Electromagnetic Field Computation in Human Body Exposed to Wireless Inductive Charging System

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***Abstract*—We carry out a pilot study to evaluate the electromagnetic fields in human body exposed to wireless inductive charging system of electric vehicles based on the numerical simulation. A fully parameterized human body model is built and low-frequency inductive coils are used for the wireless charging system. Low-frequency formulations in terms of magnetic vector potential are utilized and solved by the Finite Element Method. The electromagnetic radiation is calculated in terms of the magnetic flux density upon the human body. This study provides a useful guideline for the industry to develop inductive charging systems following the safety standards of radiation protection.**

***Index Terms*—Radiation safety, inductive power transmission, finite element methods, numerical simulation.**

I. Introduction

Exposure to non-ionizing electromagnetic fields (EMFs) is unavoidable in vehicles environment and this exposure is growing mainly because of the new wireless charging system and electronic equipments inducing EMFs [1][2]. However, while EMFs have been an important part of our daily life, the question as to whether or not they can damage our health is a significant one. It is a challenging work to investigate the effects of electromagnetic radiation on human beings in order to gain valuable experience that will help to determine the extent of design freedom and thus support the standardization process to make the vehicle environment safer.

The advent of electric vehicles, due to its zero-emission travel and noiseless power trains, has been a profound technological transformation of automotive industry. The wireless charging by Inductive Power Transfer (IPT) is an attractive technology for electric vehicles. Until now, there are no adequate studies regarding to wireless charging system and its effects on health issues [2]. Thus, the purpose of this research work is to investigate the magnetic field generated by the charging system in the human body and to check if it remains in the predefined limits given by the authorized standards. We will design a simple inhomogeneous adult phantom and take into account inductive coils of the wireless charging system. Then the finite element method (FEM) electromagnetic solver will be utilized to perform the simulation. It is important to note that this electromagnetic simulation study would analyze the influence of the practical wireless charging system on the radiation, and provide the valid data for the further work on the development of IPT systems for electric vehicles.

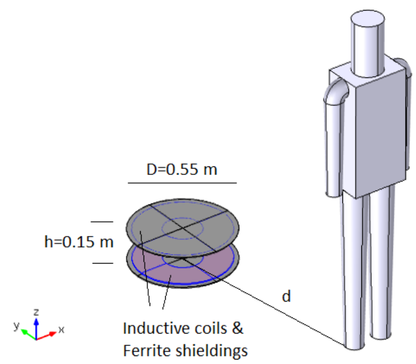

Figure 1: The standing human model and inductive charging system.

Table I: Material parameters of human body model at the operating frequency (50 kHz)

Human model	Relative permittivity	Relative permeability	Conductivity S/m
Head	8323.4	1.0	0.1233
The other parts	8312	1.0	0.2316

II. Models and Methods

A. Human Body Model

In order to obtain accurate results of EM radiation on human body, numerical anthropomorphic models have been developed, e.g., [3], [4]. Since the main purpose of this work is to study the radiation of the wireless charging system on the human body and to provide a guideline for the further study, it is adequate to build a human model while keeping its positioning in a flexible way. We design a simple inhomogeneous adult phantom, based on dimensions of the voxel Virtual Family's Duke phantom [1], as shown in Fig. 1. We select the material properties of the head as those in brain grey matter at the operating frequency, as shown in Table I. The "two-thirds muscle" approximation is used for the properties of the other parts of human model [5].

B. Numerical Methods

The basic formulations for low-frequency simulations are

$$\nabla \times \mathbf{H} = \mathbf{J} \tag{1}$$

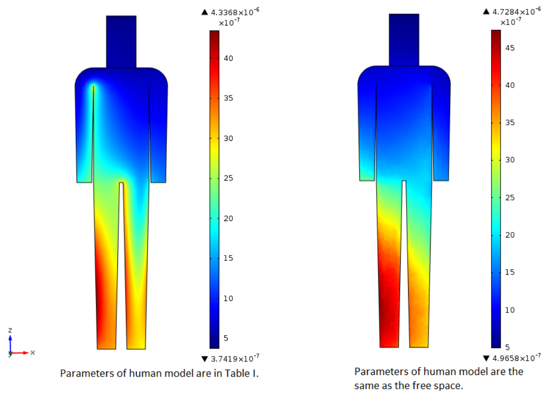

Figure 2: Magnitudes of magnetic flux density **B** inside the human body corresponding to two cases.

$$\mathbf{E} = -\nabla V - j\omega\mathbf{A} \quad (2)$$

$$\mathbf{B} = \nabla \times \mathbf{A} \quad (3)$$

During the preprocessing phase, in order to efficiently perform simulations and adequately capture the characterization of the electromagnetic radiation on the human model, we choose the mesh size ranging from 0.0105 m to 0.245 m based on the geometry of the models. To neglect the influence of the boundary of the simulation domain, the spherical external boundary, with the radius 3.5 m, is set to magnetic and electric insulation conditions. Additionally, due to the irregular surface of the geometry, the flexible tetrahedral mesh is selected for the discretization of the formulations.

