CALCULATION OF THE MAGNETIC FIELD OF THE STATOR WINDINGS OF THE SYNCHRONOUS MACHINE

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Abstract. This article discusses the possibility of applying a cylindrical coordinate system when examining the magnetic field of a synchronous machine.

1 Introduction

For the study of the magnetic field (MF) in the air gap created by the stator winding is not clearly a pole synchronous machine (SM) and the parameters of the machine, caused by this field, the most convenient is the application of analytical method of study, as the distribution of the magnetic field on the circumference of the air gap has a sharply pronounced peak character and in the study of such field numerical methods arise difficulties and inaccuracies [1]. In addition, when using numerical methods calculation is performed for each set of parameter values and the overall picture of the magnetic field is obtained as a result of a large number of calculations.

From the current analytical methods of the solution of the field equation, the method of direct solution is applied; there is a solution of the equation Laplace by the method of dividing variables. It is known [2–6] that the method of direct solution of the equations of the field is reduced to finding a potential function that satisfies the equations of Laplace or Poisson, as well as the specified boundary and other conditions defining the field in a particular investigated area of the space where the electric machine is located.

When analyzing a field, it is particularly important to select a coordinate system in which a constant value of one or two coordinates describes the boundary configuration between regions with different values of magnetic RDP, which allows finding a solution standard way.

2 Main part

The method of dividing variables is usually used for analytical calculation of electromagnetic fields in areas whose boundaries are coordinate surfaces. At the current time, Cartesian and cylindrical coordinate systems are mainly used for the analytical study of the magnetic field of electric machines. Cartesian coordinates are convenient for analyzing fields
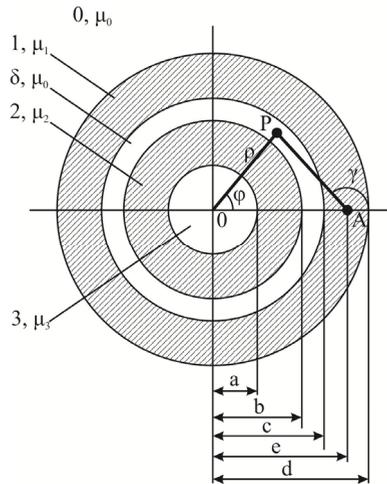
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with rectangular boundaries, and a cylindrical system for defining fields in areas whose boundaries in the plane are concentric circles and radii.

As this article aim is to investigate the magnetic field of standard electric machines of alternating current, in which the boundaries between areas with different magnetic properties are basically cylindrical forms, then for convenience of accounting Boundary conditions connecting gradients of potential functions, the cylindrical coordinate system is applied. In the analytical solution of the field equation, it is especially important to consider the amount of space splitting where the electric machine is located. The method of calculating the electromagnetic field of the stator winding does not revolving the synchronous machine by solving the Laplace equation first for the point conductor with current i, the method of dividing the variables when presenting the space of the machine location let's imagine the five areas [7] (Figure 1):

1. External area $\rho > d$ with index 0 and magnetic permeability $\mu_0 = 4\pi 10^{-7}$ gn/M;
2. Stator area with $d > \rho > c$ with index 1 and permeability μ_1;
3. Air gap $c > \rho > b$ with δ index and permeability μ_0;
4. The area of the rotor $b > \rho > a$ with index 2 and permeability μ_2;
5. Inner area $a > \rho >$ with index 3 and permeability μ_0.

Fig. 1. Distribution of areas.

Due to the absence in this 2d model of volumetric distribution of current density, the magnetic field can be characterized by scalar magnetic potential V and in the cylindrical system of coordinates to be considered as satisfying differential equation Laplace in private derivatives,

$$\frac{\partial}{\partial \rho}\left(\rho \frac{\partial V}{\partial \rho}\right) + \frac{1}{\rho}\frac{\partial^2 V}{\partial \varphi^2} = 0 , \tag{1}$$

where ρ-distance from the investigated point of the space to the center of the machine; φ-polar angle.

