ISSN 1392 – 1215 ELECTRONICS AND ELECTRICAL ENGINEERING 2008. No. 3(83)
ELEKTRONIKA IR ELEKTROTECHNIKA

T 190 ELECTRICAL ENGINEERING
ELEKTROS INŽINERIJA

The Influence of Exciting Current Unbalance to Parameters of Rotating Magnetic Field

O. Romaškevičius
„UNERA“, M. Pretorijaus str. 7-1, LT-06227 Vilnius, Lithuania, phone: +370 698 81830
M. Šiožinys, J. A. Virbalis
Kaunas University of Technology, Department of Theoretical Electrical Engineering
Studentų str. 48, LT-51267 Kaunas, Lithuania, phone: +370 37 300267

Introduction

The mean area of rotating magnetic field applications is design of electrical machines. But it can be use for technological purposes, too, and the area of successfully applications of rotating magnetic field enlarges continually in the last time. There is very large area: sewage treatment, crystallography, granulation, medical diagnostics, pharmacological industry and other [1-3]. The rotating magnetic field activates the useful technological processes. We name the *active zone* a zone in which the technological processes proceed under the influence of rotating magnetic field.

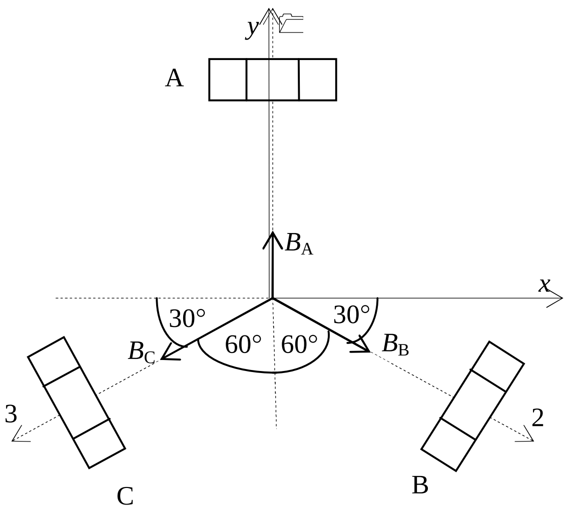


Fig. 1. The inductor of rotating magnetic field

The mean distinction between magnetic fields in electrical machines and in technological devices is that the air space is large in active zone of technological devices. The magnetic field of technological devices is non-uniform, the considerable influence to magnetic field distribution has the shape of magnetic flux inductor. We investigate the influence of the three-phase exciting current unbalance to the magnetic field distribution.

The problem formulation

We investigate the three-phase inductor of magnetic field (see fig. 1). The axes of coils A, B and C are in the plane z=0 which is perpendicular to active zone axis. They are rotated one to other by angle 120°. The magnetic field exciting coils are connected to the three-phase source: the initial oscillation phase of coil A current is equal to 0, the initial oscillation phase of coil B current is equal to -120°, and the initial oscillation phase of coil C current is equal to 120°. The unbalance of source is evoked by non-equality of coil current amplitudes. Let the amplitude of created by coil A magnetic flux density be B_0, the amplitude of created by coil B magnetic flux density be $B_{mB}=\beta B_0$, and the amplitude of created by coil C magnetic flux density be $B_{mC}=\gamma B_0$. We suppose, that coefficients β and γ are positive and have values being in interval [0, 1]. The coefficients β and γ can be named as unbalance coefficients.

