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Technological developments in protection from non-ionizing radiation: instrumental procedures and software to support operators

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Abstract

This study aims to address the limitations identified in the risk assessment procedure, associated with exposure to various sources of electromagnetic fields. The authors promote the utilization of an online procedure designed to enhance the evaluation of occupational exposure. These quantities include, e.g., clearance distances and weighted peak indices, particularly for non-sinusoidal signals. The study also presents a detailed case study focusing on magnetic resonance imaging (MRI).

1. Introduction

The assessment of the risk in the work environment due to exposure to electromagnetic fields (EMF) has emerged as a topic to be investigated, mainly after the publication of the European Directive 2013/35/EU [1]. Although several years have passed since publication, to date, risk assessment still presents several difficulties mainly associated with the lack of cutting-edge measurement instruments. This study aims to provide an efficient calculation tool to improve the method of the risk assessment.

A collaboration aimed at improving methods related to the assessment of exposure to electromagnetic fields, in order to improve health and safety in the workplace, has been active for several years. This collaboration involves several institutions, such as the Institute of Applied Physics "Nello Carrara" of the National Research Council - CNR-IFAC, the Physical Agents Sector of Tuscany Regional Health Laboratory, the Italian National Institute of Health - ISS, the Scientific Hospitalization and Care Institute - IRCCS of the Policlinico San Matteo, engaged in a series of collaborative projects funded by the Italian National Institute for Insurance against Accidents at Work - INAIL (Department of Occupational and Environmental Medicine, Epidemiology and Hygiene).

Thanks to these collaborations, it has been possible to develop methods and instrumental measurement chains for assessing the exposure of workers in the workplace to electromagnetic fields, as well as computer tools for processing measurement results [2]. The latter is precisely the focus of this contribution, given their importance in supporting prevention practitioners during the complex process of EMF exposure risk assessment. The usability of these tools is made even easier, thanks to the creation of an entirely free website (i.e., https://webnir.eu) [3] where they are contained in specific sections. In this paper, the authors aim to give an overview of the potential of these web tools and secondly focus on a specific application, which is the RMI occupational exposure. The choice to show this case study is related to the huge importance of this application in the medical practice, jointly with the difficulty in the evaluation of the EM necessary quantities needed.

2. WebNIR

WebNIR (https://webnir.eu) [3, 4] is an open-access web platform developed by CNR-IFAC used for the assessment of the risk derived from exposure to electromagnetic fields. A specific EMF section gives access to web tools for exposure assessment, which can be selected either by searching for them by type, or by going through a structured list of occupational sources of electromagnetic fields, for each of which the applicable tools are indicated. Web tools are currently available in the form of fully operational prototypes that allows to:

• have standardized intervention procedures for some classes of occupational sources of EMF;

• analyze the sector regulations, view the trend of the relevant limit values as a function of frequency and calculate the exact value at a specified frequency;

• graph and compare two or more regulatory limits as functions of the frequency;

• determine the required distance from an EMF source by interpolating the data measured along a straight line, at progressively increasing distances also accounting for measurement uncertainties;
• develop a sequence of perceived magnetic field measurements in the case of movement of a subject in a magnetostatic field and determine the relevant radiation protection indices;
• analyze an appropriately sampled low or intermediate frequency waveform in the time domain and calculate the weighted peak indices relating to the applicable regulations.
All these tools have a user interface created through a web page, while the computational load is divided between the computer used by the user and the server platform that distributes the applications.

3. Regulatory limits

Key elements of a correct evaluation of electromagnetic fields are the minimum safety and health provisions relating to the exposure of workers to the risks deriving from exposure to electromagnetic fields made by Directive 2013/35/EU of 26 June 2013. The directive contains several key pieces of information that indicate the provisions that must be complied with to reduce the risk of worker exposure. Furthermore, it identifies in Annex 1 the physical quantities to be considered and in Annexes 2 and 3 the Exposure Limit Values (ELV) and the Action Levels (VA) in the frequency range 0 Hz ÷ 10 MHz and 100 kHz ÷ 300 GHz.
Furthermore, in the case of non-sinusoidal signals evaluation, it requires that the evaluation of workers' exposure, in the frequency range 1 Hz ÷ 10 MHz (Table 1), be carried out by applying the Weighted Peak (WP) method. Considering that the Action Levels (VA) vary with frequency, this method allows to define an index, I_{WP}, that accounts for the exposure due to all the relevant spectral components. According to the WP method, the frequency content of an impulsive signal is processed by weighing the amplitudes of the spectral components in relation to the relevant limits at the corresponding frequencies, also considering the phases of the components themselves. The maximum absolute value of the waveform thus weighted constitutes the sought index (I_{WP}), whose value must be less than 1 (or 100% depending on the normalization criterion chosen) to guarantee compliance with the exposure condition.

