A Demonstration of Wireless Power Transfer Roadway System based on Electric Field Coupling

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ABSTRACT: The objective of our research is to develop a practical technology for a safe and general-purpose wireless power transfer roadway system based on electric field coupling that is highly power transfer efficient and easy to repair and renew. In this paper, we present a structure of our WPT roadway system based on the electric field coupling, results of power transfer efficiency simulations and experiments. The simulation results show that maximum transfer efficiency is 92.6% and average transfer efficiency is 68.4%. Additionally, we constructed a 20m WPT roadway and conducted WPT experiment. As a result, it shows that maximum transfer efficiency is 72.8% and average transfer efficiency is 54%.

KEY WORDS: wireless power transfer, electric field coupling, electric vehicle, roadway

1. INTRODUCTION

Research on WPT (Wireless Power Transfer) attracts attention as a breakaway from wired power supply. Demonstration of magnetic field coupling WPT by MIT in 2007 gave a great impact all around the world [1]. Nowadays researchers are conducting various research for practical application. As an example of its application, WPT to vehicles based on magnetic field coupling has been proposed[2]-[5]. Many studies suppose structures in which coils, or two parallel wires are buried under the road. In addition, it is common to use ferrite material for enhancing power transfer efficiency. But it is quite challenging to bury ferrite material under the road because they are expensive and brittle.

We are studying a WPT roadway system for traveling vehicles based on electric field coupling (shown in Figure 1) [6]-[8]. In the case of the electric field coupling, transmitting electrodes longer than the vehicle body are buried under the road to supply power. Behavior of the leakage electric fields in electric field coupling WPT system is shown in Figure 2. When a vehicle is on the road, an electric field is generated between the transmitting and receiving electrodes, and this field contributes to power transmission. When a vehicle is not on the road, the main component of the electric field is generated between the left and right transmitting electrodes, and there is little leakage in the direction on the road. This WPT system can continuously supply power if the vehicle is on the road. In addition, continuous power supply allows the power transmitted from the power source to be smaller than with the magnetic field coupling, and it also leads to battery miniaturization. Furthermore, the electric field does not heat in metallic objects, so the foreign object detection system can be simplified. From these points of view, we believe that the electric field coupling method is advantageous in principle. In previous works, we carried out an experimental demonstration for a running vehicle in 2016 (shown in Figure 3). But it was found that the transmission efficiency of this road was reduced due to water retention inside over time. The objective of our research is to develop a practical technology for a safe and general-purpose WPT roadway system based on electric field coupling that is highly power transfer efficient and easy to repair and renew. In this paper, we present the structure and experimental results of the WPT roadway based on electric field coupling we developed.

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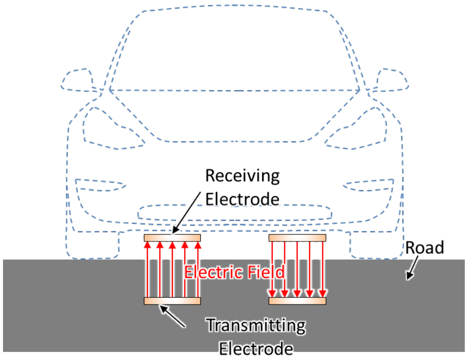
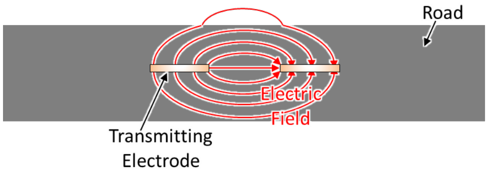
Fig. 1 Concept of our WPT roadway system.



(a) Vehicle is on the road



(b) Vehicle is not on the road

Fig. 2 Image of the leakage electric fields in electric field coupling WPT system.

Fig. 3 WPT experimental demonstration for a running vehicle in 2016.