The instantaneous values B_A, B_B and B_C of magnetic flux densities created by coils A, B and C are:

$$\begin{cases} B_A = B_0 \sin \omega t; \\ B_B = \beta B_0 \sin(\omega t - 120^\circ) = \\ = \beta B_0 (\sin \omega t \cos 120^\circ - \sin 120^\circ \cos \omega t); \\ B_C = \gamma B_0 \sin(\omega t + 120^\circ) = \\ = \gamma B_0 (\sin \omega t \cos 120^\circ + \sin 120^\circ \cos \omega t). \end{cases} \quad (1)$$

We investigate the magnetic field on the plane z=0. The vectors $\boldsymbol{B}_\mathbf{A}$, $\boldsymbol{B}_\mathbf{B}$ and $\boldsymbol{B}_\mathbf{C}$ are directed along the axes 1, 2 and 3, correspondingly (see fig 1). Let express the components B_x and B_y of vectors $\boldsymbol{B}_\mathbf{A}$, $\boldsymbol{B}_\mathbf{B}$ and $\boldsymbol{B}_\mathbf{C}$ on the axes x and y of coordinate system situated in the plane z=0. We obtain:

$$\begin{cases} B_x = (B_B - B_C)\cos 30^o = \\ = -\frac{B_0}{4}[3(\beta+\gamma)\cos\omega t - \sqrt{3}(\beta-\gamma)\sin\omega t]; \\ B_y = B_A - (B_B + B_C)\cos 60^o = \\ = \frac{B_0}{4}\{[4+(\beta+\gamma)]\sin\omega t + \sqrt{3}(\beta-\gamma)\cos\omega t\}. \end{cases} \quad (2)$$

The vector $\boldsymbol{B}=\boldsymbol{e}_x B_x+\boldsymbol{e}_y B_y$ express the value and direction of magnetic flux density in any point of plane z=0 in any moment of time. The relative value of vector length $|\boldsymbol{B}/B_0|$ is:

$$\left|\frac{\boldsymbol{B}}{B_0}\right| = \frac{1}{B_0}\sqrt{B_x^2 + B_y^2} = \\ = (1/4)\sqrt{K_0(\beta,\gamma) + K_1(\beta,\gamma)\cos 2\omega t + K_2(\beta,\gamma)\sin 2\omega t}, \quad (3)$$

where

$$K_0(\beta,\gamma) = 8 + 4(\beta+\gamma) + 5(\beta+\gamma)^2, \quad (4)$$

$$K_1(\beta,\gamma) = 4\cdot[2-(\beta+\gamma)(\beta+\gamma-1)], \quad (5)$$

$$K_2(\beta,\gamma) = 2\sqrt{3}\cdot[2-(\beta+\gamma)]\cdot(\beta-\gamma). \quad (6)$$

The angle between the vector $\boldsymbol{B}$ and axis x is $\varphi(\omega t)$. It can be expressed this way:

$$\varphi = \arctan\left(\frac{B_y}{B_x}\right) = \arctan\left[\frac{\frac{4+(\beta+\gamma)}{3(\beta+\gamma)}\tan\omega t + \frac{\sqrt{3}}{3}\frac{\beta-\gamma}{\beta+\gamma}}{1+\frac{\sqrt{3}}{3}\frac{\beta-\gamma}{\beta+\gamma}\tan\omega t}\right]. \quad (7)$$

When the system of exciting currents is balanced $\beta=\gamma=1$, $K_1(\beta,\gamma)=K_2(\beta,\gamma)=0$, $B/B_0 = 3/2$, $\varphi=\psi=\omega t$. The length of magnetic flux density vector is constant at any moment, and the vector rotates about z axis with constant angular rotation speed ω. The vector length has timeless component $K_0(\beta,\gamma)$ and periodical components with amplitudes $K_1(\beta,\gamma)$ and $K_2(\beta,\gamma)$, when $\beta\neq1$ and (or) $\gamma\neq1$. The length of vector $\boldsymbol{B}$ will vary dependently on angle φ. The vector rotates in this case, too, but the angular rotation speed will be alternate.

