http://www.moderntechno.de/index.php/meit/article/view/meit37-01-019
DOI: 10.30890/2567-5273.2025-37-01-019

УДК 621.313.175.32

FORMATION OF A TOOTH ZONE IN INDUCTION MOTORS WITH A SQUIRREL-CAGE ROTOR

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Annotation*. Recently, the problem of energy saving in induction engines is a challenge for many enterprises. To achieve it developers, agree to slightly increase the cost of the machine, realizing that the costs incurred in the production of induction motors are manyfold will pay off during their operation. Study of the electromagnetic field with varying geometry rotor showed the way how to get from a standard induction motor energy efficient. Varying the number of rotor slots with their shape unchanged and area allowed to find allowed to find the extremum of the electromagnetic torque in starting mode and at rated slip.*

Key words*: induction motor, slots, rotor, stator, torque, field induction*

Introduction. Induction motors with a squirrel-cage rotor are the most frequently used motor in modern electric drive systems today. They are widely used in industry, construction, agriculture and everyday life. Recently, the problem of energy saving in induction motors has come to the fore. To achieve it, developers go for a slight increase in the cost of the machine, understanding that the costs incurred in the production of induction motors will be recouped many times over during their operation [1]. To achieve energy efficiency, along with the use of advanced materials, an increase in active dimensions, there is a way to achieve an increase in efficiency with relatively small costs [2, 3]. We are talking about the formation of the rotor slot zone, when the developer performs parametric optimization of the rotor slot zone to obtain the final design version.

Induction short-circuit motors form the basis of a modern electric drive. They consume most of the electricity consumed by all electric motors combined. Such engines have additional requirements related to their operating conditions: energy efficiency (efficiency and cosφ), high overload capacity (multiplicity of maximum torque), high starting characteristics (multiplicity of starting torque).

The aim of the research was to develop a methodology for designing induction motors with a squirrel-cage rotor in terms of rational calculation of the rotor slot zone.

Analytical review. Estimating the efficiency of electromechanical energy conversion in three-phase induction motors cannot be performed correctly without considering and solving the equations of the electromagnetic field. An effective method of solving the tasks is the numerical method of finite elements [4, 5]. This method reduces the limit statement of the problem to a variational one, when instead of solving the partial differential equations of the field, the extremum of the functional is sought

$$W(A) = \frac{1}{2}\int \left|vA\right|^2 ds \tag{1}$$

To simplify the solution of electromagnetic field equations, it is customary to introduce an intermediate variable, which is the vector magnetic potential. This auxiliary function is introduced by the following relation

$$B = rotA \tag{2}$$

Despite the fact that the electromagnetic field in induction machines is three-dimensional, we will use its two-dimensional model, assuming that the pattern of the magnetic field repeats along the axis of rotation.

Taking into account relation (2), it is clear that the vector magnetic potential defines two vectors: B and H. According to the principle of minimum potential energy, the potential distribution in an electric machine should be such as to minimize the stored energy.

When finding the energy of the field, the integration is carried out over the entire two-dimensional domain. In the general case, when a current flows through the winding of an induction motor, located in the grooves of the magnetic circuit, the field created by it is described by Poisson's equation.

To calculate the EMF of a magnetic system acting on a selected volume, the theory of electromagnetism suggests the following methods: by increasing the magnetic energy of the system; by bulk or surface EMF density. At the same time, EMF and moments can be strictly and unambiguously determined only on the basis of calculations of the electromagnetic field. That is, in all three cases, it is assumed that the electromagnetic field is numerically or analytically calculated for a given moment of time t, while the moving part of AD or other magnetic system occupies a certain position in relation to its stationary part.

The motor with the power of 55 kW and the number of poles equal to 4 was investigated. The calculation experiments were carried out in the Ansys Maxwell program using the finite element method [6, 7]. The initial values of inductions in the magnetic circuit are shown in Fig. 1.

