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E.V. Iksar, Z.G.Nazirova, K.K. Jurayeva
Tashkent state transport university, Tashkent, Uzbekistan
E-mail: lade00@bk.ru

THERMAL PROCESSES OF ASYNCHRONOUS FREQUENCY-CONTROLLED MOTOR TAKING INTO ACCOUNT TRACTION LOADS

Abstract. In the article proposes a method for estimating the thermal state of an asynchronous traction motor. A block diagram of a thermal model of an asynchronous traction motor is presented in which the stator and rotor are modeled as concentric rotating cylinders. The convection heat exchange between two rotating cylinders is represented by modeling an air gap with an effective thermal conductivity that takes into account both thermal conductivity and convection.

Keywords. Traction motor, microprocessor control system, traction motor heating, traction calculation, thermal model, power loss, heating, traction characteristics.

Introduction.

Currently, the capacity of individual railway sections has been completely exhausted, at the same time, the efficiency of cargo transportation continues to grow due to an increase in the length and weight of trains, as this is the current way to increase the performance of the transportation process. With an increase in the weight of the train, the load on the traction motors of the locomotive increases, this leads to an increase in the values of the current flowing through the windings and their unacceptable overheating. The article discusses the thermal state of traction motors when using a microprocessor control system. When working with the converter in its volume of traction asynchronous motors (TAM), heat is released, the source of which is the energy losses that occur during the electromechanical conversion. The heat generated in the active elements spreads throughout the entire volume of the machine and is transferred to the cooling medium using a cooling system. Thus, in the volume of the machine there are heat flows and temperature differences between the individual nodes of the structure. Here it is necessary to emphasize the close connection of the thermal state of the electric motor with the operating modes. The realization of the traction properties of a locomotive is determined by the traction characteristic and has four control zones. The traction characteristic is conditionally divided into four zones, in the first zone, it is necessary to maintain the maximum possible torque according to the conditions of coupling, which are constantly changing depending on various factors, both external and internal. It should be noted that the operation of traction electric motors (TEM) of electric locomotives is associated with frequently occurring mechanical loads. The loads arising in the engine can be divided into three groups:

- loads caused by static weight loading and short-term transient modes (starting, braking, changing the operating mode of the electric motor, and so on);
- loads caused by the interaction of the railway track and the electric locomotive, the passage of rail joints and track irregularities;
- loads caused by the own vibration of the TEM and other equipment of the electric locomotive. The experience of operation of traction electric machines shows that the heating of structural components occurs unevenly, under different operating modes and conditions of their cooling.

Statement of the problem.

The task is to determine the maximum heating temperature of traction motors using the analytical heating method. The theoretical basis of this calculation is the law of conservation of energy and the theory of heating of a homogeneous body [3, 4]. A homogeneous body is understood to have infinitely high thermal conductivity and uniform energy dissipation from the entire surface, and all points of the body have the same temperature. When working with the converter, heat is released in the volume of the TAM, the source of which is the energy losses that occur during the electromechanical conversion. The heat generated in the active elements spreads throughout the entire volume of the machine and is transferred to the cooling medium using a cooling system. The results of studies on the temperature distribution along the axis of the electric motor show that in large machines with an axial cooling system, it is not enough to take into account only the average temperature of the cooling flow inside the machine. The difference between the temperatures of the frontal parts of the machine windings from the sides of the supply and outlet of cooling air from the electric motor can reach 15-35% [4]. Such a temperature gradient of TEM nodes is due to its sufficiently large size, sealing of its nodes from the external environment to protect against aggressive influences.

Materials and Methods.

When assessing the thermal state of the electric motor, it was taken into account that the main factor in the destruction of insulation is not heating by itself, but processes in insulation that occur during sudden heating and cooling. Therefore, it is relevant to develop methods for assessing the thermal state of the TAM, taking into account the impact of these processes on the insulation resource. The above allows us to conclude that information about the temperature of the stator core at one point cannot be used to correctly assess the thermal condition of the entire machine during operation, since this node may not be the most heat-stressed under certain operating conditions of the electric motor. To obtain reliable information about the technical condition and estimate the residual life of the electric motor during operation, it is necessary to have information about the complete picture of the temperature field of the machine. Obtaining experimental information requires the presence of temperature measuring instruments in the machine. Current temperature measurements in operational modes are carried out in order to prevent emergencies and assume a comparison of the achieved temperatures with the permissible parameters of the mode. Detailed information about the temperature field of the machine can be obtained theoretically based on the thermal conductivity equation. To solve the problem , the following assumptions were made:

