6TH INTERNATIONAL CONFERENCE ON ELECTROMECHANICAL AND POWER SYSTEMS
October 4-6, 2007 - Chişinău, Rep.Moldova

DETERMINATION OF THE DISPERSION CONDUCTIVITY OF CONSTANT MAGNETS IN MAGNETIC SYSTEMS OF ELECTRICAL MACHINES

Tudor AMBROS, Leonid IAZLOVEŢCHI, Maria IAZLOVEŢCHI

Technical University of Moldova

Abstract – **In this paper, the formulas for determination of the magnetic conductivity of dispersion of constant magnets, used in electrical machines most frequently of met configurations, is given. Simultaneously with it, using a mathematical method of final elements (FEMM) were simulated the fields of dispersion of magnets of the same configurations. The comparison of results and conclusions concerning an error are made.**

Keywords: *permanent magnet, conductivity, dispersion, simplified magnetic field, method FEMM.*

1. INTRODUCTION

The dispersion fluxes of the permanent magnets, magnetized in assembled electrical machines, reduce a magnetic induction in air gap reducing thus efficiency of use of permanent magnets. At assembly of magnetic system of the electrical machines with the previously magnetized permanent magnets, without use of magnetic shunts, the point of crossing of a straight line of return with the characteristic of demagnetization is defined by conductivity of dispersion of permanent magnets in a free condition. In both cases the fluxes of dispersion can essentially influence a magnetic induction in air gap and the final characteristics of the machine.

The exact determination of dispersion conductivity of the magnetic fluxes can be made on the basis of computation of the magnetic field, for example with the help of a FEMM. However, use of a FEMM for preliminary estimation is not always expedient. In many cases are used the approached methods received on the basis of simplified representation of a picture of a magnetic field. Thus is considered not only form of a magnet, but also direction of his magnetization.

The configurations of magnetic systems with constant magnets are rather various. Some analytical expressions for analyzing and calculating of dispersion conductivity of the magnetic flux similarly those, which are used for electrical machines are made below.

2. 2. MAGNET IN THE FORM OF A ROUND DISK IN A FREE CONDITION

For determination of dispersion conductivity of a disk in a free condition (Fig.1a) we shall accept the following assumptions:

- the dispersion flux flows only through flat surfaces of magnets. By the flux of dispersion through the cylindrical surface of the magnet are neglected
- the magnetic strength lines of the dispersion flux are concentrically concerning end of pole and are parallel along length of the cylinder (Fig.1b).

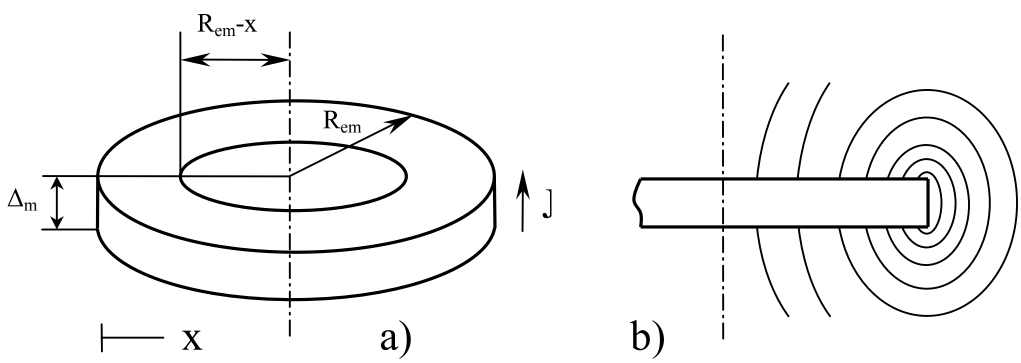

Figure 1. Scheme of the magnet in the form of a round disk in a free condition:
a) general view; b) ways of closed magnetic lines

Let's choose on distance x from edges of a magnet a ring surface with the area:

$$dS_x = 2\pi \cdot (R_{em} - x)dx \qquad (1)$$

The length of a magnetic line referred to half of magnet:

$$l_x = \pi x + 0.5\Delta_m \qquad (2)$$

Conductivity of elementary magnetic flux tube with cross section Sx:

$$dY_x = \mu_o \frac{dS_x}{l_x} = \mu_o \frac{2\pi(R_{em} - x)}{\pi x + 0.5\Delta_m} dx \qquad (3)$$

Total magnetic conductivity of a magnet:

$$Y_{sm} = \frac{1}{2} \int_0^{R_{em}} dY_x = \mu_o \pi \int_0^{R_{em}} \frac{R_{em} - x}{\pi x + 0.5\Delta_m} dx \qquad (4)$$

If the form of a magnet differs from a round disk, by analogy to hydraulic methods of calculation, it is possible to take advantage of concept of equivalent radius:

$$R_{em} = \frac{2S_m}{\Pi_m}, \qquad (5)$$

where: Sm – area of cross section of a magnet; Πm – perimeter of cross section.

