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# MEASURING MAGNETIC FIELD GENERATED BY A STENT HEAT DEVICE

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We developed a measuring method and system to analyze the magnetic field of an implantation (stent) heating device. The measuring system uses two measuring coils to measure and calculate the magnetic flux inside the device. A theoretical model was developed to show that some parts of the flesh surrounding the stent can be heated up to more than acceptable value. Based on the results an optimal heat coil arrangement is suggested to reduce the volume of flesh irritated by the magnetic flux.

Keywords: magnetic field measurement, magnetic field of electromagnetic heating device

## 1 INTRODUCTION

Stainless steel net implantation, called a stent (Fig. 1), can help overcome vascular stricture. Some stents, however, become compassed as vascular occlusion continues. This problem cannot be solved with a new or replaced stent implanted.

One way to solve the problem of occlusion is to heat up the stent with an outer electromagnetic field [1,2]. With this solution the temperature of the stent and the close surrounding cellular proliferation can reach the critical temperature where cells start deceasing. One important requirement of this technique is that the cells near to the stent and the blood-vessel cannot be burnt.

For experimental purposes a stent heating device was designed and constructed that fulfilled the requirement to heat up the stent itself. The temperature of the stent was held constant with a control system. The procedure was tested in meat and in flesh of living animal (rabbit). In some cases we sensed that, in spite of the device design, some burns and overheats could be seen in flesh. To overcome this problem, we analysed the electromagnetic field generated by the stent heat device, both theoretically and practically.

The model of the heating device (inductor) can be seen on Figure 2. The resonant circuit is composed by capacitance *C* and two half-coils *N*. Magnetic field is generated by the current flowing through the two coils. The direction of the magnetic field is axial. The magnetic field goes through surface *F* between the two coils. The outer limit of the magnetix flux is indicated with purple ellipsis.

The peak value of the inductor coil voltage is 5000 V, frequency is 3.78 MHz, effective power is 5 kW and the dimensions of the inductor coil are diameter *D*=100 mm, length *L*=50 mm.

**Fig. 1.** Photo of a stent net implantation

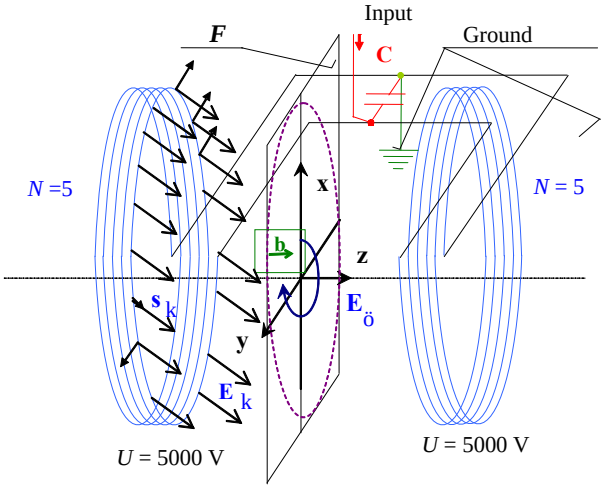


**Fig. 2.** Model of the heating device

## 2 MEASUREMENT

To measure the magnetic field, a matrix wooden plate was constructed. The plate is parallel to surface *F* and has matrix holes to hold the measuring coil head at certain places. The plate was placed in between the coils at equal distance, symmetrically. For easy assembling we indicated the position of the plate on the table.

The design of the measuring head can be seen on Figure 3. The sensor is a 2-turn coil, in which voltage is induced with 3,78 MHz frequency.

The power of the heating device is controlled with pulse modulation. The period of the modulation is 4 ms. The filling factor can be set from 0 to 70% with 1% steps. Synchronization of modulation and network frequency is not solved so rising amplitude of oscillation at the beginning of the pulse can change 5-15%. The magnetic field of this kind of device can be measured in two steps because the amplitude of the oscillation and the generated flux is not constant. In the first step we find the position on surface F where flux is near maximal. This can be a reference point. In the second step we use two measuring coils, one at the current measuring point and the other at the reference point.

