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ORIGINAL ARTICLE

Design and Fabrication of a Magnetic Field Generator with Variable Intensity and Frequency for Use in Medical and Biological Studies

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ABSTRACT

Background: The aim of this study was to build a variable magnetic field system that can be used in various medical fields such as medical physics, physiology, genetics, biochemistry, and anatomy.
Materials and Methods: In this experimental study, the magnetic field was produced between Helmholtz coils by using variable power supply and signal generator systems. The user can select the desired frequency between 0 Hz (as a static magnetic field) and 300 Hz (as a pulsating magnetic field) via the selector generator. This square wave signal produces magnetic field with intensities ranging from 0 to 8 mT with variations in current.
Results: This generator was designed with Helmholtz coils, which can produce nearly uniform magnetic fields with different frequencies and intensities. This system can simulate fields that general population are subjected to and are concerned about.
Conclusion: Calibration with a Hall probe proved the proper production of a uniform magnetic field of desired intensity and frequency. Despite the concerns about the adverse effects of magnetic fields employed for treatment procedures, these generators have become necessary devices in medical research.

Key Words: Electricity, Electromagnetic, Helmholtz coil, Pulsating magnetic field, Signal generator, Static magnetic field

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INTRODUCTION

Nowadays, electromagnetic devices are a part of civilized life and all humans are exposed to electromagnetic fields. This exposure became even more important since the purposeful use of electromagnetic energy in various areas of human activity, which resulted in the addition of artificial electromagnetic fields to the existing electric and magnetic fields of the Earth, atmospheric electricity, and solar and galaxy radio radiation. Currently, the field levels considerably exceed the level of natural electromagnetic background in most areas.

The 50 or 60 Hz industrial electrical fields, created by transmission lines and substations in urban and rural areas and roads, are more powerful than the natural level of magnetic field of the Earth. These power lines produce Extremely Low Frequency (ELF) fields (with frequencies between 0 and 300 Hz) that have biological side effects. Former studies reported discrepant results on the relationship between low frequency electromagnetic radiation and human health.

In-vitro studies established the adverse effects of sinusoidal magnetic field on cell proliferation, ion concentration, osmolality, human keratinocyte cells, and blood lymphocyte [1-3]. They also showed that magnetic field radiations affect memory consolidation [4, 5] and damage different tissues [6]. Wen *et al*. studied the effect of ELF with X-ray radiation on induction of apoptosis in BEL-7402 cell lines [7]. Some studies noted the effects of magnetic fields on blood-brain barrier [8-10]. Magnetic fields, as non-invasive methods, have some medical applications such as pain reduction [11, 12]. There is some

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concern regarding the effects of these fields on pregnancy and fetal growth in both humans and animals [13].

In addition to biological parameters, there are some physical parameters such as intensity, frequency, and type of wave exposure time that play an important role in biological and medical outcomes [14].

The aim of this study was to design and fabricate a device that generates static and pulsating magnetic fields with different frequencies, intensities, wave types, and duty factors.

MATERIALS AND METHODS

Helmholtz coil is one of the best devices for producing a region of nearly uniform magnetic field with variable and desired intensities and frequencies [14].

In this experimental study, Helmholtz coil was applied to produce magnetic field. A Helmholtz pair consists of two identical circular solenoids with N loops (Figure 1) that are placed symmetrically along the common axis and are separated by a distance (l).

$$B = B_{uper} + B_{lower} = \frac{\mu_0 N I R^2}{2}\left[\frac{1}{\left[(z-\frac{l}{2})^2+R^2\right]^{3/2}} + \frac{1}{\left[(z+\frac{l}{2})^2+R^2\right]^{3/2}}\right] \quad (1)$$

