Olegas ROMAŠKEVIČIUS[1], Povilas MARČIULIONIS[2],Valdas PAKĖNAS[2], Juozapas Arvydas VIRBALIS [2]

UAB Unera (1), Kaunas University of Technology (2)

doi:10.15199/48.2016.02.24

Technological Inductors of Rotating Magnetic Field

***Abstract**. To create the technological rotating magnetic field three phase inductors are used. For normal technological process it is needed magnetic flux density equal to 0,08 T or more. It must be distributed uniformly in active zone. The two pole inductor with concentrated diametric windings meets considerably better such requirements than four pole inductor. The apparent power can be decreased by 1,3 time and non-uniformity of magnetic field distribution by 3 times using two pole inductor vice versa four pole inductor.*

***Streszczenie.** W celu wytworzenia wirującego pola magnetycznego użyto trójfazowego, skupionego uzwojenia wzbudzenia. Na potrzeby procesów technologicznych niezbędne jest wytworzenie pola magnetycznego o wartości indukcji magnetycznej równej co najmniej 0,08 T o równomiernym rozkładzie w strefie aktywnej. Wykazano, że lepszą równomierność uzyskuje się dla rozwiązań o dwóch biegunach niż dla wzbudzenia czterobiegunowego. Wykazano, że dla uzyskania identycznej wartości indukcji magnetycznej do wytworzenia dwubiegunowego pola magnetycznego potrzebna jest moc pozorna 1,3-krotnie mniejsza niż dla pola o czterech biegunach, uzyskując jednocześnie 3-krotnie lepszą równomierność rozkładu pola magnetycznego. (**Wytwarzanie wirującego pola magnetycznego do celów technologicznych**).*

Keywords: rotating magnetic field; uniformity of distribution; two poles and four poles inductor.
Słowa kluczowe: wirujące pole magnetyczne; równomierność rozkładu; dwubiegunowe i czterobiegunowe uzwojenie wzbudzenia.

Introduction

The rotating magnetic field can be used for processing of different liquids, solutions or suspensions. The use of rotating magnetic field for crushing, mixing, chemical or physical processes activation instead of traditional technologies can improve the quality of products, reduce of power consumptions, accelerate process, perfect the work conditions. The advantages of above-mentioned technologies are explained in [1-4].

The rotating magnetic field can be used successfully for control of magnetic nanoparticles. It is very usefull for production of metal cartalysts, enzymes, terapeutic drug agents and for many other purposes [5,6].

In this paper we compare two different types of rotating magnetic field inductor specialized for technological applications.

For satisfactory technological effect the uniform magnetic field with flux density equal to 0,08 - 0,2 T is needed [1-5]. To obtain such magnetic field three phase inductor is necessary. The simplest solution is use of induction electric motor stator. But there is essential distinction between the motor and technological inductor. In the latter the magnetic field must be created in the big air gap. In the motor this arrea is occuped by rotor made of ferromagnetic material. Therefore, magnetic resistance of technological inductor is essentially bigger and considerably major magnetic field strength must be created to obtain needed magnetic flux density.

For large and enough uniform magnetic field creation the concentrate windings are used. They are mounted in the cavities of the magnetic circuit. Among the cavities are the teeths which perform the role of magnetic poles. To create the magnetic field of any phase can be used two antipodally situated windings or one winding. In the first case we have four pole inductor in the other case – two pole inductor. Still the four pole inductor was used for technological purposes usually [1-5]. But two pole inductor has some advantages which will be discovered in this paper.

Realisation of technological inductors

The design of magnetic circuit can be the same in the both types of inductors (see Fig. 1 and 2). It has the basic hollow cylinder of ferromagnetic material and six teeth. The transverse section of four poles inductor is shown in Fig. 1.

In the four pole inductor the windings of the same phase U1 and U2, V1 and V2, W1 and W2 are winded on the antipodal teeth.