2. Wireless Power Transfer Roadway System

2.1. Cross-Section Structure

Cross-section structure of our WPT roadway system is shown in Figure 4. Electric characteristics of road materials are shown in Table 1. This road is composed of Special asphalt mixture (t100mm), Transmitting electrode (t1mm), Bituminous stabilized material (t100mm), Bituminous sheet (t2mm), Drainage Course (t100mm) and Perforated metal (t1mm). The special asphalt mixture in the surface course was made dense grained to waterproof the area around the transmitting electrodes. Additionally, the drainage course and draining pavement was used for the subbase course to prevent water from accumulating in the pavement.

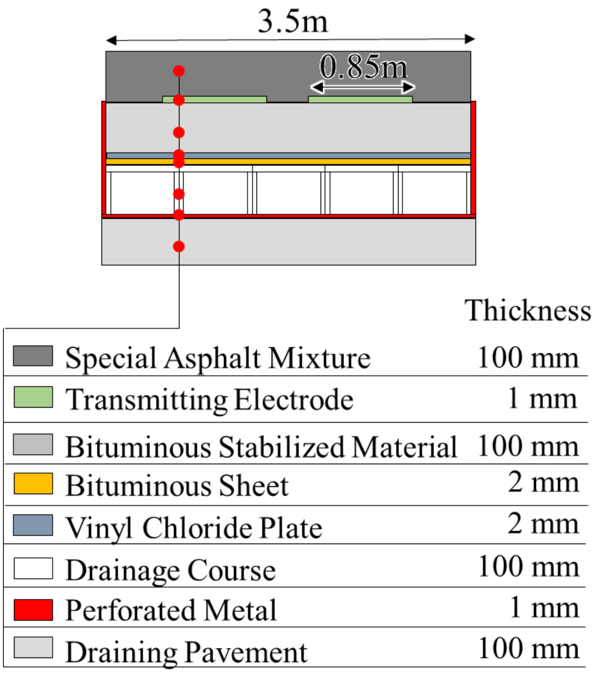


Fig. 4 A cross-section of our WPT roadway system.

2.2. Power Transfer Efficiency Simulation

We simulated the power transfer efficiency on a 20m WPT roadway in the 6.78MHz band using the dielectric constant and dielectric dissipation factor of the road materials in Table 1. The simulation model is shown in Fig. 2 and the analysis results in Fig. 3. The "low-coupling section" refers to a section where the transmitting and receiving electrodes do not overlap sufficiently. The "high-coupling section" refers to a section where the transmitting and receiving electrodes overlap. The simulation results show that transfer efficiency varied depending on the location of the receiving electrodes on the WPT roadway due to standing waves, with a maximum of 92.6% and an average of 68.4%.

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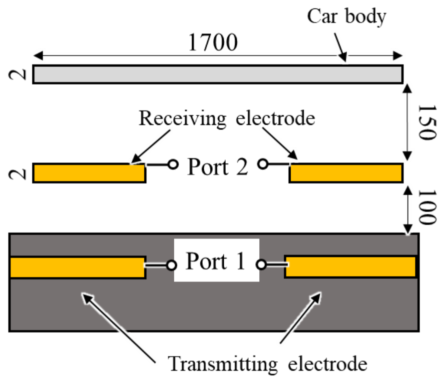
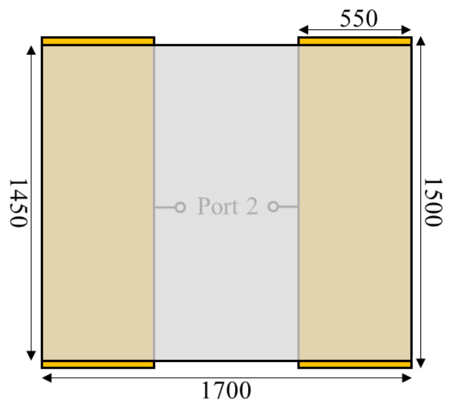
Table 1 Electric characteristics of WPT roadway materials