The solution of the equation (1) for the case of the point conductor location at the stator disposition for the five areas of space is

$$V_0 = \frac{i}{2\pi}\varphi + \sum_{n=1}^{\infty} D_{0n}\rho^{-n}\sin n\varphi , \tag{2}$$

$$V_1 = \frac{i}{2\pi}\gamma + \sum_{n=1}^{\infty}\left(C_{1n}\rho^n + D_{1n}\rho^{-n}\right)\sin n\,\varphi, \tag{3}$$

$$V_\delta = \sum_{n=1}^{\infty}\left(C_{\delta n}\rho^n + D_{\delta n}\rho^{-n}\right)\sin n\,\varphi, \tag{4}$$

$$V_2 = \sum_{n=1}^{\infty}\left(C_{2n}\rho^n + D_{2n}\rho^{-n}\right)\sin n\,\varphi, \tag{5}$$

$$V_3 = \sum_{n=1}^{\infty}C_{3n}\rho^n\sin n\,\varphi, \tag{6}$$

The constants in formulas (2) – (6) for harmonic *n*-th order, found from conditions on the boundaries of the section of environments with different magnetic permeabilities have the following form

$$D_{0n} = C_{1n}d^{2n} + D_{1n}, \tag{7}$$

$$C_{1n} = \frac{\mu_1 - \mu_0}{\mu_1 + \mu_0}d^{-2n}D_{1n}, \tag{8}$$

$$D_{1n} = \frac{c^{2n}}{1+m_1}C_{\delta n} + \frac{1}{1+m_1}D_{\delta n} + \frac{i}{\pi n} + \frac{1}{1+m_1}c^n, \tag{9}$$

$$C_{\delta n} = \mu_1\frac{i}{\pi n}\frac{c^n m_{12}}{c^{2n}\left(\mu_0 + \mu_1 m_{12}\right)+\left(\mu_0 - \mu_1 m_{12}\right)\dfrac{1-m_{21}}{1+m_{21}}b^{2n}}, \tag{10}$$

$$D_{\delta n} = -b^{2n}\frac{1-m_{21}}{1+m_{21}}C_{\delta n}, \tag{11}$$

$$C_{2n} = \frac{\mu_0}{\mu_2}\frac{1}{1-m_2}\left(C_{\delta n} - b^{-2n}D_{\delta n}\right), \tag{12}$$

$$D_{2n} = \frac{\mu_0}{\mu_2}\frac{m_2}{1-m_2}\left(b^{2n}C_{\delta n} - D_{\delta n}\right), \tag{13}$$

$$C_{3n} = C_{2n} + D_{2n}\,a^{-2n}. \tag{14}$$

From the formulas (2) – (6) are determine the radial and tangential components of the field strength in all five regions of space.

Practically for calculation of reactivities caused by components of a field of an air back-lash, the radial component of a arrears magnetic field, defined by the expression is of special interest.

$$H_{\delta\rho} = \sum_{n=1}^{\infty}n\left[D_{\delta n}\rho^{-(n+1)} - C_{\delta n}\rho^{(n-1)}\right]\sin n\,\varphi. \tag{15}$$

For a current layer of width equal to the width of the groove slot and located on the arc of the circumference of the stator's sharpening with an internal spatial angle equal to 2 α we have

$$H_{\delta\rho cл} = \sum_{n=1}^{\infty}\left[D_{\delta n}\rho^{-(n+1)} - C_{\delta n}\rho^{(n-1)}\right]\frac{\sin n\,\alpha}{n\,\alpha}\sin n\,\varphi. \tag{16}$$

Further in indices of values of notation δ and ρ will be omitted, having in view, that the one or another value characterizing a field refers to a radial component of a field of an air backlash of the machine.

Then for the intensity of the field of air gap created by the stator winding coil, consisting of $w_{\kappa1}$ turns, the sides of which stand apart on the arc of the circumference of the stator sharpening to the internal spatial angle of the β when combining the origin with the axis of this coil expression will have the appearance.

$$H_\kappa = 2w_{\kappa1} \sum_{n=1}^{\infty} K_n \sin n\frac{\beta}{2} \frac{\sin n\alpha}{n\alpha} \cos n\varphi . \tag{17}$$

where $K_n = n\left[D_{\delta n}\rho^{-(n+1)} - C_{\delta n}\rho^{(n-1)}\right]$.