Table 1 - European Directive 2013/35/EU - Action Levels for exposure to magnetic fields from 1 Hz to 10 MHz.

Fraquacy range	Magnetic Flux Density Low AL_S (µT) (RMS)	Magnetic Flux Density High AL_S (µT) (RMS)	Magnetic Flux Density AL_S for Exposure of Limbs to a Localised Magnetic Field (µT) (RMS)
$1 < f < 8$Hz	$2.0 \times 10^5 / f^2$	$3.0 \times 10^5 / f$	$9.0 \times 10^5 / f$
$8 \leq f < 25$ Hz	$2.5 \times 10^4 / f$	$3.0 \times 10^5 / f$	$9.0 \times 10^5 / f$
$25 \leq f < 300$ Hz	1.0×10^3	$3.0 \times 10^5 / f$	$9.0 \times 10^5 / f$
300 Hz $\leq f <$ 3kHz	$3.0 \times 10^5 / f$	$3.0 \times 10^5 / f$	$9.0 \times 10^5 / f$
3 kHz $\leq f \leq$ 10MHz	1.0×10^2	1.0×10^2	3.0×10^2

4. A specific study

A gradients magnetic field (GMF) measurements campaign generated by magnetic resonance imaging (MRI) tomographs, has been carried on [5]. This exposure condition is typical of both healthcare staff and any persons accompanying patients who remain inside the magnet room while performing a diagnostic investigation. The study was conducted on three MRI tomographs with a static magnetic induction field up to 1.5 T installed in two hospitals of Lombardy. The study aims to characterize electromagnetic emissions within the magnet room and the definition of a measurement method suitable for assessing the exposure level of healthcare personnel and any persons accompanying patients. The performed measurements concerned the determination of the weighted peak index for magnetic induction, due to the diagnostic GMF, relating to the action levels for the workers and the reference levels for the general population, in force in the European Union.

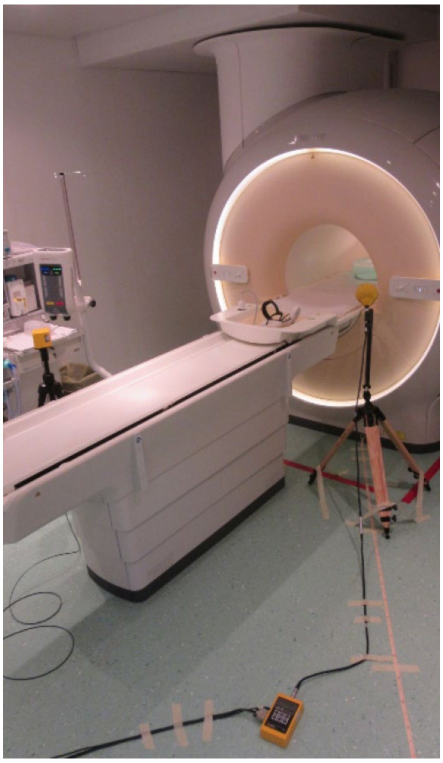

Figure 1. Instrumental setup.

5. Instrumentation chain

The chosen instrumentation chain to perform measurements consisted of a Narda ELT-400 Exposure Level Tester with a 100 cm^2 triaxial sensor, an Agilent U2531A data acquisition device connected to the analogue output of the probe, a portable personal computer connected via USB interface to the acquisition device and finally a software application created in Labview 2009 for system management and the storage of the acquired data.