The expression of rotation speed

The angular rotation speed Ω of vector $\boldsymbol{B}$ can be calculated by differentiation of expression (7):

$$\begin{cases} \Omega = \frac{d\varphi}{dt} = \frac{\omega}{A+\frac{2}{3}B\sin^2\omega t+\frac{\sqrt{3}}{2}C\sin 2\omega t}; \\ A = \frac{\beta+\gamma-\frac{\beta\gamma}{\beta+\gamma}}{1+\frac{\beta\gamma}{\beta+\gamma}}, B = \frac{\frac{2}{\beta+\gamma}+1-\beta-\gamma}{1+\frac{\beta\gamma}{\beta+\gamma}}; \\ C = \frac{(\beta-\gamma)(1+\frac{2}{\beta+\gamma})}{1+\frac{\beta\gamma}{\beta+\gamma}}. \end{cases} \quad (8)$$

When $\gamma=\beta=1$, $\Omega=\omega$. When $\gamma=\beta<1$, the angular rotation speed will be variable dependently on angular position (see Table 1).

Table 1. The dependence of magnetic flux density vector angular position φ on excitation current angular phase ψ of coil A, when $\gamma=\beta$

$\psi=\omega t$	10^o	20^o	30^o	40^o	50^o	60^o	70^o	80^o	90^o
γ=0,5	16,4°	31,2°	43,9°	54,4°	63,3°	70,9°	77,7°	84,0°	90°
γ=0,2	32,9°	53,2°	64,7°	72,0°	77,0°	81,1°	84,3°	87,2°	90°
γ=0,1	51,0°	68,6°	76,1°	80,3°	83,2°	85,3°	87,0°	88,6°	90°

We name the ratio

$$k = \frac{\Omega}{\omega} \quad (9)$$

as coefficient of rotation speed non-uniformity. The dependences $k(\psi=\omega t)$ for some values $\beta=\gamma$ are presented in Fig. 2. We can see that, when balance decreases (γ,β<<1), the non-uniformity of rotation speed k can be 5 or more.

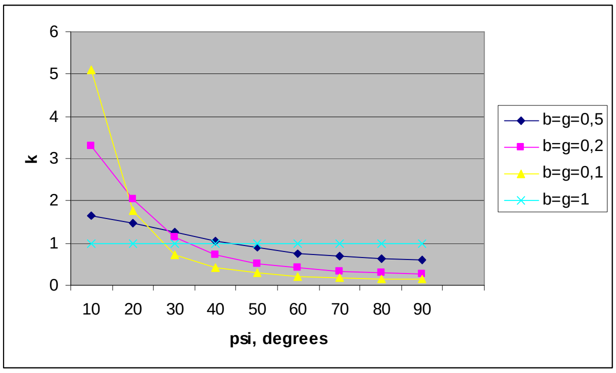


Fig. 2. The dependences $k(\psi)$, when $\gamma=\beta$, for different values β and γ (b and g in figure legend)

In the case $\gamma=\beta$ tan$\varphi\to\infty$ and tan$\psi\to\infty$ for the phase values $\varphi=\psi=(2k+1)\cdot90^o$. The dependence $\varphi(\psi)$ has the mirror symmetry for ψ value intervals [0°, 90°] and [90°, 180°] with respect to ψ=90°. The average k value of rotation speed non-uniformity is equal to one: $\bar{k}=1$ for every 1/2 period, i.e., for phase ψ variation $\Delta\psi$=180°.

When $\gamma\neq\beta$, tan$\varphi\to\infty$ for the phase values $\psi\neq90^o$. In coordinate system β, γ, ψ the discontinuity surface can be computed of equality

$$1+\frac{\sqrt{3}}{3}\frac{\beta-\gamma}{\beta+\gamma}\tan\psi = 0 \quad (10)$$

This equality will be satisfy, when

$$\begin{cases} \tan\psi = \frac{\sqrt{3}(\gamma/\beta+1)}{\gamma/\beta-1}, \\ \pi/2 < \tan\psi < \pi, \quad \beta\geq\gamma, \\ 0 < \tan\psi < \pi/2, \quad \beta<\gamma. \end{cases} \quad (11)$$

The dependences $\varphi(\psi)$ for some values γ and β, when $\gamma\neq\beta$, are presented in Table 2. Working out of expression (9), in respect of ratio γ/β we obtain:

$$\frac{\gamma}{\beta}=\frac{\tan\psi+\sqrt{3}}{\tan\psi-\sqrt{3}}. \tag{12}$$

We can identify of this equality the interval of ψ values for which the discontinuity tg$\varphi\to\infty$ is possible. The ratio γ/β is always positive. Therefore, the equality (12) will be satisfy, when $|\tan\psi|>\sqrt{3}$. The last inequality will be satisfy for $90^o>\psi>60^o$, if $\beta<\gamma$, and for $90^o<\psi<120^o$, if $\beta>\gamma$.

