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VISUALISATION OF STATIC AND STATIONARY MAGNETIC FIELDS

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Abstract

The aim of this paper is to present a way of visualisation of the magnetic field created by permanent magnets or wires and loops carrying direct current. Visualisation is achieved by using so called magnetic field viewer - a special magnetic sensing film. Except visualisation of the magnetic field around the magnetic object, measurements of magnetic flux densities are performed using a Hall sensor. Also, a number of simulations of coils carrying direct current in FEM software have been made in order to check a validation of the visualisation effects obtained. The paper shows photographs of visualised magnetic fields and the results of measurements and simulations, as well as a proper discussion. [1]

Keywords and phrases: *hall sensor, magnetic field viewer, static and stationary magnetic field, visualisation*

1 Introduction

Magnetic fields can be created by permanent magnets or conductors carrying direct current, while its presence can be observed by appearance of force on other magnets or conducting bodies placed inside the field [1]. However, the magnetic field distribution cannot be easily seen, while it can be calculated or simulated [1]. One way of magnetic field visualisation is to use ferro fluids [2]. Also, with the aim of field visualisation, magnetic field viewing films were produced [3]. They show the magnetic field by showing its location and direction. Magnetically sensitive nickel particles in this film change their positions based on the intensity and orientation of the applied magnetic field. The particles will be shown as brighter regions if the magnetic field is parallel to the surface of the film and darker regions

[1] PACS: 07.55.Db

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if the field is orthogonal to the film surface [2]. The shade of these regions depends on the intensity and direction of the magnetic field.

Experiments were conducted with permanent magnets and coils of different shapes. A photograph of permanent magnets and photographs of a magnetic viewer placed above these magnets and coils are presented in the paper, as well as a proper discussion. A part of the results obtained for coils carrying direct current is compared with the results obtained by FEM software. Moreover, results of measurements of magnetic flux density using a Hall sensor are given in the paper.

2 Theoretical Approach

Neodymium permanent magnets have been used for creating a static magnetic field [4], while coils carrying direct current have been used for creating stationary magnetic field. Different values of direct currents have been set in order to obtain different intensities of magnetic field created. These fields have been visualised with the magnetic field viewer, by placing it above the magnets and coils. Hall sensor has been used for measurement of magnetic flux density around the coils. FEM software has been used for simulations of magnetic field produced by coils. Geometry of coils, number of turns and values of direct current in the simulations were identical as for the real experiments performed with coils.

2.1 Results

Figure 1 shows a photograph of arrangement of permanent magnets used in the experiment, as follows: two magnets of the square surface placed next to each other, one curved magnet and fifteen cylindrical magnets placed next to each other. Figure 2 shows a photograph of a magnetic viewer placed above permanent magnets from Figure 1. It can be seen from Figure 2 that surfaces of the magnets, as well as the close surroundings of the magnets, are shaded dark, while the areas between magnets or close to its edges are much brighter (for two magnets with square surface). In the case of curved magnet bright line can be seen in the middle, which means that this magnet actually consists of two magnets (this cannot be observed by usual visual inspection).

On the other hand, for the arrangement of cylindrical magnets bright lines do not appear in the places where magnets touch each other, but they appear in the places slightly closer to the touching surfaces between magnets and magnetic film. Thus, appearance of darker or brighter regions and lines depends also on the shape of the magnet.

Figure 3 shows the photographs of the magnetic viewer placed above arrangement of two square permanent magnets (12 mm by 12 mm, 5 mm high) used in

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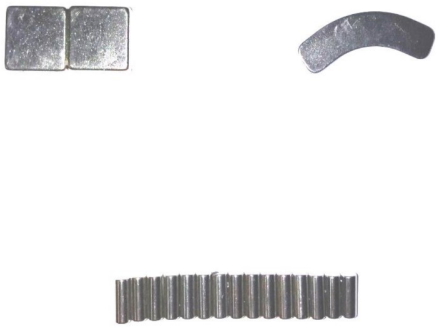


