ANALYSIS OF STRUCTURES USED TO OBTAIN UNIFORM MAGNETIC FIELDS

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REZUMAT. Lucrarea îşi propune analiza mai multor configuraţii de bobine coaxiale folosite în scopul obţinerii unui câmp magnetic uniform. Pe lângă bobinele Helmholtz folosite în acest scop, în lucrare se prezintă şi alte configuraţii de bobine menite să mărească zona de câmp uniform sau precizia de obţinere a acestuia.

Cuvinte cheie:câmp magnetic uniform, bobine Helmholtz, zonă de uniformitate

ABSTRACT. The paper proposes a study by simulation of various configurations of magnetic cores, used in order to obtain a more uniform magnetic field in a widest area. Based on the solution of Helmholtz coils, there nare analised and other structures that may be used in order to increase the uniformity of the field or the quality of that growth uniformity.

Keywords: uniform nagnetic field, Helmholtz coil, uniformity area

1. INTRODUCTION

The need to obtain uniform magnetic field areas occurs both in magnetometers calibration and for earth”s magnetic field compensation. Usually, in order to obtain a uniform magnetic field there are used Helmholtz coils. Those are a combination of two coaxial identical coils located at a distance equal to their radius, in witch equal currents flow in the same direction.

In terms of analytical calculation,the magnetic field produced by Helmholtz coils, is achieved by overlapping each coil field. Thus, if the current in the two coils flows in the same direction, in the space between the coils, on their common axis, magnetic field induction is obtained by adding the fields produced by each of the two coils. When the currents in the coils flow in opposite senses the magnetic field induction represent the difference between the two magnetic fluxes.

If the conductor is filiform, the magnetic field induction created by a single coil on his axis, calculated from Biot Savart Laplace law, is:

$$B = \frac{\mu_0 \cdot i}{4 \cdot \pi} \int_0^{2\pi} \frac{R \cdot d\theta}{(R^2 + x^2)} = \frac{\mu_0 \cdot i \cdot R^2}{2 \cdot (R^2 + x^2)^{3/2}} \quad (1)$$

where

μ_0 - vacuum magnetic permeability,

i – current flowing in the filiform coil,

R – coil radius

x – the distance measured on the axis of the coil between itscenter and the point of calculation.

Considering the structure of Helmholtz coil, in case of the same direction current flow in the two coils, the magnetic field on the axis, between the coils is:

$$B(x) = \frac{\mu_0 I}{2R}\left[\frac{1}{(R^2+(\frac{R}{2}+x)^2)^{\frac{3}{2}}} + \frac{1}{(R^2+(\frac{R}{2}-x)^2)^{\frac{3}{2}}}\right] \quad (2)$$

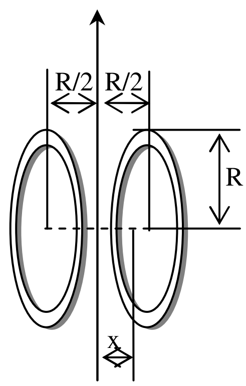

Fig.1. The geometry of Helmholtz coil

When current flows in opposite senses, the magnetic field induction results as a difference between B_1 and B_2.The origin of the axis system was considered to be halfway between the coils (figure 1). The variation of magnetic field along the common axis of the coils in those two situations is presented in figure 2. It is obvious that the magnetic field kept roughly the same value only when current flows in the two windings in the same sense, so that, this represents a prerequisite for obtaining a uniform magnetic field areas.

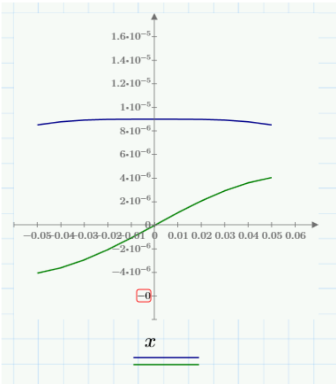

Fig.2. Magnetic flux between coils when the current flows in the same sense (blue) and in opposite senses(green)

2. OTHER COAXIAL COILS STRUCTURES

In order to increase the dimensions of uniform magnetic field zone, it might be used a third coil, coaxial with the others two coils, and placed between them at equal distances. Thisstructure is known as Maxwell coils.The three coils are placed on the surface of a sphere. In order to fulfilled this condition the radius of outside coils

must be $\sqrt{\frac{4}{7}}$R, and the distance between them and the central coil is $R\sqrt{\frac{3}{7}}$.

