VISUALISATION OF MAGNETIC FIELDS GENERATED BY HELMHOLTZ COILS

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Summary This article deals with a method of a homogenous magnetic field generation using Helmholtz coils. There is also an experiment of a magnetic field visualisation with a digital image processing performed with a magneto-resistive sensor described. At the end of this article, there is a possibility of permeability measurement using digital images of a magnetic field shown.

Key words: homogenous magnetic field, digital image, sensor

1. INTRODUCTION

We can fully describe an electromagnetic field with these four vector functions of position: electric intensity E [V.m^{-1}], electric induction D [As.m^{-2}], magnetic intensity H [A.m^{-1}] and magnetic induction B [Vs.m^{-1}].

To define an electromagnetic field in a specific area means to determine these four vectors of electromagnetic field in each point of this area.

It is possible to depict a homogenous magnetic field with iron chips when we put them into a magnetic field. If the chips are in parallel lines and these lines are in equal distances, the field in this area is homogenous. The density of chip lines gives the amplitude of magnetic induction B. The higher density means higher amplitude of magnetic induction.

Nowadays, it is possible to depict a magnetic field with digital image using sensors of magnetic field.

2. GENERATION OF MAGNETIC FIELD USING HELMHOLTZ COILS

Helmholtz coils (Fig. 1) are two identical thick circular coils with N curves and the same current I placed in the distance $2m$ that is equal to their radius ρ_0.

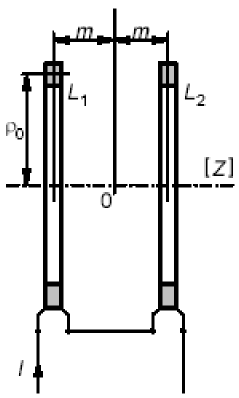

Fig. 1.: Helmholtz coils

$$m = \frac{\rho_0}{2} \tag{1}$$

The intensity of the magnetic field of two identical coils with radius ρ_0 coaxially placed on Z-axis, which centres are in the points $(0, 0, +m)$ and $(0, 0, -m)$, is the superposition of vectors H_1 and H_2 determined by equations for the amplitude of vector of magnetic intensity H on Z-axis (2).

$$H(0,0,Z) = \frac{N.I}{2} . \frac{\rho_0^2}{\left[Z^2 + \rho_0^2\right]^{\frac{3}{2}}} .u_Z \tag{2}$$

$$H_1(0,0,Z) = \frac{N.I}{2} . \frac{\rho_0^2}{\left[(Z-m)^2 + \rho_0^2\right]^{\frac{3}{2}}} .u_z \tag{3}$$

$$H_2(0,0,Z) = \frac{N.I}{2} . \frac{\rho_0^2}{\left[(Z+m)^2 + \rho_0^2\right]^{\frac{3}{2}}} .u_z \tag{4}$$

$$H(0,0,Z) = H_1(0,0,Z) + H_2(0,0,Z) \tag{5}$$

The coils are interconnected in the way that makes the currents in them orientate in the same direction so the amplitude of resultant vector is determined by equation (5). If we put the equations (1), (3) and (4) into the equation (5), we will obtain the final equation (6).

$$H(0,0,Z) = \frac{NI}{2}\rho_0^2 \left\{ \frac{1}{\left[\left(\frac{Z-\rho_0}{2}\right)^2 + \rho_0^2\right]^{\frac{3}{2}}} + \frac{1}{\left[\left(\frac{Z+\rho_0}{2}\right)^2 + \rho_0^2\right]^{\frac{3}{2}}} \right\} u_z \tag{6}$$

Helmholtz coils are used always when we need to create a homogenous magnetic field in a defined area. Fig. 2 shows the distribution of magnetic intensity of magnetic field along the axis of these coils. We can see that in the middle between the coils the intensity changes its value only a little and it is nearly independent on the position on Z-axis. It is easy to determine that the intensity of magnetic field in points *(0, 0, -m)* and *(0, 0, +m)* is only 5.38% lower than in the point *(0, 0, 0)*.