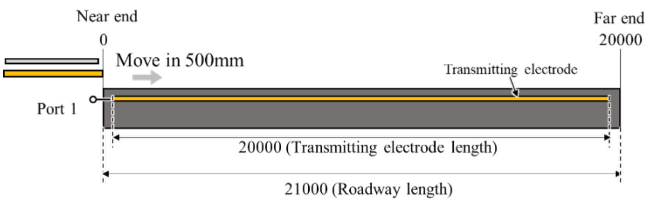
Materials	Electric Characteristics		Thickness
Special Asphalt Mixture	ε_r=4.97	tanδ=0.010	100mm
Transmitting electrode	σ=3.54×10^7	μ_r=1	0.5mm
Asphaltic bitumen	ε_r=1.99	tanδ=0.011	2mm
Bituminous stabilized material	ε_r=4.0459	tanδ=0.012	100mm
Vinyl Chloride Plate	ε_r=2.75	tanδ=0.013	2mm
Drainage Course	ε_r=1.21	tanδ=0.0002	100mm
Perforated metal	σ=3.56×10^7	μ_r=1	1mm



(a) Cross section of front view



(b) Top view of receiving unit



(c) Side view of simulation model

Fig. 5 Simulation model of WPT roadway system.

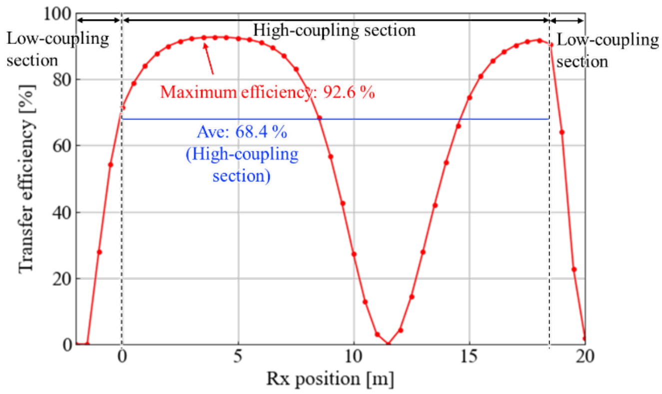


Fig. 6 Simulation result.

2.3. Wireless Power Transfer Experiment

We constructed a 20m WPT roadway shown in Figure 7. In (a), we laid out perforated metal on the ground and used Zn tape to make it conductive to each other. And in (b), drainage course (reinforced plastic) was bonded with each other.

We conducted a WPT experiment to a running vehicle using the constructed 20m roadway. The experimental configuration is shown in Figure 8 and the experimental photo in Figure 9. The experimental results demonstrated that our WPT roadway system can continuously feed power to a running vehicle at a speed of 20 km/h. The maximum and average power transfer efficiencies were 72.8% and 54.0%, respectively, which were lower than the simulated values. We consider that this is due to flooding in the drainage course caused by a typhoon that occurred during the construction of our WPT roadway system.

3. CONCLUSION

We designed a practical electric field coupling WPT roadway system and confirmed that high power transmission efficiency could be obtained by simulation. We also conducted a power transfer experiment by constructing a 20-meter length of the WPT roadway. As a result, we confirmed that it is possible to transfer power continuously to running vehicle at a 20km/h.

ACKNOWLEDGMENT

This work was supported by MLIT CART (Committee on Advanced Road Technology) Project.

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(a) Perforated metal (GND) on the ground

(b) Drainage course (Reinforced Plastic) on the GND

(c) Bituminous stabilized material
on the drainage course

(d) Transmitting electrode
on the bituminous stabilized material

(e) Special asphalt mixture pavement

(f) 20m WPT roadway construction finished

Fig. 7 Construction photo of a 20m WPT roadway

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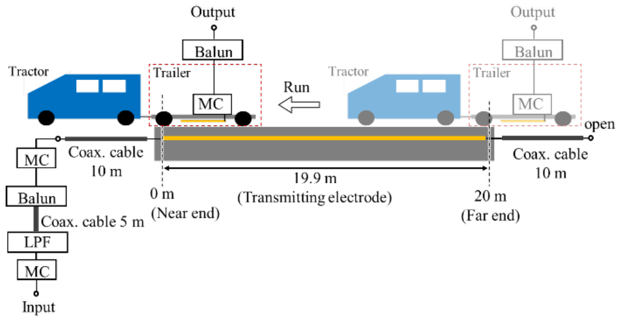

