Thermal Calculations of Asynchronous Traction Engines of Diesel Locomotives

M. A. Shrajber
Emperor Alexander I Petersburg State Transport University, Saint Petersburg, Russian Federation

Keywords: Locomotive traction motor, asynchronous traction motor, thermal calculations of electrical machines.

Abstract: The article discusses the application of the finite element method for thermal calculations of electrical equipment of diesel locomotives. The SolidWorks program builds a solid model of an asynchronous traction motor. The developed finite element model of the elements of an asynchronous traction motor makes it possible to determine the thermal state of the elements of the rotor and stator of the electric machine of a diesel locomotive. The simulation results should be recommended for use in the design of improved units of diesel locomotives, including in order to improve the reliability of existing traction motors.

1 INTRODUCTION

Diesel locomotives and electric locomotives with asynchronous traction motors were built in the Russian Federation in the 1970-1980s of the twentieth century. These locomotives were: electric locomotives of the VL80A, VL80F series and diesel locomotive of the TE120 series. The construction experience formed the basis for further design, construction and modernization, but there were also some problems that took a certain amount of time to resolve. At the moment, 12 units of electric rolling stock of the EP10 series and 10 diesel locomotives of the 2TE25A series equipped with an asynchronous traction drive are operating on the railways of the Russian Federation, and practical experience is still being accumulated.

The widespread use of asynchronous electric machines allows you to open up modern opportunities in the competition of railways with other types of transport. The clear advantages of asynchronous electric machines of autonomous locomotives are:

1) due to the high rigidity of the characteristics of the asynchronous drive, the force developed by the traction motor will be realized most fully (8-10% higher), near the adhesion limit;

2) the rated power of asynchronous electrical machines can be used in the entire range of speeds up to the design speed, as a result, the locomotive becomes universal. Operating experience shows that due to this advantage, the fleet of diesel locomotives and electric locomotives can be reduced by 10%;

3) the power of an AC machine with the same dimensions, when compared with DC machines, can be 1.5–2 times higher (due to the fact that there is no collector-brush assembly);

4) for the manufacture of an asynchronous traction drive, less expensive and less environmentally friendly materials are needed. For example, copper is required 2-2.5 times less, insulating materials - by 20-25%, asbestos and asbestos-containing materials – by 25-30%;

5) the costs for maintenance and restoration of the resource of the locomotive fleet are significantly reduced due to the absence of a collector and insulation on the rotor conductors.

Promising locomotives require the use of effective methods to improve their reliability, as well as the use of advanced technical solutions. Modern locomotive building is closely related to the use of AC traction drives, which have an advantage over DC drives due to their high reliability and power (Kiselev, 2021; Kim, 2020; Terekhin, 2020; Grachev, 2018.). An asynchronous traction motor (ATED) with a squirrel-cage rotor is the object of study in this article. Analysis of the operation of ATED under the action of mechanical, electromagnetic, thermal and other loads makes it possible to develop technical solutions to prevent malfunctions and failures during the operation of locomotives.

An analysis of the statistical data of failures of traction asynchronous electrical machines shows that

Shrajber, M.
Thermal Calculations of Asynchronous Traction Engines of Diesel Locomotives.
DOI: 10.5220/0011580000003527
In *Proceedings of the 1st International Scientific and Practical Conference on Transport: Logistics, Construction, Maintenance, Management (TLC2M 2022)*, pages 120-123
ISBN: 978-989-758-606-4

the bulk of failures occur as a result of a violation of their thermal state. About 85-95% of ATED failures are caused by various damage to the insulation of their windings. Also, the residual life of ATED depends on the operating temperatures and thermal characteristics of the materials of its elements. In this regard, solving the problem of accurately assessing the temperature parameters of ATED elements will provide an opportunity to develop relevant solutions to increase the probability of trouble-free operation of traction electric machines.

2 MATERIALS AND METHODS

Due to the design features of the underbody of diesel locomotives, the dimensions of traction motors are strictly limited, which causes higher operating temperatures of the windings and, as a result, aging of the insulation. Thermal calculations, which are used to analyze the temperature rise of armatures of DC traction motors and rotors of asynchronous electrical machines, are often based on the assumption that the winding, consisting of insulation and conductor, is a homogeneous body with an average thermal conductivity. This assumption can lead to a significant error in the results of thermal calculations (Agunov, 2017; Trianni, 2019; Filippov, 1974).

For thermal calculations of traction electric machines, the finite element method is suitable, which allows you to create thermal diagrams for complex solid structures. This method is based on the approximation of continuous functions by discrete simulation. This modeling consists in dividing the object with a grid that repeats the shape of the body; therefore, the error of this method is very small (Dvorkin, 2017). Previously, the use of this method was difficult due to the need to process a huge number of finite elements, but with the development of electronic computing technology, such problems can be solved.

The main advantage of the finite element method is the ability to move away from the usual approximate calculations based on thermal equivalent circuits, as well as move away from the simplified representations of the classical theory of heating a homogeneous body. It should also be noted that it is possible to analyze non-stationary processes of heat conduction.

