the engines from excessive load.

Keywords: electric motor, switch electric drive, railway automatics, mechanical transmission, reducer, single-mass system.

1. Introduction

There is a problem in the use of electric motors in modern practice of operation of switch electric drives of railway automatics [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].

The drive motor is connected to the input shaft of the reducer by an alignment clutch, which allows a small radial shift of the motor shaft relative to the input shaft of the reducer, while maintaining the parallelism of their axes.

In transient (dynamic) modes, all the elements of the mechanical components to which the moment is attached are deformed. Let's consider the process of transferring torque from the engine to the working machine (**Fig. 2**).

There is a twisting of the shaft at the beginning of the engine rotation. The shaft end on the engine side rotates but the shaft end on the working machine is still stationary. The shaft is deformed. Calculation of elasticities of mechanical joints in modelling causes the greatest difficulties [8].

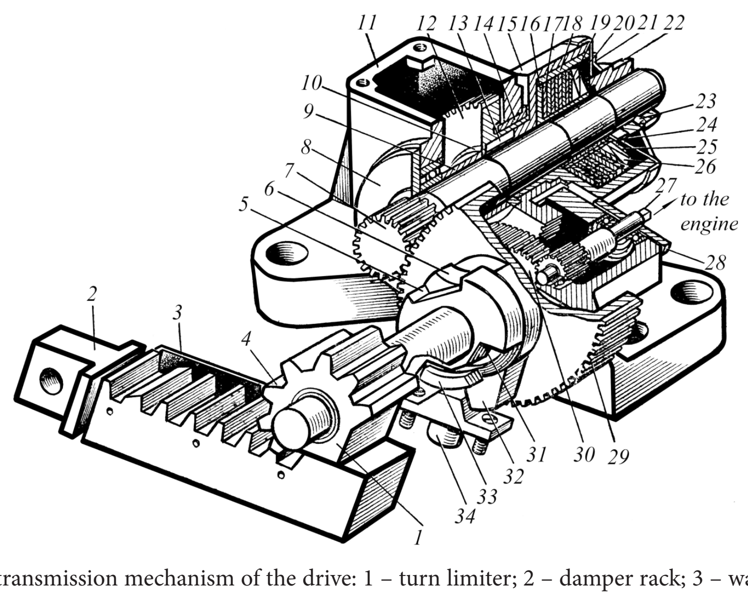

Fig. 1. General view of the transmission mechanism of the drive: 1 – turn limiter; 2 – damper rack; 3 – wall of oil bath; 4 – main gear shaft; 5 – shim of the main shaft; 6 – radial cut-out on the projecting cylindrical part; 7 – output gear shaft of the reducer; 8 – back cover of the reducer; 9 – spacer 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
Gear pairs of switch electric drives of railway automatics

Parameters	Cascade number			
	I	II	III	IV
Number of teeth:				
gear	14	14	15	7
wheel	68	60	51	–
damper rack	–	–	–	6
module	1.5	2	3	7
Cascade gear number	4.86	4.28	3.4	1
Total Transmission Number	70,5			

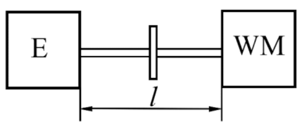

Fig. 2. Connection of engine and working machine

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].

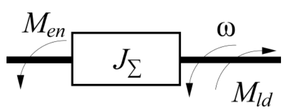

Fig. 3. Equivalent single-mass system

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 **Fig. 4** 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.

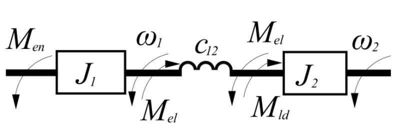

Fig. 4. Equivalent dual-mass system with elastic coupling

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 $M_{el}=f(\varphi)$ 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 $M_{el}=f(\varphi)$ has the form of nonlinearity of type “insensitivity” (**Fig. 6**).

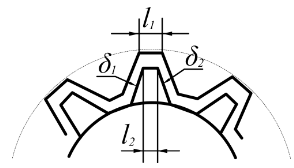

Fig. 5. Gear of mechanical transmission

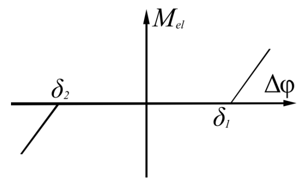

Fig. 6. Nonlinear dependence of elastic moment in the presence of the gap

The gap size δ_1 and δ_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 δ_1 and δ_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.**

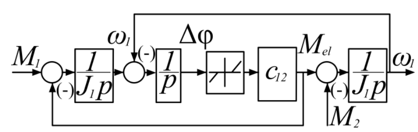

Fig. 7. Structural diagram of a two-mass system with the gap

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

$$\begin{cases} J_1 \dfrac{d\omega_1}{dt} = M_{en} - M_{el}; \\ J_2 \dfrac{d\omega_2}{dt} = M_{el} - M_{ld}; \\ \dfrac{d\Delta\varphi}{dt} = \omega_1 - \omega_2; \\ M_{el} = \begin{cases} c_{12}\left(\Delta\varphi - \dfrac{\delta}{2}\right), \ \Delta\varphi \geq \dfrac{\delta}{2}; \\ 0, |\Delta\varphi| < \dfrac{\delta}{2}; \\ c_{12}\left(\Delta\varphi + \dfrac{\delta}{2}\right), \ \Delta\varphi \leq -\dfrac{\delta}{2}, \end{cases} \end{cases} \tag{1}$$

where J_1 – moment of inertia of the engine, J_2 – load moment of inertia, ω_1 – angular speed of the motor shaft rotation, ω_2 – angular speed of the load rotation, M_{en} – moment on the motor shaft, M_{el} – elasticity moment, M_{ld} – 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**).

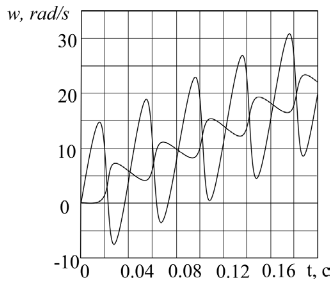

Fig. 8. The angular velocities of the first and second masses with the gaps of the mechanical transmission

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.

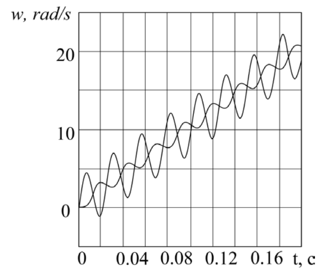

Fig. 9. The angular velocities of the first and second masses without the gaps of the mechanical transmission

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.

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