In the case of two pole inductor the half of winding of the same phase is placed in the hollow between two neighbouring teeth. Other half of the same phase winding is placed in the antipodal hollow. Therefore the winding span is equal to diameter. Practically the winding of any phase is divided into two windings: U1 and U2, V1 and V2, W1 and W2. In this case the ends of windings of any phase can be situated on the outer surface of pipe with technological liquid contrary one to other. Any pair of one phase windings creates two magnetic poles. Therefore we have the two pole inductor. For analysis we suppose that only one winding is used for exciting of any phase of magnetic field.

The uniformity of magnetic field was investigated by modelling of the both inductors types.

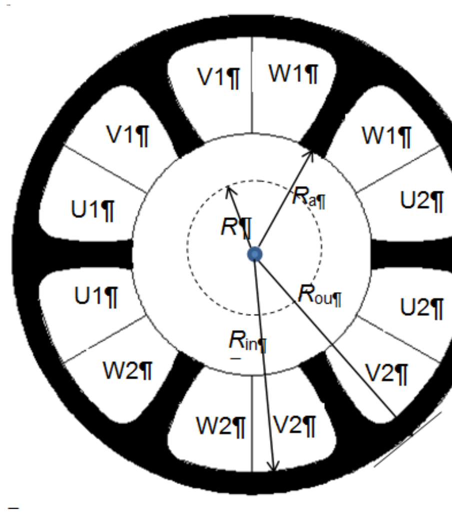

Fig. 1. View of the four-pole inductor cross-section.

Modelling of inductors

The finite element modelling package JMAG was chosen. This package is specialized for electric motors. It can be used successfully for investigation of the technological rotating magnetic field inductors. We investigate the distribution of magnetic flux density in the areas of two and four poles technological inductors active zone (the area in which technological process proceeds) limited by some radius *R* (see Fig. 1). Modelling was performed with the same magnetic circuit in the both cases. The outer radius of magnetic circuit basic cylinder was chosen R_{ou}=120 mm, the inner radius was R_{in}=100 mm. The outer radius of pipe with technological liquid was R_a=62,5 mm. It is limited by teeth edges. The number of winding turns was the same, N=300. The voltage amplitude was the same, too, equal to U_m=311V. The two-dimensional problem was solved.

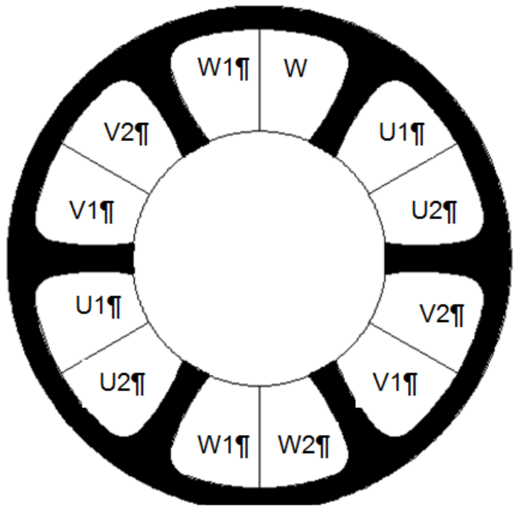

Fig. 2. View of the two-pole inductor cross-section.

For both cases: 1) the value B_0 of magnetic flux density in the center of active zone was found; 2) some circles with different radii R of interval [0, R_a] were chosen; 3) the minimal B_{minR} and maximal B_{maxR} values of magnetic flux density were found in any circle and the relative deviations δ_{minR}, δ_{maxR} and δB at value in center B_0 for any circle with radius R were calculated by expressions:

$$\delta_{\mathrm{minR}} = [(B_0 - B_{\mathrm{minR}}) / B_{\mathrm{vidR}}] \cdot 100\%,$$

$$\delta_{\mathrm{maxR}} = [(B_{\mathrm{max}R} - B_0) / B_{\mathrm{vidR}}] \cdot 100\%, \ \delta B = \delta_{\mathrm{minR}} + \delta_{\mathrm{maxR}}.$$ The obtained results are presented in Table 1.

