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Development of Short-range Frequent-recharging Small Electric Vehicle Equipped with Non-contact Inductive Power Supply System

Y. KAMIYA[1], S. NAGANO[1], M. NABETA[1], Y. IHARA[1], Y. DAISHO[1],
S. TAKAHASHI[2], T. SATO[2]
[1]*Waseda University, 55S-704, 3-4-1 Ohkubo, Shinjuku Tokyo, JAPAN, kamiya@waseda.jp*
[2]*Showa Aircraft Co. Ltd., JAPAN*

Abstract

This paper reports on the development of the Waseda advanced Electric Vehicle - 0 that is equipped with a non-contact inductive power supply (IPS) system. By using the developed IPS system, charging can be carried out safely, easily, and in a short period. We summarize the vehicle performance evaluation results obtained from related tests.

Keywords: battery charge, BEV, inductive charger, lithium battery

1 Introduction

In recent years, there have been increasing demands on automobile manufacturers in various countries to develop vehicles incorporating a clean power source to replace the conventional internal combustion engine. Such demands are being made to address energy and environment issues, including the depletion of fossil fuels, global warming and air pollution due to emissions produced by various power sources. Among the several alternatives to the internal combustion engine that have been studied, the research and development of electric-driven vehicles has continued for decades as a candidate system. Due to limited battery capacity and charge performance, however, electric vehicles have not really taken off [1].

Given this background, and with the aim of finding a solution to the problems associated with battery charging, the research group has progressed with the research and development of a non-contact rapid charging inductive power supply (IPS) system with safe, simple, and rapid charging characteristics for electrically driven vehicles (principally for electric vehicles and plug-in hybrids) [2], [3]. Outstanding features of the system include high efficiency, significant size and weight reduction, and a long air gap, achieved by optimizing the shapes of the track and pickup components. Past papers [4] have discussed a 30 kW system first developed for an electric microbus WEB.

This paper discusses a recently developed 1 kW IPS for small electric vehicles. It also discusses the small electric test vehicle (Waseda advanced Electric Vehicle-0, shown in Figure 1) that was constructed for IPS evaluation, and summarizes the performance evaluation results obtained from related tests. Like the advanced electric WEB [4] microbus developed previously, the Waseda advanced Electric Vehicle-0 is based on a concept that combines a short driving range with frequent recharging. As shown in Figure 2, it was envisaged that mobility would be supported by several non-contact recharging stations positioned within a large area such a university or a manufacturing facility. The network connecting these stations would then enable unlimited driving.

2 Developing and Evaluating the Performance of the IPS system

The overall configuration of the IPS is shown in Figure 3. The track and pickup part of the system is similar to a high-frequency transformer with a gap. The system incorporates this track and pickup part with the high frequency power supply, rectifier and the other peripheral devices. The designs of the IPS system's track and pickup component shapes were developed based on external drive circuit compound finite-element electromagnetic field analysis [5] as shown in Figure 4. Specifically, a variety of studies were carried out such as hollowing out the central part of the core and making the core thinner without affecting performance. As a result it was possible to increase efficiency, reduce size, weight and thickness and extend the air gap. The final pickup shape is shown in Figure 5. The drive frequency was set as 22 kHz because of reasons including compatibility with the previously developed 30 kW system [2].

3 Installing IPS on a Short-range/Frequent Recharging Electric Vehicle and Evaluating the Performance

This chapter summarizes information relating to the test vehicle recently developed for IPS evaluation and the results from performance evaluations carried out on this IPS-installed vehicle.

3.1 Constructing the Waseda advanced Electric Vehicle-0

The Waseda advanced Electric Vehicle-0 (WEV-0) is a small vehicle developed for the purpose of this research. The base vehicle selected to build onto was the small Suzuki 2-seater car called the Twin. The parts that constitute the engine and exhaust of this gasoline-operated vehicle were removed and electric vehicle components, starting with the motor and battery, were installed to complete its electric conversion. Table 1 shows the vehicle specifications and Figure 6 shows the system layout.

A manganese-type lithium-ion battery was selected as the main battery (Figure 7a, b). Selected on the basis of the previously mentioned concept of short driving range and frequent recharging, this battery reduced the cost and weight factors normally associated with a large battery. For driving power, an induction motor was selected (Figure 7c). The IPS system was selected because short driving range problems can only be solved by frequent recharging, and the IPS system can ensure that charging is carried out safely, easily and in the shortest possible time (Figure 7d, e, f).

