MAGNETIC FIELD FOR BIOMEDICAL EXPERIMENTS

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Abstract: In this paper is described the geometry modification of Helmholtz coil which creates homogenous magnetic field in required space approx. 1 liter with maximal amplitude 1mT and frequency 110kHz. This coil is intended for biomedical experiments with cell culture. The coil is part of parallel resonant circuit. This circuit is powered from transistor converter. Amplitudes of current and voltage reach 170A and 120V in the resonant circuit.

Keywords: Helmholtz coil, switching in zero voltage, resonance, resonant converter

1. INTRODUCTION

The device described in this article was developed for needs of biomedical research. Principle of experiments is the examination of an impact of the oscillating magnetic field on the cell culture in nutrient solution.

The device must generate an oscillating magnetic field with amplitude 1mT and frequency 100kHz moreover in space with free volume 1 liter. This volume is given by requirements of the experiments. If is possible, the magnetic field must be homogenous in the full volume of the space. This requirements are the best complied by a Helmholtz coil. Therefore, the properties are listed of Helmholtz coil both the basic configuration and modified configuration of Helmholtz coil which reach bigger volume with homogenous magnetic field. Further problems about concerning values of voltage and current in coil will be discussed.

The reaching of the amplitude of magnetic intensity 1mT and frequency 100kHz in the volume 1liter is very difficult, either it is necessary too high voltage on the coil or too high current flowing in the coil. It carries high voltage or current stress of the transistor in the converter. In next chapters the power converter for feeding the coil will be described.

2. HELMHOLTZ COIL

Helmholtz coil is used for creating homogenous magnetic field in large space. Magnetic field of Helmholtz coil is relatively weak in [1], [2] and [3].

2.1. BASIC CONFIGURATION

It is a pair of coils placed in a distance *a* in direction of axis *x*, see Figure 1. Such configuration serves for generation of a homogenous field in relatively large space, which is suitable for laboratory purposes. The Helmholtz coils can be made in basic modification.

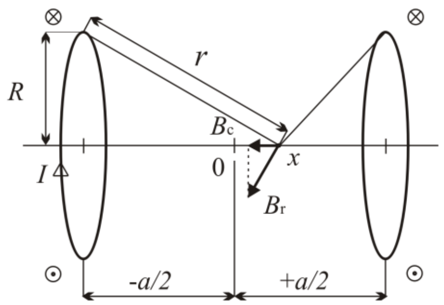

Figure 1: Calculation of the final direction of the magnetic intensity B_c

2.2. MODIFIED CONFIGURATION OF HELMHOLTZ COIL

Modified configuration of Helmholtz coil can be seen in Figure 2. This modification removes disadvantages of basic configuration. The change of configuration is that windings of each coil with radius R are spread in direction of axis x in a chosen width $R/2$. The winding can be single-layer for a lot of turns. Each of the two winding is separated into 5 coils with spacing $R/8$ for calculation. Each k-th right coil is moved on value $(+a/2 + k \cdot R/8)$ by the center. Similarly, each k-th left coil is moved on $(-a/2 - k \cdot R/8)$, where k is 0, 1, 2, 3, 4.

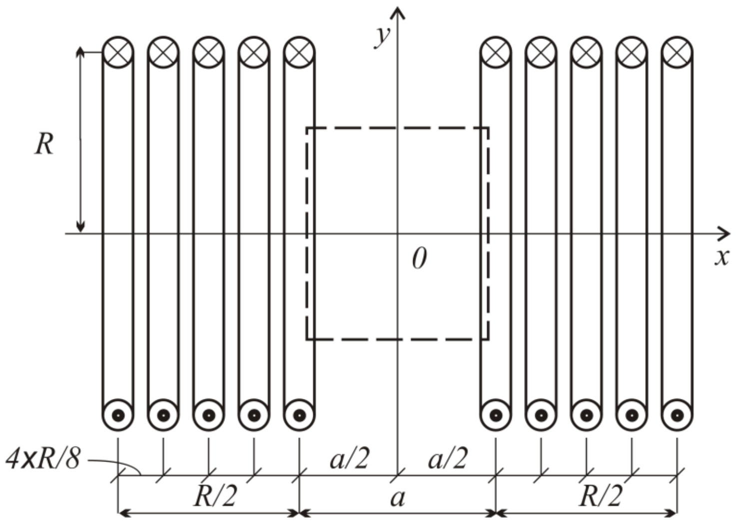

Figure 2: Modified configuration of Helmholtz coil

For flux density in coil axis x we can write

$$B(x) = \sum_{k=0}^{4} \frac{\mu_0 \, N \, I \, R^2}{2\left[R^2 + \left(x - \frac{a}{2} - \frac{kR}{8}\right)^2\right]^{\frac{3}{2}}} + \sum_{k=0}^{4} \frac{\mu_0 \, N \, I \, R^2}{2\left[R^2 + \left(x + \frac{a}{2} + \frac{kR}{8}\right)^2\right]^{\frac{3}{2}}} \tag{2-3}$$

This configuration has approximately twice bigger space with homogenous magnetic field than the basic configuration. Value of a/R ratio is very important. Best ratio is $a/R = 0.65$, it can be seen in Figure 3 which is plotted in Matlab. From simulation in FEMM on Figure 4 is seen the evident validity of the simple rule which is stated on end of previous chapter.

