DESIGN OF THE NEW LABORATORY WORKPLACE FOR MAGNETIC FIELD MEASUREMENT

Miroslav Uher, Jiří Fialka, Martin Vágner

Doctoral Degree Programme (4, 3, 2), FEEC BUT

E-mail: {xuherm02, xfialk02, xvagne04}@stud.feec.vutbr.cz

Supervised by: Petr Beneš

E-mail: benesp@feec.vutbr.cz

Abstract: This paper deals with design of new laboratory workplace for magnetic field measurement. The workplace will be used in laboratory of non-electric quantities measurement at Department of Control and Instrumentation, FEEC BUT Brno. For the workplace were designated some exercises for students, which will be used for better understanding to the function of magnetic sensor construction. Independent problematic is a design of uniform magnetic field source. This article summarizes statement of project solving and documents used solutions.

Keywords: laboratory workplace, magnetic field measurement, Helmholtz coils, uniform magnetic field, COMSOL simulation

1. INTRODUCTION

Measurement of the magnetic field has irreplaceable representation on the market among other non-electrical quantities. This measurement has many forms, from sensors measuring the distance of objects through measurement of currents up to modern applications in navigation systems, in which are measured components of Earth's magnetic field. It is desirable that the students in their training met the measurement, which could meet also in their future profession.

The project is aimed to create a new laboratory workplace that is located at the Department of Control and Instrumentation, FEEC BUT. The new laboratory exercises have been established. In this exercises students will be able to measure magnetic field using several different principles. The workplace is based on the paired coils in Helmholtz arrangement. The Helmholtz coils are the source of homogeneous (uniform) magnetic field. Amplitude of magnetic induction vector in the coil will be changed by setting the value of flowing current through the coil from the power source. The sensors will be inserted on the axis between both of coils. The new workplace will allow linking theoretical understanding of the principle of the sensor with experimental measurement, and will allow measurement of the most important magnetic field sensors and determining their basic characteristics. Based on measured data, students should create independently conclusions from their measurements. The measurement range and choice of sensors is influenced by an essential element of the workplace, which is the source of a homogeneous magnetic field - Helmholtz coils. Design of Helmholtz coils will be discussed in more detail.

2. HELMHOLTZ COIL THEORY

The paired coils in Helmholtz arrangements are commonly used in laboratories for creating of uniform magnetic field. Other method for creating of uniform magnetic field is e.g. spherical coils. The coils are named in honor of the German scientists Herman von Helmholtz, who dealed among others with electromagnetism.

Helmholtz coils in one axis are consisted from two identical coils with defined radius $\boldsymbol{R}$. The centers of both coils are placed on the same axis in distance, which is usually equal to radius ***R***. The uniform magnetic field can be used for some magnetic measurements, including sensor calibration or measuring of earth magnetic field [1], [2].

For the exact calculation of magnetic induction value in any point inside Helmholtz coils it is necessary to use Bessel functions. The simpler evaluation of magnetic field can be made along the axis of coils. A derivation of relation for point, which is placed on coils axis in distance ***R/2*** from both coils is very simple. The derivation of this relation begins with equation for computing of magnetic field B inside single wire loop, which is derived from the Biot-Savart law [3]:

$$B = \frac{\mu_0 I R^2}{2 \cdot \left(R^2 + x^2\right)^{\frac{3}{2}}} \tag{1}$$

where μ_0 is permeability of vacuum,

I is coil current,

R is coil radius and

x is distance of investigated point on axis from one of coils.

Each coil usually consist of more than one wire loop, that is the reason why we used in equations ***nI***, where n means number of loops. We can use also this substitution: the center of Helmholtz coils is placed in distance ***x***, which is equal to ***R/2***. Because the Helmholtz coils is composition of two coils we have to multiply above mentioned equation by coefficient ***2***. After above described substitution we can obtain following equation:

$$B = \left(\frac{4}{5}\right)^{\frac{3}{2}} \frac{\mu_0 n I}{R} \tag{2}$$

3. DESIGN OF HELMHOLTZ COIL

For manufactured Helmholtz coils and their physical parameters were performed numerical simulations. These simulations were made using multiphysics simulation software COMSOL. With the aid of this simulation software were obtained distributions of magnetic field in coils for all measured points and currents. For example, the magnetic field lines diagrams was created by the use of simulation. The diagrams for current *3 A* are shown in Figure 1 and in Figure 2. The direction of magnetic field vectors well corresponds with theoretically assumptions [4].