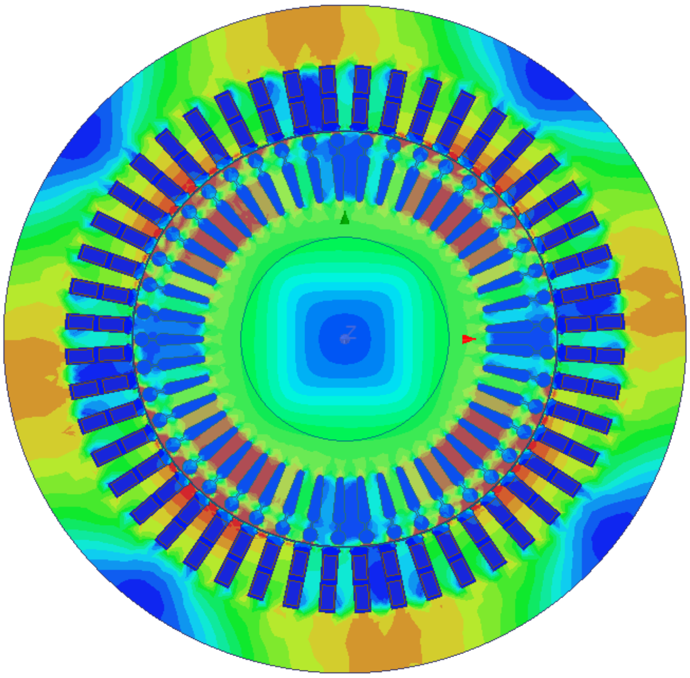

Fig. 1 – Magnetic field inductions in the basic version of the engine under study

An analysis was made of the magnitude of the electromagnetic torque when the engine was operating in nominal mode.

The presence of toothed magnetic circuits on the rotor and stator should lead to pulsations of the electromagnetic field and, as a consequence, to pulsations of the electromagnetic torque in the nominal and starting modes. The calculation model was rebuilt so that the position of the rotor and stator slots shifted by 1 degree (geometric) relative to each other (Fig. 2).

The arithmetic mean value of the electromagnetic torque at nominal slip will be equal to 51.6 Nm.

For the starting mode, we will repeat a similar sequence of calculations. To calculate the starting mode, we will take into account that the remagnetization frequency of the rotor and stator will be the same 50 Hz

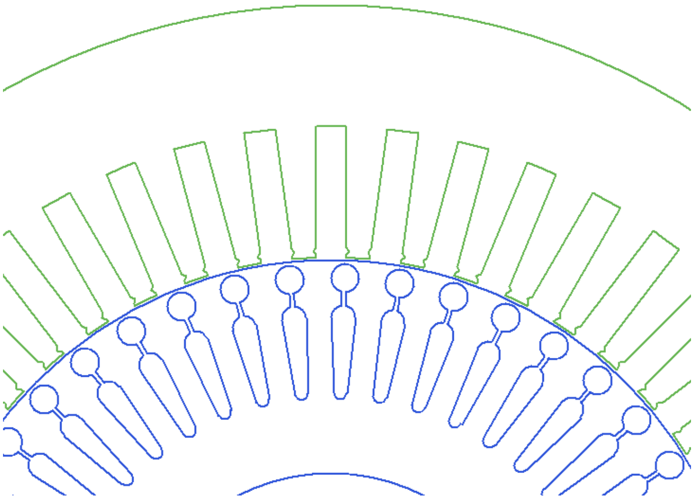

Fig. 2 – Tooth zone of the engine under study

The calculations were repeated eleven times and the results are presented in Fig. 3.

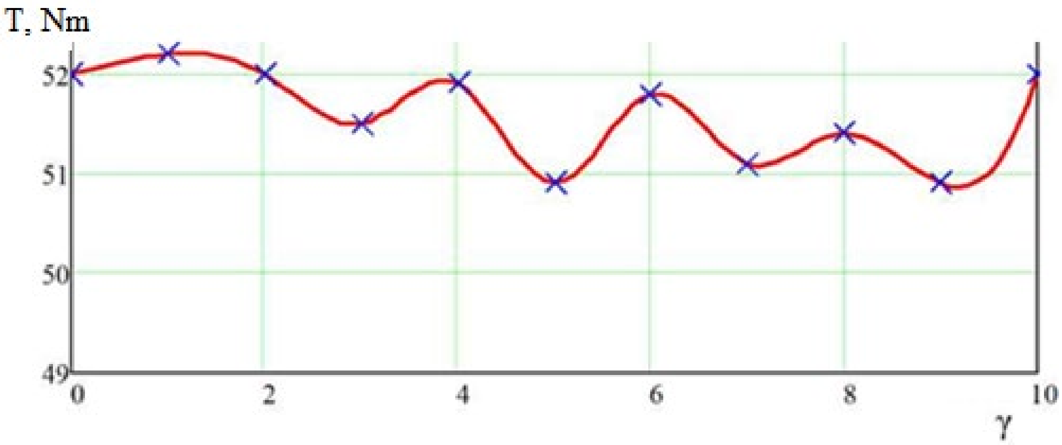

Fig. 3 - Dependence of torque on the angle determining the position of the rotor relative to the stator

The average value of the starting torque, depending on the position of the rotor teeth relative to the stator teeth, is 99.8 Nm.