On fig. 2 the model of a field of dispersion of a magnet of the mark NdFeB32MGOe in the form of a round disk by a diameter of 30 mm and thickness 5мм is submitted. The model was received with the help of a method FEMM for axisymmetric problem in infinite space [3].

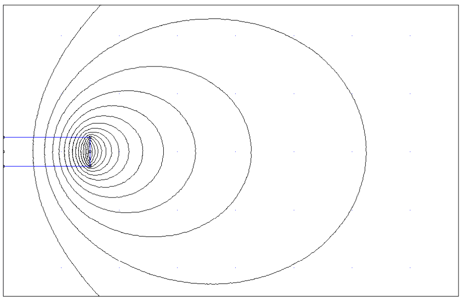

Figure 2. Magnetic field of magnet in a free condition

On Fig.3 is presented the distribution of a magnetic induction along radius of a magnet received for model Fig. 2. There the points determined by practical consideration on a real magnet of the specified sizes with the help of the Hall sensor are submitted.

The results of the calculations received by using the formula (4) and results, received with the help FEMM differ on 36%, that can be explained by neglect of the flux, which closes through a lateral surface of the cylinder.

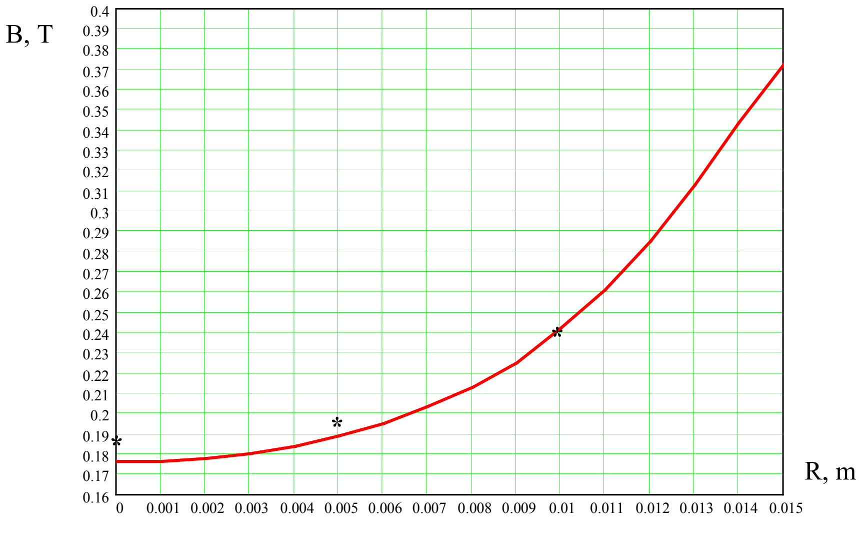

Figure 3. Distribution of a magnetic induction along radius of a magnet

3. LATERAL DISPERSION OF FLAT MAGNETS LOCATED NEAR AIR GAP, AT ABSENCE OF THE POLES TIPS

Let to have some flat magnets located near air gap, at absence of the poles tips, as shone in fig.4.
Let to accept the following assumptions:

- the sector through the lateral magnetic flux flows is divided in three sectors: $0 - x_1$, $x_1 - x_2$, $x_2 - \Delta_m$;
- the average angle of an inclination of the magnetic lines to the examined surfaces which are perpendicularly between themselves is equal 45°;
- the conductivity of dispersion is calculated for one of two lateral parts of permanent magnet.

