ISSN 1392 – 1215 *ELECTRONICS AND ELECTRICAL ENGINEERING* *ELEKTRONIKA IR ELEKTROTECHNIKA* 2010. No. 5(101)

ELECTRICAL ENGINEERING
T 190
ELEKTROS INŽINERIJA

The Investigation of Poles Shape of the Technological Rotating Magnetic Field Inductor

O. Romaškevičius
UNERA, M.Pretorijaus 7–1, LT-06227,Vilnius, Lithuania, phone: +370-698-81830
M. Šiožinys, J. A. Virbalis
Department of Electrical Engineering, Kaunas University of Technology,
Studentu str. 48, LT-51367, Kaunas, Lithuania, phone: +370 699 84937, e-mail: arvydas.virbalis@ktu.lt

Introduction

The use of the rotating magnetic field for technological purposes enlarges in the latter years. There is very wide area: sewage treatment, oilfield and petrochemistry, the crushing of different materials, pharmacological industry, food industry, production of cosmetic, chemical industry and other [1]. We name the processing of different materials by rotating magnetic field as process activating and the area in which the process activating performs as active zone.

The some concentration of ferromagnetic materials is used frequently in the active zone. It is named as vortex layer because there is proceeded intensive movement of the magnetic particles in different directions.

The electric machine stator is used usually for magnetic field creation in the process activating unit. It is not optimal solution with respect to the power consumption and the request to the field distribution.

The requests to the rotating magnetic field inductor are different in the process activating units used for different purposes. But there are some properties of technological rotating magnetic field common for all inductors:

1. The active zone is created in the tube with diameter not less then D=50-100 mm, usually. Therefore the air gap is very big.

2. The magnetic flux density equal to 0,1-0,2 T must be created in this air gap. The considerable power for such magnetic field excitation is needed and solely the three-phase inductors are used [1].

3. The uniform value of the magnetic flux density is desirable in the all active zone. It is particularly important for process activating units without the vortex ferromagnetic layer. Such units can be used in the pharmacological industry, food industry, production of cosmetic, chemical industry, for creation of new material properties and other.

The problems of uniform rotating magnetic field creation are analyzed in [2] –[4]. Because the air gap bigness it is impossible to create uniform magnetic field in all air gap. The needed uniformity of field can be obtained narrowing down the active zone bounds.

The vortex ferromagnetic layer is strong factor of magnetic field action unification. Therefore, it is not essential to create the uniform magnetic field when ferromagnetic vortex layer is used.

The important influence to uniformity and intensity of field created by technological rotating magnetic field inductor has the shape and magnetic properties of poles. The rational choice of shape and dimensions of poles allows the electric power consumption needed for creation of necessary magnetic flux density in the active zone to diminish.

Investigation of influence of poles dimensions in the circumferential direction

The modeling using JMAG program package was performed. The investigated design is showed in Fig. 1.

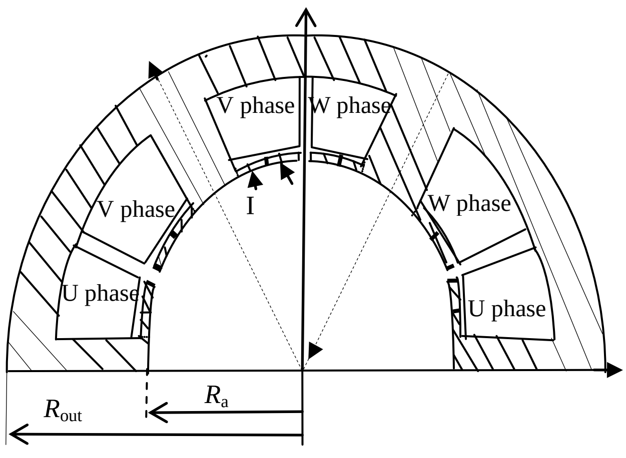

Fig. 1. The view of the upper half-plane of the magnetic field inductor cross-section

The inductor of 6 poles with uniformly arranged windings was modeled. The parameters of every winding were: N=1250, R=13 Ω. These windings were connected to the current sources with amplitude equal to I_m=3 A.

The 2D problem was performed in the cylindrical coordinate system. There was investigated the magnetic field distribution in the active zone for three different poles dimensions in the circumferential direction: for the non-salient poles, when the length of poles in the circumferential direction b_p is equal to the diameter of core of excitation winding d_e, i.e., the ratio $S=b_p/d_e=1$, for the middle length poles, when the ratio $S=b_p/d_e=2{,}17$ and for the maximal length poles, when $S=b_p/d_e=3{,}5$.

