Evaluation of Human Exposure to EMF in the Wireless Charging Environment for Electric Vehicles

- Evaluation of the human exposure to EMF according to coil topology and human model position -

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ABSTRACT: This paper presents the effects of EMF generated during electric vehicle (EV) wireless charging on the human body model through simulation. According to SAE J2954 standard, circular and bipolar coils were selected and the human exposure was evaluated under the worst EMF condition. In addition, the effect of EMF according to the posture and position of the human body model was evaluated, and as a result of the evaluation, it was confirmed that the effect of the position rather than the posture was dominant. Also, as a result of the simulation, the bipolar coil exceeded the human exposure limit of EMF by up to 135%, so the bipolar coil requires stricter design conditions compared to the circular coil.

KEY WORDS: Electric vehicle, Wireless power transfer, EMF, Human exposure, ICNIRP guideline

1. INTRODUCTION

Recently, due to environmental problems, electric vehicles (EVs) are in the spotlight as future mobility. With the commercialization and increasing demand for EVs, problems related to electric vehicle charging are also receiving a lot of attention. In the case of currently commercialized wired charging, it is accompanied by several safety and convenience problems, such as the inconvenience of having to directly charge by a person, and increased risk in case of rain. Therefore, many studies are underway to charge EVs wirelessly by applying wireless power transfer (WPT) technology. [(1)]

In the wireless charging, the principle of transmitting power wirelessly is by magnetic field using Faraday's law of induction. In this process, there is a problem that an unwanted leakage magnetic field is generated due to the separation distance between the transmitter and receiver. Therefore, it is essential to evaluate the effects of EMF on the human body in the wireless charging environment of electric vehicles.

In the case of human exposure evaluation, it can be evaluated based on the basic restriction or reference level according to the ICNIRP (International Commission on Non-Ionizing Radiation Protection) guidelines. [(2-3)] In this paper, the basic restriction criteria induced inside the human body are evaluated using a human body model. That is, since the effect of field exposure on the human body cannot be directly measured, analysis-based evaluation using a human body model is possible.

In the case of conventional research, circular coil and bipolar coil were studied for the 11kW class EV WPT system, which is the current standard maximum power, but the human exposure evaluation was conducted without applying the shielding structure such as ferrite or aluminum according to the SAE J2954 standard. [(4)] In addition, the evaluation was not conducted in the worst EMF condition such as the lower part of the side of the vehicle where the human body can be located. [(5-6)] So, additional evaluation is needed in an environment such as an extreme but possible lying posture. [(6)] In addition, since the system can be located in the front, center, or rear of the vehicle, it is necessary to evaluate when only the vehicle mimic steel plate exists without the vehicle body.

Therefore, in this paper, the evaluation was conducted based on the basic restriction of the ICNIRP guidelines according to the position and posture of the human body model and the coil topology. This paper has the following structure. Section 2. provides information on simulation setup and methods. Section 3. analyzes human exposure to EMF through simulation results. Finally, Section 4. summarizes the main conclusions of this study.

2. EXPOSURE SCENARIOS

2.1. Setup of EV WPT Model

The EV wireless charging 3D model selected for simulation analysis is the SAE J2954 standard coil setup. Based on SAE J2954 document, 3D modeling of coil setup of 11.1kVA class (WPT3 class), the highest power currently provided, was performed. In the case of ground clearance, Z2 class (170-210mm) corresponding to the general range was selected, and in order to evaluate the worst EMF situation, the evaluation was carried out in the 210mm situation. This is because, when the same power is transmitted, if the gap is large, the coupling between the ground assembly (GA) coil and vehicle assembly (VA) coil is reduced, resulting in a larger leakage magnetic field. In addition, for the same reason, in order to analyze human exposure in the worst EMF situation, the evaluation was conducted under the maximum misalignment condition in which the leakage magnetic field was maximized. For the maximum misalignment condition, the x-axis 75mm offset and y-axis 100mm offset conditions specified in SAE J2954 were applied. Also, the simulation was conducted under the condition that the maximum current of (GA) coil specified in Table 1 of the current flowing through the coil flows.

And the case according to the coil topology was analyzed in the same WPT3/Z2 class setup. SAE J2954 document provides coil specifications for circular coil and bipolar coil according to the coil shape. Therefore, EMF human exposure analysis was conducted for the two coil shapes. In summary, when ground clearance of 210mm, maximum misalignment, and maximum current conditions were applied under WPT3/Z2 class, EMF human exposure was analyzed in circular coil and bipolar coil environments. Figure 1 and 2 below shows the coil setup.

In Figure 2, in addition to GA and VA coils, structures such as shielding aluminum and vehicle mimic steel plate are applied to the test stand. Therefore, in this study, the evaluation is conducted using the vehicle mimic steel plate, not the actual vehicle model.