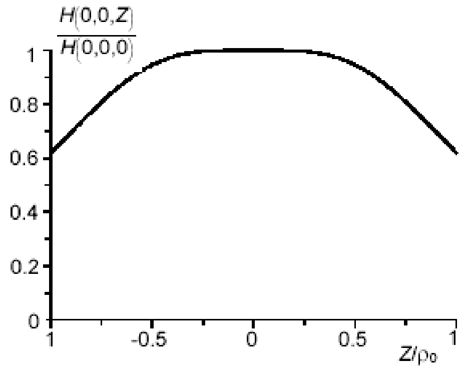

Fig. 2.: Distribution of magnetic intensity of magnetic field along the axis of Helmholtz coils

If the current through Helmholtz coils is harmonic, the magnetic field generated by these coils is harmonic. In that case the equations (2) and (6) can be transformed into eguations (7) and (8).

$$H_m(0,0,Z) = \frac{NI_m}{2} \frac{\rho_0^2}{\left[Z^2 + \rho_0^2\right]^{\frac{3}{2}}} u_z \tag{7}$$

$$H_m(0,0,Z) = \frac{NI_m}{2} \rho_0^2 \left\{ \frac{1}{\left[\left(\frac{Z-\rho_0}{2}\right)^2 + \rho_0^2\right]^{\frac{3}{2}}} + \frac{1}{\left[\left(\frac{Z+\rho_0}{2}\right)^2 + \rho_0^2\right]^{\frac{3}{2}}} \right\} u_z \tag{8}$$

The physical quantity H_m is the amplitude of vector of magnetic field intensity along the Z-axis and I_m is the amplitude of current through the coils. It is obvious that the distribution of alternate field is the same as the distribution of direct field.

3. EXPERIMENT AND ITS RESULTS

At first we designed and created the Helmholtz coils and afterwards we measured the homogeneity of magnetic field in two ways. We used two different values of amplification of amplifier AMP04, which is a part of magneto-resistive sensor HMC1001.

The value of amplification is for this amplifier defined as in (9).

$$A = \frac{100k\Omega}{Rg} \tag{9}$$

In the first case we used the value of resistor $R_g = 22\Omega$ that determined the value of amplification $A = 4545.45$. The excitation of Helmholtz coils was

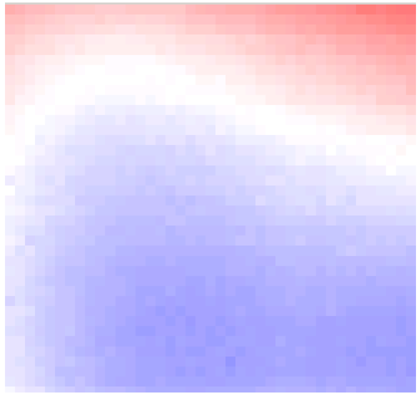

Fig.3.: The shape of magnetic field generated by Helmholtz coils with the amplification set on 4545

set on the values $U = 1.1V$ and $I = 0.08A$. In that case the sensitivity of the sensor was $3.2mV/gauss$. The distribution of magnetic field is shown in the fig. 3.

Measured values of magnetic field show differences in each particular point of explored area. The shape of magnetic field of the Earth causes these results.

In the second case we used the value of resistor $R_g = 100\Omega$ that determined the value of amplification $A = 1000$. The excitation of Helmholtz coils remained the same with the values $U = 1.1V$ and $I = 0.08A$. In that case the sensitivity of the sensor was $0.704mV/gauss$. The distribution of magnetic field is shown in the fig. 4.

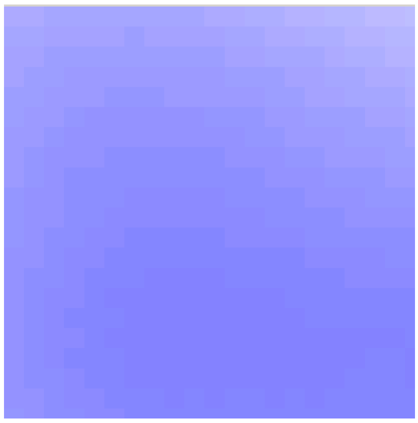

Fig.4.: The shape of magnetic field generated by Helmholtz coils with the amplification set on 1000

During the next measurement we put a piece of paramagnetic material (aluminium) with circular cross-section into the homogenous magnetic field (fig. 5). Aluminium is a paramagnetic material that means that the vector of magnetic induction is amplified only a little. So the sensor was set to the higher sensitivity. We used the resistor $R_g = 6.3\Omega$ that match the value of amplification $A = 15873$ and the excitation of Helmholtz coils was set to the values $U = 1.1V$ and $I = 0.08A$. The measured distribution of magnetic field is shown in the fig. 6.