Fig.8 Experimental configuration

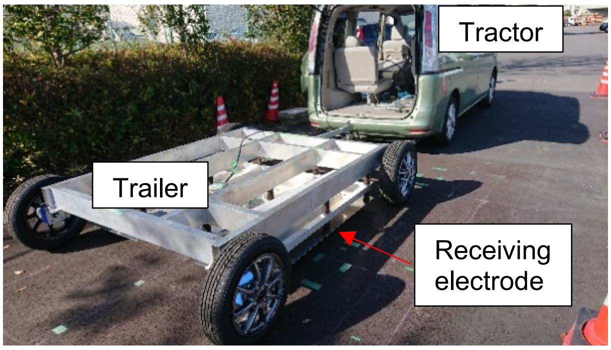

Fig. 9 Photo of WPT experiment

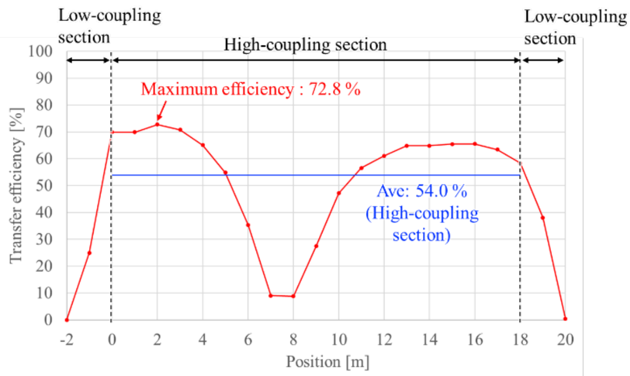

Fig. 10 Power transfer efficiency

REFERENCES

(1) A. Kurs, et. al, “Wireless power transfer via strongly coupled magnetic resonances," *Science*, vol.317, no.5834, pp.8386, July 2007.

(2) J. G. Bolger, F. A. Kirsten, and L. S. Ng, “Inductive power coupling for an electric highway system,” IEEE Vehicular Technology Conference, vol. 28, pp.137-144, March 1978.

(3) “Roadway powered electric vehicle project track construction and testing program phase 3D, “ Systems Control Technology, Inc., Palo Alto, CA, USA, California PATH research paper UCB-ITS-PRR-94-07, 10551425, March 1994.

(4) J. Huh, S. W. Lee, W. Y. Lee, G. H. Cho, and C. T. Rim, “Narrow-width inductive power transfer system for online electrical vehicles,” IEEE Trans. Power Electron., vol.26, no.12, pp.3666-3679, Dec. 2011.

(5) J. Shin, S. Shin, Y. Kim, S. Ahn, S. Lee, G. Jung, S.J. Jeon and D.H. Cho, “Design and implementation of shaped magnetic-resonance-based wireless power transfer system for roadway-powered moving electric vehicles,” IEEE Trans. Ind. Electron., vol.61, no.3, pp.1179-1192, March 2014.

(6) T. Ohira, “A battery-less electric roadway vehicle runs for the first time in the world (invited),” IEEE International Conference on Microwaves Intelligent Mobility, Nagoya, March 2017.

(7) Yoshiki Suzuki, Minoru Mizutani, Takamitsu Sugiura, Naoki Sakai, and, Takashi Ohira, “Prototype experiments on a 1/32-scale model via-wheel power transfer electric vehicle”, Electrical Engineering in Japan, Wiley Periodicals, vol.195, no.1, pp.63-71, Apr. 2016. DOI: 10.1002/eej.22813 (Translated from Denki Gakkai Ronbunshi, vol.134-D, no.7, July 2014, pp.675-682)

(8) T. Ohira, “Plane geometry inspires wave engineering starters,” IEEE Microwave Magazine, vol. 24, no. 3, pp. 93-98, Mar. 2023.

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