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STUDY OF THE MAGNETIC FIELD OF AN SINGLE-PHASE INDUCTION MOTORS

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Annotation. *Induction capacitor motors are widely used in electric drive systems of various industrial and domestic mechanisms. Every year the scope of use of these machines continues to expand, both in new areas of technology and as a replacement for more complex electrical machines of various designs. The features of electromagnetic processes of induction capacitor electric motors with a massive rotor made of composite materials, the method and some results of mathematical modeling of such electric motors are considered.*

Keywords*: single-phase induction motors, field in the air gap, starting mode, shaft load, maximum torque.*

Low-power induction capacitor motors for household electrical appliances (washing machines, vacuum cleaners, etc.) occupy a huge niche in electrical engineering. This also includes centrifuges, gyroscopes and other mechanisms with large moments of inertia.

However, in these new areas of application, new technical requirements are imposed on induction capacitor motors, to satisfy which it has become necessary to create designs with special properties and parameters [1].

It is known that a significant disadvantage of induction capacitor motors with rotors of traditional designs is their low starting torque. As a result, starting and accelerating devices with large moments of inertia takes a significant amount of time, during which the engine heats up intensively [2]. To reduce the acceleration time, special circuit solutions are used to increase the starting torque of the engine. These include an increase in rotor resistance, an increase in the capacity of the phase-shifting capacitor, and voltage boost. The first option is associated with increased losses in the engine, the second and third - with the need to complicate the switching circuits.

In electric drive systems with large inertial masses, it is rational to use capacitor electric motors with a massive ferromagnetic rotor (CMFR). These motors have the utmost simplicity of design, significant starting torques, the ability to operate at high speeds, and the absence of slots on the rotor, as a result of which the amplitudes of higher spatial harmonics of the magnetic field are reduced [3]. In addition, in such engines there is magnetostriction, i.e. the change in the shape and size of the magnetic circuit during magnetization reversal is insignificant, and, consequently, the level of magnetic noise is small.

At the same time, due to the displacement effect, the massive ferromagnetic rotor of the motor has a high active resistance. This leads to increased losses in the rotor and, accordingly, to a decrease in its efficiency.

A feature of induction machines with a massive rotor is the approximate preservation of the ratio of the inductive resistance of the rotor to the active one over a significant range of changes in rotation speed. When the parameters of the stator winding are constant, the resulting motor resistance and power factor are close to a constant value [4]. This circumstance makes it possible to maintain the circular field of the engine at different values of its slip. By choosing the capacitance of the capacitor according to the conditions for obtaining the maximum starting torque in a circular magnetic field, it is possible to preserve the nature of the field while reducing slip. As the engine accelerates, the active and inductive resistance of the rotor decreases. As a result, the mechanical characteristic takes on the appearance of an “excavator”, favorable for engine starting modes [5].

The possibility of creating a circular magnetic field in capacitor motors with a massive rotor can be explained as follows. The elliptical magnetic field arising in the engine is a combination of forward and reverse magnetic fields. The frequency of the EMF induced in the rotor is determined by the sliding value of the forward field L [6]. The frequency of the EMF from the reverse field is close to double the network frequency, and the massive rotor becomes practically “opaque” to the reverse field.

It should be especially noted that it is possible to improve the energy performance of the engine by changing the composition of the rotor material.

The use of massive ferromagnetic rotors made of composite materials is a promising direction for improving the technology for manufacturing low-power induction machines. The use of powder metallurgy methods makes it possible to change the characteristics of the rotor material over a wide range due to the qualitative and quantitative composition of the various components of the charge. In addition to simplifying the technology for their production, the advantage of powder composite technology is high material conservation, characterized by a material utilization rate of 96%. Powder metallurgy methods can save up to 20% of electrical steel by reducing the waste that is inevitable when stamping electrical steel sheets.

An analysis of the electromagnetic processes of an induction capacitor motor with a massive rotor shows that, due to the effect of current displacement, the nature of their flow, as well as the distribution of the magnetic field, turns out to be much more complex than in machines with rotors of traditional design. The main reasons causing this complication are:

- current displacement effect, the nature of its manifestation depends on the rotation speed;
- electrical asymmetry of the motor, which occurs when the capacitor capacitance remains constant and the rotation speed varies;
- the presence of a spectrum of higher spatial harmonics of the magnetic field, characteristic of single-phase windings with a reduced number of stator slots.

These circumstances have necessitated the study of magnetic fields and electromagnetic processes in capacitor motors with a massive rotor using a mathematical model that reflects them with a sufficient degree of adequacy.