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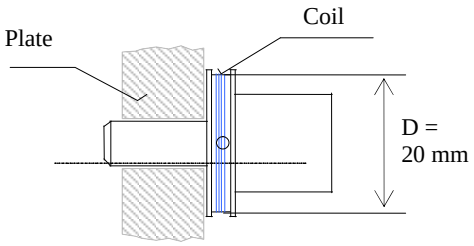


**Fig. 3.** Measuring coil

Measuring coil system was believed to have floating ground. During the measurements we found that capacitive currents influence the measuring system. The existence of capacitive current was indicated by corona discharge during earlier measurements.

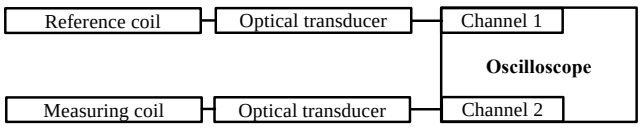


**Fig. 4.** block-diagram of the measuring system

According to the results the electromagnetic field of the stent heat device is composed by two field components, a capacitive and an inductive part. Both components can cause overheats in the flesh. The capacitive component, according to the theoretical expectations, does not heat the stent material but can heat the cells and disturb measurements. This field component can be eliminated by a properly designed potential lattice. The inductive component comprises of the magnetic field with 3.78 MHz frequency going through the induction coil and the coupled electric field which produces Eddy-currents in the conductor (*eg* flesh) placed inside the field. If the electric field reaches the stent, the Eddy-current appears in it and heats it because of the Ohmic losses.

The block-diagram of the measuring system can be seen on Figure 4. Optical transducers are Nicolet type Isobe 3000. Oscilloscope is LeCroy Lt264ML with four channels. Calibration of optical transducers was made by signal generator with 3,71 MHz 10 V signal.

The induced voltages were displayed on two channels of the oscilloscope. From the peak value (corrected with the reference value) we calculated the magnetic induction. The potential lattice, used to eliminate capacitive field effect, does not influence the Eddy-currents resulted in the stent itself. The result of the measurement can be seen on Figure 5.

## 3. THEORETICAL CALCULATIONS

If $B_{max}(x,y)$ is known, for example from the measurement, a $B_a(x,y)$ approximate formula can be calculated. Approximation can be checked with deviation calculation. Based on $B_a(x,y)$ maximal value and contour lines (for example 90,80,70…10 % of maximal value) can be constructed.

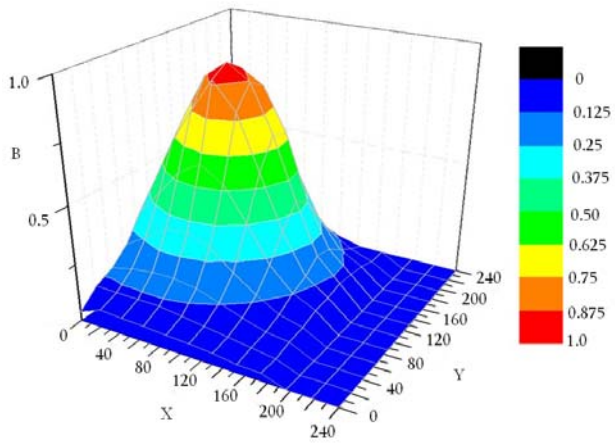


**Fig. 5.** magnetic induction inside the heating coils (mT)

Flux inside a given contour line can be calculated as:

$$\phi(x,y) = \iint_{contourline} B(x,y)\,dx\,dy \ , \tag{1}$$

Voltage along the contour line is:

$$U_{cl} = 4,44\,f\,N\phi = F \iint_{contourline} B(x,y)\,dx\,dy \tag{2}$$

where $F$ = 4,44*$f$, and $N$ = 1.

Second power of voltage is:

$$U^2_{cl} = \left( F \iint_{contourline} B(x,y)\,dx\,dy \right)^2 , \tag{3}$$

Power can be interpreted along the contour line:

$$P_{cl} = \frac{\left( F \iint_{contourline} B(x,y)\,dxdy \right)^2}{R} \ , \tag{4}$$

Where $R$ is the resistance of the channel running along the contour line with height $h$ and width $\Delta r$.

Its value is:

$$R = \frac{\nu}{\Delta r h} \int f_{ch}(x,y)\,dx\,dy \ , \tag{5}$$

where ν is specific resistivity and

$$l = \oint f_{ch}(x,y)\,dx\,dy$$

is the length of the channel.

