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Currents induced by standard movements in a 3T static magnetic field

Abstract. *MRI magnets generates strong and uniform magnetic fields within the field of wiev, but spatial field gradients are present outside this central region, and as consequence people moving within magnet room experience time-varying magnetic field inducing electric fields and currents in tissues.*
Aim of this study is the assessment, through direct static field measurements and model based calculations, of induced currents at trunk and head as effect of translating or rotational body movement within the magnet room.
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Streszczenie. *In this place the editor of journal inserts Polish version of the abstract. Please leave three lines for this abstract. Of course Polish language Authors are requested to prepare also Polish "Streszczenie". All papers should have two sets: title, abstract, keywords - Polish and English. (**Przygotowanie artykułu do Przeglądu Elektrotechnicznego** - polski tytuł na końcu streszczenia - Polish tittle at the end).*
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Keywords: nuclear magnetic resonance, magnetic field, induced currents
Słowa kluczowe: in the case of foreign Authors in this line the Editor inserts Polish translation of keywords.

Introduction

Recent developments in Magnetic Resonance Imaging (MRI) based diagnostic technologies are leading hospitals towards high static magnetic fields scanners use; current tendency indicates the use of 3T scanners for common diagnostics and 7T units for interventional procedures in operating room, this leads to increased static magnetic fields exposure for the personnel.

In year 2004 European Union adopted the 2004/40/EC Directive [1] which gives the minimum health and safety requirements to protect workers from risks due to electromagnetic fields exposure; this Directive application may lead to severe limitations in MRI based techniques use for diagnostics.

Considering all those factors, European Parliament has postponed the deadline for transposing the Directive by Member States to year 2012 in order to permit a complete limits and guidelines revision by the ICNIRP [2].

From a physiological point of wiev the only proved effect is the formation of visual stimuli, such as phosphenes, with induction thresholds varying from subject to subject. Detailed studies of physiological parameters including body temperature, respiratory rate, number of hearth pulses, blood pressure and body extremities oxygenation status, showed no significant changes in exposures up to 8 T [4].

Static magnetic field levels in proximity of MRI scanners can be easily measured using an Hall effect probe on an appropriate measure grid; but this data, can be representative only of a motionless body exposure and in total absence of physiological movements (blood flowing in veins and arteries included), as consequence it is not a reliable parameter to be considered.

Scientific literature [5,6] reports that motion induced electric fields produced in head and trunk may be considered a problem; for this reason an assessment of additional parameters taking into account the subject movement into the static field is needed. This parameter is the magnetic flux density dB/dt, related to the induced electric field by the equation:

$$\oint E_b . dl = \int \frac{d(B.ds)}{dt} \qquad (1)$$

Where E_b is the induced electric field.

The electric field is induced by changes occurring in magnetic field vector due to linear or rotational body movements into a static field.
Aim of this study is the assessment, through direct static field measurements and model based calculations of currents induced at head and trunk as effect of translating body movement within different patterns into magnet room during ordinary clinical activities.

Material and Methods

Measurements have been performed on a GE Signa 3.0 T clinical scanner, using a Metrolab THM1176 isotropic Hall effect probe able to detect static magnetic fields within the range 0 – 1999 mT with 2% of reading accuracy.

The scanner's isocentre has been chosen as reference system's origin and the axis has been identified as shown in Figure 1.

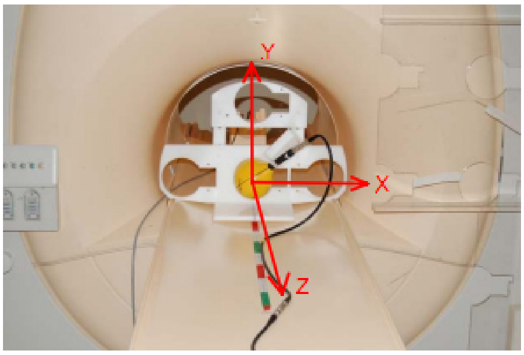

Fig.1. Reference system

The magnet room has been divided into four quadrants symmetrical in respect to x and z axis; the symmetry of the static magnetic field make it possible to perform measurements only on a single quadrant.

