ATEE - 2004

STANDARD SOURCE AND SENSOR FOR THE 50 Hz MAGNETIC FIELD

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Se prezintă o introducere în temă, pe baza literaturii de specialitate şi apoi se dezvoltă următoarele aspecte:

- *Calculul şi construcţia unei surse de energie pentru generarea şi cuantificarea câmpului de 50 Hz.*
- *Calculul şi construcţia unui senzor de câmp magnetic, potrivit pentru măsurarea câmpului magnetic de 50 Hz, succesiv, după trei direcţii carteziene;*
- *Măsurători experimentale care dovedesc acurateţea calculului şi utilitatea echipamentului format din sursa de energie şi senzorul de câmp magnetic.*

It is presented an introduction into task, based upon technical literature, and then are developed the following aspects:

- *The calculation and construction of an energy source for quantifying the 50 Hz magnetic field.*
- *The calculation and construction of a magnetic field sensor suitable for measuring the 50 Hz magnetic field, successively after three cartesian directions.*
- *Experimental measuring providing the accuracy of calculation and the utility of the equipment composed of energy source and magnetic field sensor.*

INTRODUCTION

The expanding of electrical networks and the developing of powers, transferred at 50 Hz frequency, lead to appearance of a new medium factor: the low frequency magnetic field. Therefore, have appeared numerous studies concerning the effects of industrial frequency magnetic field upon beings, especially upon humans [1, 2]. The studied medium extended also upon the soil under high currents electrical lines [3]. Were developed new measuring equipments concerning electrical and magnetic fields of industrial frequency [4, 5]. There were also established limits for the magnetic fields levels compatible with human beings [6, 7]. It also appeared an international standard IEC [8] regarding power frequency magnetic field immunity test, for electrical and electronic equipment in case existence of industrial frequency magnetic field.

It is described a calculation method and a constructive solution for the 50 Hz magnetic field source. In this purpose a Helmholtz coil was used for providing, within a specific space, a quasi-constant intensity of magnetic field. The Helmholtz coil's properties, with *circular sections*, are presented in Simonyi's book [9]. In this paper the Helmholtz coil has *square sections* because the coil, at large dimensions, is easier to construct.

It is also described the calculation and construction of a 50 Hz magnetic field sensor, with facilities for successive measuring after three cartesian directions. Were made magnetic field measurements following two orthogonal axis for establishing the optimal zone of magnetic field intensity produced by Helmholtz coil. Was tested equipment concerning the immunity level at 50 Hz magnetic field.

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1. THE STANDARD SOURCE

In Fig. 1 is depicted the scheme for the magnetic field standard source which, in essence is a Helmholtz coil. On the scheme may be read the component pieces parameters. The coil is composed of two sections: B1 and B2. Every section has two turns, situated on the outline of a 1 m - side square. The distance between sections is 0.4 m. The energy, for the coil is provided with twisted cable. For measuring the current, which pass through the coil's sections it is used a 0.2 class shunt.