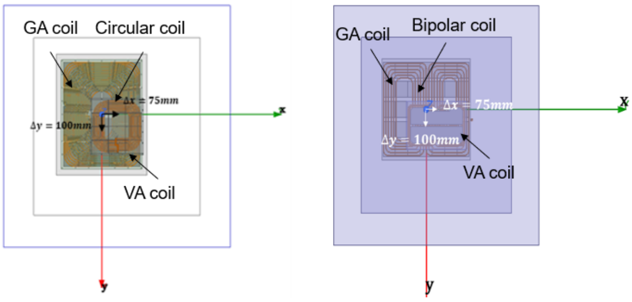

Fig. 1 Setup of circular coil and bipolar coil (top view)

Table 1. GA coil maximum current

	Circular coil	Bipolar coil
GA coil Maximum current [Arms]	75	47

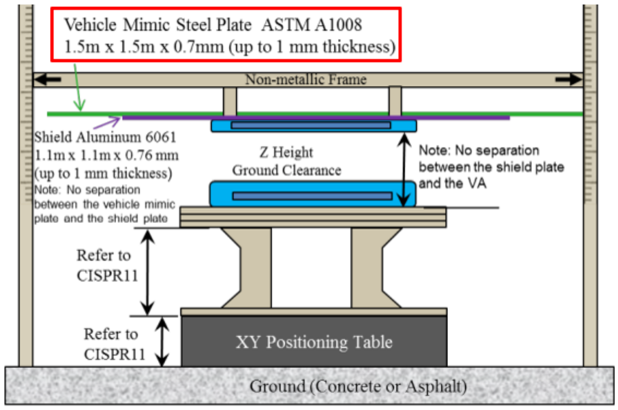

Fig. 2 SAE J2954 test stand (side view) (4)

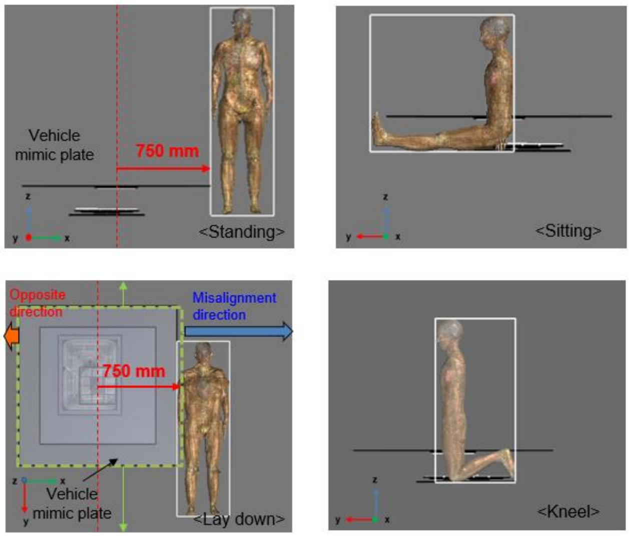

Fig. 3 Postures of human body model

2.2. Posture and Position of human body model

There are four main postures of the human body model selected for simulation. All phantom box of postures is positioned 1mm away from the vehicle mimic plate. A description of the four postures is shown in Figure 3. After evaluating the postures of the human body model in the + and - directions based on the x-axis, the posture with the greatest influence was selected and the human exposure simulation was performed by distance from the vehicle mimic steel plate.

3. SIMULATION RESULTS

3.1. Simulation Setup

In the case of the EV wireless charging system, the operating frequency of the system is about 79 kHz to 91 kHz, and the wavelength is very long compared to the size of the WPT system. Therefore, the analysis proceeds by applying the quasi-static (QS) approach. To apply the QS approach, the FEM-based LF solver from Sim4Life (Zurich MedTech, Switzerland) was used. In the case of the 85kHz operating frequency used in this paper, the magnetic field is not deformed by the current induced in the tissues inside the human body. Therefore, the method of analyzing the physical quantity induced inside the human body by applying the human body model after the magnetic field analysis in the case where there is no human body model was used.

For the human body model, Ella, an MRI-based voxel model provided by the sim4life tool, was used. This was selected because the Ella model is an adult female model with a physique intermediate that of an adult male and a child.

3.2. Simulation Results according to Posture of Human body Model

EMF human exposure was evaluated according to the exposure scenario presented in Chapter 2. Table 2 shows the ICNIRP guidelines for human exposure and internal physical quantities. For evaluation, the 99th percentile was applied to the electric field and current density to eliminate computational errors as recommended by ICNIRP. As a result of evaluation of human exposure according to posture under the same conditions, the bipolar coil has a higher human exposure level than the circular coil. This is shown in Tables 3 and 4. In the circular coil, neither the electric field nor the current density exceeds the human exposure limit. However, in the bipolar coil, the current density may exceed the standard. In particular, it exceeds the current density standard by up to 135% or more in the lying position, where the physical distance from the GA coil is relatively close. In the bipolar coil, if the human body model is located in the -x axis direction, the current density greatly exceeded the criterion, because the distance between the GA coil and the human body model is closer than the +x axis.

Therefore, based on the ICNIRP guidelines, analysis is required for the bipolar coil structure more. Since the simulation results exceed human exposure limit in bipolar coil system.