Then, for the first sector two cases can be considered. The first case concerns to switching a magnetic line from a position a magnet - rotor in a position agnet - magnet. To this case there corresponds the relation:

$$x_1 = \frac{b_n}{2\sqrt{2}} \tag{6}$$

Obviously, that in this case $\Delta_m - x_1 \geq 0$, whence follows, that

$$b_n \leq 2\sqrt{2}\Delta_m \tag{7}$$

In a case if the switching of magnetic lines does not occur, then

$$x_1 = \Delta_m$$

Width of the elementary tube of a magnetic flux is equal $db_{1x} = \frac{dx}{\sqrt{2}}$

Length of the flux tube is equal $l_{1x} = \sqrt{2}x$

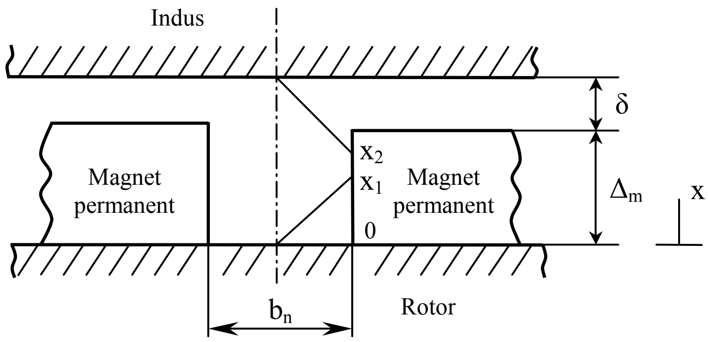

Figure 4. Schematic arrangement of magnets in air gap of the machine for illustration of lateral dispersion

Magnetizing force of elementary flux tube in the closed magnetic system will depend not only on current coordinate x, but also from a relation between size of an air gap and thickness of a magnet. Using the simplified diagram of a magnet and characteristic of magnetization of an external circuit without the account of saturation, it is possible to receive the equation for account magnetizing force of elementary flux tube:

$$F_x = \frac{\mu \cdot \delta}{\Delta_m + \mu \cdot \delta} \cdot H_c \cdot x\,, \tag{8}$$

where: H_c – coercitive force of the material of the magnet; μ – relative magnetic permeability of a material of a magnet.

Then a magnetic flux flowing through elementary tube is

$$d\Phi_{1x} = \mu_0 l_m \frac{db_{1x}}{l_{1x}} \cdot F_x = 0.5 \cdot \mu_0 l_m \cdot \frac{\mu \cdot \delta}{\Delta_m + \mu \cdot \delta} \cdot H_c dx \tag{9}$$

where: l_m – length of a magnet.

Thus magnetic flux for the first sector is

$$\Phi_1 = \int_0^{x_1} d\Phi_{1x} = 0.5 \cdot \mu_0 l_m \cdot \frac{\mu \cdot \delta}{\Delta_m + \mu \cdot \delta} \cdot H_c \cdot x_1\,, \tag{10}$$

and magnetic conductivity:

$$\Lambda_{1l} = \frac{\Phi_1}{F_m} = 0.5 \cdot \mu_0 l_m \cdot \frac{\mu \cdot \delta}{\Delta_m + \mu \cdot \delta} \cdot \frac{x_1}{\Delta_m}\,, \tag{11}$$

where $F_m = H_c \cdot \Delta_m$ - magnetizing force of a magnet.

The position of a point x2, that is point of switching of a magnetic line from a position "magnet-magnet" in a position "magnet - armature" corresponds to a condition:

$$x_2 = \Delta_m + \delta - \frac{b_n}{2\sqrt{2}} \tag{12}$$

For this case $\Delta_m - x_2 \geq 0$ and

$$b_n \geq 2\sqrt{2} \cdot \delta \tag{13}$$

If this condition is not carried out, point x2 leaves from zone of a lateral surface of a magnet, and in this case is necessary to accept $x_2 = \Delta_m$.

Width of the elementary tube of a magnetic flux for sectors 2 is equal: $db_{2x} = dx$. Length of a magnetic line is: $l_{2x} = 0.5 \cdot b_n$. The magnetizing force of elementary flux tube is defined by the equation (12). Then, by analogy to the sector 1, the magnetic flux of dispersion for sector 2 is defined by expression:

$$\Phi_2 = \int_{x_1}^{x_2} \mu_0 l_m \frac{db_{2x}}{l_{2x}} \cdot F_x = \frac{\mu_0 l_m}{b_n} \cdot \frac{\mu \cdot \delta}{\Delta_m + \mu \cdot \delta} \cdot H_c \cdot \left(x_2^2 - x_1^2\right) \quad (14)$$

