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Dosimetry for Resonance-Based Wireless Power Transfer Charging of Electric Vehicles

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Abstract

This paper presents the dosimetry of a resonance-based wireless power transfer (RBWPT) system for electric vehicles applications. The compact RBWPT system is designed to transfer power at 150-mm distance. The electric and magnetic fields generated by the RBWPT system and the specific absorption rate in the human body model, which stands around the system, are calculated. These analyses are conducted in two cases: the alignment and the misalignment between the transmitter and the receiver. The matching loops are adjusted to maximize the power transfer efficiency of the RBWPT system for the misalignment condition. When the two cases were compared for the best power transfer efficiency, the specific absorption rates (SAR) in the misalignment case were larger than those in the alignment case. The dosimetric results are discussed in relation to the international safety guidelines.

Key Words: Dosimetry, Electric Vehicles, FDTD, Wireless Power Transfer.

I. INTRODUCTION

Recent research has developed a wireless power transfer (WPT) technique to eliminate the charging hazards and drawbacks of cables. An MIT research team proposed the resonance-based wireless power transfer (RBWPT) technique [1]. Unlike the conventional magnetic induction technique, The RBWPT technique improves the power transfer distance. Much related research has studied a design method, efficiency characteristics, and so on [2−4]. However, the WPT technique produces considerable electric and magnetic fields around the WPT system. In particular, electric vehicle (EV) applications show the potential to produce stronger electric and magnetic fields than mobile telecommunications devices and home appliances. Therefore, it is necessary to conduct the dosimetry of the WPT system to determine the safety of humans exposed to electromagnetic fields.

This paper reports the design of the RBWPT system for electric vehicles charging. Numerical dosimetry is conducted for the system in the condition of alignment and misalignment between the transmitter and the receiver. The compliance of the system with international safety guidelines is discussed in relation to the dosimetric results.

II. MODEL AND METHOD

The characteristics of the RBWPT system are computed using a full-wave analysis electromagnetic solver (HFSS) based on the finite element method. The specific absorption rates (SARs) in the anatomical human model are investigated in a scenario in which the human stands near the RBWPT system for EVs, as shown in Fig. 1. The dosimetry is conducted with the anatomically realistic Japanese adult male model TARO [5], which possesses a 2-mm spatial resolution and 51 tissues

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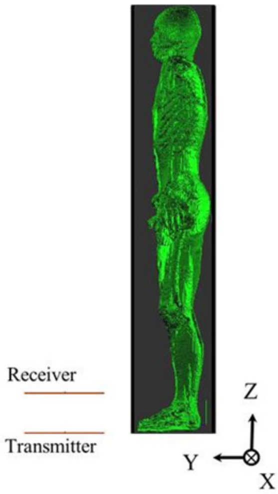


Fig. 1. Side view of an anatomically realistic model of the human body positioned with respect to the resonance-based wireless power transfer system for electric vehicle charging.

and organs, which are based on the accumulated magnetic resonant imaging (MRI) of an adult Japanese volunteer. The permittivity and conductivity of the model are taken from Gabriel's Cole-Cole models [6]. The numerical dosimetry for the RBWPT system is computed using the two-step approach [7]. In the first step, the electric fields in the space occupied by the human model are obtained using the HFSS under the condition when the human model is removed. In the second step, the SARs are computed using the scattered-field, finite-difference time-domain (FDTD) method; the fields obtained in the previous step are regarded as the incident fields. This approach cannot be considered an interaction between the RBWPT system and the human model. However, the approach is applicable to this work only if the effect of the back-scattering from the human body on the source of the WPT system is negligible.

III. Resonance-Based WPT

The RBWPT system designed in this work consists of two loops and two resonant coils, as shown in Fig. 2. The entire system is compactly designed for EV applications. The electromagnetic energies can be efficiently transferred using these resonant coils. The loop located inside the resonant coil plays the role of a matching circuit. The coil radius of the RBWPT system (r_1) is 150 mm, and the power transfer distance (d) is set at 150 mm. Copper wire with a radius of 2.3 mm is used for the system. The coils have five turns and a pitch of 4 mm. The radius of loop (r_2) is adjusted by 110 mm to reduce two resonant modes [8] to only one resonant mode. The capacitance of 3.2 pF is added to the coil to achieve resonance at 13.56 MHz frequency. The power transfer efficiency ($|s_{21}|^2$)

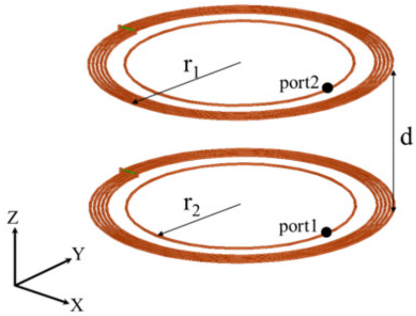


Fig. 2. Configuration of a compact resonance-based wireless power transfer system. The transmitter and receiver are aligned, and the system is matched for only one resonant mode (case 1).