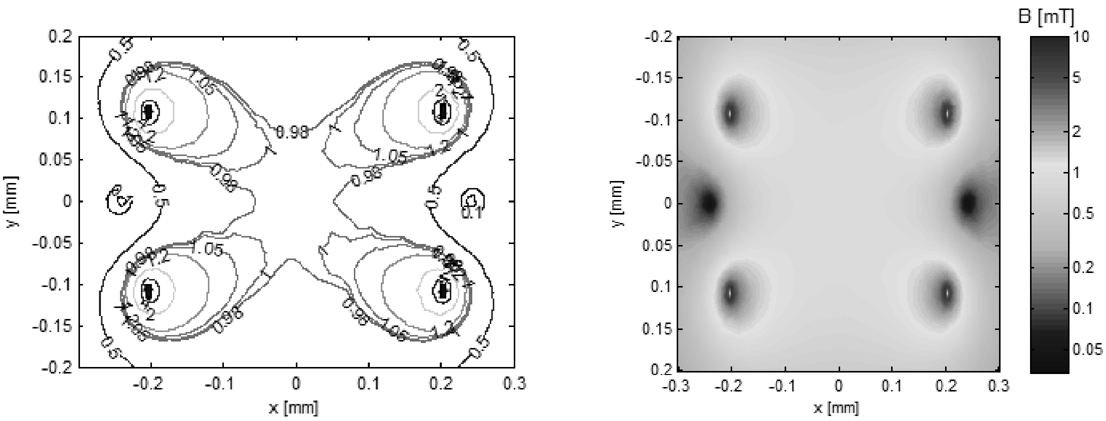

Figure 1: Helmholtz coils - numerical simulations of magnetic uniformity at 3 A.

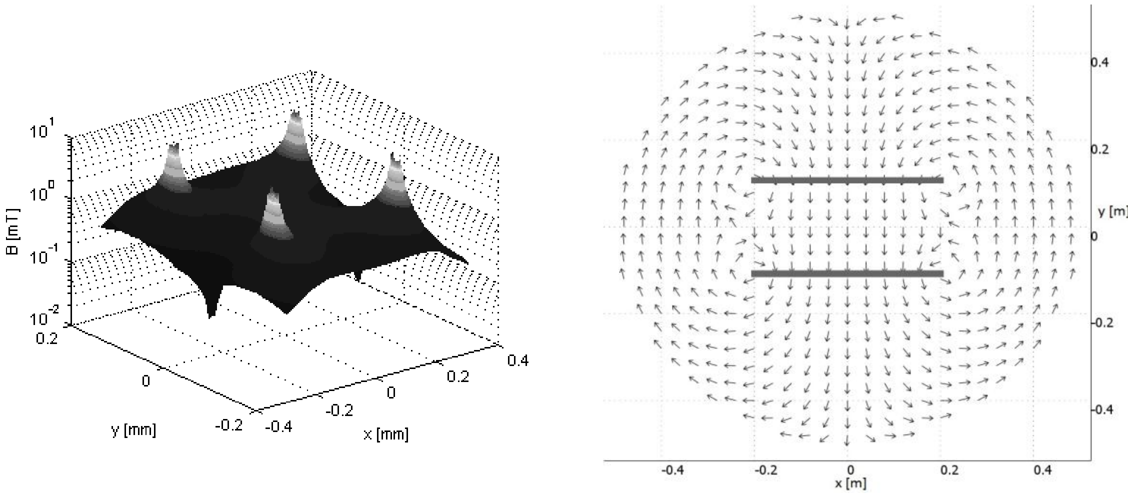

Figure 2: Helmholtz coils – magnitude and direction of magnetic field at 3 A.

The suitable paired coils in Helmholtz arrangement was made for our laboratory in accordance with our proposition. The whole construction is made of electrically and magnetically non-conductive materials, that allow using of Helmholtz coils for AC applications. The skeleton of both coils is made of hardened cotton fabric (textit) and the coils are fasted together by polyamide screwed bars. At the base of each coil there are terminals for wire connection. The radius ***R*** of coil is equal to *0,2 m*. Each coil contains *80* wire loops, which were made of enameled copper conductor. Maximally current rating of coils is approximately *10 A*. Final construction of Helmholtz coils and their connection diagram which was used for all measurement is shown on Figure 3.

