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Study of an Asynchronous Traction Motor with Inclined Slot Rotor

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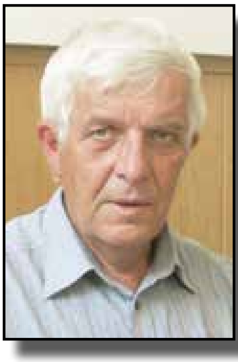

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ABSTRACT

Modernisation of railway rolling stock which is quite relevant from the perspective of growing performance of railways can be achieved among other ways through improvement of features of traction drive, namely of traction electric motors, that defined the objective of the study.

The inclined shape of the rotor slots is characteristic of a proposed design of asynchronous traction electric motor with a squirrel-cage rotor winding for a passenger electric locomotive which features are subject to the analysis.

The results of experimental and computer modelling confirmed the positive effect of using a rotor with inclined slots in the design of an asynchronous traction motor, which consists in reducing the current in the windings and reducing motor power losses.

The obtained results of improving the technical features of an asynchronous traction motor due to the use of a rotor with inclined slots in its design allow expand recommendation for its use on locomotives.

Keywords: railways, asynchronous electric motor, traction electric motor, experiment, physical modelling, energy saving, electricity losses, power losses, optimisation.

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INTRODUCTION

In competition with modern modes of transport, such as road and air transportation, railways invented two centuries ago, requires adoption of new technical solutions to increase its efficiency, reduce capital and operating costs, including those referring to energy consumption. The task of increasing income and investment attractiveness of business in the transportation sector is quite relevant today.

Modernisation of rolling stock can be carried out by improving the characteristics of the traction drive, namely the design of traction motors.

The *objective* of the work was to improve the technical characteristics of traction asynchronous electric motors.

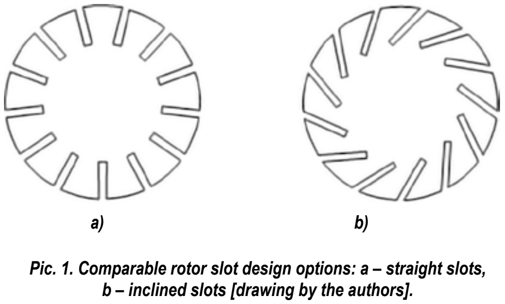
The purposes of the research were to select a technical solution, create a model, experimentally study the effect of the modernisation, develop a model of a locomotive traction motor, and calculate the technical effect using computer modelling.

The work was based on the *methods* of analysis of patents and scientific publications in the field of traction motor designs, an experimental study of an operating electric motor model (based on an experimental installation developed for its testing), computer modelling of electromagnetic processes in a traction motor and its loss calculation.

RESULTS

Statement of the Problem. Selection and Rationale of the Proposed Design of an Asynchronous Motor

An analysis of scientific publications (e.g., [1–3]) and patents [4] revealed the interest of scientists from around the world for development of electric machines with inclined rotor slots. Since currently the issue of adoption of such electric machines for locomotives is open, it was advisable to conduct a study of the characteristics of such a traction motor and determine the feasibility of its implementation.



Pic. 1. Comparable rotor slot design options: a – straight slots, b – inclined slots [drawing by the authors].

Asynchronous traction electric motors with a short-circuited rotor winding (squirrel-cage rotor) are installed on new electric locomotives, electric trains and diesel locomotives of Russian railways. For such a rotor design, in the scientific literature and patents of different years, a technical solution was found that involved the production of rotors not with radial slots (Pic. 1*a*), but with those with an inclination relative to the radius (Fig. 1*b*). According to G. K. Gervais, this «squirrel cage» design allows increasing the power of the electric motor [5].

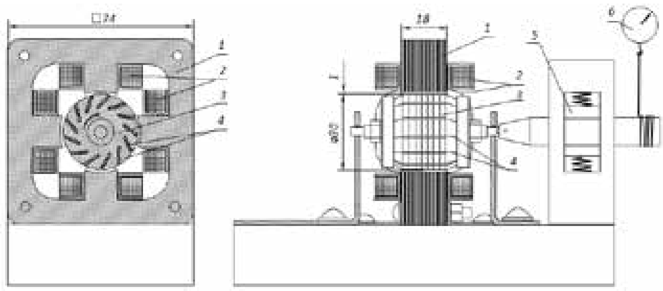
The novelty of this research lies in the fact that the found design of the rotor slots will be studied not from the point of view of increasing power, but from the point of view of reducing power losses in the engine.