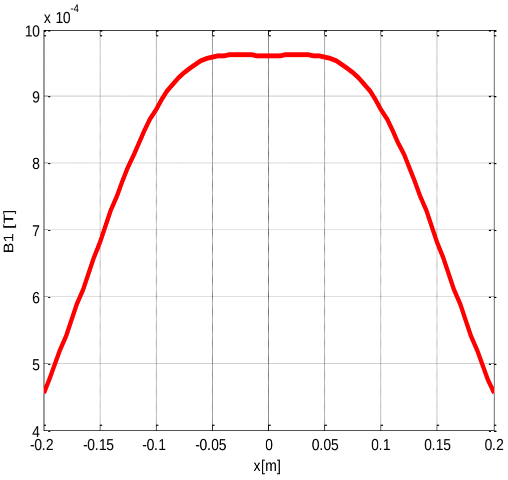

Figure 3: Flux density for modified configuration, for a = 0.65R

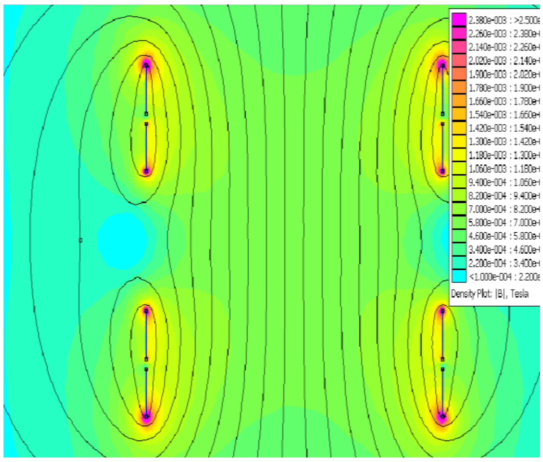

Figure 4: Flux density for modified configuration, for a = 0.65R. Simulated in FEMM

3. POWER COVNERTER

The task of a power converter is to cover losses in a resonant circuit, thus permanent oscillation is retained in the resonant circuit. The converter is formed with one power transistor MOS-FET as it is seen in Figure 5. The transistor works in the switching mode. In transistor are not generated the switching losses, because the transistor is switched at the zero voltage. Q factor for resonant LC circuit is expressed by the form described in literature [4], [5] and [6]:

$$Q = 2\pi \frac{\frac{1}{2} L I_a^2}{W_{dissip}} = 2\pi \frac{\frac{1}{2} L I_a^2}{U_d\, I_d\, T} . \tag{3-1}$$

Where U_d is DC voltage in DC-link, I_d is mean value of current in DC-link and I_a is amplitude of current in resonant circuit. The converter must supply the active power to the resonant circuit:

$$P_{dissip} = \frac{W_{dissip}}{T} = U_d\, I_d . \tag{3-2}$$

In [2] is derived the switching time which is responded this active power:

$$t_{on} = \frac{1}{U_d} \sqrt{\frac{2\, P_d\, L}{f}} . \tag{3-3}$$

The switching time t_{on} = 0.3μs is demanded for losses P_d = 84W.

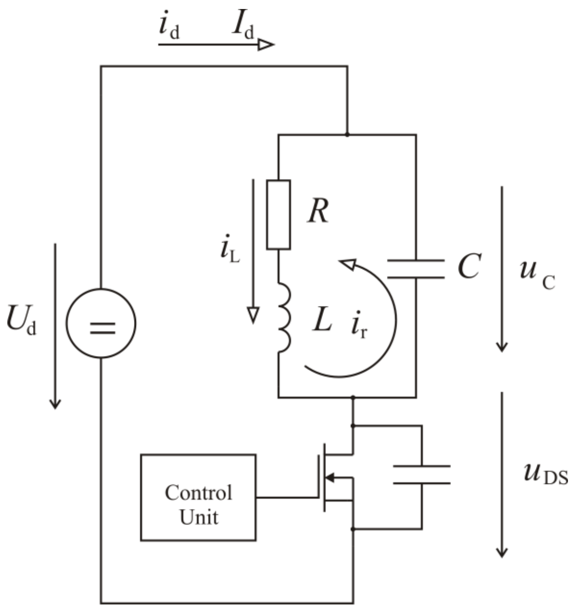

Figure 5: Resonant circuit with converter

The theoretic waveforms are seen in Figure 6. Real waveforms are measured by an oscilloscope and they are seen in Figure 7 and Figure 8.