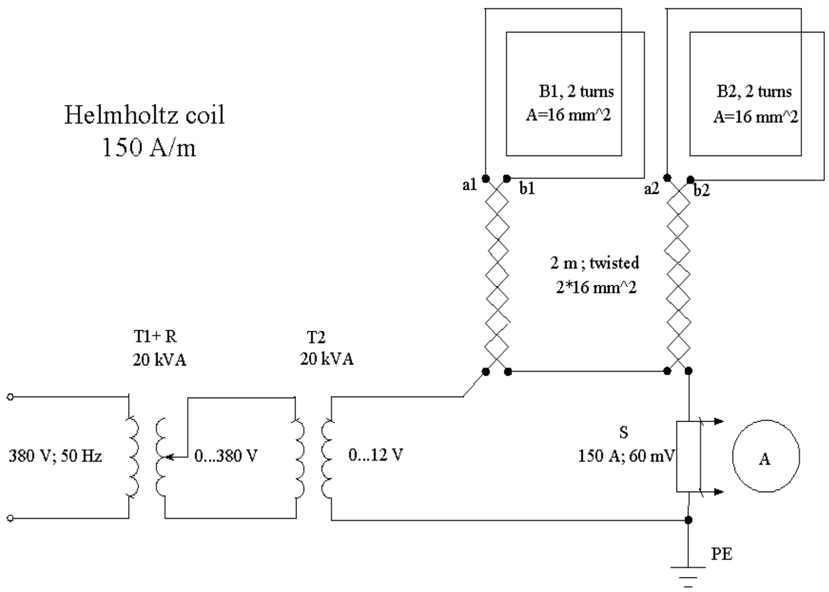

Fig. 1. Standard source

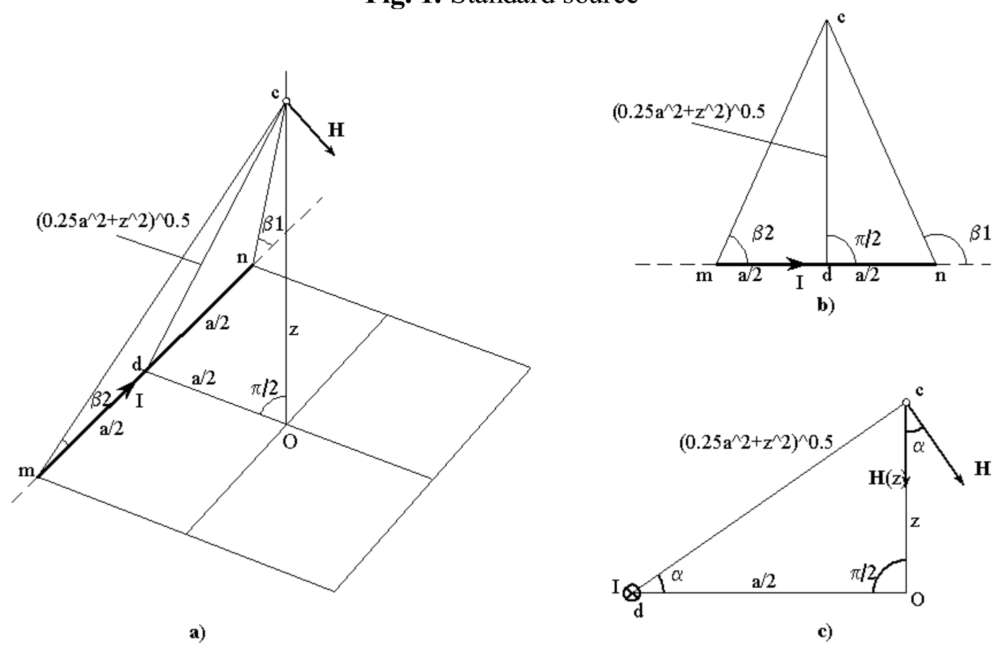

Fig. 2. Auxiliary graphics

For establishing the magnetic field generated by B1 and B2 sections connected serially, covered by the current *I*, it is used the auxiliary graphics as shown in Fig. 2 a), in which is depicted only a single turn of a square section, with *a* - side. On the *Oz* axis, which goes orthogonally from the section's plan, will be calculated the magnetic field's component. The Biot-Savart theorem [10] offers the possibility of simplifying the problem, what, thus, consists in establishing the magnetic field on the axis *Oz*, at the passing of current *I* through a single side a from one turn. In this case, using the notations in Fig. 2b) and 2c), the form of the Biot-Savart theorem becomes [11]:

$$H(z) = \frac{I}{4\pi x} \cdot (\cos\beta_2 - \cos\beta_1) \cdot \cos\alpha \tag{1}$$

With the notations: $x = \sqrt{0.25a^2 + z^2}$ and $\cos\alpha = \dfrac{0.5a}{\sqrt{0.25a^2 + z^2}}$ (2)

The relationship (1) transforms into:

$$H(z) = \frac{I}{4\pi} \cdot \frac{0.5a}{(0.5a)^2 + z^2} \cdot (\cos\beta_2 - \cos\beta_1) \tag{3}$$

For calculating the *H(z)* component, regarding a Helmholtz coil section it is considered the number (4) of sides of the outline and the number (2) of spirals of one section, so:

$$H(z) = \frac{\mathrm{n}I}{4\pi} \cdot \frac{0.5a}{(0.5a)^2 + z^2} \cdot (\cos\beta_2 - \cos\beta_1) \tag{4}$$

The relationship (4) is used for numeric calculation, with the following explanations: n = 8, the number of turns of a section × the number of sides of the section, a = 1 m, the length of a side, I = 1 A, the normed current. The numeric calculation is presented in the calculation *appendix*, in which *H(z)* has the form in relationship (A1). The β_1 and β_2 angles may be inferred from Fig. 2b).