Experimental Study

An analysis of the literature showed that physical models of electrical machines had previously been widely used in experimental studies of the Department of Electromechanics of the Moscow Power Engineering Institute [6].

To better solve the tasks of an experimental study of the effect of the inclination of the rotor slots on energy losses in the electric motor, within the framework of this study, a micromodel of a two-phase asynchronous electric motor (Pic. 2) with two rotor options differing in the shape of the slots (Pic. 1) was manufactured under laboratory conditions. One rotor has straight slots, the other rotor has inclined slots. The cross-sectional areas between the slots of the squirrel cage rotor are the same for both options. The prototype is equipped with a unit for specifying and measuring friction load. The load was measured with a dynamometer during a power outage. The stand is also equipped with such measuring instruments as a laser tachometer, wattmeter, ammeter, and voltmeter. The electric motor receives a two-phase sinusoidal power supply from a source with an adjustable voltage level. The value of the selected supply voltage frequency was 182 Hz. This value corresponds to the power supply frequency of the traction motors of EP20 electric locomotive at maximum speed.

During the tests, the motor prototype was launched with a smooth increase in supplied voltage and instrument readings were recorded at rotation speeds of 1200, 1800, 2200 rpm. 20 measurements were made for each of three motor



Pic. 2. Scheme of the experimental installation: 1 – stator; 2 – stator windings; 3 – rotor; 4 – rotor conductors; 5 – adjustable friction load; 6 – dynamometer [drawing by the authors].

Table 1

Test results of a two-phase asynchronous motor prototype with rotors with straight and inclined slots [authors' experimental data]

Direction of rotation	Average values in two directions	forward	backward
Rotor slot shape	straight	inclined	inclined
Rotation speed n, rpm	1579	1574	1613
Torque M, N·m	0,00209	0,00213	0,00212
Motor power P_2, W	0,341	0,349	0,353
Stator phase current I_{ph1}, A	0,548	0,398	0,627
Stator phase voltage U_{ph1}, V	22,06	13,43	21,41
Power consumption P_1, W	11,04	8,06	14,04
Power factor cos ϕ (averaged over 20 values)	0,468	0,741	0,517
Losses ΔP, W	10,70	7,71	13,69

configuration options: straight slots, slots inclined in the direction of rotor rotation, slots inclined against the direction of rotor rotation.

The measurement results are shown in Table 1.

Power factor is determined based on the following ratio [7]:

$$\cos\varphi = \frac{P_1}{mU_{ph1}I_{ph1}},$$

where $m = 2$ – number of stator phases of the motor prototype;

P_1 – power consumed by the motor prototype, W;

U_{ph1} – stator phase voltage, V;

I_{ph1} – stator phase current, A.

During testing, a 28 % reduction in power loss ΔP in the electric motor was recorded in the direction of rotation indicated by the arrow in Pic. 2, after installing a rotor with inclined slots at comparable torques and rotation speeds. In this case, in the direction of rotation opposite to that indicated by the arrow in Pic. 2, increased power losses ΔP were recorded.

In the prototype of the innovative motor in the forward direction of rotation, a significant increase in the power coefficient cos ϕ by 58 % was recorded compared to the classic version.

Table 2

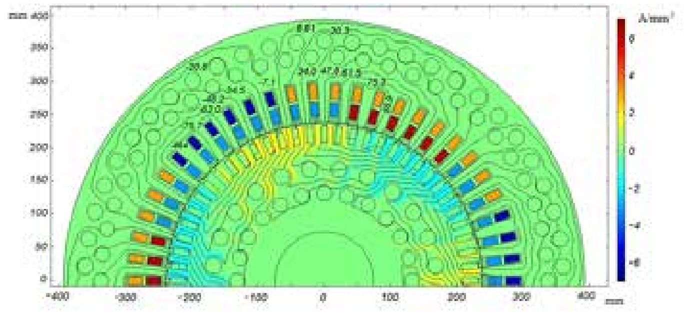
Analysis of power losses, kW, in traction motors standard and developed designs [data calculated by the authors]