3.2 Performance Evaluation

3.2.1 Performance Evaluations Based on Chassis Dynamometer Tests

This section summarizes the measured evaluation results for the WEV-0's electricity consumption, reduction in CO2 emissions, driving range and other performance factors taken in chassis dynamometer tests. In these tests, the same conditions were applied to the WEV-0 and to an internal combustion engine vehicle acting as the test control vehicle. To ensure that driving conditions were suitable for evaluation, it was decided that the WEV-0 should use an environment with the same range of speed limits as that found in urban areas such as that provided by a large university or manufacturing facility site. The driving mode studied and devised by the research group is shown in Fig. 8a. Battery voltage and current measurements from the battery installed on the vehicle when driving in this driving mode are shown in Fig. 8b for reference. Also for reference, the power consumption attributable to the WEB-0's auxiliary devices was measured as 0.32 kW.

The results from comparatively evaluating both the WEV-0 and the control vehicle in terms of electricity consumption, fuel consumption and CO2 emissions are summarized in Table 2. Due to a combination of the low CO2 emissions characteristics of electric energy [6] and the "well to wheel" overall efficiency of electric cars, analysis of both vehicles' overall efficiency confirmed that the WEV-0's CO2 emissions were approximately a quarter of the control vehicle's CO2 emissions.

3.2.2 Performance Evaluations Based on Road Driving Tests

These tests were carried out to check the WEV-0's mobility potential within the constraints of the short driving range and frequent recharging

concept. This section discusses the results of road driving tests with simulated real-life conditions. The campus driving mode studied and devised by the research group is shown in Figure 9a. Battery voltage, current and electric power behaviour measurements from the battery installed on the vehicle when driving under these conditions are shown in Figure 9b for reference.
For this test, inclusive of the weight of the two occupants and the on-board measurement equipment, the full weight of the vehicle was 820 kg. SOC data results are shown in Figure 10. Details of the test procedures are as follows:

1. Driving was started with the battery having been fully charged overnight to approximately 80% SOC

2. Mode driving was implemented four times.
(Driving range/driving time: 1.4 km/approx. 5 min., implemented 4 times)

3. After 3 minutes IPS recharging, the mode driving was implemented once

4. After 5 minutes IPS recharging, the mode driving was implemented once

5. After 4 minutes IPS recharging, the mode driving was implemented once

The reason why driving was repeatedly carried out at 50% SOC is because it is thought that the battery's charge-sustaining performance is at its best around this level.
This test confirmed that IPS installation enhances the safety and ease of charging for electric vehicles. It was also confirmed that the charging time required to replace the amount of energy used in a five-minute period of driving was exactly 5 minutes. It may be thought that this time period is too long, however this is only because the battery used was only a 1 kW-0.5 C battery. To address this point, currently the possibility of installing a medium output type IPS, capable of charging 4 C, into a vehicle is being considered. In these tests, driving procedures were combined with overnight charging. However, obviously, driving is also possible with batteries that have not been charged overnight and are at approximately 50% SOC. In this case, it is thought that using HEV system batteries with their superior input and output characteristics is worth considering to narrow down the SOC range.

4 Conclusion

This paper has summarized the design and development processes relating to a non-contact inductive charging system for small electric vehicles and the results of related performance evaluation tests. This paper has also discussed the construction of the WEV-0, a small electric vehicle created for the purpose of evaluating the charging performance of the developed system, and also the related performance evaluations. The obtained results are as follows:
a) A 1 kW non-contact inductive charging system for small vehicles was designed and developed. The developed system is centred around a track and pickup part whose component design was based on electromagnetic field analysis.
b) The Waseda advanced Electric Vehicle-0, a small electric vehicle based on the concept of short driving range and frequent recharging was developed. The results achieved within constraints that included having to install a battery of minimum weight, confirmed that the WEV-0's CO2 emissions were just a quarter of the CO2 emissions produced by the normal control vehicle.
c) Road driving tests simulating real-life conditions were carried out and the results confirmed that installation of the developed IPS system brought about safer and easier charging of the electric vehicle. It was shown that by repeating a cycle of 5 minutes driving followed by 5 minutes recharging, endless driving is possible.

Acknowledgments

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Also, sincere gratitude is expressed to Mr. Kohei Inaba and Mr. Yuya Marumoto of Waseda University's Daisho Laboratory, and to Mr. Mitsuaki Ito of Showa Aircraft Industry Co., Ltd for their contributions towards developing the WEV. Finally, sincere gratitude is expressed to Mr. Kazuyuki Narusawa of the National Traffic Safety and Environment Laboratory for his daily endeavour toward making the non-contact charging system a practically viable product.