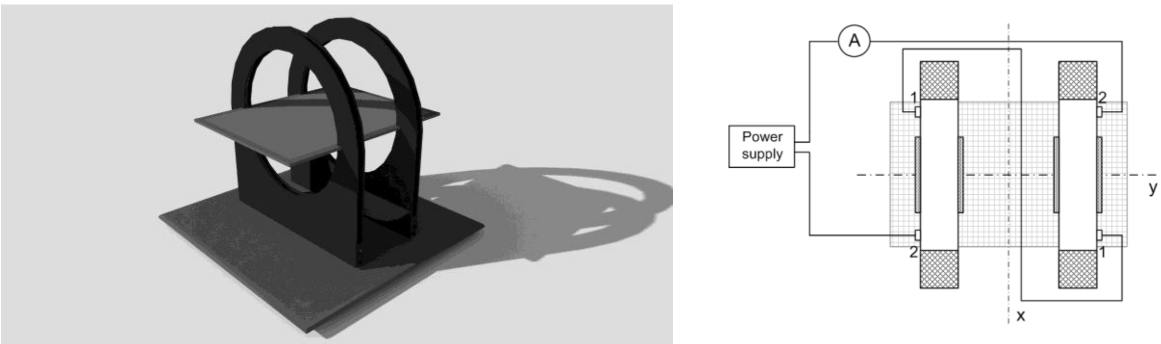

Figure 3: Helmholtz coils – practical realization and connection diagram.

4. DESIGN OF LABORATORY EXERCISES

The content of laboratory exercises designed to measure the magnetic field will be divided into 5 basic parts. The first part is a studying available literature and theoretical principles which can be used for magnetic field measurements, including problematic of Earth's magnetic field measurement. Further tasks are only practical. Initially, the students will measure uniformity of the magnetic field in the paired coils in Helmholtz arrangement. It is important to define an area, in which are further measurements reasonable. They will also establish a constant of Helmholtz coils and they will make comparison with theoretical calculations of this constant. Furthermore, students will measure basic characteristic of the reference flux-gate sensor, Hall sensor, magneto resistive sensors (AMR and GMR effect) and electronic compass module. Students will also be able to determine in the next task Earth's magnetic field vector by different sensors (electronic compasses) and compare this measurement with the method of determining the size of Earth's magnetic field based on the knowledge of the Helmholtz coils constant and by using of two-axis compass. With the electronic compass they will have to determine the declination, inclination and the direction and magnitude of the magnetic field of the Earth, measured values could be compared with the mathematical model NOAA. The last part of the laboratory exercises will be presentation of the measurement results, discussion and determination of measurement uncertainties. Students would obtain an imagination, about accuracy of sensors and exercises may help with understanding of Earth's magnetic field determination. To the new created laboratory exercises will be processed learning materials - instructions for exercises.

5. EXPERIMENTAL CONFIRMATION OF MAGNETIC FIELD UNIFORMITY

In the created Helmholtz coils were executed some verifying measurements. At first, the uniformity of magnetic field inside Helmholtz coils was measured during our experiment. For all performed measurements was used gaussmeter F.W.Bell model *5080*. Magnetic field was investigated in 2D area *30x30 cm*, which was situated symmetrically from center of Helmholtz coils. The distance of measuring points was in both axes *5 cm*. The measurement was proceeded for interval of supply currents from *1 A* to *8 A* with resolution *1 A*. The results of this part of the experiment were 3D graphs, which show distribution of magnetic field in Helmholtz coils. For example, the uniformity of magnetic field on the coils axis is shown in right graph on Figure 4.

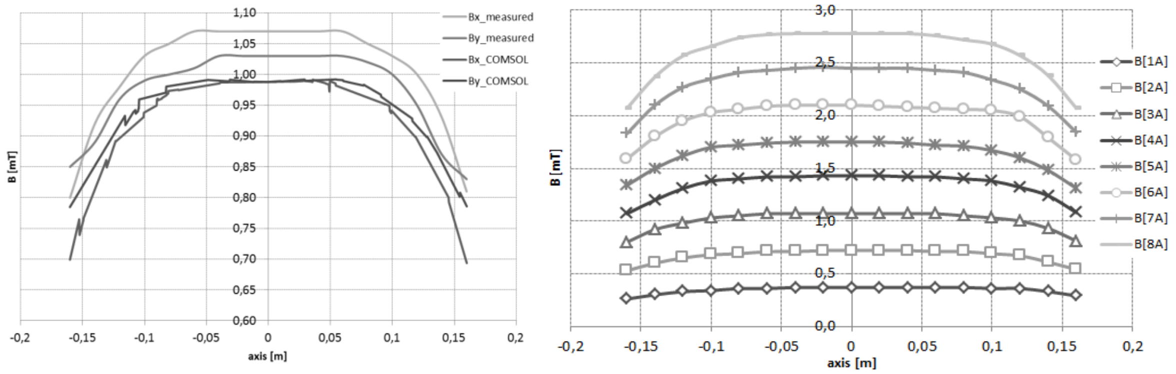

Figure 4: Magnetic field B_x, B_y vs. position on axis, parameter is current (on the right only B_x).