Maxwell's system of equations is reduced to a partial differential equation written for the axial component of the vector potential. Taking into account that in a stationary mode all the studied quantities change according to a harmonic law, and the rotor current density under the assumptions used has only a vortex component, the complex amplitude of the vector potential of the CDMR is determined by solving a field problem described by an equation with periodic boundary conditions along the φ coordinate and zero conditions of the first kind along the coordinate R.

$$\frac{1}{R}\frac{d}{dR}\left(\frac{1}{\mu}R\frac{dA}{dR}\right)+\frac{1}{R^2\mu}\frac{d^2A}{d\varphi^2}-\mu_0\gamma\varpi\frac{dA}{d\varphi}-j\mu_0\gamma\varpi A=-\mu_0J_p-\mu_0J_k$$

Various methods can be used to solve the magnetic field equation with known boundary conditions. In this case, a combination of the finite difference method and the method of separation of variables using the fast Fourier transform is used. The combination of these methods makes it possible to solve a boundary value problem with minimal mathematical operations.

As a result of replacing differential operators with finite-difference expressions and representing the vector potential and the right-hand side of the equation in the form of expansions in eigenfunctions of the discrete Laplace operator, we arrive at a system of algebraic equations

$$\frac{1}{R_nh_R}\left[\left(\frac{R}{\mu}\right)_{+0.5}\cdot\frac{y_{n+1}-y_n}{h_R}-\left(\frac{R}{\mu}\right)_{-0.5}\cdot\frac{y_n-y_{n-1}}{h_R}\right]-$$

$$-\left(\frac{1}{\mu R^2}\right)_n\lambda_k y_{k,n}-i\mu_0\gamma\varpi_0-\Theta_k\varpi y_n=-\phi_{k,n}$$

eigenvalues of the discrete Laplace operator:

$$\lambda_k=\frac{4}{h_\varphi^2}\sin\frac{2k\pi}{N_\varphi}$$

Coefficients θ_k are written as:

$$\Theta_k=\frac{1}{h_\varphi}\sin\left(\frac{2k\pi}{N_\varphi}\right)$$

k =1, 2, ..., N_2; n = 1, 2, ..., N_1, where N_1 and N_2 - number of partitions of spatial coordinates. The right-hand side of the magnetic field equation is calculated using the fast Fourier transform.

$$\phi_{k,n}=\frac{1}{N_\phi}\sum_{j=0}^{N_2-1}F_{n,j}e^{j\frac{2\pi}{N_2}kj}$$

where n 1, 2, ..., N_{R-1}, k 1, 2, ..., $N_{\varphi-1}$, j 1, 2, ..., $N_{\varphi-1}$.

The calculated values of the vector potential make it possible to determine the magnetic induction in various elements of the CMFR, current density and electromagnetic forces acting on the massive rotor, losses and other machine parameters.

In Fig. 1 shows the magnetic field distribution for a sample of a capacitor motor with a stationary rotor. The engine parameters and the capacity of the phase-shifting capacitor were calculated in such a way that when the engine starts, the magnetic field is circular. The stator current load was taken in the form of a traveling wave. The vector potential, as one would expect, is uniformly distributed along the stator bore, and its envelope has a constant value.

