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Human Electromagnetic Exposure Safety Assessment of EV-WPT System Based on PCE Method

Le Gao [1], Enning Guo [2] and Lei Liu [2]

[1] College of Instrumentation and Electrical Engineering, Jilin University, Changchun Jilin, 130026, China

[2] Changchun Automotive Test Center Co., Ltd., Changchun Jilin, 130011, China

Abstrac

Wireless power transfer (WPT) offers a safe and convenient charging solution for electric vehicles (EVs). However, electromagnetic exposure may pose risks to humans, especially with metallic implants. This paper builds an EV-WPT model and a human anatomical model with tibial implants to analyze induced fields. Using Polynomial Chaos Expansion (PCE), the uncertainties of tissue properties and implant positions are quantified. Results show field concentration near implant edges and provide a probabilistic safety assessment.

Keywords

Wireless Power Transfer; Electric Vehicles; Polynomial Chaos Expansion.

1. Introduction

With the rapid development of the automotive industry, the pollution caused by the exhaust emissions of traditional fuel vehicles to the atmospheric environment has drawn widespread attention worldwide. Various countries have successively formulated policies to reduce carbon emissions. To reduce carbon emissions, the electric vehicle industry has developed rapidly. However, the existing wired charging methods have problems such as inconvenient charging operation and the danger caused by damaged cables, which have aroused widespread concern.

Compared with traditional charging methods, the wireless power transmission system for electric vehicles has many advantages such as high space utilization, high safety, and low wear and tear [1]. Wireless charging can theoretically achieve complete insulation, flexible charging at any time, and reduce dependence on battery capacity; it realizes fully automated and intelligent charging. It solves the problems of low battery charging capacity, long charging time, and time-consuming and laborious insertion charging [2]. The application of wireless charging technology for electric vehicles can achieve charging in static parking spaces and dynamic charging during driving by burying coils under the track. The wireless charging technology for electric vehicles will strongly promote the development of the new energy industry and is conducive to vigorously promoting the intelligent and networking development of the electric vehicle industry.

The working principle of the wireless charging system for electric vehicles is to transfer energy through the spatial electromagnetic field. While power transmission occurs in the resonant coil, there is always a certain amount of radiation of electromagnetic waves in the surrounding space [3]. When exposed to the electromagnetic environment, the induced current in the human body will directly stimulate the human nervous system and tissue cells, causing discomfort reactions. Another effect is the thermal effect, which comes from the electric field force of the electromagnetic field, causing particles in the human body to shift, resulting in frictional heating, conduction heating, and dielectric loss heating, thereby affecting the health of the organism [4, 5, 6]. Hiroshima University conducted research on the safety of electromagnetic fields in the

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human body in the context of percutaneous energy transmission systems, calculating the specific absorption rate (Specific Absorption Rate, SAR) [7]; Nagoya Institute of Technology calculated the induced currents in the human body of different genders exposed to low-frequency electromagnetic fields, proving that the differences between genders were less than 20%, mainly depending on the differences in organs and tissues [8]; The KAIST Institute in South Korea used numerical simulation methods to calculate the electromagnetic exposure of the human body lying near the WPT system, and verified the results against international standard limits [9].

Considering that some human bodies contain metal medical implants, and metals have the ability to alter the distribution of electromagnetic field energy, this further increases the risk of electromagnetic exposure to the human body. Due to the fact that in practical engineering applications, the production and manufacturing of EV-WPT systems and changes in the position of the human body, there is a large amount of uncertainty in the electromagnetic exposure of the human body, bringing more unknown factors to the safety of electromagnetic exposure to the human body. Therefore, conducting research on the safety of electromagnetic exposure to the human body in EV-WPT systems is of great significance.

The chapter arrangement of this paper is as follows. The second section introduces the working principle of WPT, establishes the EV-WPT system model and high-precision human internal organ model, and considers the actual application to establish the model of the tibial intramedullary nail implant; The third section introduces the sparse uncertainty quantification method; The fourth section uses the introduced UQ method to evaluate the safety of electromagnetic exposure to the human body in the electromagnetic environment inside the vehicle, and conducts analysis; The fifth section summarizes the research content of this paper.