The modeling result was rotating magnetic field, the mean values of which vary depending on relative active zone diameter D/D_a (D_a –distance between the contrary poles) in limits between B_{min} and B_{max}. The obtained results were processed for comparison the magnetic flux density B deviation from its value B_0 in the active zone center. The value B_0 was calculated, as the mean value of the magnetic flux density inside cylinder D/D_a=0,2 by expression

$$B_0 = \frac{B_{\max 0,2} + B_{\min 0,2}}{2}. \quad (1)$$

The relative deviation δ of magnetic flux density in every relative cylinder was calculated by expressions

$$\delta_{\min} = \frac{B_0 - B_{\min}}{B_0} \cdot 100\%, \quad (2)$$

$$\delta_{\max} = \frac{B_{\max} - B_0}{B_0} \cdot 100\%, \quad (3)$$

$$\delta = \frac{\delta_{\min} + \delta_{\max}}{2}. \quad (4)$$

The obtained results are presented in table 1.

Table 1. The maximal and minimal values of magnetic flux density in the active zone cylinder, limited by relative diameter D/D_a

D/D_a, mm	Non-salient poles			Middle poles			Maximal poles		
	$B_{min}\cdot 10^{-1}$T	$B_{max}\cdot 10^{-1}$T	δ%	$B_{min}\cdot 10^{-1}$T	$B_{max}\cdot 10^{-1}$T	δ%	$B_{min}\cdot 10^{-1}$T	$B_{max}\cdot 10^{-1}$T	Δ%
0,2	1,351	1,355	0,17	1,750	1,760	0,28	1,962	1,972	0,25
0,3	1,336	1,369	1,25	1,727	1,784	1,6	1,934	1,994	1,55
0,4	1,310	1,401	3,4	1,676	1,839	4,6	1,879	2,045	4,30
0,5	1,244	1,466	8,2	1,569	1,957	11,1	1,742	2,174	10,9
0,6	1,127	1,598	17,9	1,259	2,205	27,4	1,444	2,453	25,6
0,7	0,844	1,832	36,5	0,881	2,646	50,2	1,056	3,115	52,3
0,8	0,520	2,300	65,7	0,533	3,654	84,9	0,535	4,770	108

We can see that the strongest field is obtained using the maximal length poles. In this case magnetic flux density arises on the average 45%, comparing with non-salient poles. Because the power consumption P is proportional to the second power of current I^2 and B~I, for creation of 1,45 time major magnetic flux density it is needed two times major power. Therefore, we can two times diminish the power consumption by poles widening in circumferential direction.

Unfortunately, the maximal deviation of magnetic flux density was obtained using the maximal length poles. The deviation arises especially near the poles. In the cylinder with relative diameter D/D_a=0,5 the deviation δ is not exceeded of 11% for all dimensions of poles. But this cylinder occupies only ¼ of maximal volume of the active zone. The cylinder limited by relative diameter D/D_a=0,7 occupies the half of the maximal volume, but the maximal deviation of magnetic flux density arises to (36 – 52)%, depending on the poles length.

Magnetic field distribution along the active zone axis

The 3D problem was modeled using JMAG program package to clear the distribution of magnetic field along the axis z. The modeled design is showed in Fig. 2. The modeling was performed for maximal poles with $S=b_p/d_e=3{,}5$. The shape of pole was circle with diameter $d_p=b_p$.

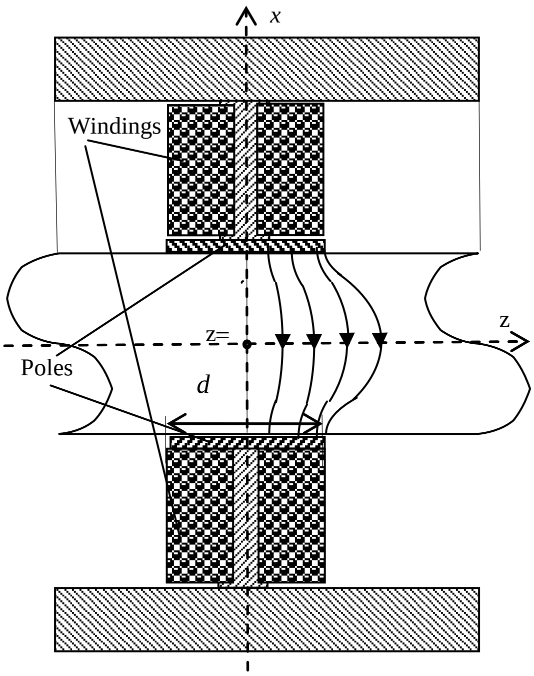

Fig. 2. The view of modeled design in zx plane and the magnetic field distribution in the active zone

The distribution of the mean value B_0 of the magnetic flux density inside the cylinder with relative diameter D/D_A=0,2 was investigated. There was accepted that the relative permeability all magnetic materials $\mu_r \to \infty$. The relative deviation δ of all values B_0 in these cylinder was not exceeded 0,4%.