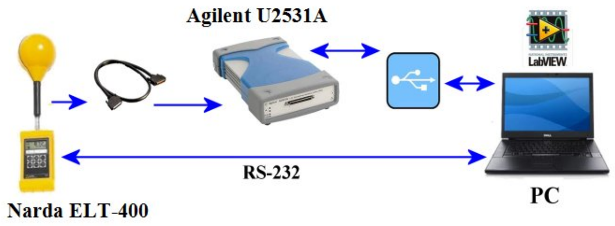

Figure 2. Instrumental chain for measuring fields in MRI.

This allows to acquire and process offline the raw data acquired from the measurement chain, determining the weighted peak index relating to any other regulatory limit. For this purpose, a specific processing software was implemented and made available on the WebNIR platform. This software makes it possible to elaborate the GMF measurements acquired with the presented instrumentation chain and to determine the clearance from the source through the interpolation of the data measured along a straight line at progressively increasing distances.

6. Results

The results of the measurements performed around the open magnet of the 1 T tomograph show that even in a point close to the mouth of the gantry, the RLs for the population and the ALs for workers regarding magnetic induction are always respected.
For the two 1.5 T cylindrical closed magnet devices, we highlight the need to keep a minimum distance of about 100 cm from the entrance mouth of the gantry to ensure respect of the general public RLs.
For staff, magnetic induction exposure levels were always compliant with the applicable ALs. There are no significant differences between the weighted peak indices referring to the High ALs and the Low ALs, demonstrating that the spectral content of the GMF signals is mostly above a frequency of 300 Hz.

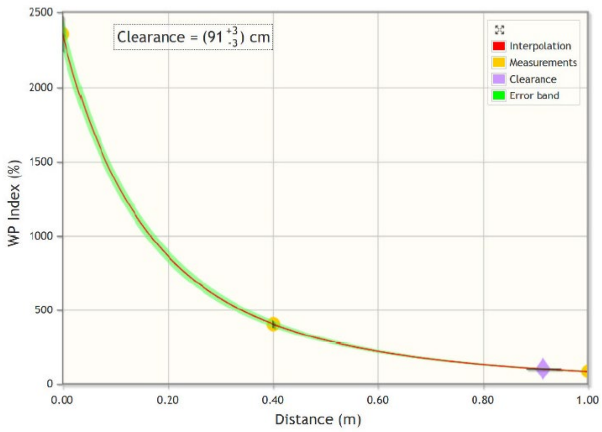

Figure 3 - Interpolation of I_{WP} at different distances and 100 cm from the ground.

The interpolation result, shown in Figure 3, also accounts for measurements uncertainties that are converted in the correspondent uncertainties in terms of distances.

7. Conclusions

The method adopted for the measurements proved to be adequate to the needs of the evaluations to be carried out. With this method, consisting of the instruments mentioned in section 5 and the WebNIR platform, it should be possible to carry out in a simple way a sufficiently accurate assessment of the level of exposure to GMF within the magnet room of any MR equipment, even with a static magnetic induction value higher than 1.5 T.
The assessments performed provided clear indications in relation to the level of exposure to GMF of medical personnel (doctors, radiology technicians, anesthetists, and nurses) assigned to MRI tomographs up to 1.5 T. A reassuring scenario emerges under normal operating conditions, even when it is essential to remain inside the magnet room during acquisitions. A modest lateral movement of a few tens of centimeters from the entrance of the gantry is sufficient to ensure compliance with the occupational limits for magnetic induction, even during the fastest diagnostic sequences.
In conclusion, the method used showed that the exposure levels to GMF are substantially safe for professionally exposed workers who do not carry specific risks. For workers particularly sensitive to the specific risk, (with the exception of workers with active implantable medical devices), as well as for members of the public, it is however advisable to maintain a distance from the magnet of about one meter to prevent adverse health effects.

The presented web application can be used interactively for the determination of the weighted peak index in the time domain and in the frequency domain, for a wide category of magnetic induction sources. Furthermore, it will be adaptable to the widest possible typology of measurement instruments and sampled waveforms.
The intention is to provide a simple operational tool that makes it possible, even in the absence of specialist knowledge, to carry out reliable exposure assessments with sufficient accuracy, giving priority to the most widespread sources of exposure and of protectionist interest.

8. Acknowledgements

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