INNOVATIVE TECHNOLOGICA
METHODICAL RESEARCH JOURNAL
ISSN: 2776-0987 Volume 4, Issue 11 November 2023

DIFFERENTIAL SCATTERING ASYNCHRONOUS MACHINE

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Abstract

The article presents a method for calculating the differential dissipation of inductances, which makes it possible to take into account all the factors affecting the inductances, except for the influence of the unevenness of the air gap between the stator and rotor cores and the damping influence of currents induced in the secondary circuits by higher spatial harmonic fields created by the stator winding of an alternating current machine. The proposed calculation method is based on the model of the air gap field of an alternating current electric machine.

Keywords: asynchronous motor with a wound rotor, differential dissipation, scalar magnetic potential, air gap of the current layer, radial component of the magnetic field strength, magnetic permeabilities of the stator and rotor bodies.

In practice, designing an asynchronous motor with a wound rotor, the inductive reactance of the differential leakage of its rotor winding is determined by the value of the leakage magnetic conductivity coefficient [1,2]. However, the calculation formulas for these coefficients are usually semi-empirical and it is difficult to take into account a number of design and operating factors that influence them.

In this work, the inductive reactance of the differential leakage of a three-phase symmetrical winding of a wound rotor of an asynchronous machine is determined from the pattern of magnetic field distribution in the air gap created by this winding. Based on the expression of the radial component of the magnetic field strength in the air gap, obtained by solving the Laplace equation for the scalar magnetic potential, written in a cylindrical coordinate system, expressions were compiled for the field in the air gap of the current layer, coil, group of coils and single-phase two-layer rotor winding [3]. In particular, for the last case the expression is given in the following form

$$H_o = 2w_{\kappa 2}\sum_{n=1}^{\infty}\left[C_n\rho^{(n-1)} - D_n\rho^{-(n+1)} - \frac{i}{2\pi n}b^n\rho^{-(n+1)}\right]\frac{\sin n\alpha_2}{\alpha_2}\sin\frac{\beta_2}{2}\frac{\sin n\left(q_2\frac{\alpha_{z2}}{2}\right)}{\sin n\left(\frac{\alpha_{z2}}{2}\right)}\times$$

$$\times\left\{\cos n\varphi - \cos n\left(\varphi - \frac{\pi}{p}\right) + \cos n\left(\varphi - \frac{2\pi}{p}\right) - \ldots - \cos n\left[\varphi - \frac{\pi}{p}(2p-1)\right]\right\}, \qquad (1)$$

Where, $w_{\kappa 2}$ – number of turns in the rotor winding coil;

n – spatial harmonic order;

C_n, D_n – constants for harmonic nth order.

Having made transformations and introducing the notation from (1), we obtain

$$H_o = 4w_{\kappa 2}q_2 p\sum_{n=1}^{\infty}K_n\kappa_{\text{обn}}\kappa_{pqn}\sin n\left(\varphi - \frac{2p-1}{p}\frac{\pi}{2}\right), \qquad (2)$$

Similar to (2), the formula for calculating the radial component of the magnetic field strength in the air gap of a machine created by a three-phase two-layer rotor winding with an integer q2 when a symmetrical sinusoidal current flow through it with a frequency f2 will have the form