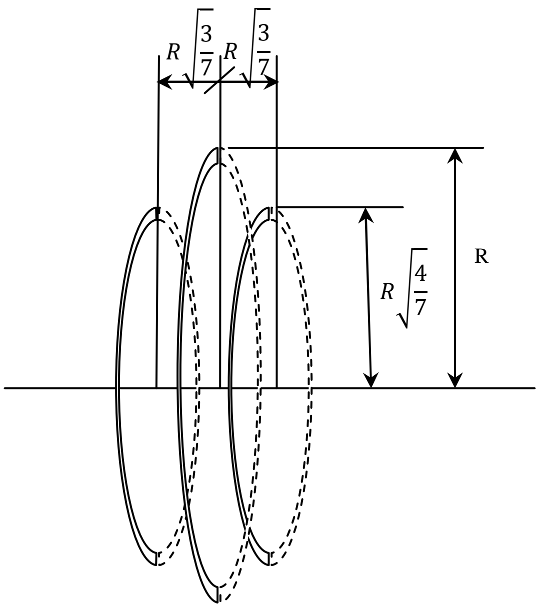

Fig.3 The geometry for Maxwell coils

Magnetic field on the common axis of the coils is determined by superposition. Taking into account the geometry described above, the analytic expressionn for magmetic field flux on the common axis is:

$$B(x)=\frac{\mu_0 n I R^2}{2}\left\{\frac{1}{\left[R^2+\left(R\sqrt{\frac{3}{7}}+x\right)^2\right]^{\frac{3}{2}}}+\frac{1}{\left[R^2+\left(R\sqrt{\frac{3}{7}}-x\right)^2\right]^{\frac{3}{2}}}+\frac{7}{4\left(\frac{7R^2}{4}+x^2\right)}\right\} \quad (3)$$

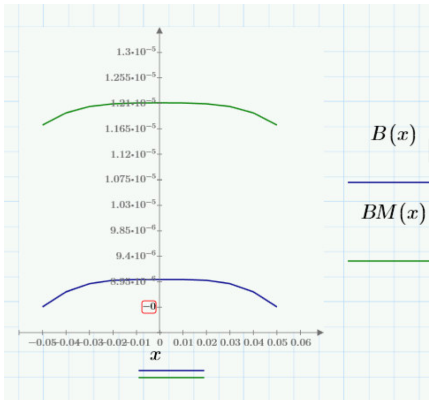

Fig.4. Magnetic flux on the coils axis for Helmholtz coil(blue) and for Maxwell coil (in green)

Compairing magnetic field induction variation on the coils axis, for Helmholtz and Maxwell configuration, as is presented in figure 4, it is worth noting a lower gradient of magnetic field to the limit of uniformity area for Maxwell coils. This growth of the uniformity area is not very complex and does not justify building a more complex configuration like Maxwell coils. This configuration is used only if the requirements about magnetic field uniformity are severe. As compared with Helmholtz coils, the introduction of the third coil whose structural characteristics depend essentially on the other two, which requires additional effort.

Another solution proposed in 1984 (Merritt) consist in using three coaxial coils with square section and the same size. The outer coils are traversed by the same current, while the current in the central coil is smaller. The optimal ratio of the currents in the inner and outer coils is 1,95. If the current of the three coils is the same, a requirement concerning the number of the turns for each coil must comply. Because both current and number of turns vary proportionately with magnetic induction, optimum in terms of magnetic field uniformity is obtained for a turns ratio of the three coils equal to 33/17/33 or 39/20/39 with better accuracy.

Based on the same superposition principle, magnetic flux on the axis will be obtained by adding three similar terms corresponding to the square coil:

$$B(x) = 80nI \frac{a^2}{(a^2+x^2)\sqrt{2a^2+x^2}} \quad (4)$$

where 2a is the dimension of the square, and x the distance from the center of the square to any point on its axis.

Another configuration witch can be used in order to obtain a uniform magnetic field area consists of five square coils arranged on the same axis, at equal distancesto one another, so that the distance between the extreme coils is equal to the coil side. In this way, the five coils form a cube. If the turns ratio of the five coils is 19/4/10/4/19, theoretical calculations show that there are five distinct points located on the common axis where the value of the magnetic field is the same. These points are located in the center, and coordinate points ± 0.15 a, ± 0.25a, where a is the side of the cube.

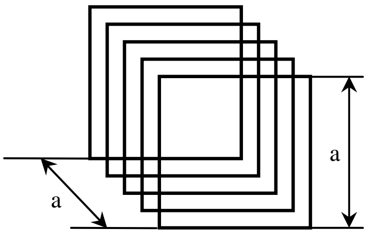

Fig. 5 The geometry for the five square coils

From analytic point of view, magnetic field flux results by adding the flux values generated by each coil. Each of these can be expressed based on (4), as they all are squre coils.The currents senses are the same in all coils, so the direction of magnetic flux on the axis will be along that.

Even though in terms of construction, this configuration poses no major technical problems, the access to the uniform field area is difficult for larger objects.

3. MODELING RESULTS

The size of the area with uniform magnetic field can be analytically determined by imposing a certain deviation in relation to the magnetic field value in the center of the system. This deviation can be set acording to the level of required accuracy uniformity.