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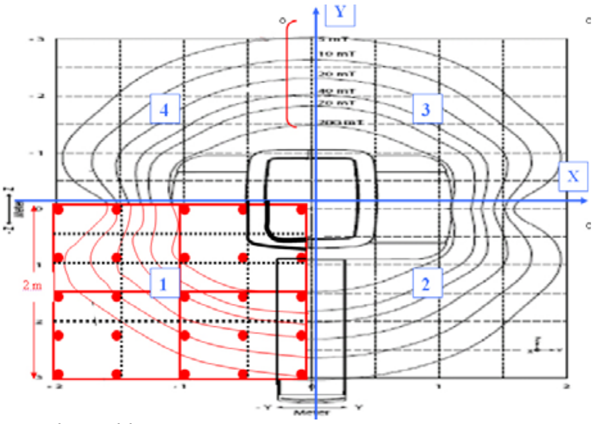

Fig.2. Micro grid

A 25 cm square microgrid was traced in the room; the instrument was placed at the top of every single square at 100, 120, 150, 170 cm from the floor; seven different standard walking patterns, reported in Figure 3 have been investigated. Pattern selection is based on operators answers to an interview on ordinary activity standards.

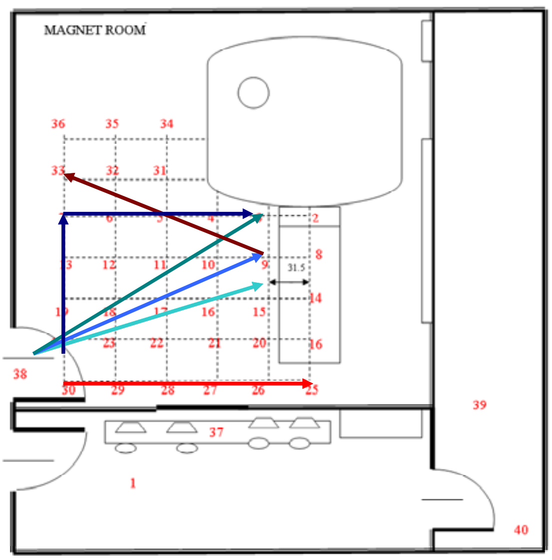

Fig.3. An example of a graph

The analytical model used to calculate induced current provides the human body section modelled as a radius R, constant conductivity homogeneous disk, thus ignoring the biological tissues anisotropic proprieties. Under these conditions, from the integral form of magnetic flux

(2) $$\oint_L E.dl = -\frac{d}{dt}\int_S B.u_n ds$$

where L is the disk circumference and S its surface, follows

(3) $$J(R) = \frac{\sigma_t R}{2}\left|\frac{dB_{ave}}{dt}\right|$$

where J(R) is the current density induced in the radius R section, σ_t is the tissue conductivity (0.2 S/m), B_{ave} is the average value of the magnetic field through the coil..

The quantity described in (3) can be decomposed in the product:

(4) $$\left|\frac{dB_{ave}}{dt}\right| = \left|\frac{dB_{ave}}{dx}\right|\left|\frac{dx}{dt}\right|$$

as consequence the induced current density can be calculated as:

(5) $$J(R) = \frac{\sigma_t}{2} R\, v \left|\frac{dB_{ave}}{dx}\right|$$

Where R is assumed to be 0.1 m for the head, 0.2 m for the trunk, translational v have been considered 1 m/s [9], this speed value is a rational choice, as it leads to a maximization of the dosimetric quantity J(R).

In order to perform the measurements necessary to the model application each path has been divided into multiple subpaths, represented by segments on the floor. ΔB and Δx values have been directly measured for every single segment and relative J(R) has been calculated using the expression in (5).

Results

For what concerns body movements in static magnetic fields effects, calculations performed for seven different paths, have shown current densities at head and trunk contained in the range 0.02 – 7.14 mA/m^2, well below the Directive 2004/40/EC 40 mA/m^2 basic restriction. The trajectory segmentation shows that the highest contribution to the induced current density is referable to the last 70 cm of the path, when, approaching to the magnet the quantity ΔB_i significantly increases: the relative contributions of the external part of the trajectory are. Table 1 shows the data for room entrance-bore edge diagonal walking path, B has been measured at 170 cm from the floor for the head and 150 cm from the floor for the trunk .