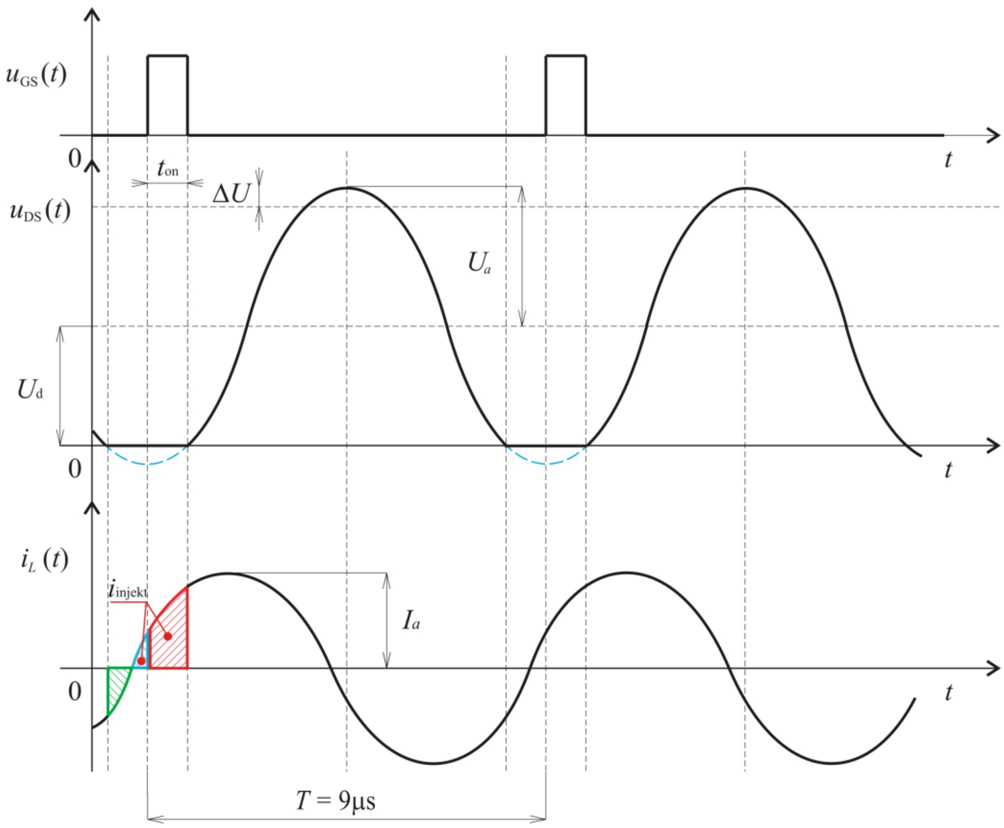

Figure 6: Theoretic waveform of current and voltage in resonant circuit and converter.

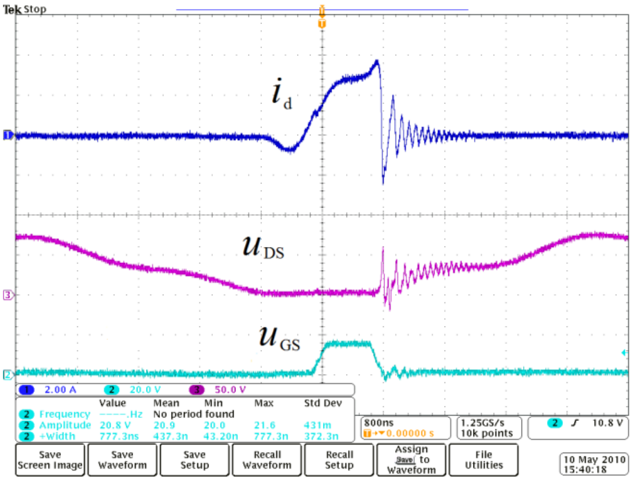

Figure 7: A waveforms of current i_d, voltage u_{DS} and u_{GS} on the transistor.

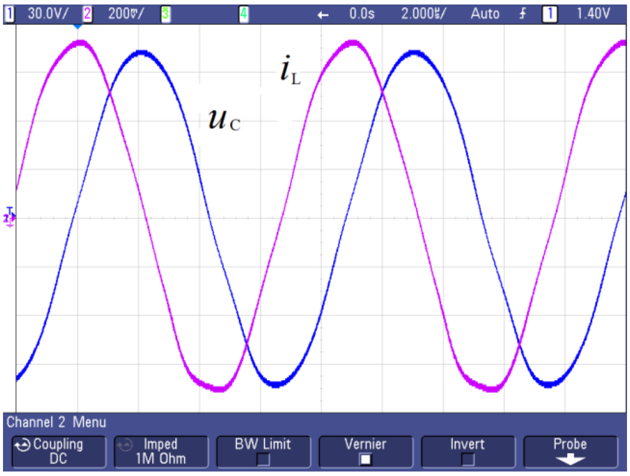

Figure 8: A waveforms of real current i_L and voltage u_C in the resonant circuit.

4. CONCLUSION

The device was tested on the warm-test in long time testing operation. The converter supplies from DC-link the current with mean value 1.2A and active power with value 84W. This power is equal to the total losses in coil, capacitors and transistor. The measured values of the temperature were 52°C on the coil surface and 40°C on the capacitors. The total electric resistance of parallel connecting coils was R_{Al} =4.06mΩ for frequency 110kHz. The losses in the coil had value 59W. It's evident, that most losses are generated in the coil.

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