According to the practical applications, this wireless charging system of electric vehicles consists of inductive coils and ferrite shieldings, as shown in Fig. 1. The input current density of one inductive coil is chosen as 45.8 $\mathtt{kA/m}^2$ and the operating frequency of this charging system is set to 50 kHz.

Based on the complicated geometry and preprocessing requirements, we select the FEM electromagnetic solver COMSOL as the simulation tool.

III. Numerical Results

It is known that it is better to place the source of EM radiation as far as possible from the bodywork, in order to minimize the risk of radiation damage. But the challenge is to study the relationship between the distance considered and radiation levels, and to provide valid results for defining safety standards.

The first example is to compare the magnetic flux density distribution on a two-dimensional surface inside the human body when the parameters of human model are chosen as Table I and the same as the free space, respectively. The results are shown in Fig. 2; the distance d is set to 0.5 m. The second example is to perform simulations with different distances between the radiation source and human body, in order to observe the changing trend of induced EMFs on human body. Fig. 3 shows the magnitudes of magnetic flux density when d=0.5 and 2.0 m, respectivly. The corresponding maximum values are 5.8 μT and 5.2 μT respectively, which are below

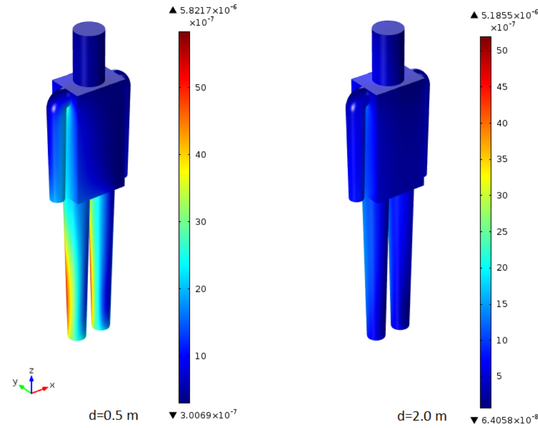

Figure 3: Magnitudes of magnetic flux density on the surface of the human body when d=0.5 and 2.0 m, respectively.

the radiation guidelines (6.25 μT at 50 kHz) defined by International Commission on Non-Ionizing Radiation Protection (ICNIRP) [6]. The magnitude of the magnetic flux density when d=2.0 m is 85% of the value when d=0.5 m.

IV. Conclusions

In this paper, the EM radiation of wireless charging system of electric vehicles on human body has been modeled and evaluated, with the purpose of studying the exact radiation level to help the development of wireless charging system out of hazardous effects. This numerical simulation consists of a standing human model and the inductive charging system. Based on the FEM method, the magnetic flux density is calculated for the human model. This work paves the path to provide useful design guidelines for the practical inductive charging system, to minimize electromagnetic field radiation on human body.

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References

[1] L.-R. Harris, M. Zhadobov, N. Chahat and R. Sauleau, “Electromagnetic dosimetry for adult and child models within a car: multi-exposure scenarios,” *International Journal of Microwave and Wireless Technologies*, vol. 3, no. 6, pp. 707-715, 2011.

[2] P. Concha, J. Lourd, M. Lafoz and J. R. Arribas, “Evaluation of the magnetic field generated by the inverter of an electric vehicle,” *IEEE Trans. Magnetics*, to be published, 2013.

[3] E. Gjonaj, M. Bartsch, M. Clemens, S. Schupp and T. Weiland “High-resolution human anatomy models for advanced electromagnetic field computations”, *IEEE Transactions on Magnetics*, vol. 38, no. 2, pp. 357-360, 2002.

[4] T. Steiner, H. De Gersem, M. Clemens and T. Weiland, “Local grid refinement for low-frequency current computations in 3-D human anatomy models,” *IEEE Trans. Magnetics*, vol. 42, no. 4, pp. 1371-1374, Apr. 2006.

[5] Online at http://niremf.ifac.cnr.it/tissprop/

[6] International Commission on Non-Ionizing Radiation Protection, “Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz),” *Health Phys.*, vol. 74, no. 4, pp. 494-522, 1998.