Figure 1: Waseda advanced Electric Vehicle-0

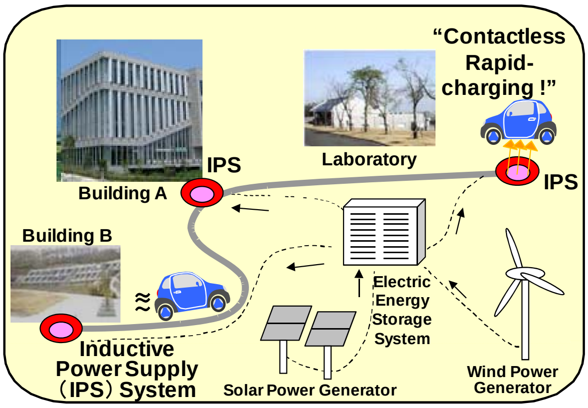


Figure 2: Short-range BEV transport system with IPS stations

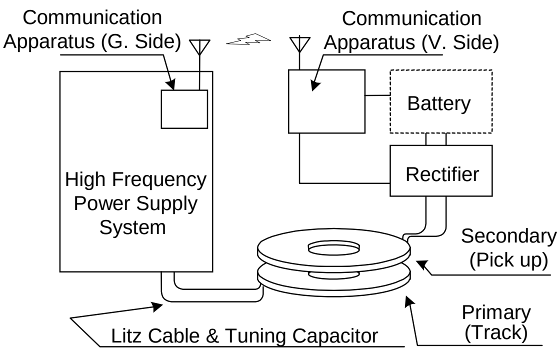


Figure 3: Schematic view of the IPS system

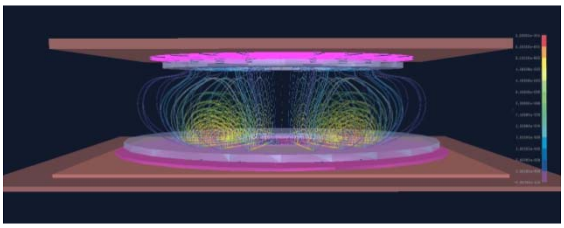


Figure 4: Results of finite element electromagnetic field analysis for optimizing the IPS track and pick up

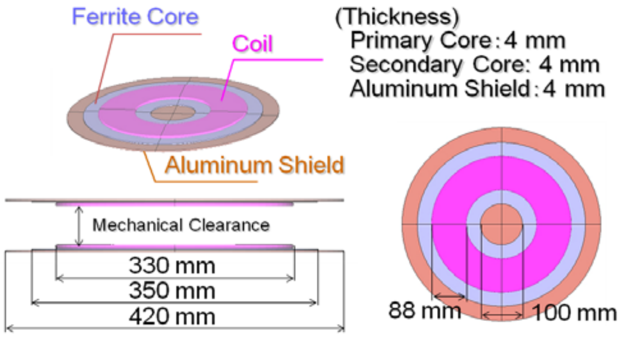
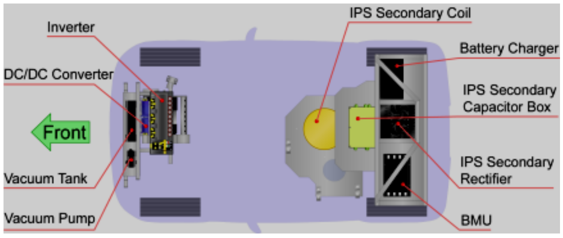
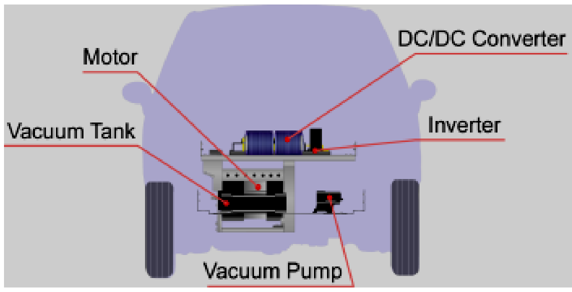