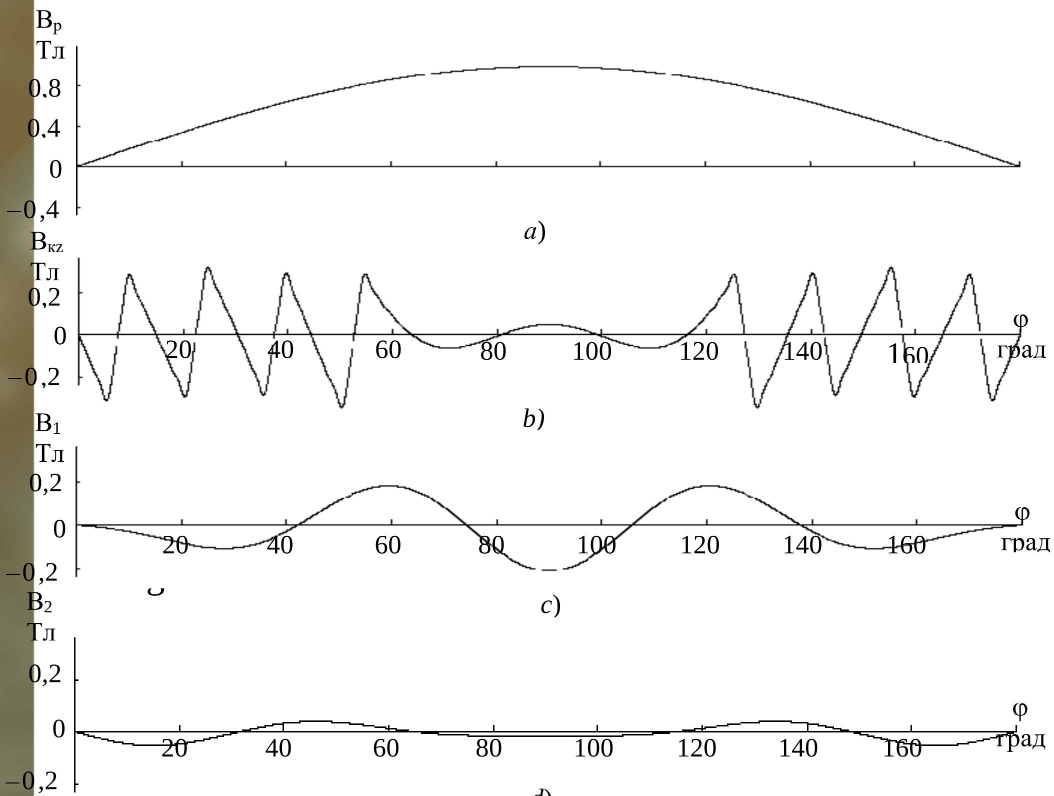
$$H_{\text{т}} = 4pq_2 w_{\kappa 2}\sum_{n=1}^{\infty}K_n\kappa_{\text{обn}}\kappa_{pqn}\left[\sin n\left(\varphi - \frac{2p-1}{p}\frac{\pi}{2}\right)\sin\left(\omega_2 t + \frac{2\pi}{3}\right) + \right.$$

$$\left. + \sin n\left(\varphi - \frac{2p-1}{p}\frac{\pi}{2} - \frac{2\pi}{3p}\right)\sin\left(\omega_2 t - \frac{2\pi}{3}\right) + \sin n\left(\varphi - \frac{2p-1}{p}\frac{\pi}{2} - \frac{4\pi}{3p}\right)\sin\omega_2 t\right], \quad (3)$$

Where ω_2 – angular frequency of current change in the rotor winding, $\omega_2 = 2\pi f_2$
.

Expressions (1), (2) and (3) make it possible to calculate at a particular point in the air gap the radial component of the magnetic field strength created by the three-phase symmetrical rotor winding, taking into account the influence on the field of the design dimensions of the core, as well as the finiteness of the equivalent magnetic permeabilities of the bodies stator and rotor of an asynchronous machine. When calculating the field in the air gap created by one or another rotor winding, taking into account the finiteness of the values μ_1 and μ_2, similar to when calculating the magnetic field in the air gap created by the stator winding, it is convenient to consider it consisting of three components to achieve greater calculation accuracy : 1. Fundamental harmonic with order n = p; 2. Scattering field along the tooth crowns, which is the sum of all spatial harmonic fields in the air gap created by the rotor winding with orders ranging from sub-tooth and higher, with $n_{pz} = Z2/2\text{-}p$; 3.