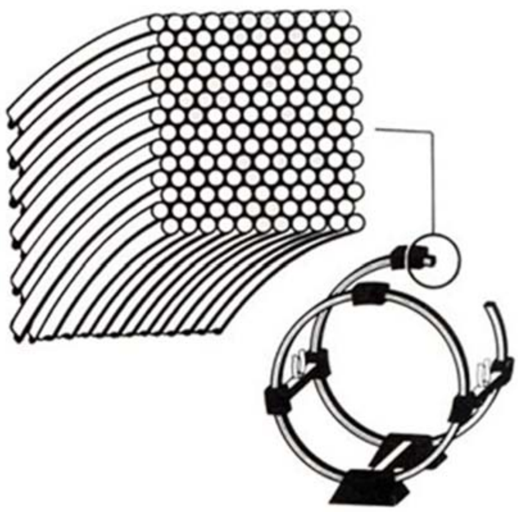

Figure 1. Cross-section of Helmholtz coil

The magnetic field at the center of each loop ($z=\frac{l}{2}$) can be calculated by the following formula (Figure 2) [15].

The curve of plotting $B/_{B_0}$ versus $Z/_{R}$ is illustrated in Figure 3.

This curve shows a setting of l=R, which defines a Helmholtz pair, and minimizes the non-uniformity of the field at the center of the

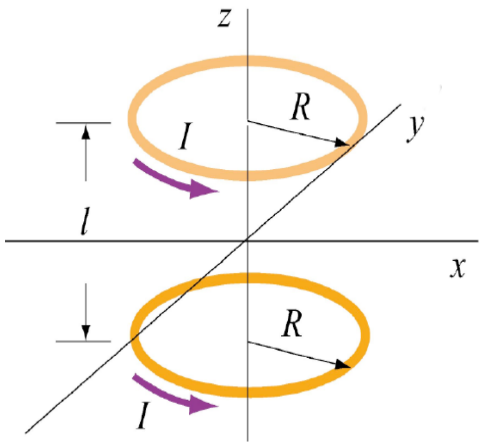

Figure 2. Helmholtz coil

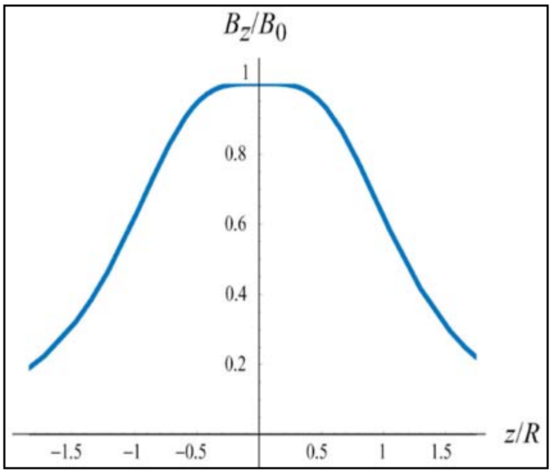

Figure 3. The magnetic field as a function of distance

coils. In this setting, $\frac{d^2B}{dz^2} = 0$

Therefore, for the first derivation we can write:

$$\frac{dB_z}{dz} = \frac{\mu_0 N I R^2}{2}\left[-\frac{3(z-l/_2)}{\left[\left(z-\frac{l}{2}\right)^2+R^2\right]^{5/2}} - \frac{3(z+l/_2)}{\left[(z+\frac{l}{2})^2+R^2\right]^{5/2}}\right] \quad (2)$$

and for the second derivation we have:

$$\frac{d^2B}{dz^2} = \frac{\mu_0 N I^2}{2}\left[-\frac{6}{\left[\left(\frac{l}{2}\right)^2+R^2\right]^{5/2}} + \frac{15l^2}{2\left[(\frac{l}{2})^2+R^2\right]^{7/2}}\right] = -\frac{\mu_0 N I^2}{2}\frac{6(R^2-l^2)}{[(l/_2)^2+R^2]^{7/2}} \quad (3)$$

In special settings, for biological studies employed in this article, to have a uniform magnetic field, the distance between coils (l) was considered equal to the radius of coils (l=R, z=0). Therefore, the formula was changed to:

$$B_0 = \frac{\mu_0 N I}{(\frac{5}{4})^{3/2} R} \quad (4)$$

Accordingly, we applied this geometry for

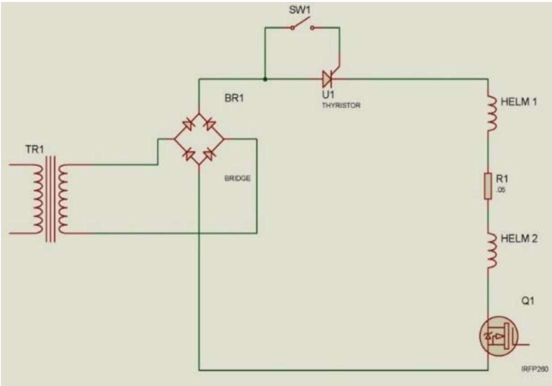

Figure 4. Planning circuit design

perfect condition to produce a uniform magnetic field necessary for medical studies.