The finite element method is also used to predict the internal temperatures of ATEDs with a large number of parts in the design. When creating thermal models, the following assumptions were made:

- the flow of cooling air inside the ATED moves along the axis of the rotor through the ventilation ducts and through the air gap, the temperature of the cooling air changes linearly:
- heat removal on the surfaces of the ATED housing and bearing assemblies, as well as on the end surfaces of the rotor sheets due to its insignificant value, is not taken into account;
- fragments of the rotor are divided into volumes where the thermophysical properties of the materials are the same.

Thermal conductivity is the process of heat propagation with direct contact of individual parts of electrical machines or its individual sections, characterized by temperatures.

When taking into account the assumptions, the finite element model of ATED, built in the form of a grid, will have the following differential equation in matrix form:

$$CT + KT = Q \quad (1)$$

Where T is the nodal temperature vector of the finite element mesh, K is the finite element matrix corresponding to thermal conductivity, C is the finite element matrix corresponding to thermal conductivity, Q is the internal heat release vector.

In the air gap between the rotor and the stator, heat transfer and convective heat transfer will occur. To obtain effective thermal conductivity, the rotor is represented as a concentric rotating cylinder.
The convection heat exchange between the stator and the rotor, represented by rotating cylinders, can be calculated using the Reynolds, Taylor and Nusselt numbers. The initial data for modeling the thermal state of the ATED will be: the temperature of the cooling air, heat transfer coefficients, rotor speeds and current values. These parameters are decisive when creating thermal models.

3 RESEARCH RESULTS

To analyze thermal processes in the ATED rotor by the finite element method, a solid model of an electric motor of the DAT type was built in the SolidWorks software package. Traction electric motors of the DAT type are installed both on mainline (510 kW power) and shunting diesel locomotives (305 kW power).

The rotor of this traction motor consists of an adapter sleeve on which a core of laminated sheets of electrical steel 0.5 mm thick is installed. The grooves of the core are filled with aluminum. Aluminum rods are connected to short-circuited rings. The rotor shaft is made of steel 30 HMA with heat treatment. The free end of the shaft is designed to fit the gear of the traction reducer.

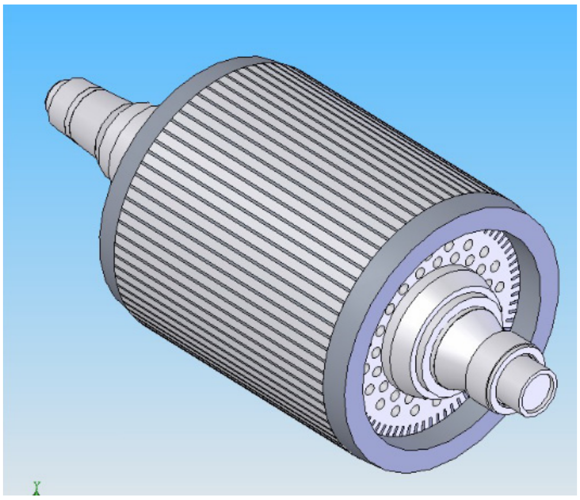

Figure 1: General view of the squirrel-cage rotor of the DAT type traction motor.

As an example of such a calculation, consider the simulation of thermal processes occurring in a squirrel-cage rotor of an asynchronous traction motor. Figure 1 shows a fragment of the rotor of a DAT type traction motor, which shows a finite element grid. After creating and assembling a solid model of the rotor, it is necessary to set the boundary conditions for the calculation (for example, the initial temperature of the model nodes, the time of current flow that heats the conductors, etc.).

The rotor of the DAT type traction motor will have a maximum phase current equal to 600 A for mainline diesel locomotives, and 320 A for shunting locomotives. Such modeling of thermal processes makes it possible to analyze the thermal state of both individual elements of the rotor and the entire assembly as a whole. It is also possible to set the element heating time from a specific value (for example, 1 minute, 30 minutes, 1 hour, etc.) until thermal equilibrium is reached. Since all modern locomotive traction motors have a forced ventilation system, the cooling air consumption will be taken into account by specifying convection on heat-releasing surfaces.

An example of calculating the thermal state of the rotor slot is shown in Figure 2. The temperature field of the temperature distribution during the flow of the rated phase current during the operation of the electric machine for 1 hour will depend on the quality of cooling. In this case, the quality of cooling will depend on the insulation parameters (insulation layer thickness, impregnation, air gaps).

When modeling, an electric machine was considered that did not have damage to the insulating layer, and also without unimpregnated areas and voids filled with air. The heat generated in the rotor winding is removed through the rotor core, so there is a temperature drop along the height of the rotor slot. In the upper layers of the rotor, heat is removed through the closing of the slot, where the heat transfer coefficient to the environment has lower values.