The conductivity of sector 2 has a kind:

$$\Lambda_{2l} = \frac{\mu_0 l_m}{b_n \Delta_m} \cdot \frac{\mu \cdot \delta}{\Delta_m + \mu \cdot \delta} \cdot \left(x_2^2 - x_1^2\right) \quad (15)$$

In the result the sequence of calculation can be submitted as follows:

- Calculate coordinates of the point x_1. If $b_n \le 2\sqrt{2}\Delta_m$, then $x_1 = \frac{b_n}{2\sqrt{2}}$.

  otherwise $x_1 = \Delta_m$;
- Calculate coordinates of the point x_2. If $b_n \ge 2\sqrt{2} \cdot \delta$, then $x_2 = \Delta_m + \delta - \frac{b_n}{2\sqrt{2}}$.

  otherwise $x_2 = \Delta_m$;
- after that, calculate conductivity of the lateral dispersion for one magnet on one side.

  If $x_2 \ge x_1$, then

$$\Lambda_l = \frac{\mu_0 l_m}{\Delta_m} \cdot \frac{\mu \cdot \delta}{\Delta_m + \mu \cdot \delta} \cdot \left[\frac{x_1}{2} + \frac{\left(x_2^2 - x_1^2\right)}{b_n}\right]. \quad (16)$$

Otherwise

$$\Lambda_l = \frac{\mu_0 l_m}{2\Delta_m} \cdot \frac{\mu \cdot \delta}{\Delta_m + \mu \cdot \delta} \cdot x_2 \quad (17)$$

In general event, in the formulas (16) and (17) it is necessary to substitute δ by equivalent size of the air gap:

$$\delta_e = K_\delta \cdot K_\mu \cdot \delta, \quad (18)$$

where: K_δ – factor of air gap; K_μ – factor of saturation of external magnetic circuit.

On a fig. 5 is submitted the model of lateral field of dispersion for a magnet of the mark NdFeB32MGOe, which has the following geometrical sizes: b_n = 10mm, Δ_m = 5mm, δ = 1mm. The results of calculations received by using expressions (16), (17) differ from results received by modeling with the help FEMM on 31%, as not are taken into account saturation of the ways of flowing of the magnetic flux and as consequence of simplified presentation of the picture of the magnetic field.

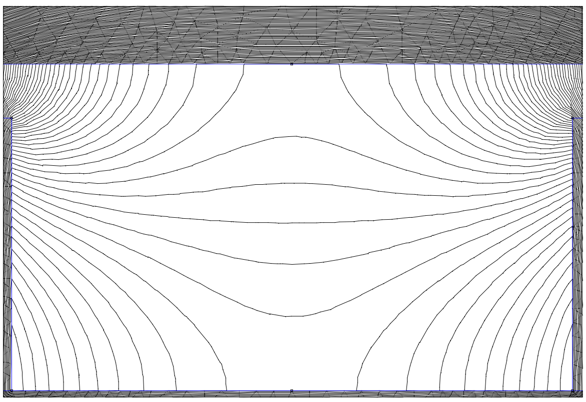

Figure 5. Magnetic field of the lateral dispersion

4. CONDUCTIVITY OF LEAKAGE FLUX OF THE FRONTAL PARTS OF PERMANENT MAGNETS

For finding the conductivity of dispersion of frontal parts of poles of electrical machines with permanent magnets the picture presented on fig.6 is used.

For simplification of a statement of a material the following simplifications were accepted:

- the lines of a magnetic induction are submitted as segments of concentric circles;
- the line of zero value of magnetic potential passes in the middle of a constant magnet;

- the magnetic flux of dispersion is supposed symmetric concerning a line of zero magnetic potential.

The deduced equations are carried out for a zone specified in a fig. 6, and concerns to one party of a magnet. The area of flows of a magnetic flux of dispersion is divided into 2 sectors.

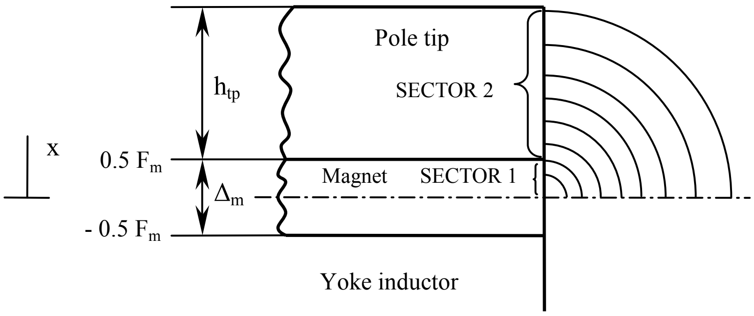

Figure 6. The schematic presentation of the frontal dispersion of the magnetic poles

For the first sector, at changes of size x within the 0 – 0.5Δ_m, width elementary tube of a magnetic flux of dispersion is $db_{1x} = dx$.