Table 2. The dependence of magnetic flux density vector angular position φ on exciting current initial phase ψ of coil A, when $\gamma\neq\beta$.

Ψ	10°	20°	30°	40°	50°	60°	70°	80°	90°
γ/β=0,8/0,6	8,3°	21,7°	34,7°	47,0°	58,1°	68,2°	77,4°	85,8°	93,7°
γ/β=0,5/0,1	4,0	32,4°	54,5°	69,0°	78,5°	85,3°	90,5°	94,8°	98,6°
γ/β=0,2/0,8	31,1°	40,2°	47,5°	53,5°	58,8°	63,7°	68,4°	73,2°	78,3°
γ/β=0,1/0,3	41,7	55,8	64,1	69,7	73,9	77,3	80,2	82,9	85,5
ψ	100°	110°	120°	130°	140°	150°	160°	170°	180°
γ/β=0,8/0,6	101,2	108,7°	116,3	124,2	132,6	141,8	151,9	163	175,3
γ/β=0,5/0,1	102,1	105,5	109,1	113,0	117,6	123,3	130,9	142,0	158,9
γ/β=0,2/0,8	84,0	90,7	99,0	109,7	124,0	142,4	163,4	3,2	19,1
γ/β=0,1/0,3	88,2	91,2	94,7	99,1	105,2	114,5	130,6	159,4	16,1

The dependences of rotation speed non-uniformity coefficient $k(\psi)$ for some values ratio γ/β are presented in Fig. 3.

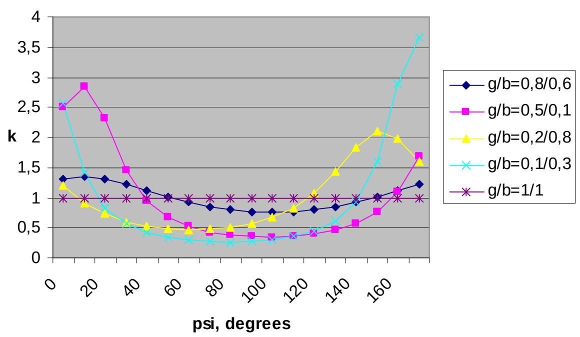


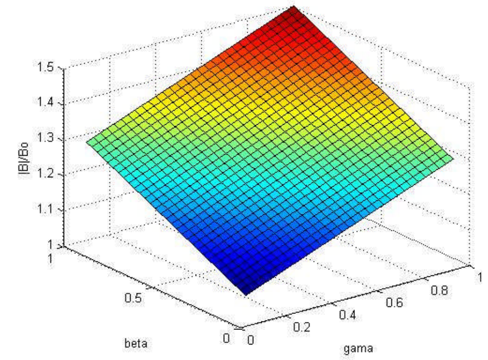
Fig. 3. The dependence of rotation speed non-uniformity coefficient $k(\psi)$ for some values ratio γ/β (g/b in figure legend)

The dependence of magnetic flux density value on non-balance of exciting three-phase current