Table 1. calculated J for diagonal path (entrance – bore edge)

Point	B_{meas} (mT)	Δx_i (m)	ΔB_i (mT)	$\left\|\Delta B/\Delta x\right\|_i$ mT/m	J_{itrunk} (mA/m^2)
Start	0.3				
X_1	0.7	0.70	0.4	0.56	0.011
X_2	2.8	0.70	2.1	2.97	0.059
X_3	19.9	0.70	17.1	24.2	0.48
X_4	260	0.70	240.1	339.6	6.8
Point	B_{meas} (mT)	Δx_i (m)	ΔB_i (mT)	$\left\|\Delta B/\Delta x\right\|_i$ mT/m	J_{ihead} (mA/m^2)
Start	0.3				
X1	0.7	0.70	0.4	0.56	0.0056
X2	2.4	0.70	1.7	2.40	0.024
X3	12	0.70	9.6	13.6	0.13
X4	166.4	0.70	154.4	218.4	2.18

Table 2. calculated J for diagonal path (entrance – patient couch)

Point	B_{meas} (mT)	Δx_i (m)	ΔB_i (mT)	$\left\|\Delta B/\Delta x\right\|_i$ mT/m	J_{itrunk} (mA/m^2)
Start	0.3				
X_1	1.7	1.11	1.4	1.26	0.025
X_2	7.2	0.70	5.5	7.78	0.16
X_3	51.9	0.70	44.7	63.2	1.26
Point	B_{meas} (mT)	Δx_i (m)	ΔB_i (mT)	$\left\|\Delta B/\Delta x\right\|_i$ mT/m	J_{ihead} (mA/m^2)
Start	0.3				
X_1	1.4	1.11	1.1	0.99	0.00099
X_2	6.6	0.70	5.2	7.36	0.074
X_3	25.8	0.70	21.9	30.97	

Table 3. calculated J for hybrid path

Point	B_{meas} (mT)	Δx_i (m)	ΔB_i (mT)	$\left\|\Delta B/\Delta x\right\|_i$ mT/m	J_{itrunk} (mA/m^2)
Start	270				
X_1	81.6	0.5	178.4	356.8	7.14
X_2	16.5	0.5	65.1	130.2	2.60
X_3	2.4	0.5	14.1	28.2	0.56
X_4	0.4	0.70	2	2.8	0.024
Point	B_{meas} (mT)	Δx_i (m)	ΔB_i (mT)	$\left\|\Delta B/\Delta x\right\|_i$ mT/m	J_{ihead} (mA/m^2)
Start	166.4				
X_1	57.6	0.5	108.8	217.6	2.18
X_2	11.0	0.5	46.6	93.2	0.93
X_3	2.1	0.5	8.9	17.8	0.18
X_4	0.4	0.70	1.7	2.4	0.02

The calculated values as well as being affected by instrumental errors represent an overestimation of the parameter under study, because the calculation was performed assuming that the motion takes place perpendicular to the bore axis; in real situations the trajectory angle differs from a perfect 90°.

Conclusions

Measurements and model based calculations have been performed on seven different patterns: diagonal, parallel and perpendicular to z axis trajectories divided into specific subpatterns. In each case the estimated values are well below the Directive 2004/40/EC 40 mA/m^2 basic restriction.

The proposed simplified analytical model represents a good way to perform "in first approximation" induced currents calculation.

For what concerns workers protection the proposed approach provides a simply and quite non expensive method to assess induced currents based on. a preliminary exhaustive environment investigation, interviews to the operators,, field measurements performed within established patterns and subsequent calculation.

This methodology can be applied for working exposure periodic assessment, requiring a relatively short time for measurement activities and therefore not interfering with the normal clinical activity; measurement activity can be carried out very fast before or after the regular daily clinical activity.

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