2. WPT Principles and Modeling

The core principle of wireless charging technology is to achieve wireless energy transmission through electromagnetic fields, allowing for the transfer of electrical energy without physical contact. The power of the EV-WPT model used in this article is 11 kilowatts. The wireless charging technology for electric vehicles and the human anatomy model were constructed using the commercial finite element simulation software Comsol as shown in Fig.1. The electrical conductivity and dielectric constant of the human body and major tissues are listed in Table 1.

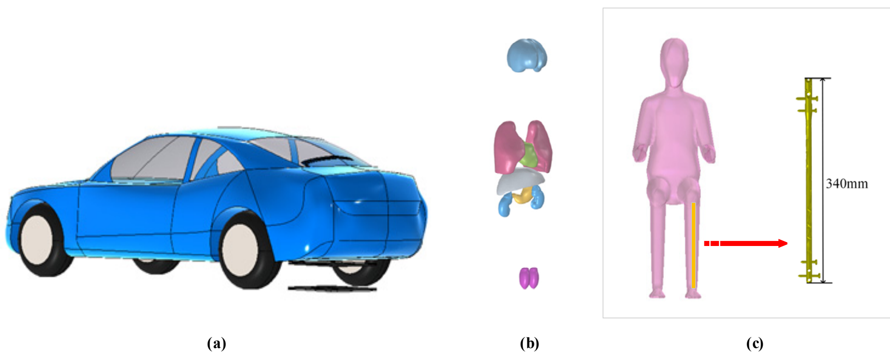

Fig 1. Simulation Model Diagram(a)wireless charging device(b)human organs(c)sitting body and tibial nail implants

Table 1. Electrical conductivity and permittivity of human body and major organ tissues at 85 kHz

organ tissues	electrical conductivity (S/m)	relative permittivity εr
two-thirds muscle	0.24	5664.43
brain	0.13	3628.76
heart	0.21	11137.5
lung	0.11	2888.63
liver	0.08	8131.57
stomach	0.54	2988.34
kidney	0.17	8352.08

3. Polynomial Chaos Expansion

The fundamental idea of the polynomial chaos method is to expand the uncertain output response as a weighted linear combination of orthogonal polynomials of the input random variables, transferring the stochastic features of the response function onto the coefficients of the orthogonal polynomials. For any random variable x, if its probability density function f_x(X) satisfies condition (1), namely that the square of the function is integrable over its domain, then this variable can be expressed as a function of a series of independent standard random variables.

$$\int_{-\infty}^{+\infty} \left| f_x(\mathbf{X}) \right|^2 = R \tag{1}$$

In general, if the output response Y = g(X) is a function of d independent input variables X = (X_1, X_2, ..., X_d), its polynomial chaos expansion can be expressed as:

$$Y = g(X) \approx \sum_{i=0}^{\infty} c_i \psi_{\alpha_i}(X) \tag{2}$$

In the equation, c_i denotes the coefficient of the i-th polynomial in the chaos expansion, $\alpha_i = \{\alpha_{i,1}, \alpha_{i,2}, \cdots \alpha_{i,d}\}$ represents the multi-index set whose components indicate the orders of the univariate polynomials, and $\psi_{\alpha_i}(X)$ is the i-th multivariate polynomial in the chaos basis, which can be computed as the tensor product of the univariate polynomials $\phi_{\alpha_{i,j}}(X_j)$.

$$\psi_{\alpha_i}(X) = \phi_{\alpha_{i,1}}(X_1)\phi_{\alpha_{i,2}}(X_2)\cdots\phi_{\alpha_{i,d}}(X_d), i = 0, \cdots, \infty \tag{3}$$