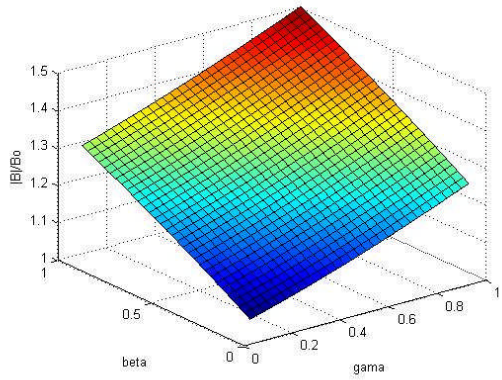
The expression (3) will be real for any values ωt when β and γ are positive. We can express the average relative value $\left|\frac{B}{|B_0|}\right|$ of vector $\boldsymbol{B}$ this way:

$$\left|\frac{B}{B_0}\right|=\sqrt{\frac{1}{T}\int_0^T\frac{1}{16}\left|\frac{\mathbf{B}}{B_0}\right|^2 dt}=\sqrt{\frac{1}{16T}\int_0^T(K_0+K_1\sin2\omega t+K_2\cos2\omega t)dt}=$$

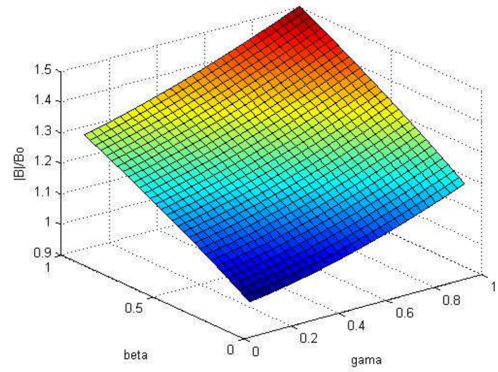
$$=\sqrt{\frac{1}{16}K_0}=\frac{1}{4}\sqrt{8+4(\beta+\gamma)+5(\beta+\gamma)^2}. \tag{13}$$



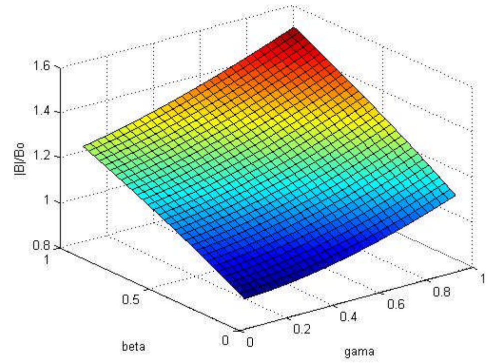
a



b



c



d

Fig. 4. The dependences of relative value B/B_0 on non-balance coefficients β and γ for the values $\varphi=\omega t$: a) 0°, b) 22,5°, c) 45°, d) 67,5°

Using MATLAB we investigate the variation of $\frac{|\boldsymbol{B}|}{B_0}$ in the half of period varying the values β and γ in limits

[0,1-1] and choosing the values $\varphi=\omega t$ 0, 22,5°, 45° and 67,5°.

The obtained results are presented in Fig. 4. The values of coefficients K_0, K_1 and K_2, vary in large limits, but the value $\frac{|\boldsymbol{B}|}{B_0}$ varies uniformly and weekly depends on three-phase non-balance. When $\gamma=\beta=1$, $\frac{|\boldsymbol{B}|}{B_0}=1{,}5$. Varying coefficients β and γ along interval [0,1-1] the $\frac{|\boldsymbol{B}|}{B_0}$ varies between 1 and 1,5, when $\varphi=0$ and $\varphi=22{,}5^{o}$, between 0,8 and 1,5, when $\varphi=45^{o}$ and $\varphi=67{,}5^{o}$, between 0,7 and 1,5, when $\varphi=90^{o}$. The average relative value of magnetic flux density $\frac{|\overline{B}|}{B_0}$ for every half period is in interval [0,6 - 1,5].

Conclusions

1. When the components of magnetic flux created by particular coils of three-phase current source are non-balanced, the value and angular speed of magnetic flux density vector varies periodically between limits which depend on non-balance coefficients. The vector will rotate, but the rotation speed will be non-uniform.
2. The average rotation speed for every half rotation period will be the same as in the balance case independently on non-balance coefficients values.