The dependence of relative magnetic flux density value $\delta B = B_0(z')/B_0(0)$ on the relative distance $z' = z/(d_p/2)$ is presented in Fig. 3. Axis z is directed along the active zone axis. The origin z=0 is in the plane which contains axes of the excitation windings.

We can see of Fig. 3 that the magnetic flux density on the zone bounds diminishes not more than 5% when the length of active zone l_a is not exceeded the 0,7d_p. When $l_a = d_p$, the magnetic flux density on the zone bounds diminishes to 11%. The raison of this diminution is the magnetic field lines deflection (Fig. 2).

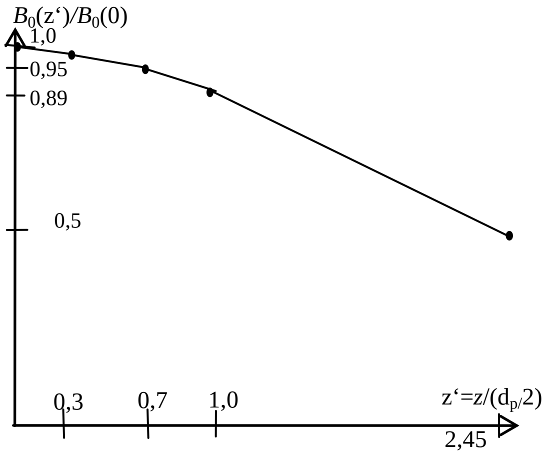

Fig. 3. Relative variation of magnetic flux density along z axis

The possibility of active zone expansion along the axis

The poles length in circumferential direction is limited by poles of other phases. But in the axial direction the poles can be extended theoretically without restriction. If we could warrant the constant difference of scalar magnetic potentials on the poles we could be have approximately the same magnetic flux density between the poles. Therefore extending the poles we can extend the active zone of device. We clear restrictions of such expansion investigating the equivalent electric schema of the magnetic circuit, showed in the Fig. 4.

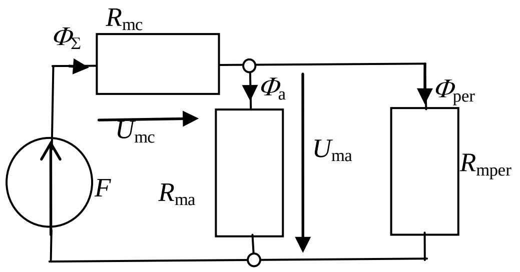

Fig. 4. The equivalent electric circuit of the magnetic flux distribution

The simplified circuit is presented in Fig. 4 supposing that poles are made of the ferromagnetic material with relative permeability $\mu_p \to \infty$. In this figure there are presented R_{mc} – the total magnetic resistance of excitation windings core and magnetic screen, R_{ma} – the magnetic resistance of active zone, R_{mper} – magnetic resistance to peripheral flux Φ_{per}, which is situated outside active zone. The peripheral flux Φ_p was equal to 12% of total flux Φ_Σ by modeling results of design, showed in Fig. 2. The ratio Φ_p/Φ_Σ can vary minutely extending the poles in z direction. The flux of active zone Φ_a is generated by all area of poles and the peripheral flux is generated on the poles perimeter. But the poles area and perimeter are varied proportional in this case. The magnetic resistances R_{mc} and R_{ma} can be expressed as

$$R_m = \frac{l}{S\mu_r\mu_0}, \qquad (5)$$

where l – the mean length of the magnetic line; S – the area of cross-section of investigated part of magnetic circuit; μ_r – the relative permeability; μ_0 – magnetic constant.