In the calculation *appendix* were used the following conventional notations:

– *H(z)* the magnetic field's component of section B1, as in the relationship A1, in the interval 0 m – 0.4 m, between the two sections.

– *D(z)* the magnetic field's component of section B2, in the interval mentioned above.

– *H(z)* + *D(z)*, the resulting component of the magnetic field, produced by both sections.

Fig. 3. The axial, normed magnetic field

In Fig. 3 were depicted the functions *H(z)*, *D(z)*, *H(z)* + *D(z)*. Is important the graphic *H(z)* + *D(z)* drawn with intermittent line, which shows that the normed value of the magnetic field's intensity (at the excitation current of 1A) is preserving in the interval z = 0 m ... 0.4 m with a deviation of 0.6988 dB, for the highest value of 2.988 and the lowest value of 2.75. Compared to the medium value of magnetic field the deviation is ± 0.35 dB.

Note. From the Fig. 3 results that for calibrating a magnetic field sensor it is recommended that the sensor to be placed at distances a = 0.2 m, where the magnetic field has the highest level of uniformity. The evaluation of the magnetic field's intensity is obtained by multiplying the normed value 2.998 A/m with the number which indicates the current's intensity passing through the coil.

2. THE MAGNETIC FIELD SENSOR

For detecting and quantifying the 50 Hz magnetic field it is used a calibrated sensor. Essentially, it is made of relatively small diameter coil, compared with the linear dimension of the Helmholtz coil, in conjunction with which it will be used. Working as a sensor is based upon the electromagnetic induction law. Thus, if $\Phi = \hat{\Phi} \cdot \cos\omega t$ is the magnetic flux, perpendicular on the N turns coil's plan, the resulting induced tension has the effective value:

$$E = \mathrm{N}\omega\mu_0 H\pi r^2 \tag{5}$$

where r is the equivalent turn's radius. From the relationship (5) can be obtained the magnetic field's intensity value:

$$H = \frac{E}{\mu_0 \omega \pi r^2 \mathrm{N}} = \mathrm{k}E \left[\frac{\mathrm{A}}{\mathrm{m}}\right] \tag{6}$$

where k is the sensor's constant. For the constructed sensor N = 2000 turns, r = 0.04625 m and therefore the constant is k = 188.65 [A/(V?m)]. The induced tension E may be measured with a common digital multimeter. The measuring system with magnetic field sensor is sketched in Fig. 4. The sensor's coil is electrostatically screened with an interrupted screen, for not forming a turn in short-circuit. The captured signal is transmitted, through a coaxial cable, to a digital multimeter, also screened. The constructed magnetic field sensor's kinematics permits successive measurings of the components H_x, H_y, H_z, following the cartesian axis x, y, z, thus resulting the evaluation of the magnetic field intensity's module:

$$H = \sqrt{H_x^{\,2} + H_y^{\,2} + H_z^{\,2}} \tag{7}$$

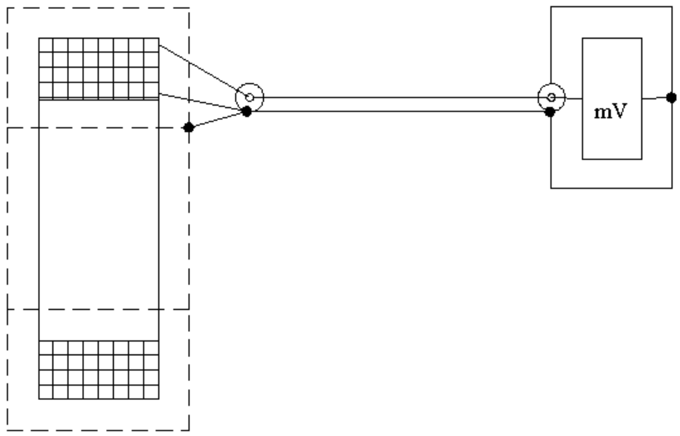

Fig. 4. The magnetic field sensor

3. EXPERIMENTAL DETERMINATIONS

In Fig. 5 is depicted, schematic, relating with sections B1 and B2 the Helmholtz coil, the axis *Oz* and *Ox* on which was virtually placed the magnetic field sensor, described in chapter 2; were obtained diagrams as it follows:

a) In Fig. 6, for 0 m < z < 0.4 m, the magnetic field on the *Oz* axis, the continuous line curb is the one calculated with relationship (A1), the one with intermittent line is experimental. Can be observed a significant approach between the calculated values and the values experimentally obtained.

b) In Fig. 7, for 0 m < x < 1 m, the magnetic field, experimentally obtained with the help of the magnetic field sensor, it's almost stationary around the coordinate x = 0.5 m; thus results the fact that the most adequate zone for placing a sensor at calibration is situated at the coordinates x =0.5 m and z = 0.2 m.

