ELECTROMAGNETIC SYSTEM FOR PHYSIOLOGICAL RESEARCH

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INTRODUCTION

Pulsed electromagnetic fields are widely used for treatment on non-united and congenital pseudarthrosis. Several electrical stimulation systems such as air-cored and iron-cored coils and solenoids have been used [1]. Current parameters such as pulse shape, magnitude and frequency differ widely and the exact healing mechanism is still not clearly understood. Positively evaluated effects on physiological state of a patient can be described as follows: increase in blood-perfusion (without heat generation) in the deep tissues of the body, improvement of oxygen supply, alleviation of pain, acceleration of regeneration after nerve injuries, myoenergetic effects, etc..

Cancer or other health problems may be linked to a person’s long-term exposure to low-frequency electromagnetic fields. Many studies have investigated this possibility but anomalous results make a clear conclusion vague. Little is known about how such a health link might operate or what aspects of electromagnetic fields might cause these problems [2].

Potential risks of Nuclear Magnetic Resonance Imaging using magnetic fields fall into three categories: those caused by a static magnetic field of moderate strength; those caused by rapidly changing magnetic fields (the gradients); and those caused by the RF magnetic fields [3,4].

Stationary magnetic fields generate flow potentials across moving blood. Spurious EKG changes have been observed in patients being exposed to stationary magnetic fields. These changes are not correlated with any other physiologic parameter (heart rate, arrhythmia), and they cease when the field is removed. The maximum strength of the stationary magnetic field recommended by Bureau of Radiologic Health is 2 Tesla [5].

Sophisticated biological experiments using single cell preparations at conditions present in NMR imaging have demonstrated no hazard [6]. An animal exposed to magnetic fields of the order of those likely to be used have shown measurable metabolic disturbances only after being kept in the field for several days or weeks, and all changes were reversible on removal of the field [7].

Static magnetic field effects on sinocarotid baroreceptors in humans are reported in [8]. A broad range of safety considerations pertaining to magnetic fields in the operation of NMR imagers is reported in [9].

The effect of the MR environment on vital signs of term neonates has been investigated [10]. All of the test infants exhibited substantial changes in blood pressure, heart rate, and/or oxygen saturation during the MR examination. No such changes were observed in the control infants.

Experiments using stationary magnetic fields as a therapeutic tool are not new. Experimental interpretation is very difficult especially in psychotherapy. Besides the investigation of local influences of magnetic fields on selected tissue of a brain, it is also necessary to correctly interpret the electroencephalographic or magnetoencephalographic signals from a microscopic point of view. First experiments using stationary magnetic fields on volunteers showed that some kind of mind relaxation appeared. This was the first impulse to use this technique on patients with depressive syndrome.

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The goal of this paper is to show theoretical and technical possibilities for the creation of stationary magnetic fields. The quasi-homogeneous, located and gradient fields will be used as a new experimental instrument for the physiological laboratory.

MAGNETIC FIELD MODELLING

Experimental equipment designed for a local magnetic field generation consisted of an iron- core cylindrical electromagnet with exchangeable pole extensions. For modelling, there is a set of parallel coils creating a solenoid magnet with a narrowed pole.

For the axial components of the magnetic field we can write a formula deduced from the Biot-Savart law as a sum of the particular coils contributions as follows:

$$B_z = \frac{\mu_0 I}{2\pi} \sum_{i=1}^{n} \left\{ \left[\left(z - z_i \right)^2 + \left(R + r \right)^2 \right]^{-0.5} \left[K(k) + \frac{R^2 - r^2 - \left(z - z_i \right)^2}{\left(R - r \right)^2 + \left(z - z_i \right)^2} E(k) \right] \right\} \qquad (1)$$

where μ_0 - permeability $= 4\pi 10^{-7}$,

I - current in the loop in amperes,

R - radius of the loop in meters,

r, z - radial and axial co-ordinate variables in meters,

$K(k)$ and $E(k)$ are the complete elliptic integrals of the modulus $k^2 = 4Rr/[(R+r)^2 + (z - z_i)^2]$

In practical applications a multi-layer solenoidal coil with an iron core would replace the set of parallel coils. The shape of the axial magnetic field is determined by exchangeable pole extensions.