The length of a line of a magnetic induction is: $l_{1x} = 0.5 \cdot \pi \cdot x$.

Magnetic potential of elementary tube is : $F_{1x} = \frac{F_m}{\Delta_m} \cdot x$.

Magnetic flux flowing through elementary tube is:

$$d\Phi_{1x} = \mu_0 b_m \cdot \frac{db_{1x}}{l_{1x}} \cdot F_{1x} = \mu_0 b_m \cdot \frac{2F_m}{\pi\Delta_m} dx \text{ , (19)}$$

Where: b_m – width of a magnet.

Conductivity for the first sector

$$\Lambda_{1f} = \frac{1}{F_m} \int_0^{0.5\Delta_m} d\Phi_{1x} = \frac{1}{\pi}\mu_0 b_m \quad (20)$$

Width elementary tube and length of a line of a magnetic induction for sector 2:

$$db_{2x} = dx\,;\; l_{2x} = 0.5 \cdot \pi \cdot x\,.$$

Magnetic potential of elementary tube $F_{2x} = 0.5 \cdot F_m$

Magnetic flux flowing through elementary tube is

$$d\Phi_{2x} = \mu_0 b_m \cdot \frac{db_{2x}}{l_{2x}} \cdot F_{2x} = \mu_0 b_m \cdot \frac{F_m}{\pi} \cdot \frac{dx}{x} \quad (21)$$

Conductivity for the sector 2:

$$\Lambda_{2f} = \frac{1}{F_m} \int_{0.5\Delta_m}^{0.5\Delta_m + h_{tp}} d\Phi_{2x} = \mu_0 \cdot \frac{b_m}{\pi} \cdot ln\left(1 + \frac{2h_{tp}}{\Delta_m}\right) \quad (22)$$

Conductivity of dispersion of frontal parts for one half of pole is:

$$\Lambda_f = 0.5 \cdot \left(\Lambda_{1f} + \Lambda_{2f}\right) = \mu_0 \cdot \frac{b_m}{2\pi} \cdot \left[1 + ln\left(1 + \frac{2h_{tp}}{\Delta_m}\right)\right] \quad (23)$$

In a fig. 7 the model of a field of dispersion of frontal parts for a magnet with the following geometrical sizes: h_{tp} = 17.5mm, Δ_m = 5mm, the mark NdFeB32MGOe is submitted.

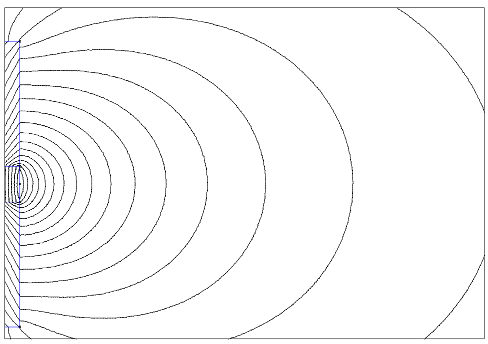

Figure 7. Magnetic field of frontal dispersion

The results of calculations received according to expression (23) differ from results received at use FEMM on 39 %, what can be explained by distinction between real magnetic field and schematic picture of the magnetic field, which was used at the simplified calculations.

5. CONCLUSIONS

The accounts of flows of dispersion of permanent magnets used in electrical machines have the errors caused by simplified representation of a picture of a magnetic field. Use of a method FEMM enables to specify these accounts by reception of a picture of a magnetic field approached to real.

In paper is shown, that use of a method FEMM reduces a mistake of account approximately on 35%.

References

[1] Балагуров В.А., Галтеев Ф.Ф. Электрические генераторы с постоянными магнитами. – М.: Энергоатомиздат, 1988.

[2] Бут Д.А. Бесконтактные электрические машины. – М.: Высшая школа, 1990. – 416 с.

[3] Meeker D., Finite Element Method Magnetics, User’s Manual, 2006. – 112 p.