Table 1. The intervals of magnetic flux density in the part of active zone limited by relative radius R/R_a

R/R_a	Four pole inductor			Two pole inductor		
	$B_{min}\cdot 10^{-1}$T	$B_{max}\cdot 10^{-1}$T	δB%	$B_{min}\cdot 10^{-1}$T	$B_{max}\cdot 10^{-1}$T	δB%
0,2	1,351	1,355	0,17	1,898	1,906	0,19
0,3	1,336	1,369	1,25	1,892	1,912	0,54
0,4	1,310	1,401	3,4	1,874	1,930	1,5
0,5	1,244	1,466	8,2	1,831	1,971	3,7
0,6	1,127	1,598	17,9	1,749	2,062	8,1
0,7	0,844	1,832	36,5	1,620	2,189	16,1
0,8	0,520	2,300	65,7	1,481	2,560	28,4

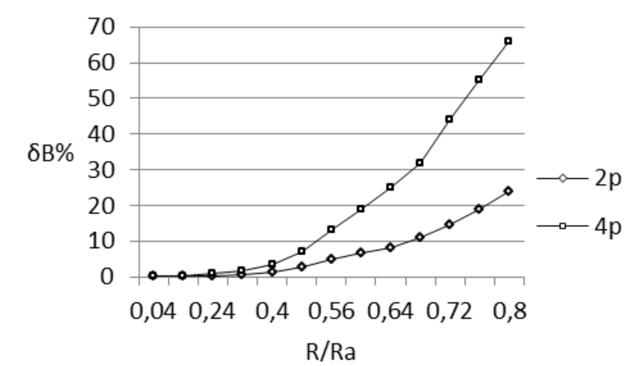

Fig.3. Dependence of magnetic flux density deviation δB on relative radius R/R_a in the two pole (2p) and four pole (4p) inductors

The intervals of relative deviations δB for some ratios of radii R/R_a are presented in the Table 1. The radius R_a coincides with distance at active zone center to the edges of magnetic circuit teeth (see Fig. 1). The outer surface of technological reactor pipe touches these edges. The technological process performs in the inner volume limited by inner pipe surface, so the analysis was doing only to ratio value equal to R/R_a=0,8**.**

In Fig. 3 there are presented dependences of the magnetic flux density maximal relative deviation on relative radii in four pole and two pole inductors. We can see that two pole inductor allows obtain considerably more uniform magnetic field than four pole inductor. In the periphery of active zone the non-uniformity of magnetic field created by four pole inductor is more than 3 times large than non-uniformity of magnetic field created by two pole inductor.

Comparison of magnetic properties of four- and two-pole inductors

The same magnetic flux density in all volume of the active zone must be created in both cases. But modelling shows that inductance of any winding of two pole inductor with the same number of turns is 3,2 times more than inductance of four pole inductor. To explain such difference we can analyze the magnetic circuits of both inductors. In four pole inductor the magnetic field is created by the excitation windings which are winded on the upper and lower teeth of magnetic circuit. The upper winding creates the magnetomotive force F. We suppose that the positive scalar potential $V_{mp}=F$ of this force is connected to the tooth edge. The scalar potential equal to zero is connected to the magnetic circuit basic cylinder. The negative potential of magnetomotive force created by lower winding, vice versa, is directed to the tooth edge, the positive potential is connected to magnetic circuit with magnetic potential equal to zero V_{mM}=0. In this case the magnetic potential equal to zero will have central diameter C, which divides the upper and lower parts of magnetic circuit. We suppose that magnetic voltage is not fall in the magnetic circuit of inductor, i.e., the magnetic resistance of magnetic circuit is equal to zero.