The obtained data indicate that in order to increase the accuracy of the calculation of the electromagnetic torque, several calculations should be made at different positions of the rotor teeth relative to the stator. The arithmetic mean should be taken as the desired value of the electromagnetic torque, understanding that it will inevitably differ from the instantaneous value. Thus, the electromagnetic torque during one revolution of an induction motor with a squirrel-cage rotor periodically changes relative to the average value.

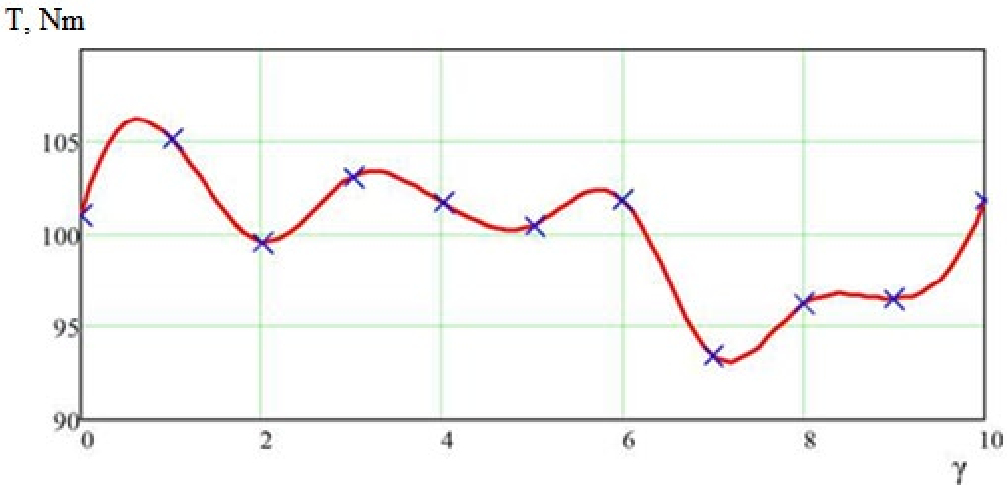

Fig. 4 - Dependence of the electromagnetic moment on the angle, determining the position of the rotor relative to the stator at the moment of starting

Let us analyze the effect of changing the rotor geometry on the magnitude of the electromagnetic torque.

The following assumptions are made in this study:

1 The current density in the stator slot is taken to be constant and equal to the current density that the motor under consideration has in the analyzed mode.

2 The frequency of magnetization reversal in the problem is taken to be equal to the frequency of the current in the rotor, which is determined by the slip of the mode under consideration.

3 The number of rotor slots is subject to variation. The lower limit of the number of slots cannot be less than five.

4 The shape of the rotor slot, its dimensions and area are constant.

The number of grooves will be changed in increments of one groove.

We will use harmonic analysis and finite element methods. Based on the results of calculating the electromagnetic torque for nominal slip, the dependencies are plotted in Fig. 5.

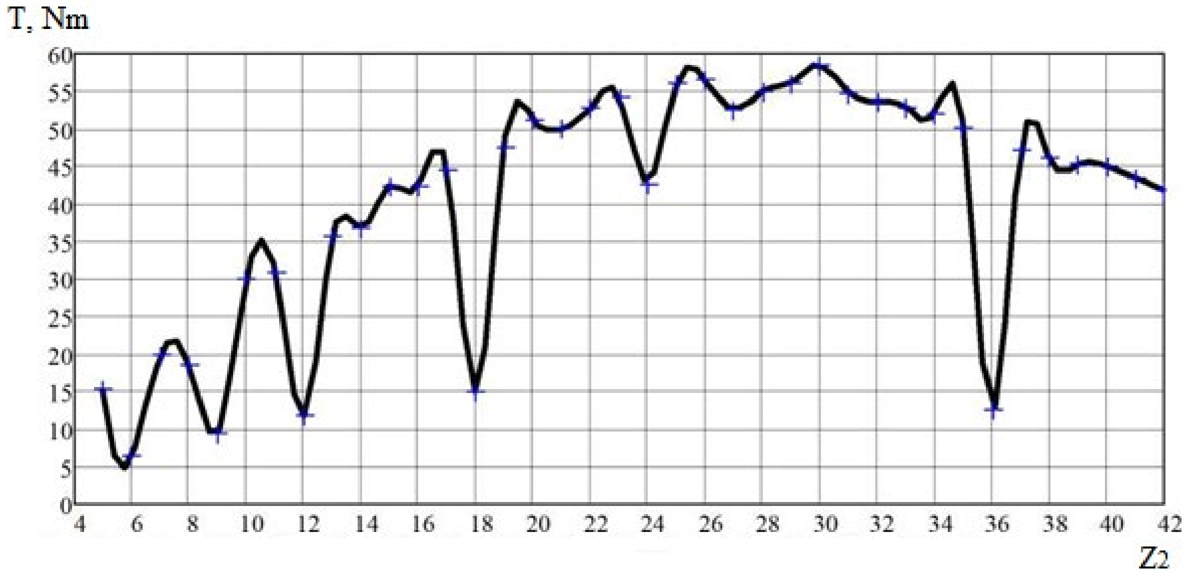

Fig. 5 - Dependence of the electromagnetic torque on the number of rotor slots at nominal motor slip

