Measurement Methodologies of Occupational Exposure in MRI Environment

Daniele Andreuccetti[3], Gian Marco Contessa[2], Rosaria Falsaperla[2], Rossella Lodato[1], Nicola Zoppetti[3], Vincenzo Brugaletta[2], Sergio Mancini[1], *Paolo Rossi[2]

[1]*Section of Toxicology and Biomedical Sciences, ENEA, Rome, Italy,* [2] *National Institute for Occupational Safety and Prevention, ISPESL, Rome, Italy,* [3]*Institute for Applied Physics "N. Carrara", CNR, Florence, Italy*

**Corresponding author e-mail: paolo.rossi@ispesl.it*

***Summary*— The preliminary results of a research project launched by ISPESL on occupational exposure assessment in clinical use of Magnetic Resonance Imaging are presented. MRI uses EMF in three frequency ranges: the static field (0.5–3.0 T currently in Italy), the gradient fields (1–5 kHz) and radiofrequency fields (21–128 MHz). All relevant measurement set-up are presented, including movement in static field.**

I. Movement Through Static Field

An operator moving inside a space-varying static magnetic field experiences a very low frequency time-varying magnetic field, and electrical currents are induced in the conductive tissues of the body. This is very common when the nurse prepares the patient close to the bore, and moves in the region where the spatial gradient of static field is maximum.

Measurements during movement were made to reconstruct the exposure of the staff during the phase of preparation of the patient before MR scan, and when the presence of the operator is requested while the MR scanner is operating.

In order to evaluate the induced current due to these movements, the static field variation was assessed while a volunteer was moving in a RM room simulating typically routine movements around the scanner. A static magnetic field probe was fixed on a proper helmet-holder dressed by a volunteer (Fig.1), and all data were recorded with a magnetometer. In this configuration the probe moves in agreement with volunteer's head, which is a very sensitive part of the body with regard to EMF exposure and potentially experiences the fastest movements during practise, due to possibility of fast rotation. All movements of the subject were filmed.

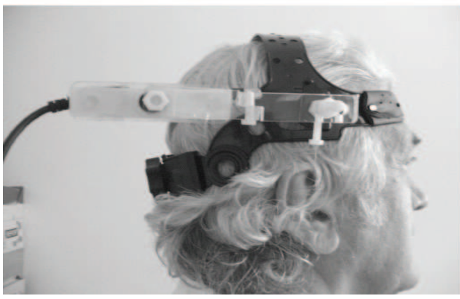

Fig.1 Volunteer wearing a helmet-holder with the magnetic probe

Measurements were performed with Metrolab Three-axis Hall Magnetometer THM1176 (Narda Safety Test Solutions, Pfullingen, Germany) that provides the three independent components (frequency range DC to 1 kHz – measurement range up to 20 Tesla).

The field probe was connected with a PC laptop and the acquisition step was set at 0.1 s. This number of samples was considered sufficient to record all actual time variations of the static magnetic field strength during the movement of the staff.

As an example, Fig. 2 shows the data recorded during an acquisition (in a 1.5 T whole body machine), where the volunteer stood in a steady position in front of the bore on the rear side of the gantry, leaning out into the bore to simulate a check on an anesthetized patient.

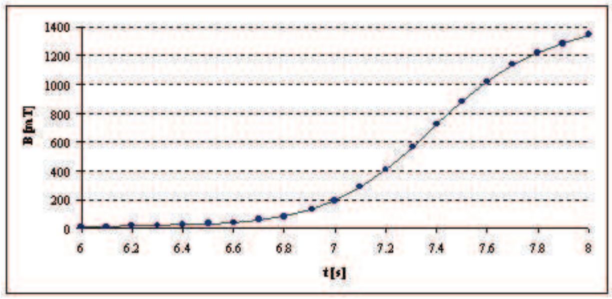

Fig.2: detail of B field acquisition during movement

The graph highlights a maximum value of 1.5 T/s for the dB/dt gradient. This information will be used by numeric calculation to derive induced currents values.

II. Time-Varying Magnetic Field

There are situations where the staff is present inside the MR room during scan, for instance when the anaesthetist has to manually control the apnoea of an anaesthetized patient during cardiac examination.