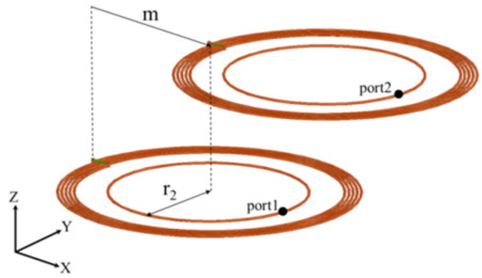
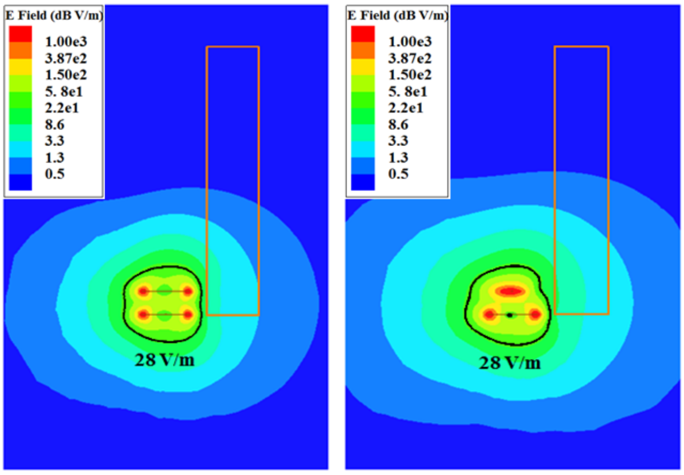


Fig. 3. Configuration of a misaligned resonance-based wireless power transfer system. The matching loop is adjusted to obtain the best power transfer efficiency (case 2).

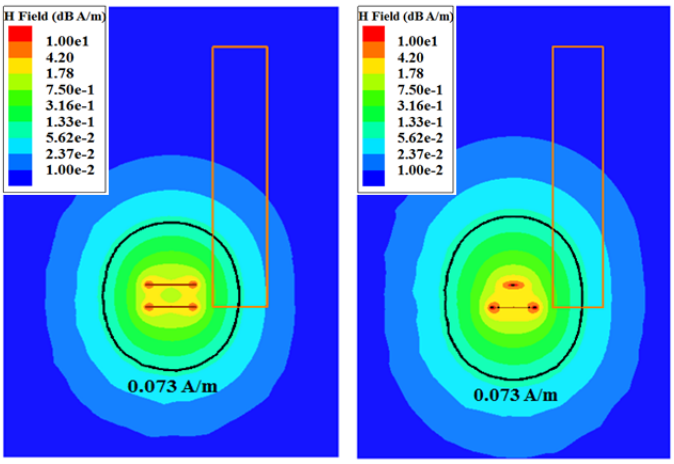
is 99% in this case (case 1). When a car is parked for RBWPT charging, it is often the situation that the transmitter and the receiver are misaligned, as shown in Fig. 3. Thus, the misalignment case (case 2) is also investigated in this work. The power transfer efficiency in case 2 decreases by 59% without matching. Generally, the system will be tuned for the best power transfer efficiency. The dosimetry should be conducted when the WPT system transfers the maximum power. Thus, the radius of the loop is set at 97 mm for the best power transfer efficiency in case 2. The power transfer efficiency of this misalignment case is 99%.

Figs. 4 and 5 show the electric and magnetic field distributions around the RBWPT in case 1 and case 2 with matched conditions, respectively, when the input power is 1 W. The both ends of the system are terminated by 50 Ω. In the misaligned case 2, the power transfer distance becomes longer than in the aligned case 1. However, in order to increase the decreased power transfer efficiency, the system is matched by adjusting the loop size. Hence, the electric and magnetic fields in case 2 are distributed more broadly and strongly than in case 1. Therefore, the electric and magnetic fields in case 2 distribute more strongly in a large area than those in case 1 are. In Figs. 4 and 5, the black solid line indicates the reference level recommended by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [9]. The rectangle



(a) (b)

Fig. 4. The xz-plane distributions of the electric field strength around the RBWPT system in the alignment condition (a) and in the misalignment condition (b). The black solid lines represent the reference level. The rectangular area is the space occupied by the human model.