Fig. 5.: Aluminium material in the homogenous magnetic field

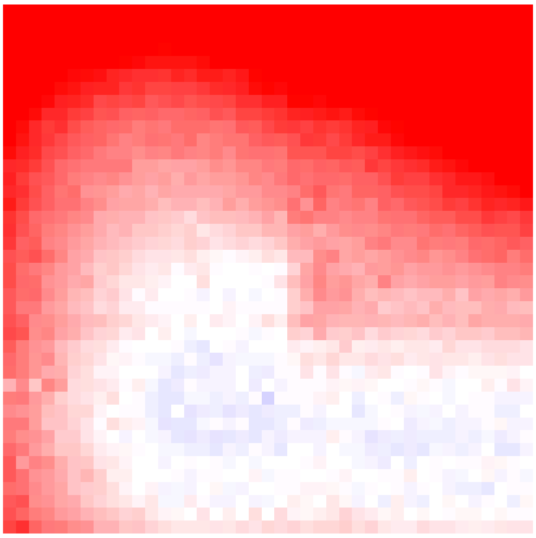

Fig. 6.: The distribution of magnetic field with paramagnetic material inside

During the fourth measurement we put two pieces of ferromagnetic material with circular cross-section into the homogenous magnetic field (fig. 7). This kind of material amplifies the vector of magnetic induction a lot, so we set the sensitivity of the sensor to a lower level. The value of amplification was set to A = 1000 and the excitation of Helmholtz coils was set to the values $U = 0.8V$ and $I = 0.05A$. The measured distribution of magnetic field is shown in the fig. 8.

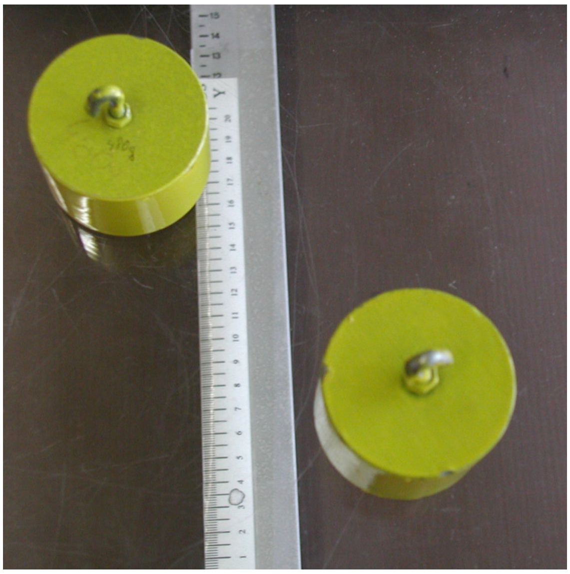

Fig. 7.: Ferromagnetic material in the homogenous magnetic field

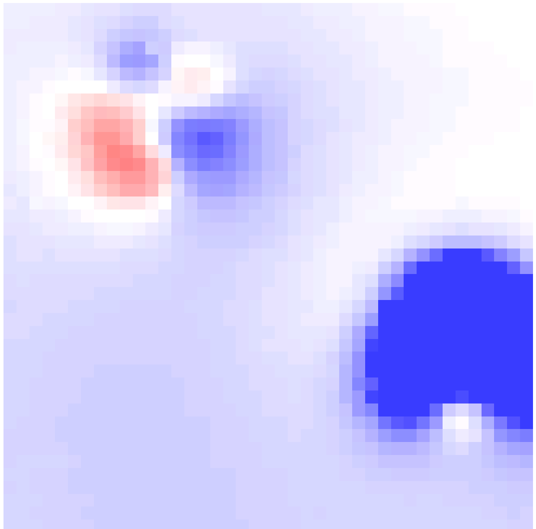

Fig. 8.: The distribution of magnetic field with ferromagnetic material inside

4. CONCLUSION

This experiment is only the first step in our development of a device that will make possible to measure the parameters of electromagnetic field in the three dimensional space.

The result of this experiment is that it is possible to determine the permeability of materials using methods of digital image processing and analysis of digital image of magnetic field.

The developed system is capable to measure big and also small changes of parameters of magnetic field depending on the sensitivity of sensor that can be set by the amplification of amplifier AMP04.

It is also possible to examine paramagnetic materials that affect the magnetic field only a little.

But the system is not appropriate for diamagnetic materials.

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