1) in an asynchronous traction motor (ATM) with an axial ventilation system, the cooling air moves along the axis of the rotor along two parallel branches – in the ventilation ducts of the rotor and the air gap;

2) the stator and rotor of ATM are represented as a system of multilayer bodies, the connections between which are determined by the type and conditions of heat exchange;

3) heat removal from the surfaces of the ATM housing and bearing shields due to their insignificant size can be neglected;

4) the temperature of the cooling air along the length of the rotor varies linearly;

5) the heat sink through the end surfaces of the stator and rotor sheets can be neglected due to its small value;

6) the calculated sectors of the stator and rotor are divided into volumes within which the thermophysical properties of the materials are the same with the preservation of thermal bonds;

7) power losses in the stator winding are represented as distributed sources of thermal energy.

Results and Discussion.

To assess the thermal state, a model of a traction asynchronous motor is used, compiled for the number of specially heated nodes, taking into account convection from cooling. Half of the stator in the longitudinal is selected as the calculation element. The initial data for thermal calculation are: the distribution of energy losses over the volume of the machine, the values of physical quantities, primarily thermal conductivity and heat capacity, and cooling conditions on the boundary surfaces. To calculate the temperatures of the active parts of the TEM, the method of thermal substitution schemes is used [4], based on the heat exchange equation, the block diagram of the thermal model of the ATM is shown in Fig. 1. The input data for the developed model are the cooling air temperature, heat transfer coefficients, rotor speed and phase current of the stator winding. The rotation frequency and phase current determine the initial data for calculating losses.

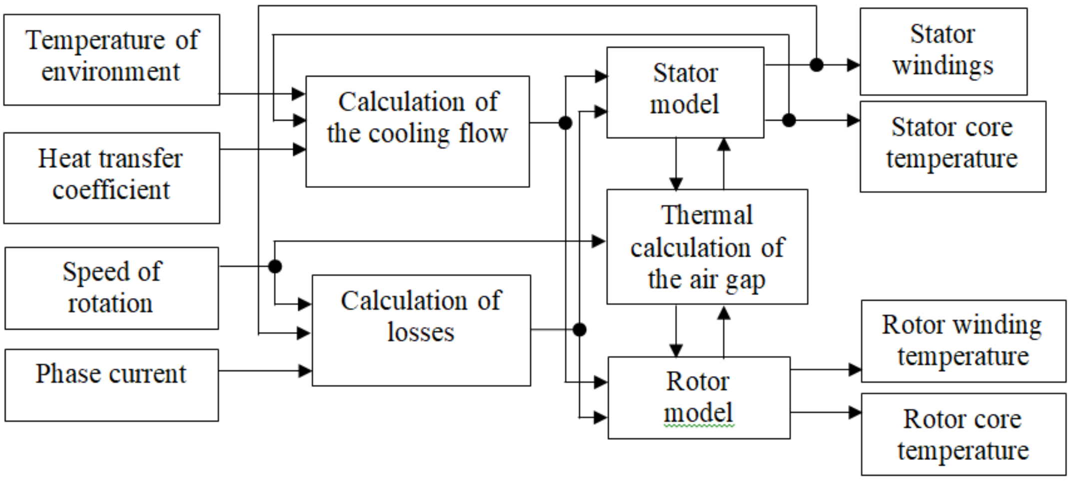

Figure 1 - Block diagram of the ATM thermal model

The output data of the model is the temperatures at various points of the winding and core of the stator and rotor of the ATM.

The presented thermal model of the ATM for calculating the temperature distribution of the stator and rotor windings adequately reflects the physical processes occurring in a closed-circuit motor with forced cooling, and can be used to quickly determine its temperature. To obtain effective thermal conductivity, the stator and rotor are modeled as concentric rotating cylinders. Convection heat exchange between two rotating cylinders.