Wiener's original polynomial chaos method employs Hermite orthogonal polynomials as the basis functions, whose weighting function coincides with the probability density function of a Gaussian distribution. Therefore, when the input variables follow Gaussian distributions, the method exhibits exponential convergence. However, for non-Gaussian inputs, convergence is significantly reduced. To address this, input variables are often transformed into standard Gaussian variables so that Hermite polynomials may still be used as basis functions. To simplify computation, the polynomial expansion in (2) is truncated to a p-th order model:

$$Y \approx \sum_{i=1}^{P} c_i \psi_{\alpha_i}(X) \tag{4}$$

where P denotes the total number of terms in the polynomial chaos basis, ai represents all non-negative integer solutions satisfying condition $0 \le \sum_{j=1}^{d} \alpha_{i,j} \le p$, and there are C_{p+d}^{d} such combinations. Consequently, the total number of terms P is related to the dimension d and the order p as follows. The total number of polynomial basis terms P is determined by the dimensionality d and truncation order p as:

$$P = \frac{(d+p)!}{d!p!} \tag{5}$$

4. Result Analysis

In this section, this paper uses the PCE method to quantitatively assess the safety of electromagnetic exposure for human bodies with intramedullary tibial nail implants. Firstly, using the multi-physics field simulation software, the electromagnetic exposure dose to the human body under a fixed condition is calculated, and the result can be obtained as shown in Fig.2.

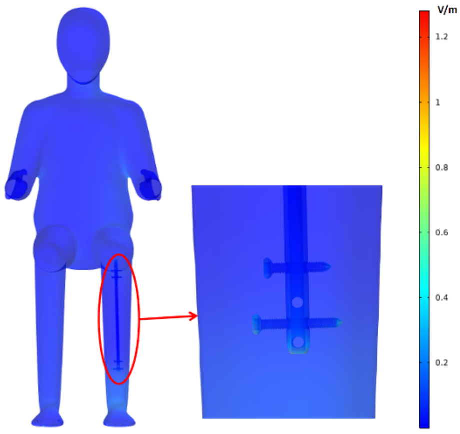

Fig 2. Distribution of electromagnetic exposure dose for a fixed human body position

It can be observed that the maximum value of the induced electric field in the human body is mainly concentrated at the sharp ends of the tibial bone marrow implant. This is because metals have the ability to alter the distribution of electromagnetic energy. Next, considering the actual engineering application scenarios, the parameter settings for quantifying the uncertainty of input variables are shown in Table 2.

Table 2. Variable distribution type and parameters

Variable	Distribution	Parameter/mm
Coil Lateral offset	Uniform	[-100，100]
Coil Vertical offset	Uniform	[-100，100]
Distance between coils	Uniform	[-20，20]
Human lateral displacement	Normal	[-200，200]

Taking the maximum value of the induced electric field in the human body as the output variable, the uncertainty quantification calculation is carried out using the PCE method described in Section 3. The results are shown in Fig.3.

5. Summary

This study evaluates human electromagnetic exposure in EV-WPT systems. Simulation results reveal that metallic tibial implants intensify local fields. To address uncertainties, PCE-based analysis quantifies variability in exposure. The findings highlight implant influence and provide guidance for safety evaluation in practical EV-WPT applications.

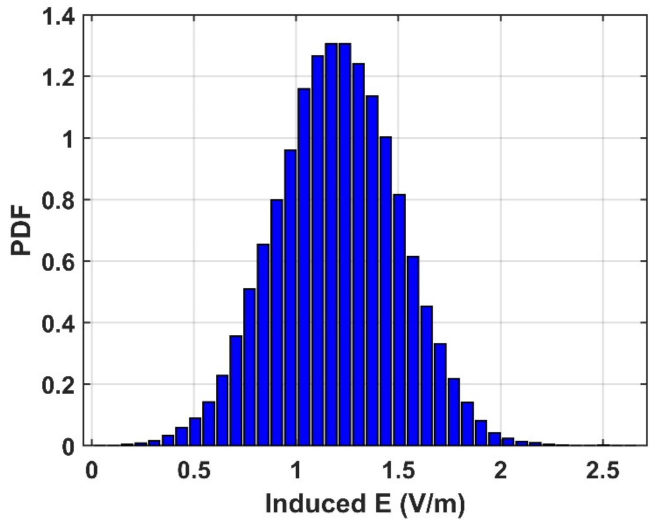

Fig 3. Probability density function of human body induced electric field intensity

Acknowledgments

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