Power generated during time $dt$ causes temperature rising.

$$\int_0^t P_{cl}\ dt = \Delta T c\,\rho\,\Delta r\,h\,l \ , \tag{6}$$

Where ρ is volume density, $c$ is specific heat and $\Delta T$ is temperature rising.

Using equations (4) (5) and (6) we get:

$$\int_0^t \frac{\left(F \iint_{contourline} B(x,y)\,dxdy\right)^2}{\frac{\nu}{h\Delta r} l} dt = \Delta T c \rho h l \Delta r \ , \qquad (7)$$

We inspect temperature range 30 °C < $\vartheta$ < 60 °C. This range is small so we assume that ρ and *c* are independent of temperature. As ρ is independent of temperature, placement and time, we conclude that:

$$\Delta T = \frac{F^2}{c\rho\nu l^2} \cdot \int_0^t \left( \iint_{contourline} B(x,y)\,dx\,dy \right)^2 dt \ , \qquad (8)$$

Maximum value of induction *B* is held constant so:

$$\Delta T = C_1 \left( \iint_{contourline} B(x,y)\,dxdy \right)^2 t \ , \qquad (9)$$

Where $C_1$ is

$$C_1 = \frac{F^2}{c \cdot \gamma \cdot \varsigma} \ , \qquad (10)$$

If

$$\left( \iint_{contourline} B(x,y)\,dx\,dy \right)^2$$

is known for a contour line, and it is constant, then:

$$\frac{\Delta T}{t} \frac{1}{\left( \iint_{contourline} B(x,y)\,dx\,dy \right)^2} = C_1 \ , \qquad (11)$$

or:

$$s = \frac{\Delta T}{t} = C_1 \left( \iint_{contourline} B(x,y)\,dx\,dy \right)^2 \qquad (12)$$

where *s* is the slope of temperature rising.

We conclude that slope of temperature rising is proportional to

$$\left( \iint_{contourline} B(x,y)\,dx\,dy \right)^2 ,$$

where proportional-action factor is $C_1$. Temperature rises steeply as surface surrounded by the Eddy-current increases. Critical surface can be measured with temperature measurement.

Let us place a flesh inside the heating device so that it covers the whole flux region (contour lines). Maximum value of flux is known by measurement. Temperature sensor is placed at the point having the maximal value. Temperature rising is minimal at this point, though is greater than zero as the size of the sensor is finite. Let us place the stent at this point. Electrical resistivity of the stent material is much smaller than the resistivity of flesh, and the size of the stent is greater than zero, so the stent will be heated. From this measurement we can conclude the time $t_{up}$ that is needed to heat up the stent to the target temperature.

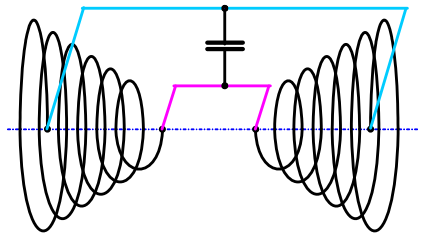

**Fig. 6.** cone-shaped heating coil arrangement

Now let us place the temperature sensor to greater and greater distances from this point having the maximal flux value. We measure $\Delta T=f(t)$ temperature during $t_{up}$ heating time. Let be $\Delta T_{max}$ the maximal temperature that can be allowed in flesh to have no burning. If $\Delta T=f(t)$ gets over $\Delta T_{max}$ than the maximal area for the flux during $t_{up}$ is the area covered by the previous contour line. With this method the maximal area for the flux generated by the heating device can be measured and calculated.

Based on this result an optimal stent heat coil arrangement, for example a cone-shaped coil (Figure 6) [3] can be used to reduce the volume of the flesh irritated by the magnetic flux and eliminate burnings and overheating.

## CONCLUSIONS

We developed a measuring method and system to analyze the magnetic field of a metal implantation heating device.

We concluded theoretically and indicated practically that there can be a certain space volume and distribution of specific conductance of the flesh, where some parts of the volume can be heated up to more than 42 C degree while the stent is held on the target temperature.

Based on this result an optimal stent heat coil arrangement, for example a cone-shaped coil can be used to reduce the volume of the flesh irritated by the magnetic flux.

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