Measurements of the intensity of the magnetic flux density (MFD) fields produced by the gradient coils were accomplished through the use of a measurement system comprising three basic elements: a ELT-400 magnetic field meter (Narda Safety Test Solutions, Pfullingen, Germany, frequency range: 1 Hz – 400 kHz) equipped with a three-axial coil-type probe and providing three analog outputs; an Agilent U2531A (Agilent Technologies, Santa Clara CA 95051, USA) 4-channel data acquisition device (DAD, 14 bit resolution, sampling rate up to 2MSa/s synchronously on all channels) connected to the three ELT-400 analog outputs (one U2531 input channel is unused) and a laptop PC connected both to the DAD (via an USB link) for data collection and directly to the ELT-400 (via an RS232 link) for control purposes.

The ELT-400 provides several measuring modes, that can be remotely selected through the RS232 interface; its analog outputs deliver three voltage signals proportional to the three components of the magnetic flux density; these signals are synchronously sampled at 50 kSa/s by the Agilent DAD. A NI LabVIEW 2009 (National Instruments, Austin, Texas) application has been purposely developed in order to manage the measurement procedure from the laptop, i.e. to control the ELT-400 operating mode and to acquire and store on disk both the digitized samples and the display indications. The field probe was positioned in the point to be characterized, usually close to the bore aperture of the MR scanner. It was maintained fixed with a proper inclination, in order to align the three measurement axes with the predefined horizontal and vertical directions.

Measurements were mainly taken in the ELT-400 FS (field strength) mode, in which the instrument frequency response is flat from the user-selectable low-cut frequency (usually set at 30 Hz for minimum noise) up to 400 kHz. Sampled magnetic flux density (MFD) data were digitally post-processed out of line, by means of purposely developed software weighting applications (SWA), designed to calculate the exposure indexes needed to evaluate compliance with ICNIRP reference levels and to provide inputs for the numerical dosimetry procedure. The weighting algorithms have been implemented according to the weighted peak approach introduced by the ICNIRP-2003 Statement for complex waveforms [1].

Some measurements were also taken in the STD (Shaped Time Domain) mode, in which the three MFD waveforms are internally processed by the ELT-400 with analog filters in the time domain, in order to apply the ICNIRP-2003 [1] weighted peak approach directly in hardware. These STD measurements, together with the display indications, were principally used to validate our SWA.

Results of exploratory measurements on a 1.5 T MR whole-body scanner indicate the possibility of exceeding the ICNIRP MFD reference levels even more than 210% in a measurement point very close to the bore during scanning with EPI BW MIN sequence.

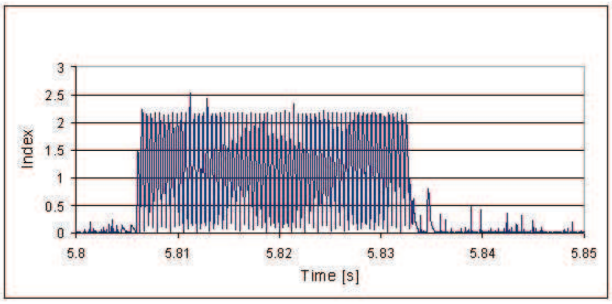

Fig.3: ICNIRP-2003 "weighted peak" Index

III. Radiofrequency Fields

In order to measure the RF fields, the SRM3000 spectrum analyser (Narda Safety Test Solutions, Pfullingen, Germany) was used. A biconical probe (100 kHz – 300 MHz) was employed for the electric field measurement, and a coil probe (100 kHz – 300 MHz) for the magnetic field. The position of the probes of SRM3000 was chosen according to the common practice of the operator during scanning. Due to the pulsed nature of the signal to analyse, the read out of the meter was set in Max Hold mode, and the duration of acquisition was long enough (about 2 minutes) to properly catch the maximum.

During measurements a phantom (with saline solution) was placed in the couch. Preliminary results in a 1.5 T machine for EPI BW MIN sequence indicated level of exposure well below international guidelines on occupational exposure.

IV. Numerical Dosimetry

Numerical methods will be used to evaluate dosimetric quantities induced in the body of the exposed subject. The numerical dosimetry procedure will make use of a modified version of the well-known “scalar potential finite difference” (SPFD) method, an approach widely used to solve quasi-static dosimetry problems, adapted here to cope with non sinusoidal waveforms.

References

[1] ICNIRP 2003. Guidance on determining compliance of exposure to pulsed and complex non-sinusoidal waveforms below 100kHz with ICNIRP guidelines. Health Physics, 84 (3): 383-7.