Table 2 ICNIRP guidelines (Basic restriction)

	Current density, **J**	Electric field, **E**
ICNIRP Guideline @ 85 kHz	170 mA/m^2	11.475 V/m

Table 3 Current density results according to posture

J [mA/m^2]	Circular coil		Bipolar coil	
	+x axis	-x axis	+x axis	-x axis
Standing	10.84	10.48	69.25	78.35
Sitting	32.45	58.29	298.1	350
Lay down	46.43	43.7	269.3	398.6
Kneel	27.62	21.73	172.7	215.5

Table 4 Electric field results according to posture

E [V/m]	Circular coil		Bipolar coil	
	+x axis	-x axis	+x axis	-x axis
Standing	0.137	0.075	1.05	1.17
Sitting	0.248	0.215	1.46	1.89
Lay down	0.201	0.209	1.51	1.79
Kneel	0.262	0.126	1.07	1.68

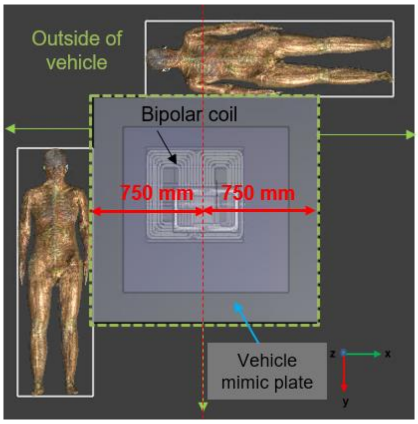

Fig. 4 Position of human body model

So, it is necessary to present a standard about how far away the human body model must be from the vehicle mimic plate to satisfy the standard.

3.3. Simulation Results according to Position of Human body Model

In the case of the bipolar coil, the simulation was performed by moving the human body model in units of 50 mm to secure the limit distance between the human body model and the vehicle mimic plate. Based on the results of Chapter 3.2, simulations were performed not only in the -x axis direction but also in the -y axis direction close to the GA coil. The human body model setup is shown in Figure 4.

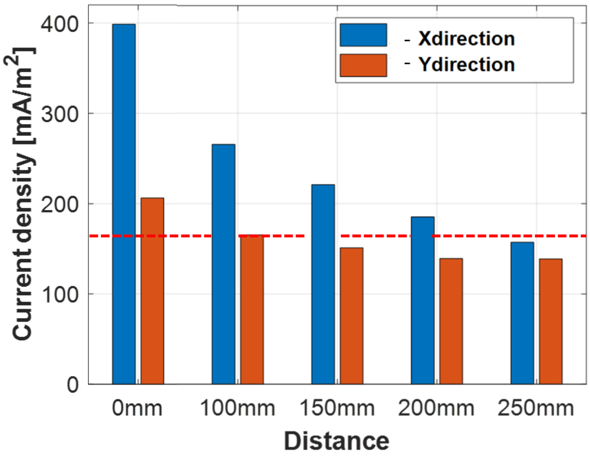

Fig. 5 Current density according to distance

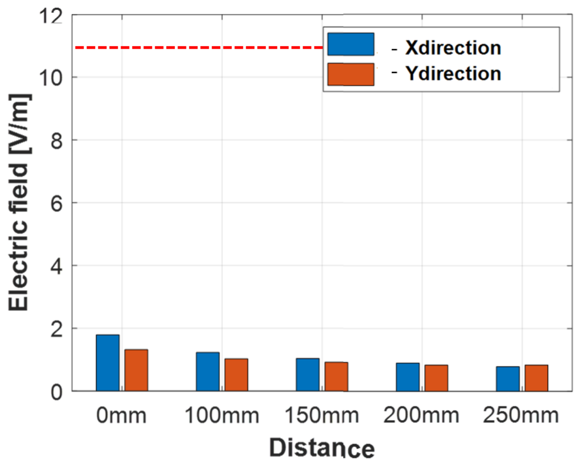

Fig. 6 Electric field according to distance

Figures 5 and 6 show the simulation results of current density and electric field according to the position of the human body model. Figure 5 shows that up to 250mm, the current density in the -x-axis direction is greater than that in the -y-axis direction. This is because the coupling coefficient of the GA and VA coils decreases more severely when an offset occurs in the x-axis direction of the bipolar coil. [7] This means an increase in the leakage magnetic field due to a decrease in the coupling coefficient between the GA coil and the VA coil at the same power condition.

The electric field satisfies the evaluation criteria for human exposure in all conditions from a distance of 0 mm from the vehicle mimic plate to 250 mm. Therefore, when evaluating based on current density, the human body model must be at least 250mm away from the vehicle mimic plate.

4. CONCLUSION

In this paper, EMF human exposure simulation was conducted using a human body model in an EV wireless charging environment designed according to the SAE J2954 standard. For the worst-case analysis, human exposure was evaluated according to the distance from the vehicle mimic plate and the posture of the human body model. Human exposure was evaluated in circular and bipolar coils according to typical coil topology, and in the case of EV wireless charging environments to which bipolar coils were applied, the ICNIRP guideline standard value was exceeded by up to 135%. Therefore, when designing the EV including WPT technology, the distance between the vehicle mimic plate and the person should be considered as 250mm or more for the bipolar coil when considering the worst case. Also, this is the result of evaluation based on the basic restriction in the ICNIRP guidelines, and a follow-up study on the reference level is needed.

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