

## Evaluation of the Exposure to Magnetic Field Generated by Welding Equipment with Reference to Induced Current Density

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Acute effects due to electromagnetic (EM) fields are largely documented and studied. In order to protect people from electromagnetic emissions, ICNIRP (International Committee Non Ionizing Radiation Protection) [1] has suggested some limits for workers and the general public in order to avoid acute effects that are consequences of the field exposure.

Numerical simulation using simplified homogeneous or heterogeneous models can be used in order to estimate induced current density in a conductive medium, and so it can help in the verification of the compliance of basic restrictions in term of induced currents instead of magnetic flux density [2].

Flux 3D [3] is a powerful tool to evaluate the induced current in biological tissues due to a magnetic field produced by electrical welding equipment [4]. The comparison between data obtained by a very simplified model (a cylinder) and the ones arising from a more human model, obtained from real Computer Tomography (CT) data and imported in Flux 3D, has been proposed. The human body tissues have been described with the value of their resistivity,  $\rho$ , that vary between 1 and 50  $\Omega\text{m}$  [5]. In the cylindrical model the resistivity is a weight average value that considers the real tissues inhomogeneity and has been fixed to 5  $\Omega\text{m}$  [4].

The magnetic field source is a wire positioned as prescribed by standards. Amplitude and frequency of current source is derived from the Fast Fourier Transform (FFT) of the current waveform as measured on the welding machine. In general a simulation for each current-frequency couple has been performed in order to evaluate the limits compliance.

The computation of the magnetic flux density and the induced current density is obtained by means of a time-harmonic eddy current solution for each frequency of the system.

The simulated geometry is sketched in figure 1. In this case the Flux3D MD3AV formulation has been used to compute the induced current density,  $\vec{j}$  in the conductive region. The magnetic field,  $\vec{H}_s$ , in a free space region produced by a wire that carries an electrical current is modeled using analytical Biot-Savart formula and so it has been modeled by means of Flux 3D non meshed coils. The use of non meshed coils sources has the advantage that they can be displaced without changing the mesh. The use of the non-meshed coils is very convenient to compute the minimum distance that provides the satisfaction of exposure limits. In this case the source of magnetic field has an analytical formulation, the evaluation of the magnetic field in the vacuum volume, that contains the source ( $\Omega_{EXT}$ ), is solved by a reduced scalar potential formulation (MD3RED). To properly couple the scalar and vector formulations, the region  $\Omega_{COND}$ , where the EM problem is solved in terms of  $\vec{A}$  and  $\vec{V}$  potentials, is surrounded by a region where the EM problem is solved in terms of vector potential  $\vec{A}$  (MD3VEC formulation). At the boundary between  $\Omega_{INT}$  and  $\Omega_{EXT}$  proper interface conditions have been automatically posed by Flux 3D. At the boundary of the simulation domain,  $\Omega_{INF}$  infinite boundary conditions have been posed in order to let the magnetic field vanish at infinite distance by means of the Infinite Box.

Flux 3D has been used in order to evaluate the current density induced by a magnetic field produced by a resistance

welding equipment in the human body model. The source has been posed in two different configurations, "GA" and "GB", for the complete human model, for the simplified cylinder only "GA" configuration has been considered as shown in figure 1.

For each tissue the maximum values of the magnetic flux density and the induced current density have been derived from simulation results, using a Python script that cycles on all volumes of the geometry. The program extracts the maps of the magnetic flux density and induced current density from each volume of the geometry. The Flux 3D procedure can be resumed with following main steps:

1. Evaluation of the welding current and determination of the amplitude and frequency of sinusoidal components,
2. Construction of a simplified geometry (cylinder) or the human body geometry,
3. Physical definition (in the human body model the tissues resistivity must be varied with the frequency),
4. Generation of a set of scenarios, one for each couple current amplitude and frequency,
5. Simulation of the models,
6. Use of Python scripts for the results extraction.

In Table 1 the sum of the ratio between the computed value at a specific frequency and its corresponding limit,

Tissue	GA		GB		
	$\rho[\Omega\text{m}]$	$\alpha(B)$	$\alpha(J)$	$\alpha(B)$	$\alpha(J)$
Liver	27.26	0.78	0.03	0.26	0.02
Brain	18.77	0.07	0.01	1.17	0.08
Bone	49.85	2.68	0.05	33.38	0.18
Kidney	11.21	2.2	0.1	0.24	0.03
Spleen	11.67	3.37	0.2	0.33	0.04
Intestine	1.92	5.3	1.22	0.2	0.09
Muscle	4.29	7.29	0.73	27.75	1.8
Cylinder	5	49,3	1,97	47,4	1,5

Table 1: tissue resistivity value, ratio of equation (1) for the magnetic flux density and induced current density in human body tissues and in the homogeneous cylindrical model.

ratio  $\alpha$ , is reported for some human organs for both geometries GA and GB. The ratio  $\alpha$  has been computed for magnetic flux density,  $\alpha(B)$ , and for the induced current density,  $\alpha(J)$ , values. In this case, the evaluation of the exposure on the basis of the magnetic flux density can be worst with respect to the one evaluated from the induced current density.