Figure 1: *Photograph of permanent magnets*

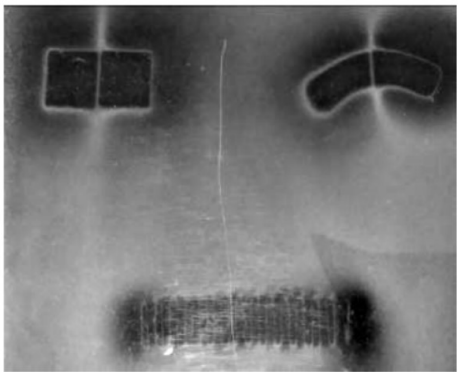


Figure 2: *Photograph of magnetic viewer placed above permanents magnets*

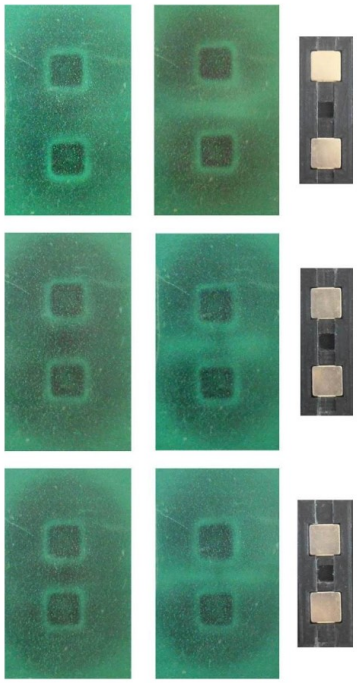


Figure 3: *Photographs of permanent magnets inside plastic holder and corresponding photographs of magnetic viewer when magnets attract and repel*

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the experiment, as follows: two magnets of square surface placed in plastic holders with three different sizes of gap (15 mm, 20 mm and 25 mm) between these magnets (in the right side). Magnets have been arranged so that in one case they attract each other and in another case they repel. Both cases have been visualised with magnetic viewer and the corresponding photographs are presented in Figure 3. Left part of the figure shows magnetic field of the magnets when they repel and middle part shows magnetic field of the magnets when they attract.

One significant difference can be observed in the area between two magnets. During the repelling, magnetic viewer shows a dark area between magnets, which means that the magnetic field is almost normal to the plane of magnetic viewer. The same area is mostly bright during the attraction, which means that the magnetic field is almost parallel to the plane of magnetic viewer.

Two coils have been made by winding a copper wire on plastic holders of circular and square cross-section. A diameter of the circular holder was 30 mm and 18 windings has been wound, while one side of the square holder was 25 mm and 17 windings has been wound. Height of both coils is 5 mm.

Figure 4 shows the photographs of magnetic viewer placed above coils with circular and square shape obtained for different values of direct currents from 0 to 20 A, in steps of 5 A (0 on the top and 20 A at the bottom). These photographs show a gradual increase of intensity of the dark area, corresponds to the internal area constrained by the coil, which indicates the appearance of magnetic field mostly normal to the plane of magnetic viewer. This dark area is surrounded by brighter area, corresponds to the area of the coil itself, which indicates a presence of a mostly horizontal magnetic field. Outside of this brighter area there is again darker area, but with lower intensity.

Models of coils of the same geometry and number of turns as real coils have been created in FEM software, as it is presented in Figure 4 for square coil.

A number of simulations have been made with the same values of direct current as for actual experiments. Several results have been obtained from these simulations, such as: plots of magnetic flux density in the horizontal plane just above the coil, the plot of the magnetic flux density vector in the vertical plane and graph of horizontal and vertical component of magnetic flux density in the vicinity of the coil. Plots of magnetic flux density in the horizontal plane (xyplane in Figure 5) have been grouped in the same manner as for the experiment and they are presented in Figure 6. These plots are very similar to photographs given in Figure 4 and they confirm previously made observations of magnetic field around the coil.

