EVALUATION OF COMMUTATION AND CALCULATION OF ADDITIONAL POLES OF THE TRACTION DIRECT CURRENT MOTOR

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Introduction. The ever-increasing intensity of traffic on urban highways is accompanied by a high deceleration during braking and acceleration when starting moving vehicles. Commutation in direct current (DC) traction motors is a phenomenon caused by a change in the direction of the electric current in the sections of the armature winding of the electric motor during the transition from one parallel branch to another. In other words, this occurs when crossing the line along which the brushes are located. Such processes take place in the collector or commutator.

The commutator is a rotating mechanical transducer that changes the current direction of the current. It consists of a cylinder assembled from a large number of metal contact strips attached to the rotating shaft of the armature (rotor) of the engine [1]. The armature windings are connected to the commutator segments to transmit electric current. Converters are also used in other designs, for example, based on transistors or magnetically controlled contacts. But in the mechanical version, the switches have more advantages, which include compact overall dimensions, energy and other indicators.

When the engine is started, the commutator and the armature winding begin to move in a circle with a certain frequency n, while the brushes of the device are stationary. Before the start of switching processes, the armature current Ia flows through the brush, the right collector plate. At this point, it is divided in half between parallel armature windings. At the end of the switching process, conductors 2 and 3 pass into an adjacent parallel branch, while the flow of electric current in them changes to the opposite. The brushes in the motor may overlap several commutator plates during commutation, but this in no way affects the commutation process. The time during which the brush moves from one collector plate to the adjacent one is called the commutation period. This time interval is very short in duration (thousandths of a second).

When the end of the switching process is nearing, the area of the contact surface of the brush and the right plate decreases, and the electric current density increases. After the commutation is completed, the pairing of the brush and the right collector plate breaks, an electric arc is formed. The higher the current strength id, the more powerful the electric arc will be.

There are 3 types of commutation: 1) accelerated curvilinear commutation during which the current density under the part of the brush running onto the plate is higher than under the part running away from it. 2) Brush sparkings are observed; rectilinear commutation when the electric flux density is the same under the running and running edges of the brush. The conductor almost does not spark. 3) Slow curvilinear commutation when the electric current density under the incoming edge is lower than under the escaping one. Important indicators of the commutation process are speed of electric current change in the anchor section, current density flowing through the incoming and outgoing plates and continuity of electric current flow.

The aim of the work is to evaluate the commutation of a DC traction motor with a power of 150 kW, a nominal speed of 1480 rpm and the possibility of smooth speed regulation in a wide range, and provide recommendations for choosing a method of improving commutation by constructive means.

Materials of research. In the working condition the DC motor continuously switches sections of the armature coil from one turn to an adjacent one, and the electric current changes its direction. Due to the fact that such switching periods are short in time, the rate of change of current direction in the section is always quite high. The formed electric arc and the appearance of sparks at the final moment of switching between the brush and collector plates leads to damage to the outer sides of the switch. Its surface burns, as a result, the contact between the brush and the collector deteriorates. Such switching is considered unsatisfactory. The calculation of the commutation is carried out by using method described in [2].

The main factors which contribute to the occurrence of a circular fire on the collector of the traction engine, are: slippage of electric locomotive wheel pairs due to improper selection of engines and unqualified management of the electric locomotive, low quality of the straightened feeder stresses, as well as deficiencies in constructive and technological implementations. Analysis of failures in direct current machines of general industrial application showed that most operational failures occur due to malfunctions collector [3]. Failures of the collector-brush unit occur in the following main ways reasons: wear of the collector, wear of electric brushes and deformation of the collector. Wear and tear collector is described by the truncated normal distribution law. Great influence on the wear of the collector is caused by the condition of the polish, the nature of the switching process, and the availability burn on the collector. The reliability of the collector-brush assembly is significantly affected by the wear of electric brushes. The switching reliability of electric machines depends on the correct geometry of collector The collector changes due to the influence of technological and operational factors the shape of a circle. In the process of processing and manufacturing the collector, there are technological deviations causing such defects as eccentricity, ovality, pitting (at individual points of the surface), which progress under operating conditions under the action of dynamic and electromagnetic forces, as well as as a result of weakening tightening of collector pins, shrinkage of insulation.

According to the recommendations calculationof the reactive electromagnetic force (EMF) are follows.