Structural element	Typical design	Developed design with inclined rotor slots
Steel stator package	12,59	13,97
Stator winding	10,62	9,86
Copper rotor cage	0,22	0,20
Steel rotor package	28,04	23,41
Bearings	5,54	5,54

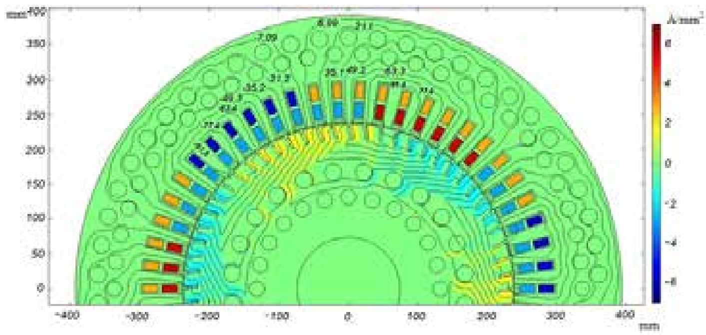
Study of an Asynchronous Traction Motor with Inclined Rotor Slots for a Passenger Electric Locomotive

To evaluate the effectiveness of the application of the technical solution found in the technical literature [5] in the design of the DTA-1200A traction motor of the EP20[1] passenger electric locomotive [8], two-dimensional computer modelling of the magnetic field and electromechanical processes was performed using the COMSOL finite element software package, also used in the works [9–11]

[1] TS.085.003 RE3 Mainline electric locomotive EP20. Manual. Book 3. Electric machines. TRTrans LLC, 2012, 21 p.



Pic. 3. Asynchronous traction motor of DTA-1200A model of the EP20 electric locomotive, current distribution and vector potential of the electromagnetic field, mWb/m, in cross section in continuous operation [data calculated by the authors].



Pic. 4. Design of an innovative traction motor, current distribution and vector potential of the electromagnetic field, mWb/m, in cross section in continuous operation [data calculated by the authors]..

(to simulate electromagnetic processes, researchers also use the software packages ANSYS Maxwell [12–14], ELCUT [15], ELMEC, FEATool, FEMM [16], Siemens Simcenter MAGNET, Simcenter Motorsolve, JMAG Designer [17], ANSYS Motor-CAD.

In continuous operation at a power of 1100 kW and a rotation speed of 1766 rpm, the minimum power loss in the traction motor corresponds to an inclination angle of the rotor slots of 12° to the radial direction of the rotor. This angle value turned out to be the maximum achievable under the condition of achieving the power balance for the motor mode:

$mU_{ph1}I_{ph1}\cos\varphi = P_2 + \Delta P$,

at the same time, it was necessary to increase the thickness and reduce the height of the teeth by reducing the width and depth of the slots to prevent a decrease in the magnetic flux, the value of which is related to the supply voltage.

Due to this optimisation of the geometry of the motor magnetic circuit from the point of view of long-term operation in one of the directions of rotation in the developed traction electric motor, power losses are reduced by 7 % due to a reduction in power losses in the rotor steel by 17 % (Table 2). The reduction in losses in the stator winding and the copper short-circuited rotor cage is caused by a decrease in current consumption by 3,8 %, the increase in losses in the stator steel package is caused by an increase in magnetic flux by 3,4 %.

The existing version of the traction motor design with the results of magnetic field modelling is presented in Pic. 3. The developed innovative version of the traction motor with the results of magnetic field modelling is presented in Pic. 4.

CONCLUSION

The study carried out using experimental methods and mathematical simulation, demonstrated the energy-saving effect of using the selected technical solution – the developed design of rotor slots of an asynchronous electric motor, which are inclined to the radial direction of the rotor.

Using computer simulation, the technical effect of using the selected technical solution in the design of the traction asynchronous electric motor of a passenger electric locomotive was calculated, which consists in reducing power losses in the motor by 7 %.

Analysis of the finite element model of the motor revealed a decrease in power losses in most structural elements of the motor: in the steel rotor package by 17 %, in the copper rotor cage by 9 %, in the stator winding by 7 %, with an increase in power losses in the steel stator package by 11 %.

The proposed motor design allows reducing its power loss by 7 % and current consumption by 3,8 %.

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