Figure 7 presents plot of magnetic flux density vector in the vertical plane (xz plane in Figure 5) that contains the vertical axis of square coil. This plot shows that inside internal area surrounded by the coil the vector of magnetic flux density

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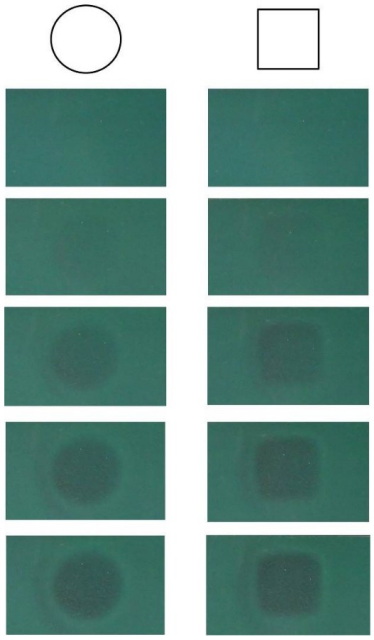


Figure 4: *Photographs of magnetic viewer above circular and square coil with direct current of different levels*

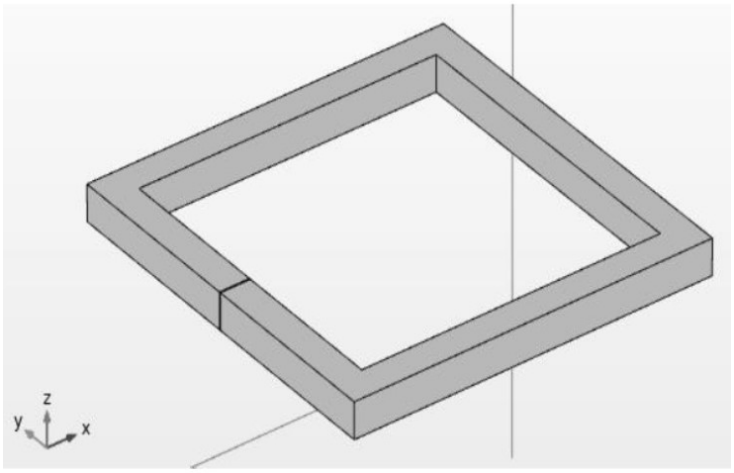


Figure 5: *Model of square coil*

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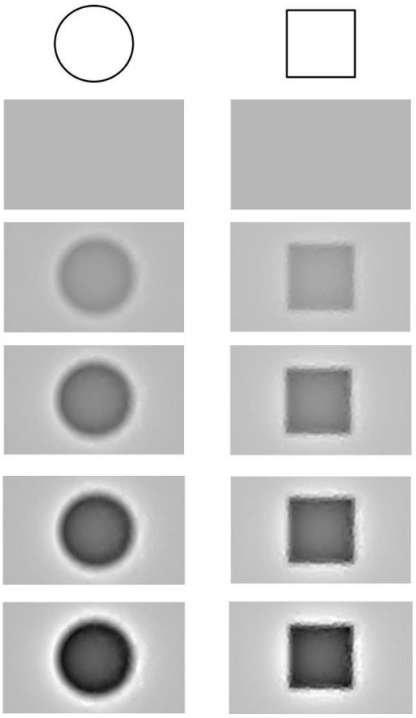


Figure 6: *Plots of magnetic flux density obtained from simulations*

is vertical, while closer to the coil it changes direction and just above the coils it becomes horizontal. Furthermore, it can be observed that vector is also vertical outside the coil, but with smaller intensity. All this supports observations given for photographs in Figure 4.

Figure 8 presents variation of horizontal B_x and vertical B_z component of magnetic flux density across the horizontal line parallel with y axis, at height z equal to half of height of coil (Figure 9). Graphs in Figure 8 have been obtained at direct current of 10 A.

Several measurements of magnetic flux density have been made with both coils in order to check the quality of simulation. Hall sensor has been placed in the centre of the coils, at the height equal to the half of the height of the coil. Direct current has been set to 5 A and 10 A in these measurements. The results of the vertical component of magnetic flux density are given in Table I. The relative difference between results obtained is around 3 % for circular coil and around 12 % for square coil.