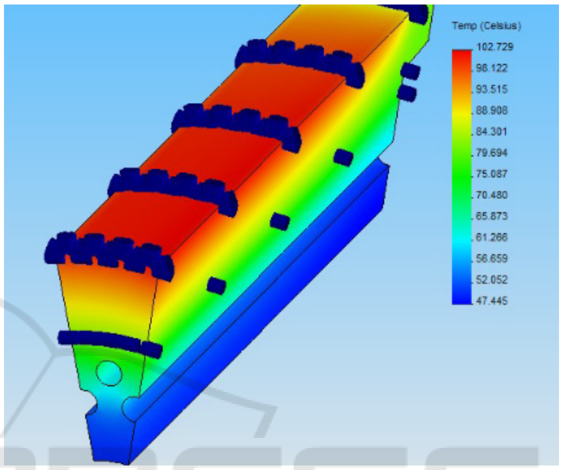

Figure 2: Simulation of the thermal state of a rotor fragment at a maximum phase current of 600 A in the absence of cooling (hourly mode).

When studying the thermal processes of aging of the insulation of traction electric motors of locomotives, attention should be paid to the effect of the layering of the insulation on the conditions of heat transfer and stress concentration in operation. Humidification of the insulation with its subsequent drying leads to the formation of swollen and non-swelled zones, which cause an increase in internal stresses. In a humid environment, zones of latent destruction are formed in the impregnating varnish, perpendicular to the diffusion of moisture.

An increase in internal stresses leads to damage to the impregnating layer of insulation, and an increase in internal stresses is aggravated by vibrations and electrodynamic effects. As a result, an increase in internal stresses leads to a decrease in the strength of the insulation, cracking of the impregnating varnish.

Insulating laminated material damage can be created simultaneously in several zones: inside the insulating layer or at the metal-fiber interface. Cracks can merge in various directions, but usually in the insulation layer, a crack occurs across the entire width of the conductor, covering the entire thickness of the layer. During cracking, the values of local stresses decrease, and the load is transferred to other layers.

Cracks can interact, forming zones that can withstand only minor loads.

Moisture and solid particles from the surrounding space enter the crack and begin to participate in hydrolysis if the temperature starts to rise. The pressure in the crack leads to its expansion and the appearance of a through defect, and water significantly reduces the electrical strength of the material and shortens the duration of the residual life of the ATED windings.

As a recommendation, impregnating compounds should be used in the repair and manufacture of electrical machines of locomotives, since the compounds do not contain such an amount of solvents in the composition. Also, the advantages of compounds are the absence of toxicity and fire hazard.

4 CONCLUSIONS

The resulting solid-state finite element model of a diesel locomotive traction electric machine quite fully describes the thermal processes occurring in the ATED in operation, which allows it to be used to predict the temperatures on the surfaces and inside the parts of AC traction motors, as well as electrical equipment similar in design. In the future, such modeling can be complicated by taking into account additional factors.

The resource of traction electric machines depends on thermomechanical stresses and the thickness of the insulating layer. Insulation properties depend on temperature cycles and fatigue from thermomechanical stresses.

A significant difference between the temperature values near the top and at the bottom of the groove causes thermomechanical stresses in the insulating layer. Even if the value of thermomechanical stresses is below the permissible value, their cyclic action destroys the insulating layer.

The results of the analysis of thermal processes that occur in the rotating parts of the ATED make it possible to conclude that the study of the elements of AC electric machines in the SolidWorks program is an accurate (with an error of no more than 5%) and a modern way to study the thermal state of the ATED of promising locomotives.

REFERENCES

Kiselev, I. G., Kurilkin, D. N., Shraiber, M. A., 2021. Thermal model of an asynchronous traction electric motor of a diesel locomotive. *Proceedings of the Petersburg University of Communications* 4, pp. 460-468.

Kim, K. K., Panychev, A. Y., Blazhko, L.S., Rybin, P. K., 2020. Properties of a Synchronous Machine with Self-Regulating Magnetic Suspension of the Rotor when Its Axis Is Skewed. *Russian Electrical Engineering* 91 (10), pp. 597-603.

Terekhin, I. A., Maznev, A. S., Ivanov, I. A., Tretyakov, A. V., Kremlev, I. A. 2020. The Influence of Moisture and Temperature on the Electrical Properties of Reinforced-Concrete Structures of a Catenary System. *Russian Electrical Engineering*, 91 (10), pp. 613-616.

Grachev, V. V., Grishchenko, A. V., Kruchek, V. A., 2018. Automation of Adjustment of the Selective Characteristic of a Locomotive Traction Generator with Electric Transmission. *Russian Electrical Engineering* 89 (10), pp. 581-587.

Agunov, A. V., Grishchenko, A. V., Kruchek, V. A., Grachev, V. V., 2017. A method of using neural fuzzy models to determine the technical state of a diesel locomotive's electrical equipment. *Russian Electrical Engineering* 88 (10), pp. 634-638.

Trianni, A., Cagno, E., Accordini, D., 2019. A review of Energy Efficiency Measures Within Electric Motors Systems. *Energy Procedia* 158, pp. 3346-3351.

Filippov, I. F., 1974. Fundamentals of heat transfer in electrical machines. *Energy,* p. 384.

Dvorkin, P.V., 2017. Methodology for constructing temperature fields of parts of the cylinder-piston group. *Bul. scientific results. research* 4, pp. 14-17.