For generation of quasi homogeneous and gradient magnetic fields for the brain application 10 flat coaxial coil segments placed on a hemisphere cap were designed and constructed (see Fig.1). For calculation of the magnetic field equation (1) has been used replacing the sum by integration expressing geometrical dimension and position of every coil.

By programmable control of switching (on/off) of selected coils and their polarity several combinations of magnetic field shapes are adjustable. In Fig.2 an approximately homogeneous field is depicted as an example (contour plot). The dashed arc indicates the upper part of the horizontal human head position during the investigation.

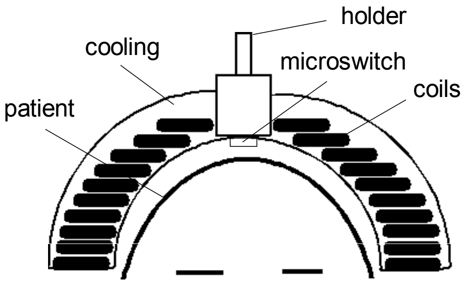

Fig.1

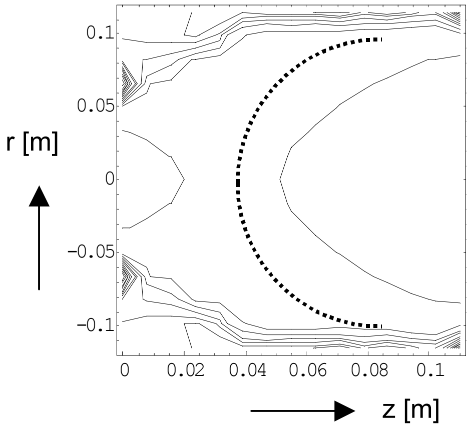

Fig.2

MECHANICAL PARTS

The electromagnet (cap type or solenoidal) is hung on a rack to adjust all positions of the electromagnet for a sitting or lying patient. The stand enables all the movements of the electromagnet to be controlled by rotators. In the lower part of the holder there is a pedal for fast emergency elevation of the magnet for about 25 cm.

The magnets are water-cooled. Between every two coils there is a copper disc with a welded cooling tube. Gauges connected to the cooling circuit measure the water pressure. With decreasing pressure the electrical power supply is switched off.

For the indication of the head position (in cap-type of electromagnet) there is a proximity microswitch on top of the electromagnet. An optical signal indicates the mechanical contact between the human head and the electromagnet.

CONTROLLED CURRENT POWER SUPPLY

The main task of a controlled current source is stabilisation of manually adjusted current and its soft rise and fall (see Fig. 3).