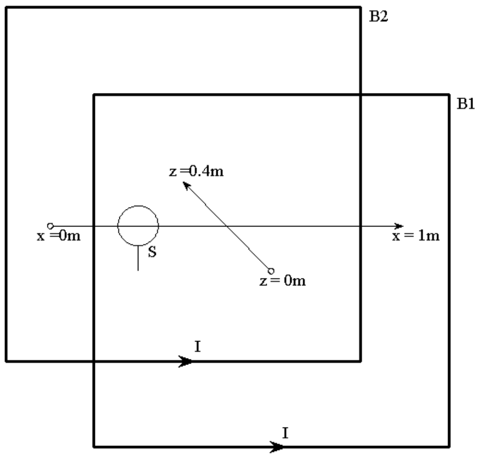

Fig. 5. *Oz, Ox* axis

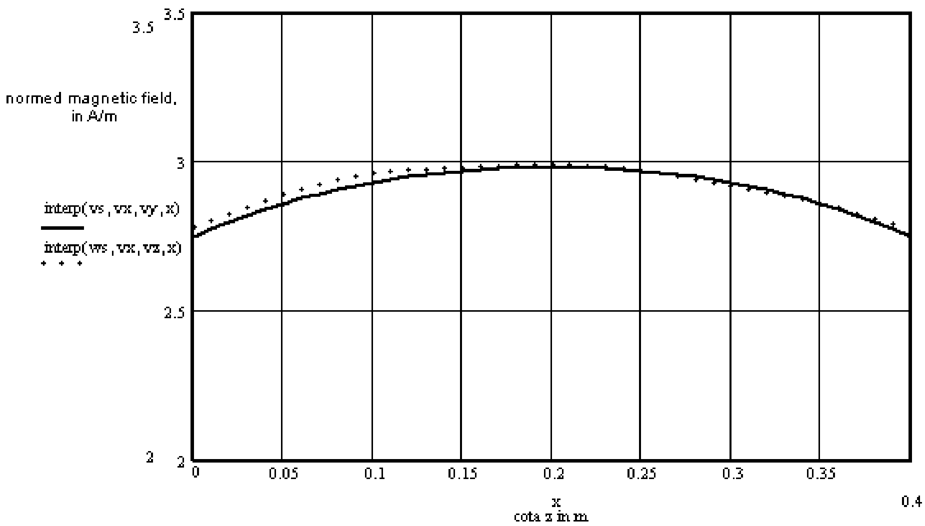

Fig. 6. Compared chart

Fig. 7. *H(z)* on longitudinal axis

Note. In this experiment, the sensor is orientated for measuring the magnetic field's component in a direction parallel with axis *Oz*.

The constructed device offers the following usage possibilities:

- *A sensor's calibration*. The sensor is placed in the Helmholtz coil within the area defined by the following coordinates: $z = 0.2$ m and $x = 0.5$ m (Fig. 5). In this area, the magnetic field's intensity is *H(z)* = 2.988?*I* where *I* is the current that is covered through the Helmholtz coil (as shown in Fig. 3). It results the sensor's constant k = *H(z)/E* as in relationship (6). In Fig. 8 is depicted the coil's picture, with the sensor situated in the calibrating area.
- *Establishing the level of immunity at magnetic field*. Were placed the electronic objects (functioning) from *table 1* in the calibrating area and, progressively increasing the current's intensity through the coil, was established the magnetic field at which the objects aren't working properly.

Table 1

Values of immunity at magnetic field

No.	Object	Field [A/m]	Framing [8]
1	PC display 753 DFX	4.68	4
2	Oscilloscope GOS 622	3.70	4
3	Digital multimeter GDM-392	150	unaffected functioning

- *Measuring the intensity of magnetic field in laboratories and in factories*. For this purpose was used the magnetic field sensor together with a digital multimeter as shown in Fig. 4. The measurings were made following three orthogonal directions according to relationship (7). The results are in *table 2*.