Planning circuit design

Our designed electrical circuit has the following components (Figure 4):

TR1: A transformer is an electrical device that transfers energy between two or more circuits through electromagnetic induction. In this design, we used an autotransformer (2 KW and 0-300 V: 2500W 12-220 V).

BR1: Full wave bridge rectifier.

HELM1 and HELM2: The two coils that make Helmholtz coil.

Q1: Switch mode transformer that acts as a key and can switch off or on in a short time.

R1: It is a key with two roles, which limits the maximum current to avoid diode damage and can be used for scope test probe.

IRFB260: It acts as a high current switch to make square wave pulse pattern.

Variac: Variable AC transformer that provides continuously adjustable AC voltage. In its autotransformer form, it is an efficient and reliable method of controlling AC voltage from zero to line voltage by amplitude modulation of the AC waveform.

SW1: A power Mosfet (IRFP260) is used for system switching.

Square wave power supply: The desired frequency of square waves is supplied by ARM7 microcontroller.

RESULTS

In this experimental study, the desired magnetic field was produced between Helmholtz coils by using variable power supply and signal generating systems. The user can select the desired frequency between 0 (as a static magnetic field) and 300 Hz (as a pulsating magnetic field) with the selector of the generator. This square wave signal can produce magnetic fields with intensities ranging from 0 to 8 mT with current variations.


Figure 5. Console control

Control console

Control console (Figure 5) is a part of system that sends the desired voltage wave onto Helmholtz coils. This part has selectors for choosing different parameters such as wave type, duty factor of square waves, frequency, and current time.


Figure 6. The monitors (arrows)

Monitors

This system has two monitors (Figure 6), through which users can change all parameters according to the required options.


Figure 7. Helmholtz coils

Helmholtz coil

As mentioned in the method section, when the Helmholtz coils receive current, a uniform magnetic field will be produced between them (Figure 7). Physical properties of coils include a

Figure 8. Main circuit

copper wire (each coil has N=48 turns), with the outer diameter of 2×R=54 cm, the inductance of about 3 mH, and resistance of about 4.2 Ohms.

Main circuit

This part (Figure 8) consists of autotransformer switching system, signal generator, and supporting circuits that change direct current into necessary current in coils for producing magnetic field.

Magnetic field calibration

Before using the designed set-up for medical studies, evaluation of the accuracy and precision of the system is mandatory. Calibration was performed with a Hall probe. One side of this probe was connected to a 5-volt power supply and the other was connected to a voltmeter. When the Hall probe is held so as the magnetic field lines pass at right angles through the sensor of the probe, the meter gives a reading of the value of magnetic flux density (B).

DISCUSSION

The main aim of this article was to fabricate a magnetic field generator for medical and biological studies. This system has some advantages. The distance between Helmholtz coils is variable so it can be adjusted for in-vitro and in-vivo studies, including studies on animals, blood samples, and cell cultures. There are some magnetic field generators with static field or with just a single frequency. However, this system can produce electromagnetic fields with different intensities, frequencies, and duty factors. This system can simulate magnetic fields that individuals are exposed to and evaluate their effects. In some studies, magnetic field generators are used for treatment procedures [16-20]. Currently, these generators are used to steer stem cells, and a whole new niche in medical studies has been opened for these devices [21].

CONCLUSION

Calibration with a Hall probe proved the proper production of a uniform magnetic field of desired intensity and frequency. Despite the concerns about the adverse effects of magnetic fields employed for treatment procedures, these generators have become necessary devices in medical research.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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