Let us evaluate the obtained results. The basic design corresponds to the number of rotor slots of 34 and, accordingly, the electromagnetic torque of 52 Nm. These data were obtained by averaging a series of values of the electromagnetic torque. In other words, each point of the graph and table is the result of many calculations and their processing. Analysis of the results shows that the optimum number of slots does not coincide with the reference data of the basic version. The maximum torque occurs with a number of rotor slots of 30, which corresponds to an electromagnetic torque of 58.5 Nm. This torque is 12.5% greater than the torque in the nominal mode.

With 30 slots on the rotor, the amount of aluminum decreased, but this decrease was compensated by electrical steel. The conductivity of the magnetic circuit increased, therefore, less magnetizing current is required. For this reason, the efficiency of electromechanical conversion in this case increases, which is confirmed by the calculations of the electromechanical torque. In this case, with a change in the number of slots on the rotor, the total area of aluminum also changed, which probably led to this effect.

Let us check what effect such variation of rotor slots will have on the electromagnetic torque of the motor in the starting mode. Based on the calculations, a graph of the dependence $M = f(Z_2)$ was constructed, shown in Fig. 6. Evaluating the obtained results, it can be noted that the maximum electromagnetic torque during starting shifts towards a decrease in the number of slots. The maximum electromagnetic torque in the mode with nominal slip was obtained with 30 slots. For the starting mode, this number of slots should be further reduced to 13 - 17.

The latter, by the way, is consistent with the well-known position, which recommends increasing the active resistance of the short-circuited rotor cage to increase the starting torque.

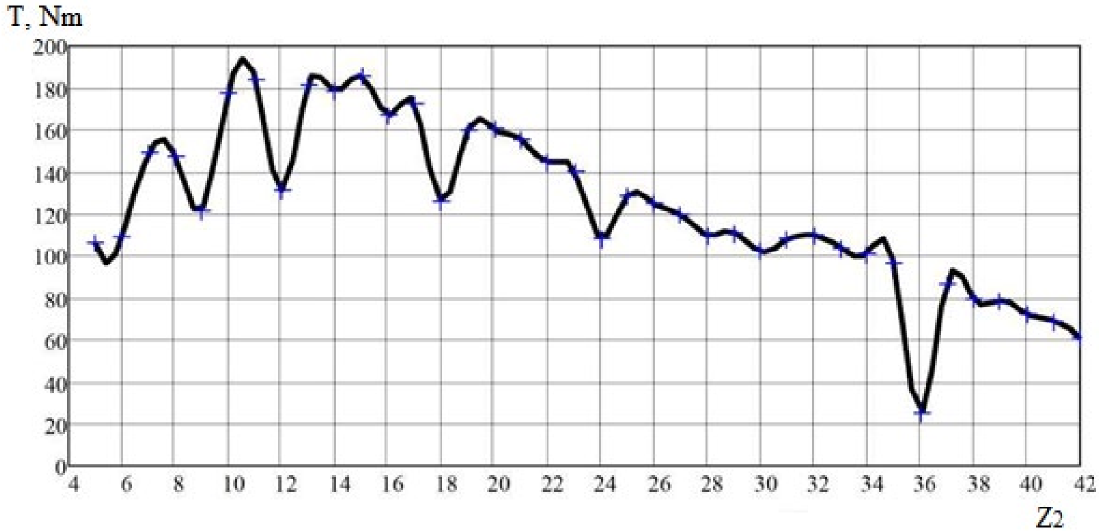

Fig. 6 - Dependence of the electromagnetic torque in the starting mode on the number of rotor slots

Conclusions.

1. When the number of rotor slots changes, which is accompanied by a proportional change in the total area of the slots, the electromagnetic torque changes at a constant current density in the stator winding. This is observed in the starting mode and at nominal slip.

2. By varying the total area of the rotor slots, it becomes possible to select its extremum, which for different modes (starting and nominal slip) is achieved at different values.

3. The rotor slot ratio (the ratio of the total area of the rotor slots to the circle circumscribed around the rotor) in optimized engines is usually less than the standard values of serial products.

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