Table 2

Magnetic field intensities

Object	A	B	C	D
Magnetic field	28.21	10.72	468.43	50.79

A) Industrial equipment with power transformer, 1000 kVA, 10 kV/400 V.
B) Two closed conductors, going and returning, $I = 500$ A.
C) Two conductors at 0.9 m between them, going and returning, centrally between conductors, $I = 500$ A
D) Dry-type transformer 20 kVA, at 0.5 m, secondary current $I = 500$ A.

In picture on Fig. 9 are presented the measuring tools: digital multimeter GDM – 392 electrostatically screened, Oscilloscope Tektronix 2211, magnetic field sensor (made in UPB).

Fig. 8. The Helmholtz coil's picture with square section

Fig. 9. Investigating instruments: digital multimeter, oscilloscope, magnetic field sensor

CONCLUSION

The developing of transferred powers through electrical networks, high and low tension, leads to the appearing of a new medium factor, 50 Hz magnetic field. This, at the exceeding of a specific level, can have damaging influence upon human beings and can cause interferences to the functioning of electronic and electrical equipment.

For controlling the 50 Hz magnetic field's level of influence to the ambient, have appeared new investigations. Thus for establishing the magnetic field in the optimal zone of the Helmholtz coil with square sections, was elaborated the relationship (A1) presented in calculation *appendix*. Within the optimal zone, the *uniformity degree* of the magnetic field is less than 0.7 dB. The experimental verifying of theoretical relationship (A1) confirms the calculation hypothesis. Was ascertained practically, a superposing of diagrams, experimental and theoretical, which describe the magnetic field in the optimal area, between the two sections of the coil constructed in the chair laboratory. In the purpose of measuring the magnetic field in the space between the two coil's sections, was elaborated own-conception magnetic field sensor.

The ensemble, made of square sections coil and the magnetic field sensor offers the following investigating possibilities:

- Establishing the immunity level at 50 Hz magnetic field, for electrical and electronic equipment, complying the international rules.
- The calibrating of 50 Hz magnetic field sensor.
- Measuring the 50 Hz magnetic field's level in laboratories and factories.

Appendix

Relationship (A1)

$n := 8 \qquad I := 1\cdot A \qquad a := 1\cdot m \qquad z := \begin{pmatrix} 0\cdot m \\ 0.05\cdot m \\ 0.1\cdot m \\ 0.15\cdot m \\ 0.2\cdot m \\ 0.25\cdot m \\ 0.3\cdot m \\ 0.35\cdot m \\ 0.4\cdot m \end{pmatrix}$

$$H(z) := \frac{n\cdot I}{4\cdot\pi}\cdot\frac{\frac{a}{2}}{\left(\frac{a}{2}\right)^2+z^2}\cdot\left[\cos\left[\operatorname{atan}\left[\frac{\sqrt{\left(\frac{a}{2}\right)^2+z^2}}{\frac{a}{2}}\right]\right]-\cos\left[\pi-\operatorname{atan}\left[\frac{\sqrt{\left(\frac{a}{2}\right)^2+z^2}}{\frac{a}{2}}\right]\right]\right] \qquad \text{(A1)}$$

$H(0\cdot m) = 1.801\,\frac{A}{m} \qquad H(0.05\cdot m) = 1.778\,\frac{A}{m} \qquad H(0.1\cdot m) = 1.714\,\frac{A}{m} \qquad H(0.15\cdot m) = 1.616\,\frac{A}{m}$

$H(0.2\cdot m) = 1.494\,\frac{A}{m} \qquad H(0.25\cdot m) = 1.358\,\frac{A}{m} \qquad H(0.3\cdot m) = 1.219\,\frac{A}{m} \qquad H(0.35\cdot m) = 1.083\,\frac{A}{m}$

$H(0.4\cdot m) = 0.956\,\frac{A}{m}$

$$H(z) := \begin{pmatrix} 1.801 \\ 1.778 \\ 1.714 \\ 1.616 \\ 1.494 \\ 1.358 \\ 1.219 \\ 1.083 \\ 0.956 \end{pmatrix} \qquad D(z) := \begin{pmatrix} 0.956 \\ 1.083 \\ 1.219 \\ 1.358 \\ 1.494 \\ 1.616 \\ 1.714 \\ 1.778 \\ 1.801 \end{pmatrix} \qquad H(z) + D(z) = \begin{pmatrix} 2.757 \\ 2.861 \\ 2.933 \\ 2.974 \\ 2.988 \\ 2.974 \\ 2.933 \\ 2.861 \\ 2.757 \end{pmatrix}$$

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