For a group of coils of winding with number of grooves on a pole and a phase q_1 and an internal spatial angle α_{z1} between axes of two neighboring coils we have

$$H_q = 2w_{\kappa1}q_1 \sum_{n=1}^{\infty} K_n \kappa_{o6n} \cos n\varphi , \tag{18}$$

where $\kappa_{win\,n} = \sin n\frac{\beta}{2} \frac{\sin n\alpha}{n\alpha} \dfrac{\sin\left(n q_1 \dfrac{\alpha_{z1}}{2}\right)}{q_1 \sin\left(n\dfrac{\alpha_{z1}}{2}\right)}$ – wrapping coefficient for harmonic n-th order. The expression for the tension of the magnetic field in the air gap created by the phase double winding of the stator with the whole q_1 at flow on it a sinusoidal symmetrical three-phase current frequency f_1 will have a kind

$$H_\tau = 4pw_{\kappa1}q_1 \sum_{n=1}^{\infty} K_n \kappa_{win\,n} \kappa_{pqn}\left[\sin n\left(\varphi - \frac{2p-1}{p}\frac{\pi}{2}\right)\sin\left(\omega_1 t + \frac{2\pi}{3}\right) + \right.$$

$$\left. + \sin\left(\varphi - \frac{2p-1}{p}\frac{\pi}{2} - \frac{2\pi}{3p}\right)\sin\left(\omega_1 t - \frac{2\pi}{3}\right) + \sin n\left(\varphi - \frac{2p-1}{p}\frac{\pi}{2} - \frac{4\pi}{3p}\right)\sin\omega_1 t \right], \tag{19}$$

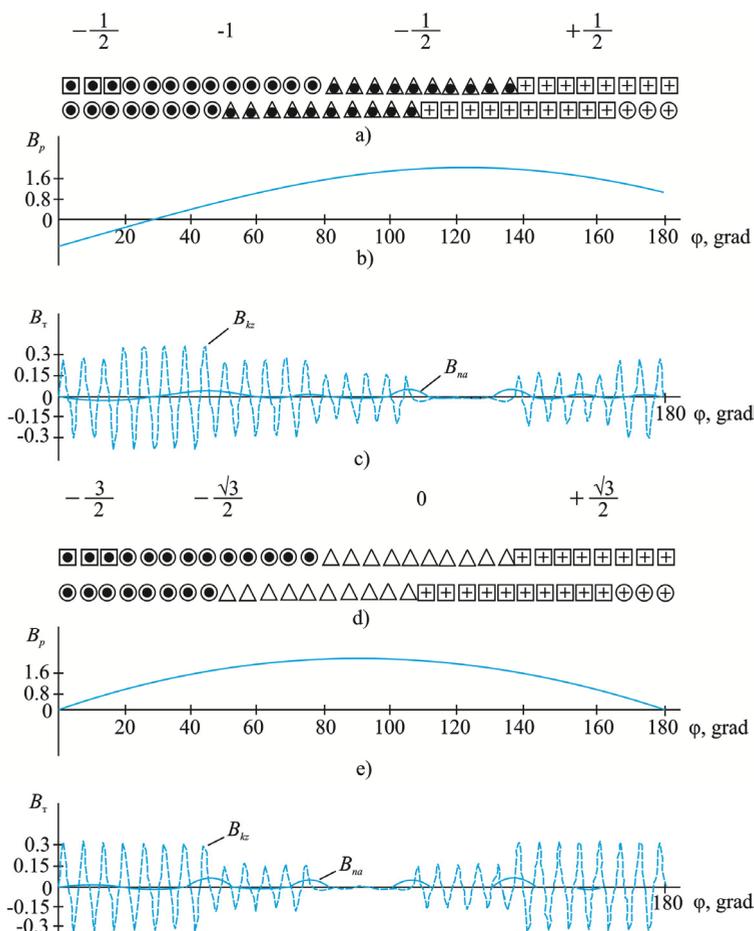where $\omega_1 = 2\pi f_1$ – angular frequency; t – time.

In Figure 2 are given the curves of distribution on the circumference of the stator of the magnetic inductions of the individual components of the result field of the air gap created by the double winding of the stator generator type TBB–200–2, as well as the distribution of the sides coils for moments of time t = 1/600 and 1/300 with within one pole division. In the study of the magnetic field in the air gap created by a winding not revolving synchronous machine alternating current. The resulting field is divided into three components:

1. Main field with magnetic induction B_p;

2. Field of scattering on crowns of teeth with induction $B_{\kappa z}$;

3. Field of Groove scattering with induction B_{na}.

The main field is a field with an order equal to the number of pairs of poles of the machine, and the field of scattering on the crowns of the teeth-the sum of all spatial harmonic fields of the air gap with the order, starting from the n_{kz} and above. The n_{kz} value can be found from the expression $n_{nz} = (Z_1/2) - p$, where Z1 is the number of stator grooves. This expression is found from the symmetry condition of the magnetic induction distribution curve of the scattering field, the crowns of the $B_{\kappa z}$ teeth and the circumference of the stator distraction in relation to the abscissa axis.