Belt scattering field, which is the sum of all spatial harmonic fields of the air gap up to sub-tooth order, except for the main one.



a)

b)

c)

d)

Fig.1. Distribution of magnetic inductions of the main working harmonic B1

The last two field components in the air gap together form the differential leakage magnetic field of the rotor winding. This separate consideration of the field in the air gap created by one or another winding is due to the fact that the values of the equivalent magnetic permeabilities of the stator $\mu 1$ and rotor $\mu 2$ for each field component, calculated for a particular operating mode of an AC machine, can differ significantly from each other from – because the magnetic circuit of each of these components is different, although the magnetic circuit is common for them. For example, Fig. 1 shows the distribution of magnetic inductions of the main working harmonic B1, the stray field along the crowns of the teeth Bz and the belt stray field B2 along the circumference of the outer surface of the rotor, created by the three-phase two-layer winding of the phase rotor of an asynchronous motor of type AK - 62/4 (14 kW ; 220/380 V; 50.5/29.3 A; 1400 rpm; Z2 = 48; $q_2 = 4$; y2 = 12; a = 0.03 m; b = 0.0996 m; c = 0, 1 m; d = 0.1635 m; $\delta = 0.0004$ m; $b_2 = 0.0037$ m) within one pole division of the machine, calculated by (3) for time t = 7/300 s and rotor current i2 = 36.5 A. The position of the studied point in space along the circumference of the air gap is characterized by the polar angle φ. Magnetic induction B was determined by the field strength H using the expression $B = \mu_0 H$. For greater clarity, angle φ is expressed in electrical degrees. When calculating the fundamental spatial harmonic field, the relative values of equivalent magnetic permeabilities were taken as $\mu_1 = 620$, $\mu_2 = 440$, calculated according to (3) for the nominal operating mode of the machine. For the air gap belt scattering field, due to the fact that its spatial period is closer than that for the main field, the equivalent magnetic permeabilities for their calculation were taken equal to the corresponding values for the main field, i.e. $\mu_{p1} = \mu_1$, $\mu_{p2} = \mu_2$. To calculate the stray field along the crowns of the teeth, the values of the relative equivalent magnetic permeabilities determined by (3) for the same nominal operating mode of the machine were equal to $\mu_{z1} = 890$ and $\mu_{z2} = 820$.

The belt component of the differential scattering field was determined as the sum of spatial harmonic fields in the air gap with orders n = 10 and 14, and the scattering field along the crowns of the teeth represented the sum of harmonics in the range n from 22 to 298. The curves in Fig. 1 a, b and c correspond diametric pitch of the rotor winding y2 = 12, and the dependence Bz = f (φ), shown in Fig. 1 d for the value y2 = 10, i.e. shortening the rotor winding pitch by 1/6 of the machine's pole division. Such a shortening of the rotor winding pitch led to a small, almost proportional to the winding pitch shortening coefficient for the main harmonic, change in the magnetic inductions Bp and Bz. However, as can be seen from a comparison of the curves in Fig. 1, c and d, such a shortening of the step significantly reduced the belt component of the differential scattering field. The root mean square value of the magnetic induction of the belt scattering field at y2 = 12 was equal to 0.1095 T, and at y2 = 10 the value was 0.0283 T. The magnetic induction of the stray field along the crowns of the teeth of the rotor winding is significantly influenced by the opening width of the rotor slot. A change in the opening width of the rotor groove bп2 has an insignificant effect on the main and belt fields of the air gap, i.e. in practice, they change inversely with the air gap coefficient of the machine. The dependence curve Bz = f(φ), presented in Fig. 1 d corresponds to $b_{p2} = 0.007$ m. From a comparison of the dependence curves in Fig. 1, b and e, it can be seen that, under other identical conditions, a doubling of bп2 leads to a decrease in the root-mean-square value magnetic induction of the stray field along the crowns of the teeth of the rotor winding from 0.1529 T at b_{p2} = 0.0037 m to 0.0808 T at b_{p2} = 0.0074 m. Thus, the width of the open slot of the rotor has a significant effect on the magnitude of the stray field along the crowns of the teeth rotor windings. All three components of the air gap field created by the rotor winding change significantly depending on the size of the air gap δ.

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