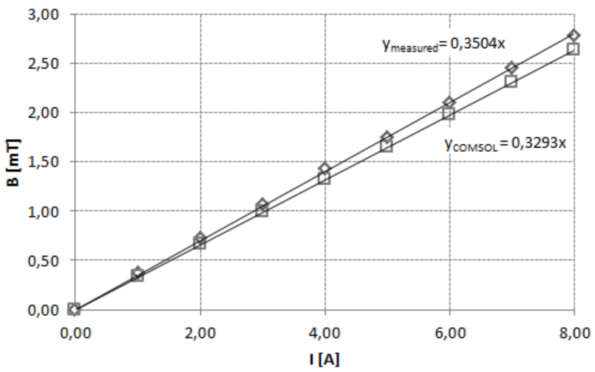

Figure 5: The comparison between measured and simulated Helmholtz coils constant [mT/A].

6. RESULT AND DISCUSSION

The measurement and the simulation were purposely designated for their mutually comparison. Comparison was made in the same points.

Initially, the uniformity of magnetic field was comparised from 3D graphs. It was found out that magnetic field from simulation very well corresponds to results achieved from measurements. In both cases, the area in which could be magnetic field considered uniform has the same dimensions. The area has dimensions approximately *20x10 cm* for all currents and was located by its longer side parallel to the common coils axis. The magnetic field was not uniform outside this area. There was an increase of field in proximity of coil, on the contrary in area far from center was observed decreasing of field.

Next, the comparison of dependencies of magnetic field B on distance x was accomplished. Each comparison (where the parameter was supply current) between measurements and simulation was made for both axes. For example, the comparison for current *3 A* is shown in left graph on Figure 4. The matching for the others currents were similar. In general, the computed magnetic field was lower almost in all cases than the measured field.

Finally, the comparison of the Helmholtz coils conversion constant was made. This constant expressed relation between measured magnetic field and supply current. Its knowledge is important e.g. for Earth magnetic field measurement. The comparison of this constant determined from measurement and simulation is introduced in Figure 5. The results correspond with the results from previous analysis.

7. CONCLUSIONS

Based on the Helmholtz coil design project has been compiled new laboratory workplace for the measurement of magnetic field by the sensors with different principle. For the workplace was chosen a suitable sensor with corresponding measuring ranges and there were developed suitable exercises for students. It was created as an interesting laboratory exercises.

The partial uniformity of magnetic field for paired coils in Helmholtz arrangements was confirmed. The measurement and the simulation agree in achieved values of magnetic field. Therefore the Helmholtz coils could be used as a source of predicable uniform magnetic field in our laboratory practices.

ACKNOWLEDGEMENT

This paper was supported in part by the Grant Agency of the Czech Republic (102/09/H082 and 102/09/H081 SYNERGY - Sensors and Intelligent Sensor Systems) and by grant "Supporting Research of Modern Methods and Approaches in Automation" from the Internal Grant Agency of Brno University of Technology (grant No. FEKT-S-11-6). Without kind support of the abovementioned agencies and institutions the presented research and development would not be possible.

REFERENCES

[1] Boll, R., Overshoott, K. J.: Sensors: A Comprehesive Survey, Magnetic Sensors, vol. 5, VCH Verlagsgesellschaft GmbH. Germany, 1989, pg. 513, ISBN 3-527-26771-9.

[2] Bronaugh, E. L.: Helmholtz coils for calibration of probes and sensors: limits of magnetic field accuracy and uniformity. 1995 IEEE International Symposium on Electromagnetic Compatibility, Atlanta - USA, 1995, pg. 72 – 76, ISBN: 0-7803-2573-7.

[3] Cacak, R. K., Craig, J. R.: Magnetic Field Uniformity around Near Helmholtz Coil Configurations. Review of Scientific Instruments, vol. 40, no. 11, pg. 1468 – 1470, 1969, ISSN: 0034-6748.

[4] Kaminishi, K., Nawata, S.: Practical method of improving the uniformity of magnetic fields generated by single and double Helmholtz coils. Review of Scientific Instruments, vol. 52, no. 3, pg. 447 – 453, 1981, ISSN: 0034-6748.

[5] Trout, S. R.: Use of Helmholtz coils for magnetic measurements. IEEE Transaction of Magnetics, vol. 24, no. 4, pg. 2108 – 2111, 1988, ISSN: 0018-9464.