The magnetic conductivities of the slot, which determines the flux coupling of the slot dispersion per unit length of the machine, are

at the nominal speed of rotation $n_n = 1480\ rpm$

$$\zeta = 0{,}6 \times \frac{h_p}{b_p} + \frac{l_s}{l_t} + \frac{500^2}{A \times l_t \times w_c \times V_a} \times \frac{a}{p} = 0{,}6 \times \frac{35}{10{,}9} + \frac{39{,}5}{32} + \frac{500^2}{280 \times 32 \times 1 \times 27{,}9} \times \frac{2}{2} = 4{,}16$$

at the maximal speed of rotation $n_{max} = 3200\ rpm$

$$\xi_{max} = 3,62$$

Reactive EMF

at the nominal speed of rotation $n_n = 1480\ rpm$

$$e_{rn} = 2\times l_t \times w_c \times A\times \xi \times V_a \times 10^{-6} = 2\times 32\times 1\times 280\times 4,16\times 27,9\times 10^{-6} = 2,08\,V$$

at the maximal speed of rotation $n_{max} = 3200\ rpm$

$$e_{r\,max} = 3,91V$$

The obtained values are in the permissible range, which ensures satisfactory commutation conditions without a compensating winding.

Union magnetic conductivities

$$\lambda_p = 1,25\times\left(\frac{h_1}{3b_p}+\frac{h_2}{b_p}\right) = 1,25\times\left(\frac{14}{3\times 11,6}+\frac{6}{11,6}\right) = 1,744\,V$$

$$\lambda_z = \frac{b_{Z1}}{2\delta_{ap}} = \frac{13}{2\times 8} = 0,813,\ \lambda_S = 0,5,$$

where $\delta_{ap} = 8\ mm$ – gap under the additional pole.

The reduced width of the brush is relative to the reduced width of the brush to the collector division

$$b_b = u_u b_b - \delta_b + \beta_K 1,25\times\left(1-\frac{a}{p}\right) = 1,6-0,08+0,437\times\left(1-\frac{2}{2}\right) = 1,52\,sm$$

$$\gamma' = \frac{b_b'}{\beta_K} = \frac{1,52}{0,437} = 3,48$$

For $\varepsilon_K = 2,5,\ u = 5,\ \gamma' = 3,48$ was defined

$$4u' = f\,(\varepsilon_K,\ u,\ \gamma') = 9$$

Unit resultant conductivity of the groove is

$$\xi' = \frac{4u'}{2\gamma'}\left(\lambda_P+\lambda_Z\right)+\lambda_s\times\frac{l_s}{l_t} = \frac{9}{23,48}\times(1,744+0,813)+0,5\times\frac{39,6}{32} = 3,93$$

Reactive EMF

at the nominal speed of rotation $n_n = 1480\ rpm$

$$e_{rn} = 2\times l_t \times w_c \times A\times \xi' \times V_{an} \times 10^{-6} = 2\times 32\times 1\times 280\times 3,93\times 27,9\times 10^{-6} = 1,96\,V$$

at the maximal speed of rotation $n_{max} = 3200\ rpm$

$$e_{r\,max} = 4,25V$$

The maximum voltage between adjacent collector terminals is

$$e_{k\max} = \frac{2p\times U_n}{\alpha K}\times K_n = \frac{4\times 600}{0,665\times 230}\times 4,49 = 70,45\,V$$

The obtained result does not allow a double current overload when the field is weakened.

According to the calculations and recommendations described in [4], it is recommended to choose additional poles between the main poles of the motor as a way to improve commutation. Their calculation is given below

Dimensions of the additional pole

$$b_{ap} = b_k - 2\delta_{ap} = 5 - 2 \times 0{,}8 = 3{,}4\,sm$$

$$l_{ap} = l_t = 32\,sm$$

Induction in the gap of the additional pole

$$B_{ap} = \zeta A \frac{l_t}{l_{ap}} \times 10^{-4} = 3{,}62 \times 280 \times \frac{32}{32} = 0{,}1014\,Tl$$

The gap under the additional pole has been clarified

$$\delta_{ap} = \frac{(k_{ap} - 1) \times \tau}{1{,}6 \times \zeta \times k_{ap} \times \frac{l}{l_t}} = \frac{(1{,}3 - 1) \times 28{,}25}{1{,}6 \times 3{,}62 \times 1{,}125} = 1{,}3\,sm$$

Since it was assumed that the gap is 0.8 cm, then between the yoke and the additional pole it is necessary to make a gap of non-magnetic spacers with a thickness of 0.5 cm. It is also worth providing for steel spacers made of sheet steel with a thickness of 0.5 mm.

Conclusions. Based on the results of the calculation and evaluation, the following conclusions can be made:

- the calculated values of the reactive EMF are in the range that ensures the specified switching modes at the nominal load;
- the maximum load between the collector plates due to field distortion during overload reaches 70,45 V, which will lead to a circular fire on the collector;
- two-fold current overload with a weakened field is unacceptable;
- the rated operating mode should be considered with a field weakening of 87%. Starting the motor with an armature current of more than 540 A is impossible due to the commutation conditions.

References

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