The distribution of one phase magnetic field of four pole inductor is shown in Fig. 4. We can see that the most part of magnetic flux is distributed in the active zone. But some part of magnetic flux is distributed of the active zone limits. The magnetic flux density is the most near the surface of tooth on which is winded the winding of phase under consideration. Near the other teeth the magnetic flux density is lesser.

Distribution of magnetic field which is created by one phase in the active zone of two pole inductor is shown in the Fig. 5.

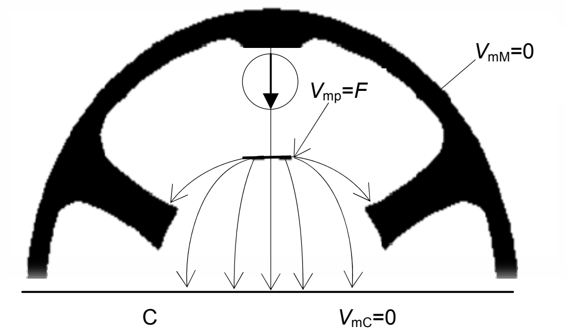

Fig. 4. Distribution of magnetic field in the upper half plane of the four pole inductor with narrow poles.

The excitation windings are mounted this way that the plane which separate two windings of the same phase coincides with central diameter C in the cross-section. We suppose that scalar magnetic potential V_{mM} of the upper part of magnetic circuit is equal to magnetomotive force of the one winding $V_{mMu}=F=NI$ (I – winding current). Analogically we suppose that scalar magnetic potential V_{mM} of the lower part of magnetic circuit is equal to magnetomotive force of the one winding with sign minus: $V_{mMl}=-F$. The distribution of magnetic flux density in the upper half plane of the cross-section is shown in Fig. 5.

By comparing this distribution with field distribution in the four pole inductor we can see that in the two pole inductor the teeth of magnetic circuit which are near the central diameter create the complementary magnetic flux. This flux is stronger than flux created by upper tooth. The magnetic flux is the most near all teeth edges. By such distribution total magnetic flux created by all windings is more uniform in the two pole inductor than in four pole inductor.

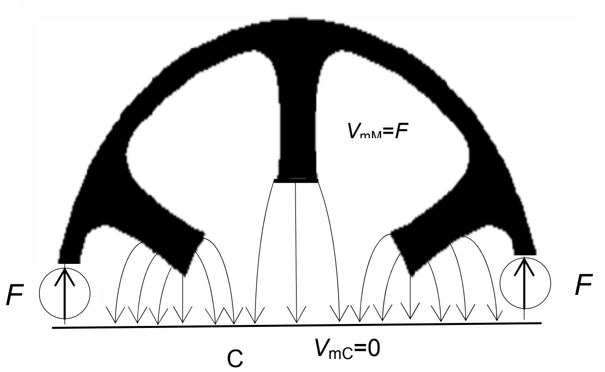

Fig.5. Distribution of magnetic field in the upper half plane of the two pole inductor.

Table 2. Dependence of magnetic flux density deviation on the relative radius R/R$_a$ for teeth with different edge width

	Non-broaden tooth		Middle width		Large width	
R/R$_a$	$B_0\cdot 10^{-1}$T	δ%	$B_0\cdot 10^{-1}$T	δ%	$B_0\cdot 10^{-1}$T	δ%
0,2	1,353	0,17	1,755	0,28	1,967	0,25
0,3	1,354	1,25	1,755	1,6	1,964	1,55
0,4	1,355	3,4	1,757	4,6	1,962	4,30
0,5	1,355	8,2	1,760	11,1	1,958	10,9
0,6	1,362	17,9	1,760	27,4	1,949	25,6
0,7	1,385	36,5	1,763	50,2	1,969	52,3
0,8	1,410	65,7	1,820	84,9	2,080	108

Power characteristics of four- and two-pole inductors

The more part of flux is distributed of the limits of active zone in the two-pole inductor. If we connect the windings of two- and four-pole inductors to the same voltage source in the active zone center of two-pole inductor the magnetic flux density B_0 was obtained 1,57 times lower than of the four-pole inductor. To obtain the same value of B_0 in the two pole inductor the voltage must be increased. The modelling was performed for voltage ratio of two U_2 and four U_4 pole inductors equal to U_2/U_4=1,57. The same value of B_0 was obtained for the current ratio of two I_2 and four I_4 pole inductors equal to I_2/I_4=0,49. Therefore, the apparent power S_2 which is operated in the two pole inductor is lesser than the apparent power S_4 of the four pole inductor: S_2=0,77S_4.