References

1. **Svoboda J.** Magnetic Techniques for the Treatment of Materials. – ISBN 978-14020-20304. – Springer, 2004 – P. 59–76.
2. **Dold P.** Czochralsky groth of doped germanium an applied rotating magnetic field // Cryst.Res.Technol. 38. – 2003. – No. 7–8. – P. 51–54.
3. **Промтов М. А.** Машины и аппараты с импульсными энергетическими воздействиями на обрабатываемые вещества. – Москва: Машиностроение, 2004. – 430 р.

Submitted for publication 2008 02 05

O. Romaškevičius, M.Šiožinys, J.A.Virbalis. The Influence of Exciting Current Unbalance to Parameters of Magnetic Field // Electronics and Electrical Engineering. – Kaunas: Technologija, 2008. – No. 3(83). – P. 85–88.

The rotating magnetic field which is created in a vide space is investigated. It can be used for any technological applications .The total magnetic field created by three exciting coils with angles between axes equal to 120° is analyzed. The exciting coils are connected to three-phase current source. The amplitudes of particular phases currents are not equal. The expressions are obtained for computation of magnetic flux density vector length and position in the plane, perpendicular to rotation axis in any moment. The values of magnetic flux density length and rotating velocity vary periodically in the time. The variation limits depend on the unbalance coefficients. The rotation will be non-uniform, but the mean value of rotation speed along the any half of period will be equal to rotation speed in the balance case. Ill. 4, bibl. 3. (in English; summaries in English, Russian and Lithuanian).

О. Ромашкявичюс, М. Шиожинис, Ю. А Вирбалис. Влияние ассимметрии возбуждающего тока на параметры вращающегося магнитного поля // Электроника и электротехника. – Каунас: Технология, 2008. – № 3(83). – С. 85–88.

Исследуется вращающееся магнитное поле, созданное в пространстве, в котором отсутсвуют магнитные материалы. Такое магнитное поле применяется для различных технологических целей. Исследуются параметры суммарного магнитного поля, создаваемого тремя катушками, оси которых сдвинуты одна относительно другой на 120°. Катушки питаются трехфазным током, но амплитуды тока отдельных фаз являются неодинаковыми. Получены выражения, позволяющие рассчитать длину вектора плотности магнитного потока и его положение в плоскости, перпендикулярной к оси вращения, в любой момент времени. Установлено, что модуль и скорость вращения плотности суммарного магнитного потока во времени периодически меняются в пределах, зависящих от коэффициентов ассиметрии. Магнитное поле вращается, но скорость вращения становится неоднородным. Среднее за каждые полпериода значение скорости вращения остается таким же, как и в случае симметричного возбуждающего тока. Ил. 4, библ. 3. (на литовском языке; рефераты на английском, русском и литовском яз.).

O. Romaškevičius, M. Šiožinys, J. A.Virbalis. Žadinimo srovės nesimetrijos įtaka sukamojo magnetinio lauko parametrams // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2008. – Nr. 3(83). – P. 85–88.

Nagrinėjamas sukamasis magnetinis laukas, sukurtas erdvėje, neturinčioje feromagnetinių medžiagų. Toks laukas gali būti naudojamas įvairioms technologinėms reikmėms. Tiriama, kaip keičiasi suminio magnetinio lauko parametrai, jei magnetinį lauką sukuria trys ritės, kurių ašys pasuktos viena kitos atžvilgiu 120°. Jos maitinamos trifaze srove, kurios amplitudės nevienodos. Gautos išraiškos, leidžiančios apskaičiuoti magnetinio srauto tankio vektoriaus modulį ir padėtį plokštumoje, statmenoje sukimosi ašiai bet kuriuo laiko momentu. Nustatyta, kad magnetinio srauto tankio vektoriaus modulio ir kampinio dažnio vertės laike periodiškai kinta tam tikrose ribose, priklausančiose nuo nesimetrijos koeficientų. Sukimasis išlieka, tačiau jo greitis tampa netolygus. Nepriklausomai nuo nesimetrijos koeficientų dydžio vidutinis sukimosi greitis per pusę periodo išlieka nepakitęs. Il. 4, bibl. 3. (anglų kalba; santraukos anglų, rusų ir lietuvių k.).