As seen in Figure 2, the curve of a field of scattering on crowns of teeth is practically symmetrical concerning an axis abscissa, and each its pair of poles is located symmetrically concerning an axis of the corresponding groove with current. The value of magnetic induction of this field under other identical conditions is proportional to the value of the full current of a groove, and magnetic power lines of one pair of poles cover only one groove with an electric shock, and magnetic poles settle down symmetrically concerning an axis each groove with a total current different from zero. With the expiration of time, that is, as the star turns the vectors of the phase currents the axis of each pair of poles remains motionless relative to the winding, coinciding with the axis of the corresponding groove, changes only the value of magnetic induction practically proportionally the size of the full groove current. The sum of all the remaining spatial harmonic fields of the air gap to a subsonic order, with the exception of the ground one, is a scattering field. The sum of the gap and crowned teeth of the components of the air gap field is the field of the differential dispersion of the winding.

Fig. 2. Results of calculations.

The field of scattering on crowns of prongs of a winding of an anchor leaving from a sharpening of a stator practically vertically its surface, that is in a radial direction, passes through an air backlash, both in radial, and in tangential directions.

The part of this field, reaching to a surface of a core of a rotor, penetrates its body and can put in its circuits EMF with the frequency different from the frequency of working cur-

rent circuits in a rotor. The component of the field of differential scattering of the anchor winding due to shortening of the pitch, distribution of coils on the grooves several times, and sometimes to order and more can be less scattering on crowns of teeth. When calculating the field, the equivalent values of magnetic RDP stator μ 1 and rotor μ 2, found separately for each component of the air gap field, which correspond to the actual operating mode of the machine, should be used. Although for all three components of the field of Air gap created by the winding, magnetic is common, but the magnetic circuits for each of them different. Therefore, the values of equivalent magnetic RDP for each component of the field are different.

3 Conclusion

External magnetic fields of the electric machine, depending on electromagnetic fields in the air gap, can have a significant impact on the electronic control equipment [6– 11], processors and computers located [12] near the machine.

References

[1] A. Alekseev, M. Kostenko, *Turbogenerators* (Moscow, 1939).

[2] P. Alger, The Calculation of the Armature Reactance of Synchronou Machines **47**, 493 (1928)

[3] I V Plotnikova, N V Chicherina, S S Bays, R G Bildanov, O Stary, IOP Conference Series: Materials Science and Engineering **289**, 012029 (2017) doi:10.1088/1757-899X/289/1/012029

[4] E. V. Beyerleyn, P.V. Tyuteva, Proceedings of 15th International Conference of Young Specialists on Micro/Nanotechnologies and Electron Devices (EDM-2014), (2014)

[5] N. V. Chicherina, V. A. Tolkacheva, European Proceedings of Social & Behavioural Sciences (EpSBS) **19**, 683 (2017) doi:10.15405/epsbs.2017.01.90

[6] B. Tsybikov, E. V. Beyerlein (Beierlein), P. V. Tyuteva, MATEC Web of Conferences **91**, 1(2017)

[7] G. Odilov. *The regenerating character of the anchor field in the air gap of the multiphase alternating current machine* (Tashkent, 1996)

[8] N. V. Chicherina, V. Kazakov, O. Yu. Korneva, E. A. Titenko, The European Proceedings of Social & Behavioural Sciences (EpSBS) **19**, 349 (2017) doi:10.15405/epsbs.2017.01.47

[9] B.V. Lukutin, Y.Zh. Sarsikeyev, M.A. Surkov, D.Yu. Lyapunov, Proceedings of 2014 14th International Conference on Environment and Electrical Engineering, EEEIC, 6835913 (2014)

[10] A.S. Petrusev, V.M. Rulevskiy, Ye.Zh. Sarsikeyev, D.Yu. Lyapunov, Proceedings of 2nd International Conference on Industrial Engineering, Applications and Manufacturing ICIEAM, 7911461 (2016)

[11] S.G. Obukhov, I.A. Plotnikov, M.A. Surkov, L.P. Sumarokova, IOP Conference Series: Materials Science and Engineering **177**, 012143 (2017)

[12] D.S. Akhmetbayev, D.A. Aubakir, Y.Z. Sarsikeyev, Results in Physics **7**, 1644 (2017)