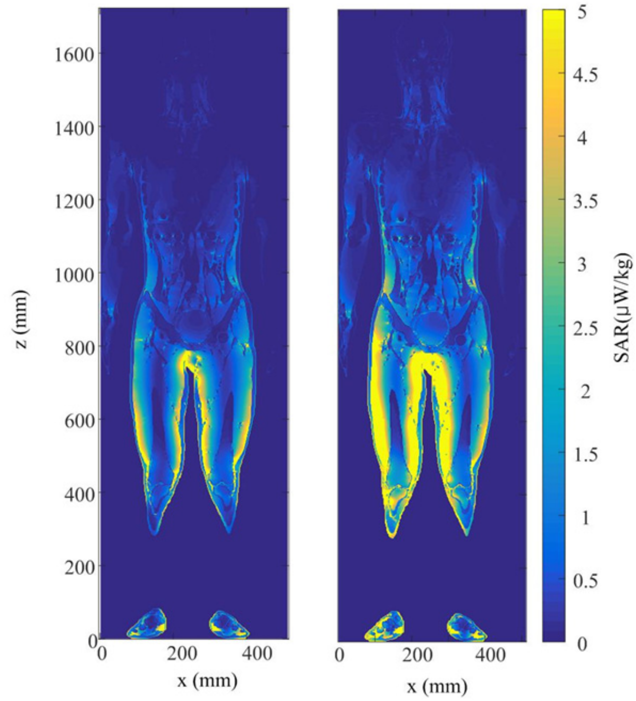
(a) (b)

Fig. 5. The results of the magnetic field distributions in the alignment condition (a) and in the misalignment condition (b). The black solid lines represent the reference level. The rectangular area is the space occupied by the human model.

on the field distributions represents the space occupied by TARO. Fig. 5 shows that the magnetic field strength does not comply with the reference level of ICNIRP even at 1 W of input power in this calculation.

IV. Dosimetric Results

In the calculation scenario, the TARO model stood away from the RBWPT system by a distance of 100 mm. Fig. 6 shows the SAR distribution in the x-y plane in cases 1 and 2. As Fig. 6 shows, the SARs in the human body model are strongly apparent in the lower half of the body because the RBWPT system is located near the feet.



(a) (b)

Fig. 6. Specific absorption rate (SAR) distribution in the alignment condition (a) and the misalignment condition (b).

Table 1. SAR results in the human body model exposed to the RBWPT system with 1 W input power in case 1 and case 2

	Case 1	Case 2
10 g SAR (μW/kg)	29.63	58.77
Tissue name	Muscle	Muscle
WB SAR (μW/kg)	1.07	2.03

SAR=specific absorption rate, RBWPT=resonance-based wireless power transfer, 10 g SAR=the localized SAR average of any 10 g cubical volume of tissue, WB SAR=the whole-body average SAR.

The localized SAR and the whole-body SAR results for 1 W input power are listed in Table 1. In the two cases, localized SARs were found in the muscle tissue. The SAR results for case 2 were higher than those for case 1. We are predictable this result from the field distributions of the two cases, as described in Section III.

According to the basic restrictions of the ICNIRP, localized SARs are 2 W/kg for head and trunk, 4 W/kg for limbs, and the whole-body SAR is 0.08 W/kg [9]. Fig. 7 shows that the maximum allowable powers (MAPs) in both case 1 and case 2 satisfied the basic restrictions. The results showed that MAP of the whole-body SAR was lower than that for the localized SAR. This finding indicates the possibility that the whole-body SAR does not comply with the guidelines whereas the localized SAR comply with the guidelines.

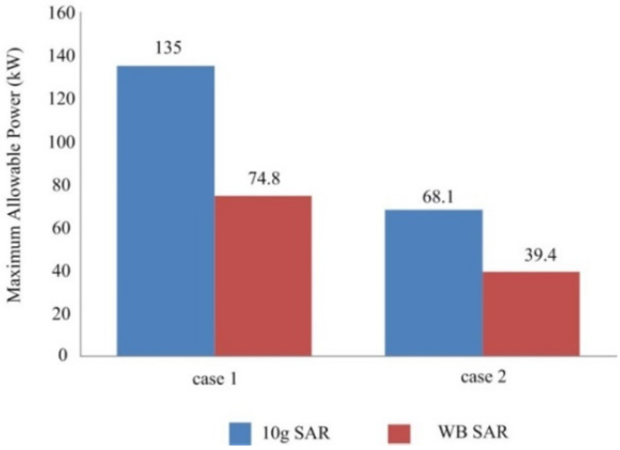


Fig. 7. Maximum allowable power satisfying the basic restriction. SAR=specific absorption rate, 10 g SAR=the localized SAR average of any 10 g cubical volume of tissue, WB SAR=the whole-body average SAR.

V. CONCLUSION

Dosimetry was conducted for the RBWPT charging system of EV in the conditions of alignment and misalignment between transmitter and receiver. The SARs in misalignment condition were higher than those in alignment condition were. The dosimetric results of RBWPT system indicated that both the whole-body SAR and the localized SAR should be considered.

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