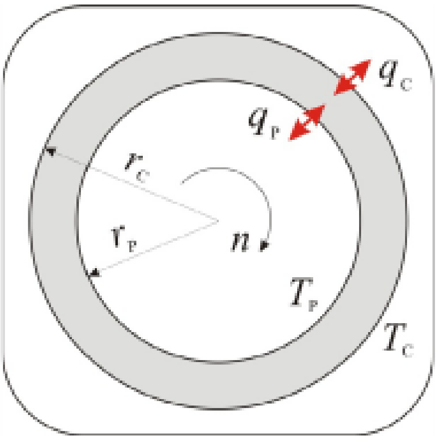

Figure 2 - Flow ratios for rotating cylinders

Heat exchange in the air gap. In the air gap, both heat transfer and convective heat exchange occurs between the moving medium and the surfaces of the rotor and stator. In the proposed thermal model, this problem is solved by modeling an air gap with an effective thermal conductivity that takes into account both thermal conductivity and convection. The convection heat exchange between two rotating cylinders is represented as a dimensional Reynolds number (Re), Taylor number (Te) and Nusselt number (Nu). Expressions for determining the Reynolds number and the Taylor number are given in [1]:

$$\mathrm{Re} = \frac{l \cdot n \cdot r_{\mathrm{r}}}{v}, \ \mathrm{Te} = \mathrm{Re}\sqrt{\frac{1}{r_{\mathrm{r}}}},$$

where l - is the length of the air gap;

n - is the rotational speed of the rotor;

r_{p} - is the radius of the rotor;

v - is the kinematic viscosity of the air.

The Nusselt number can be found by the corresponding Taylor number

$$Nu = \begin{cases} 2{,}2, & \mathrm{Te} < 41, \\ 0{,}23\,\mathrm{Te}^{0{,}63}\,\mathrm{Pr}^{0{,}27}, & 41 \le \mathrm{Te} \le 100, \\ 0{,}425\,\mathrm{Te}^{0{,}5}\,\mathrm{Pr}^{0{,}27}, & \mathrm{Te} > 100, \end{cases}$$

where is $\mathrm{Pr} = vh$ - the Prandtl number;

h - is the coefficient of air thermal conductivity.

Convective heat transfer, which is determined by the Nusselt number, can be combined with conductive heat transfer in the heat transfer equation to form an effective thermal conductivity for both conductive and convective heat transfer [2]:

$$\infty_{э}(n) = \frac{Nu\infty_{\mathrm{в}}}{2},$$

where ∞_{a} - is the thermal conductivity of stationary air.

After determining the equivalent thermal conductivity, we will use the fact that the air gap is a cylindrical annular space, as shown in Figure 2. Solving the Laplace equation and taking a homogeneous normal heat flux density q and temperature T at the boundaries of the stator and rotor air gap, we obtain the following heat flux and temperature ratios between the stator and rotor

$$q_s = \frac{\infty_{э}(n)}{r_{\mathrm{s}} \ln\left(\frac{r_{\mathrm{s}}}{r_{\mathrm{r}}}\right)}$$

$$q_{\mathrm{r}} = \frac{\infty_{э}(n)}{r_{\mathrm{r}} \ln\left(\frac{r_{\mathrm{s}}}{r_{\mathrm{r}}}\right)(T_{\mathrm{r}} - T_{\mathrm{s}})}$$

in which $q_{\mathrm{s}}, q_{\mathrm{r}}$ – the heat flow of the surfaces of the stator and rotor, respectively;

$T_{\mathrm{s}}, T_{\mathrm{r}}$ - the temperature of the surfaces of the stator and rotor, respectively;

$r_{\mathrm{s}}, r_{\mathrm{r}}$ - the radii of the stator and rotor.

The input data for the developed model are the cooling air temperature, heat transfer coefficients, rotor speed and phase current of the stator winding. The rotation frequency and phase current determine the initial data for calculating losses. Losses and cooling conditions are applied in thermal models of the stator and rotor, which are subsequently linked together using the ratio of heat transfer through the air gap. The output data of the model is the temperatures in various places of the winding and core of the stator and rotor of the ATM.

Conclusion.

Thermal calculation of traction asynchronous motors allows you to analyze the thermal state of all elements of the TAM structure.

Additional losses in the stator and rotor nodes from higher harmonics significantly affect their temperature even when operating in traction modes and account for 70% of the main losses.

With an increase in the engine load, the effect of additional losses is significantly reduced and for the stator winding is 11.3%, for the rotor winding 45%.

The temperature distribution along the length of the motor is not symmetrical for different forms of supply voltage.

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