There is possibility to increase the magnetic flux density B_0 created in the four pole inductor with the same apparent power. It is needed to enlarge the edges of teeth on which the windings are mounted. But the teeth edges of neighbouring phases can't to touch one other. Therefore, the maximal width of tooth edge l_{pmax} must meet the requirement $l_{pmax}<(\pi/3)\cdot R_a \approx R_a$. The modelling was performed for three cases: 1) the tooth edge is not broadened, l_{ps}=15 mm (non-broaden tooth), 2) width of tooth edge is l_{pv}=30 mm (middle width), 3) width of tooth edge is l_{pmax}=60 mm (large width). The modelling results are presented in the Table 2.

We can see that in the inductor with maximal width teeth magnetic flux density increases 1,45 times in comparison with non-broaden teeth inductor. In this case the apparent power which is needed to create the same magnetic flux density B_0 in the two and four pole inductors is the same. But in the case of teeth with large edges the non-uniformity of the field distribution increases about 1,5 times in comparison with non-broadened teeth. Therefore, the use of two pole inductor is desirable in this case, too.

Conclusions

1. The rotating magnetic field needed for technological purposes must be distributed uniformly in the large air gap.
2. In the technological rotating magnetic field inductors the concentrated windings mounted in large cavities of magnetic circuit are used.
3. To obtain the same magnetic flux density value in the active zone center of the two-pole inductor we can with the 1,3 times lesser apparent power and 3 times lesser non-uniformity than of the four pole inductor.
4. In four pole inductor the apparent power can be decreased if the edges of teeth are broadened, but in this case the non-uniformity of magnetic field distribution increases.

***Authors**: inż. Olegas Romaškevičius, UAB Unera, Pretorijaus 7-1, 06-227 Vilnius, Lithuania E-mail: uneralithuania@gmail.com; dr inż. Povilas Marčiulionis, dr inż. Valdas Pakėnas and dr hab. inż. Juozapas Arvydas Virbalis all Kaunas University of Technology, Department of Electrical Power systems, Studentu 48, 51-367 Kaunas, E-mails: povilas.marciulionis@ktu.lt, valdas.pakenas@ktu.lt, arvydas.virbalis@ktu.lt.*

REFERENCES

[1] Инюшин Н.В. и др. Аппараты для магнитной обработки жидкостей. Уфа: государственное издательство научно-технической литературы «Реактив», 2001 - с. 147.

[2] Адошев А.И. Ферровихревой аппарат для обеззараживания жидкого навоза.- Автореферат диссертации. – Ставрополь. – 2011. – с. 19.

[3] Rakoczy R. and Masiuk S. Influence of transverse rotating magnetic field on enhancement of solid dissolution process, *Aiche J.* , 56(2010), 1416-1433.

[4] Lu X.S., Li H. Fluidization of $CaCO_3$ and Fe_2O_3 particle mixtures in a transverse rotating magnetic field, *Powder Technol.,* 107 (2000, 66-78.

[5] Chaves A., Rinaldi C., Elborai S., He X., Zahn M. Bulk flow in ferrofluids flow in a uniform rotating magnetic field, *Phys.Rev.Let.,* 96 (2006). 0194501.

[6] Pouya Hajiani New magnetic stimulation routes with magnetic nanoparticles from process intensification in chemical engineering. Doctorat en genie chimique Philosophiae Doctor (Ph.D.) Quebec, Canada 2013. – P.162.