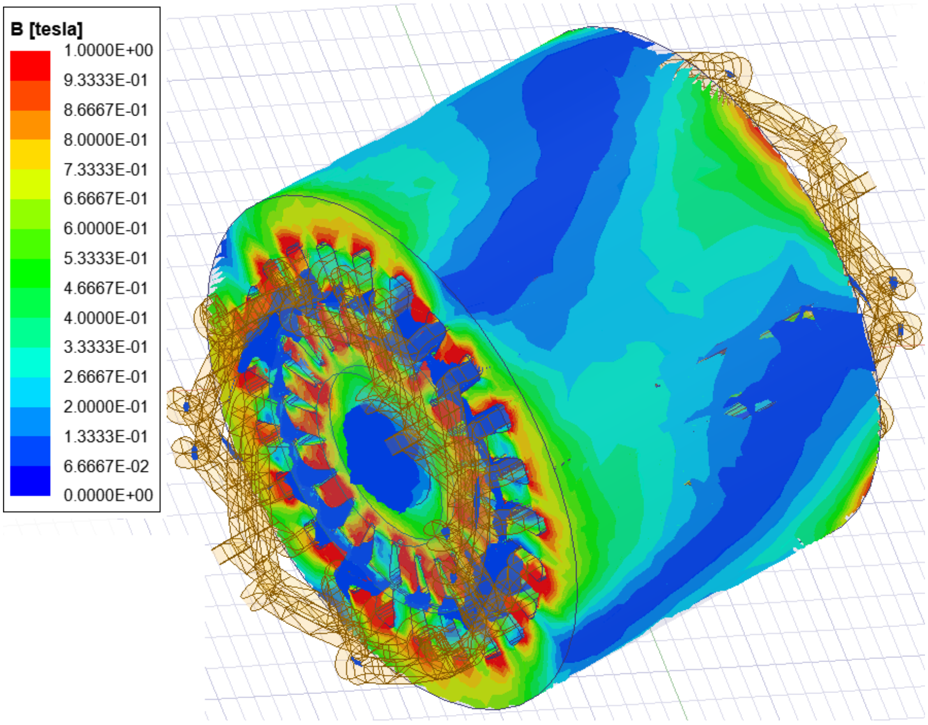

Fig. 1. Magnetic field distribution with a stationary rotor

Given the real nature of the current load, the symmetry of the phase currents and the same parameters of single-layer windings, the vector potential has a clearly defined third harmonic, which is confirmed by the nature of the envelope in Fig. 2.

In Fig. 3 shows the mechanical characteristics of a capacitor motor with a massive rotor. To calculate the mechanical characteristics, the magnetic field was calculated for each slip, and the magnetic induction and current density in the massive rotor were determined. The magnitude of the magnetic moment acting on the rotor was determined by integrating the tangential moments over the entire rotor array.

Mechanical characteristics form close to “excavator” with a high degree of filling. As a result, the electromagnetic torque of the motor in this frequency range can maintain an almost constant value. This mechanical characteristic of the engine allows the engine to be started from 0 to the rated rotation speed in the minimum possible time.