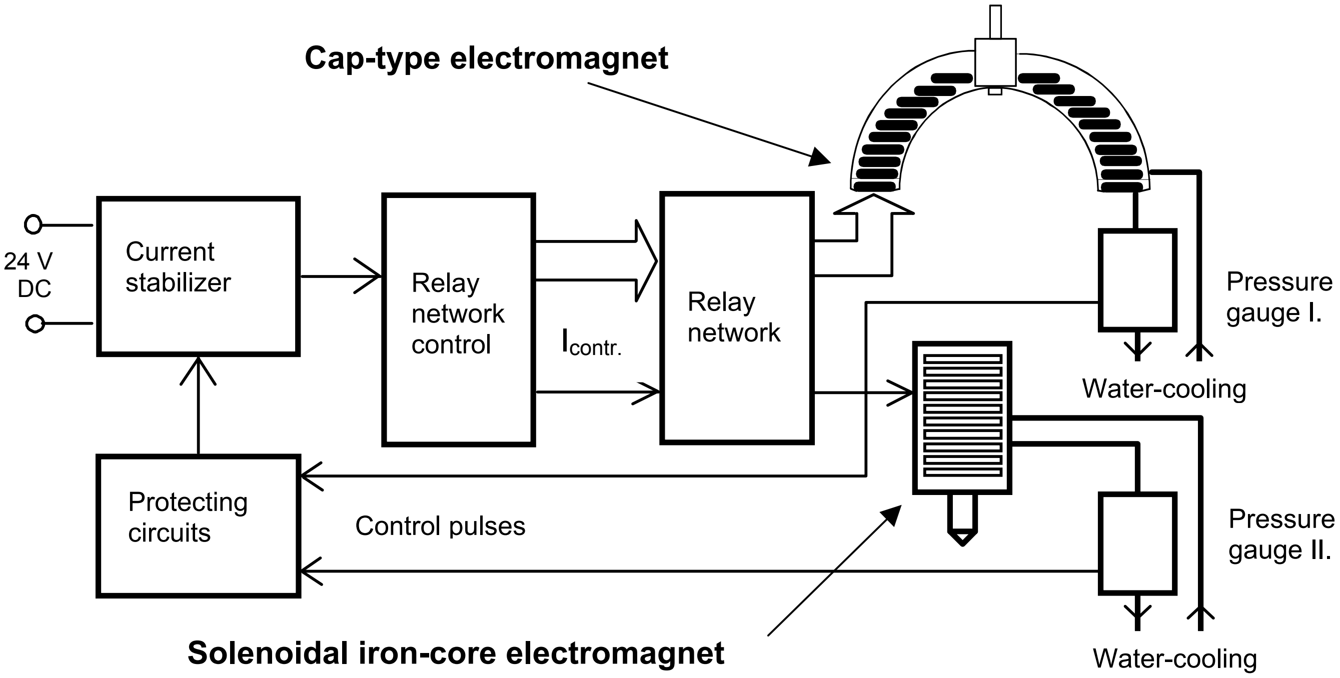

Fig. 3

The current stabiliser works in switching mode as “buck converter” with frequency of 50 kHz. We have used a twin of power MOS transistors IRFZ 44 with very low on-state resistance (28 mΩ) and short switching times to keep power losses at an acceptable level even for currents above 20 A. Driving of the power transistor is performed by driver IR2125 which provides high driving current (and hence short switching times of MOS transistors), low signal delay and fast protection of transistors against overcurrent. The shunt resistor, compared with a pre-set value, measures output current and resulting differential signal drives pulse-width modulator (B 260D). Electronics also allow manual current adjustment within 1-20 A and soft output current switching with rise and fall times of 5 seconds. Power efficiency is above 95% depending on load resistance (number of by-passed coil segments).

In order to achieve desired magnetic field space distribution, the relay network ensures driving of currents through selected coil segments (in 10 channels) of the cap-type electromagnet with required current direction. It uses high reliability miniature relays (producer defines maximum current 30 A and 10^7 cycles) as a compromise between power losses, driving complexity, price and reliability. To protect relay contacts the current reversion and switching off in a given segment is always performed by segment short-circuiting. Current reversion (after internally controlled time delay) is performed in zero current state. Relay contacts are also dynamically protected by diodes.

Manual control of the relay network is performed by a relay network control system. It consists of three state switches and electronics which ensures necessary timing during reversion (short circuiting of segment during approx. 2s prior to reversion) and signalling of actual switching configuration.

Protecting circuits protects the power source against all possible hazards, namely output short circuit, loss of cooling and non-standard switching of the cap-type electromagnet coils (simultaneous reversion of many segments).

RESULTS

A new experimental instrumentation for physiologic laboratory was built according to the requests of physicians. The maximum achievable located field generated by a solenoidal electromagnet is 50 mT in distance 40 mm from the magnet pole by current supply 20 A. The maximum magnetic field in the center of the cap-type electromagnet is about 40 mT with a 20 A current. The electronic control unit controls its shape and intensity.

The coils system is fed by a current stabilised power supply capable of producing from 1 to 20 A. The current in every coil is controlled (switch on/off and polarity) by a separate controlled current power supply. The switching on/off a magnetic field slew rate is electronically controlled for to prevent very fast changes of magnetic field. The fast changes are not acceptable for the brain investigations.

ACKNOWLEDGEMENTS

This work has been supported by the Grant Agency of Ministry of Education SR and Slovak Academy of Sciences (Grant No. 2/6020/99).

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