Expressing magnetic flux Φ_a in the active zone

$$\Phi_a = B_a S_p = U_{ma}/R_{ma} \qquad (6)$$

and evaluating (5), where $l = l_a$, $\mu_r = 1$, $S = S_p$, we can assure, that in active zone the magnetic flux density B_a is not depended on poles area S_p, when magnetic voltage U_{ma} is constant

$$B_a = \frac{\mu_0 U_{ma}}{l_a}. \qquad (7)$$

Before the poles area S_p are not big the fall of magnetic voltage U_{mc} in magnetic resistance R_{mc} can not be evaluated. All voltage $U_{ma} = F$ acts in the magnetic resistance R_{ma}, i.e., in the active zone. With arising of poles area S_p the magnetic resistance R_{ma} decreases but the magnetic resistance R_{mc} rests the same and the fall of magnetic voltage U_{mc} becomes meaningful. For example, in the design, showed in Fig. 1 and 2, when radius of active zone is R_a=50mm and the pole length along axis z l_z=100mm, the ratio $R_{ma}/R_{mc} \approx (0{,}05\text{-}0{,}1)\,\mu_r$. Therefore if we want that the B_a could be not decrease meaningful the condition $\mu_r \geq 1000$ must be content.

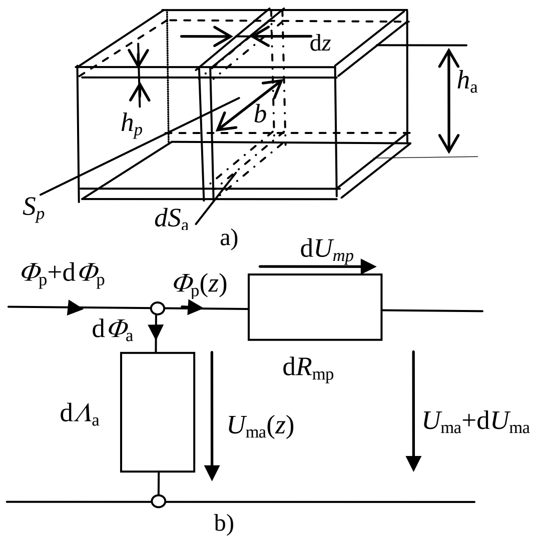

Fig. 5. Dividing of pole magnetic resistance and active zone magnetic conductance into elementary elements (a) and its equivalent electric circuit (b)

When the pole is thin its magnetic resistance can have the influence on the magnetic field distribution. We can evaluate this influence using the theory of distributed-parameter line. Let the magnetic flux Φ_p inside pole be directed along z axis and the part dΦ_a be branched into active zone in every length element dz. Let the flux dΦ_a be directed along axis x. For every element dz we can express the elementary magnetic conductance of the active zone $d\Lambda_{ma}$ and the elementary magnetic resistance of the pole dR_{mp}, evaluating that there are two poles (Fig. 6, a)

$$d\Lambda_{ma} = \frac{\mu_0 dS_a}{h_a} = \frac{\mu_0 b}{h_a} dz = \Lambda_{ma0} dz, \quad (8)$$

$$dR_{mp} = \frac{2dz}{\mu_{rp}\mu_0 S_p} = \frac{2}{\mu_{rp}\mu_0 h_p b} dz = R_{mp0} dz, \quad (9)$$

where Λ_{ma0} – magnetic conductance of a unit of active zone length; R_{mp0} – magnetic resistance of a unit of pole length along axis z

$$\Lambda_{ma0} = \frac{\mu_0 b}{h_a}, \quad (10)$$

$$R_{mp0} = \frac{2}{\mu_{rp}\mu_0 h_p b}. \quad (11)$$

The equivalent electric circuit of the elementary elements of the active zone and poles of length dz is showed in Fig. 6, b. By Ohm low we can write

$$dU_m = \Phi dR_{mp} = \Phi R_{mp0} dz, \quad (12)$$

$$d\Phi = U_m d\Lambda_{ma} = U_m \Lambda_{ma0} dz. \quad (13)$$

We obtain differentiating the equations (12) and (13) by z and expressing U_m via Φ

$$\frac{d^2\Phi}{dz^2} = R_{mp0}\Lambda_{ma0}\Phi. \quad (14)$$

It is the simplest variant of well-known wave equation which solution non-evaluating reflection is

$$\Phi = \Phi_\Sigma \cdot e^{-\sqrt{R_{mp0}\Lambda_{ma0}} \cdot z}. \quad (15)$$

By (10) and (11) we can write

$$\Phi = \Phi_\Sigma \cdot e^{-\sqrt{\frac{1}{\mu_{rp}(h_p/2z)(h_a/z)}}}. \quad (16)$$

Using this equation we can evaluate diminution of magnetic field and choose the design and materials of inductor. For example when h_a=100mm, h_p=2mm, μ_{tp}=1000, on the distance z=100mm we obtain Φ=0,74Φ_Σ. Therefore, the flux diminishes 26% in the zone bound. Changing μ_{tp}=1000 to μ_{tp}=10000 we obtain Φ=0,9Φ_Σ. The flux diminishes 10%. If we will thicken the poles the diminution of field will decrease.