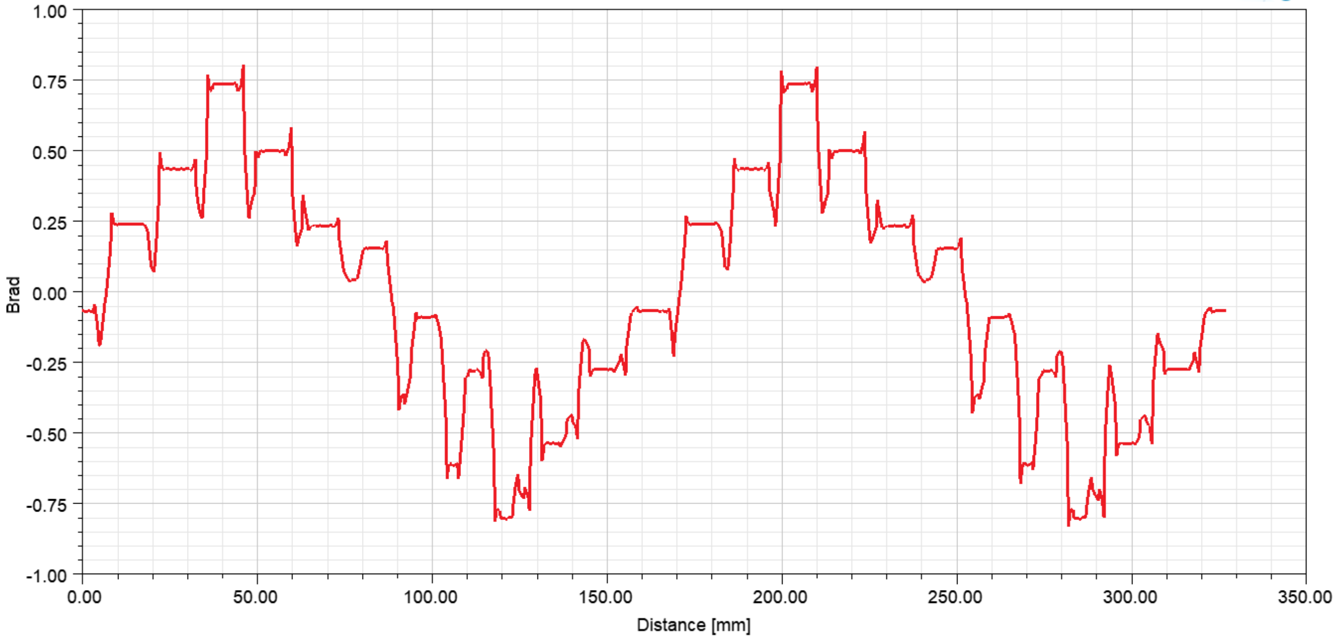

Fig. 2. The nature of magnetic induction in the air gap

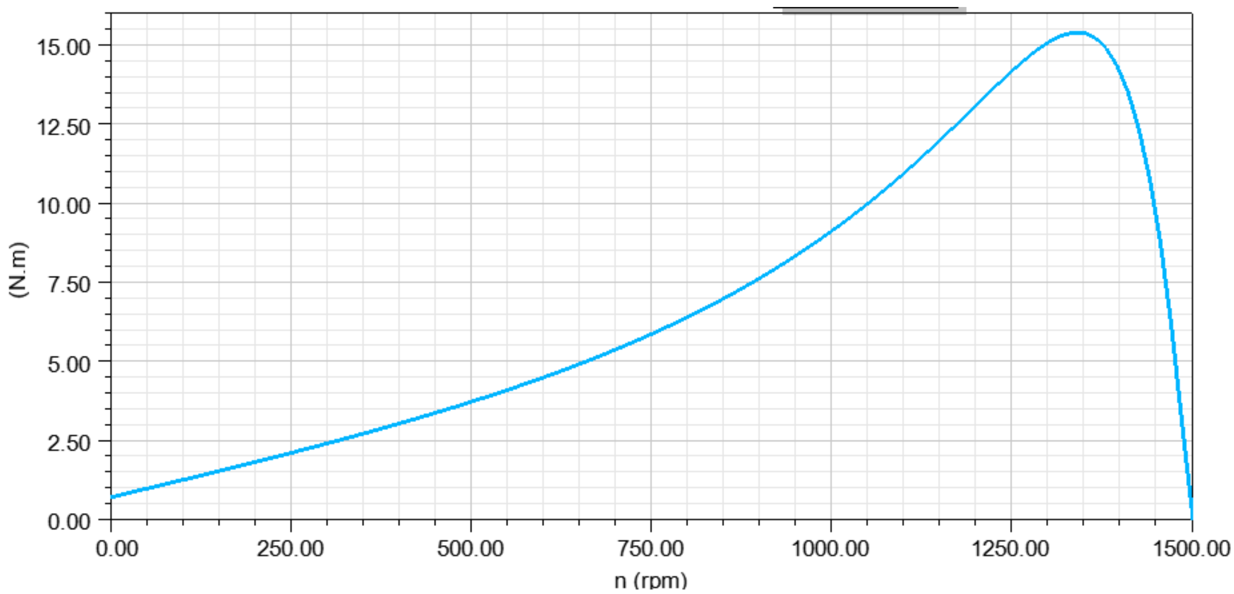

Fig. 3. Mechanical characteristics of a capacitor motor with a massive rotor

Conclusions. The modeling method discussed in the article is intended to study magnetic fields and electromagnetic processes of the magnetic resonance motor in a linear approximation, without taking into account the saturation of the ferromagnetic elements of the engine. The results obtained can be used as a first approximation for modeling saturated machines. The next stage of the work is to improve mathematical models of the CMFR, taking into account the spatial unevenness of the magnetic and electrical properties of ferromagnetic powder materials of a massive rotor.

References

1. Bobozhonov, Y., Seytmuratov, B., Fayzullaev, B., & Sultonov, A. Study of the influence of different designs of massive rotor of asynchronous generator on their maximum power. In E3S Web of Conferences (2020, Vol. 216, p. 01177). EDP Sciences.

2. O. Iegorov, O. Iegorova, O. Miroshnyk and O. Savchenko, “Improving the accuracy of determining the parameters of induction motors in transient starting modes”, ENERGETIKA, vol. 66, no. 1, 2020, pp. 15–23.

3. Yunusov, R. F., Imomnazarov, A. B., Rajabov, M. N., Karimov, I. N., Oblaqulov, S. T., & Mamatkulov, A. N. Electromagnetic quality of a linear asynchronous motor with different designs of the secondary element. In E3S Web of Conferences (2023, Vol. 434, p. 01006). EDP Sciences.

4. Finkelshtein V., Iegorov O., Maleev A. Comparison of characteristics of the converter-fed motor at supply from the single-phase network and from the source of the direct current. Електротехніка і електромеханіка. 2015. № 4. P. 15–19.

5. Iegorov O., Iegorova O., Kundenko M., Milenin A. Single-Phase Induction Motors Winding Parameters Optimization with Maximum Efficiency. 2020 IEEE Problems of Automated Electrodrive. Theory and Practice (PAEP). 21-25 Sept. 2020.

6. Kurvinen, E., Di, C., Petrov, I., Nerg, J., Liukkonen, O., Jastrzebski, R. P., ... & Kangasmäki, T. Design and manufacturing of a modular low-voltage multimegawatt high-speed solid-rotor induction motor. 2021 IEEE Transactions on Industry Applications, 57(6), 6903-6912.