As an alternative to the study of the magnetic field distribution, each configuration described above was modeled. The study by modeling easily allows obtaining both qualitative and quantitative results. Analysis was performed on a two-dimensional model, taking into account the section perpendicular to the coils, passing through their centers.

Presented models represent center line sections in order to analyse mainly the variation of the magnetic field on axis coils.

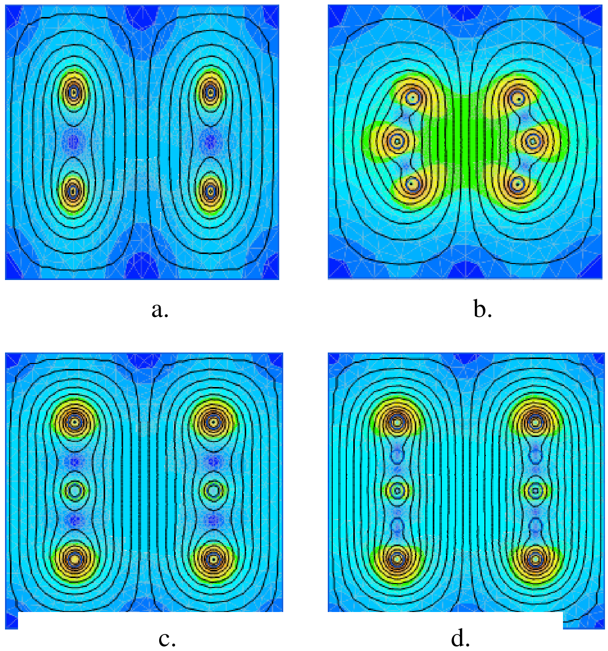

Fig.6 Magnetic flux density map for different coil configuration
a. Helmholtz coil
b. Maxwell coil
c. Merritt configuration
d. Five square coils

In figure 6 are given the magnetic flux density maps in the section perpendicular to the coils through their centers.The areas marked with the same color indicate the same value for magnetic field flux density. It can be noticed the increase in the size of this area as more coils are added.

To better estimate the gradient of magnetic field flux density on axis coils, in figure 7 are represented the magnetic field variations for each of the four analyzed structures. A comparison made between Helmholtz coils and Maxwell coils indicates the superiority of Maxwell coil from the standpoint of magnetic field uniformity. The role of the third coilis to partially compensate the magnetic field flux density decrease.

For the other two coil structures can also be observed the positive influence of introduction of the two supplimentary coils, which compensate for the field variations in the area between the coils.

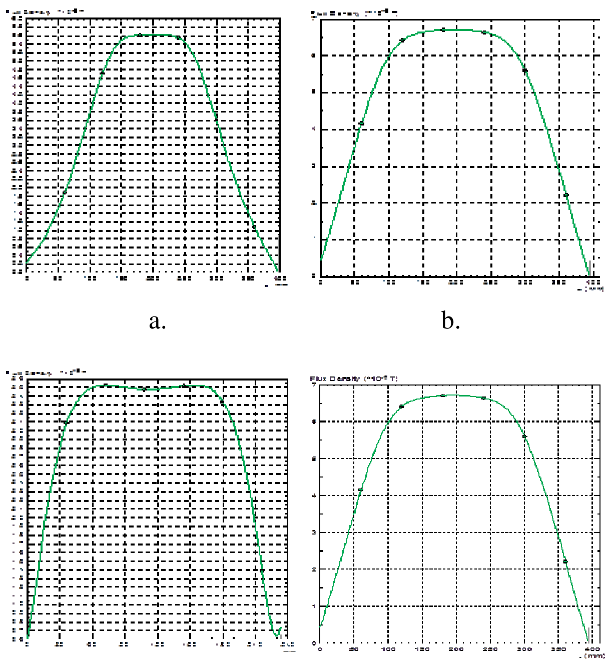

Fig.7 Magnetic flux densityon the coil axis for different configuration
a. Helmholtz coil
b. Maxwell coil
c. Merritt configuration
d. Five square coils

4. CONCLUSIONS

✓ The usual solution to obtain the uniform magnetic field is represented by the Helmholtz coils. A solution used in order to increase the uniform magnetic field dimensions area may be increasing the size of the coils. For technical reasons, it may not be increased arbitrarily. To obtain large areas, square section coils can be used.

✓ Adding additional coils can compensate the magnetic field gradient at the extremity of the uniformity area. Adding new coils means extra material consumption and sometimes constructive problems.

✓ Analysis of magnetic field regardless of the coil configuration is easier to acomplish using a FEM model.

✓ Both results obtained analytically and those provided by simulation indicate larger areas of uniform magnetic field for more complex configurations.

✓ From the point of view of cost performance ratio, it is still preferred Helmholtz coil in order to obtain uniform magnetic field.

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