Conclusions

1. The magnetic field we can increase average 45% extending poles in circumferential direction.
2. Elongating the poles along inductor axis we can extend the active zone, but it is needed to thicken the poles and to increase its relative permeability.

References

1. **Romaškevičius O., Šiožinys M., Virbalis J. A.** The Influence of Exciting Current Unbalance to Parameters of Rotating Magnetic Field // Electronics and Electrical Engineering. – Kaunas: Technologija, 2008. – No. 3(83). – P. 85–88.
2. **Rinkevičienė R., Batkauskas V.** Modeling and Investigation of Vector Controlled Induction drive // Electronics and Electrical Engineering. – Kaunas: Technologija, 2008. – No. 1(81). – P. 53–56.
3. **Bukšnaitis J.** Research of Formation Sinusoidal Three-Phase Winding (In Lithuanian) // Electronics and Electrical Engineering. – Kaunas: Technologija, 2004. – No. 1(50). – P. 46–51.
4. **Gečys S., Smolskas P.** Copper Squirrel-Cage Solid Rotor Teeth Zone Parameter Rational Choice for Induction Motor Operating under Geophysical Conditions // Electronics and Electrical Engineering. – Kaunas: Technologija, 2009. – No. 1(89). – P. 91–94.

Received 2010 02 20

O. Romaškevičius, M. Šiožinys, J. A. Virbalis. The Investigation of Poles Shape of the Technological Rotating Magnetic Field Inductor // Electronics and Electrical Engineering. – Kaunas: Technologija, 2010. – No. 5(101). – P. 17–20.

The inductor of technological rotating magnetic field must create the magnetic flux density equal to 0,1–0,2 T in the big air gap. The uniformity and intensity of created field strongly depend on the inductor poles geometry. The mean value of magnetic flux density can be increased about 45 % expending the poles in circumferential direction. The influence of pole magnetic resistance to the magnetic field distribution along axis can be evaluated, using the theory of distributed-parameter line. Elongating the poles along inductor axis the unit active zone can be extended, but the poles must be thickened and its relative permeability must be increased. Ill. 5, bibl. 4, tabl. 1 (in English; abstracts in English, Russian and Lithuanian).

О. Ромашкевичюс, М. Шиожинис, Ю.А.Вирбалис. Исследование формы полюсов индуктора технологического вращающегося магнитного поля // Электроника и электротехника. – Каунас: Технология, 2010. – № 5(101). – С. 17–20.

Индуктор технологического вращающегося магнитного поля должен создать плотность магнитного потока 0,1–0,2 T в большом воздушном промежутке. Однородность и интенсивность созданного поля очень зависит от геометрии полюсов индуктора. Влияние магнитного сопротивления полюса на рапределенние магнитного поля вдоль оси можно оценить, пользуясь теорией длинной линии. Значение плотности магнитного потока можно увеличить в среднем на 45%, расширяя полюса в радиальном направлении. Удлиняя полюса в направлении оси индуктора можно удлинить активную зону устройства. Ил. 5, библ. 4, табл. 1 (на английском языке; рефераты на английском, русском и литовском яз.).

O. Romaškevičius, M. Šiožinys, J. A. Virbalis. Technologinio sukamojo magnetinio lauko induktoriaus polių formos tyrimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2010. – Nr. 5(101). – P. 17–20.

Technologinio sukamojo magnetinio lauko induktorius turi sukurti 0,1–0,2 T tankio magnetinį srautą dideliame oro tarpe. Sukuriamo lauko vienalytiškumas ir intensyvumas labai priklauso nuo induktoriaus polių geometrijos. Vidutinę magnetinio srauto tankio vertę galima padidinti vidutiniškai 45 % plečiant polius radialine kryptimi. Polių magnetinės varžos įtaką magnetinio lauko pasiskirstymui ašies kryptimi galima nustatyti remiantis paskirstytųjų parametrų linijų teorija. Ilginant polius aktyvinimo įrenginio ašies kryptimi, galima praplėsti įrenginio aktyviąją zoną šia kryptimi, tačiau būtina storinti polius ir didinti jų santykinę magnetinę skvarbą. Il. 5, bibl. 4, lent. 1 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).