This difference is acceptable and measurements confirm simulations, even for

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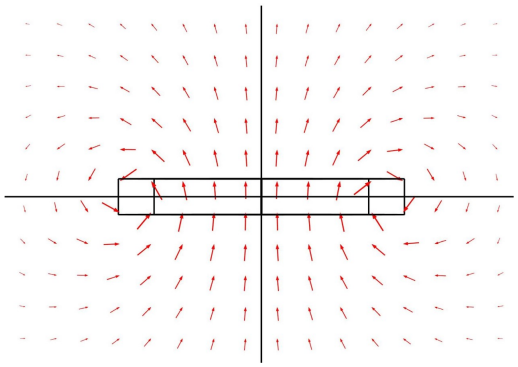


Figure 7: *Vector plot of magnetic flux density around square coil*

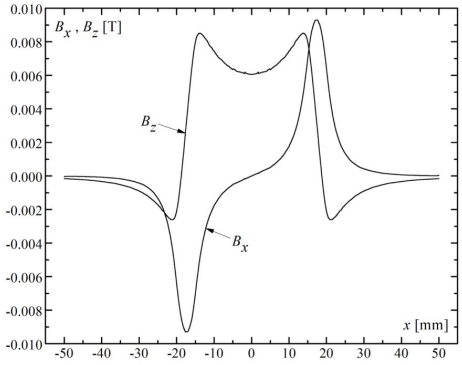


Figure 8: *Variation of magnetic flux density components: circular coil*

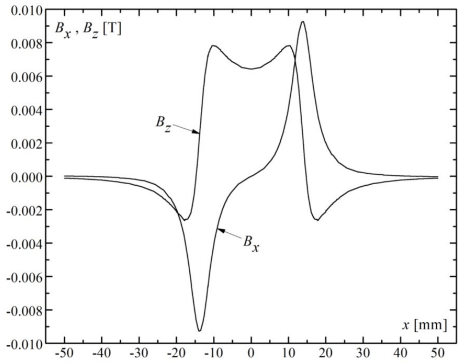


Figure 9: *Variation of magnetic flux density components: square coil*

square coil where difference is higher. Such result can be expected since real coil is not a real square and it is not produced with high precision.

3 Discussion

Several advantages and disadvantages in application of magnetic viewer have been observed during performed experiments. The advantages are: fast "reaction" on the gradual variation of magnetic field created by the coils and stability of the shade and good reproducibility. The disadvantages are: relatively high level of lowest magnetic field that can be detected (starting from about 1000 A/m), effect of saturation - at higher magnetic field viewer almost stops to be darker and

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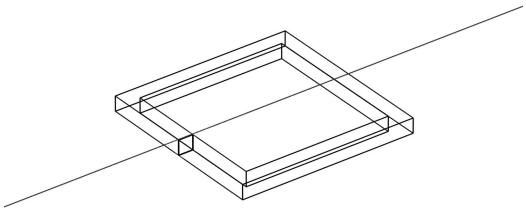


Figure 10: *Horizontal line above square coil*

Table 1: Comparison of measured and simulated results for vertical component of magnetic flux density

I [A]	B_z [mT]			
	Square		Circle	
	Hall	FEM	Hall	FEM
5	2.89	3.35	3.05	3.14
10	5.92	6.70	6.13	6.29

darker, glossy surface reflects light from point sources (like flashes and lamps) - so it is not easy to make a proper photograph, plastic foil is not resistant to high temperatures, bending and scratching, parts of the viewer disposed to magnetic field stays slightly dark after removing of magnet or coil - erasing of dark spots is needed.

An improvement of the experiment described could be made if digital camera and personal computer with adequate software for image acquisition and processing were used. The idea would be to capture a photograph of magnetic viewer placed above the magnetic object that creates known or measurable magnetic field. In the next step, the software would calculate the shade and link it with a certain value of magnetic flux density. Up to ten such measurements would be enough to perform calibration of magnetic viewer. Later, non-uniform magnetic field of other objects could be measured/calculated by processing of photograph.

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4 Conclusion

This paper presents the results of visualisation of magnetic field created by permanent magnets and coils carrying direct current. This has been achieved using magnetic field viewing film - flexible sheet coated with nickel particles. Coils of the same geometry and number of turns have been simulated in FEM software and results of simulations have been presented. Furthermore, results of measurements of magnetic flux density around coils have also been presented. A proper discussion of all results has been given.

Magnetic viewing film can be successfully used for educational purposes, while its application in real scientific research need to be further examined.

References

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