(continued on page 3)

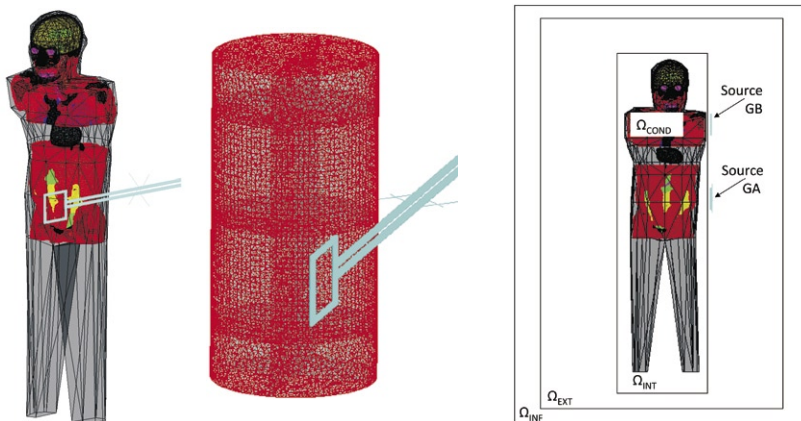


Figure 1: Human model geometry simulated in FEM SW tool. GA and GB are the sources of the magnetic field that have the same geometry of the source than in the cylindrical model.

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Figure 2 reports the colour map of induced current density in the human body tissues for the geometry GA. Obtained results with human body model and geometry GA have been compared with the ones of the cylindrical model (last bottom row in Table 1). It is pointed out that the cylindrical model is proposed by Standards [4] for the evaluation of the exposure to the magnetic field generated by welding equipments. Data in Table 1 show that the more accurate model might show a worst exposure in term of induced current density than the one of the cylindrical model. This fact is reasonable because the resistivity of some tissues is lower than the one used in the cylinder. The homogeneous models might give lower induced current densities than heterogeneous ones. The more complex model gives more accurate information than the simplified homogeneous one. A lower induced current density in some tissues with respect to the one computed in the simplified model is due to their relative position from the source, their real dimension and their own resistivity.

In this work a procedure for the evaluation of the exposure to magnetic field generated by welding equipments has been implemented. Python script for a partial automation of the computation has been also implemented in order to reduce Flux 3D model generation. New feature, like "scenario" has been used in order to reduce the number of models used. In fact in each scenario the frequency can be changed without generate another physical model. This investigation shows that Flux 3D is a powerful tool really suitable for the evaluation of the human exposure to magnetic field.

### Acknowledges

Work supported by means of a research contract with Telwin S.p.A.

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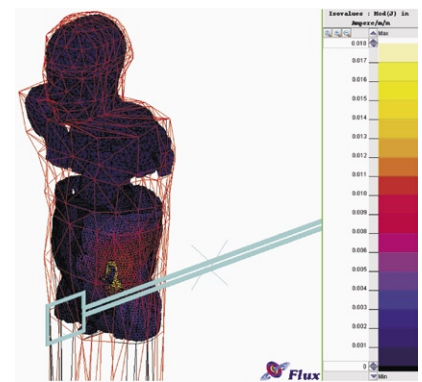


Figure 2: Induced current density in human body model.}

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## The O2M Project: a Mechatronic Design and Modeling Tool

Yann Le Floch - CEDRAT Group.

The automotive business is the most advanced in terms of mechatronic component design. The multiplicity of components is certainly one of the reasons for this pioneering position. However, the wide variety of professions and sectors involved is a highly demanding factor which is approaching its limits. In order to make units and control systems perform better, it is important to work globally on all components of a system and create a multi-profession modeling continuum, including the ability to use a single digital 3D model.

This is the purpose of the O2M program, produced by the MOV'EO competitiveness cluster initiative led by VALEO with support from Dassault Systèmes, but also involving major groups and SMEs like CEDRAT.

### The CEM sub-project (leaders: CEDRAT - IRSEEM)

So as to avoid any future dysfunctions, the designers of electronic systems must take EMC phenomena into account along with other major environmental constraints (climatic and mechanical), during the various design phases.

In response to this issue, the SP4-CEM sub-project was set up, involving:

- Industrialists from the automotive, aeronautic and electrical energy sectors: VALEO, RENAULT, ACOME, THALES AIR SYSTEMS, SCHNEIDER ELECTRIC, SCHNEIDER TOSHIBA
- A software publisher: CEDRAT SA
- Research laboratories: AMPERE (UMR CNRS n°5005, école centrale de Lyon), SPEE LAB / SATIE (UMR 8029), IRSEEM (EA 4353), G2ELAB (UMR 5269 INPG-UJF-CNRS)

The first objective of this sub-project is to generate EMC models of electronic power components. The second objective is to carry out simulations of radiated and induced phenomena using previously generated models. This simulation flow will be based in particular on the InCa3D-Portunus pairing for both phenomena. The work carried out has permitted the setting up of the measurement benches required to characterise the EMC of components according to thermal constraints. A development exercise has also been performed to models power components and implement them using VHDL-AMS language under Portunus. Another part of the project concerns the definition of modeling methodology for couplings between passive elements (inductances, capacities, connector technology) and using analytical and digital approaches. The final phase concerns an enhancement of the InCa3D simulation tool with, in particular, the use of dielectric materials coupled with the PEEC method so as to accommodate stray capacities and the development of reduced radiation models.