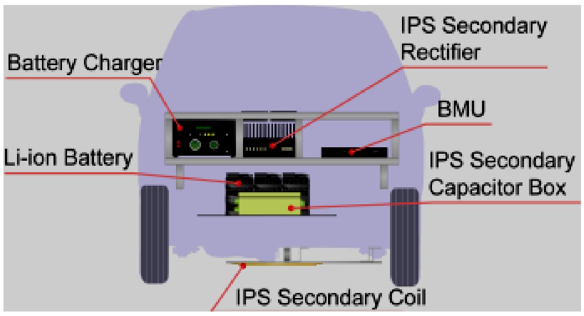
Figure 5: Final shape of the pick up



(a) Top view



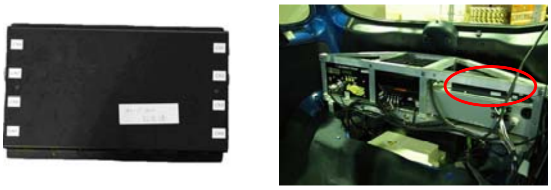
(b) Front view



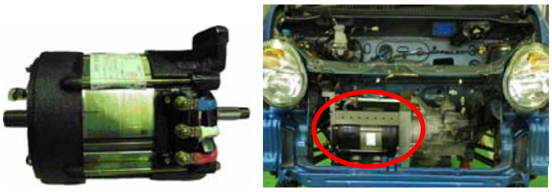
(c) Rear view

Figure 6: WEV-0's system layout

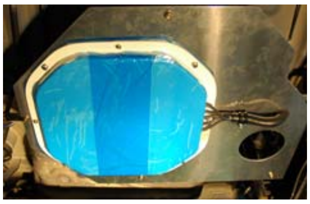
(a) Battery



(b) BMU

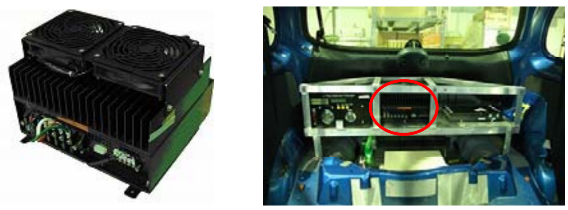


(c) Motor



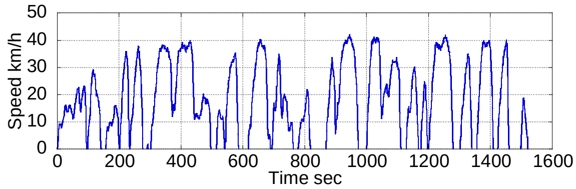
(d) IPS pick up

(e) IPS secondary capacitor



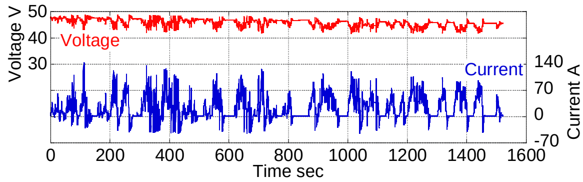
(f) IPS secondary rectifier

Figure 7: Equipment installed on the WEV-0



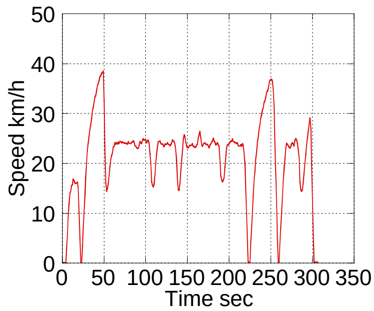
(a) Speed Pattern

(Distance: 7.4 km, v_{max}: 40 km/h, v_{ave}: 18 km/h)



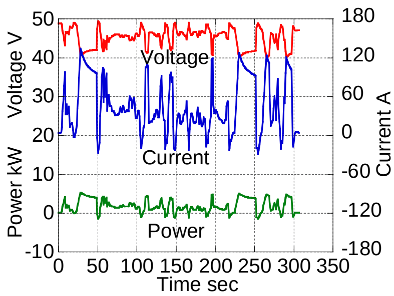
(b) Battery Voltage and Current

Figure 8: Results of the City Area Mode Test



(a) Speed Pattern

(Distance: 1.4 km, *vmax*: 39 km/h, *vave*: 19 km/h)



(b) Battery Voltage and Current

Figure 9: Results of the City Area Mode Test

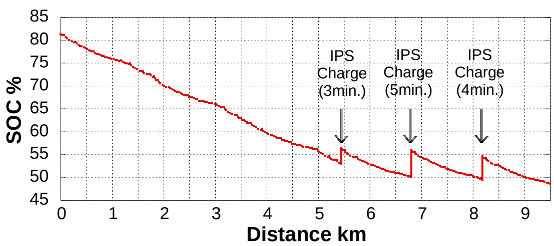


Figure 10: SOC Data from the Campus Mode Test

Table 1: Vehicle Specifications Comparisons between the Developed Vehicle and the Base Vehicle

		WEV-0	Base Vehicle
Vehicle	Weight	665 kg	615 kg
	Size	*L*2.73 x *W*1.47 x *H*1.45 m	
On-Board Unit	Type	Induction Motor (Nippon Yusoki)	Gasoline Engine L3- 0.66 L
	Max. Power	6.4 kW	32 kW @5500 rpm
	Max. Torque	68 Nm @0-1000 rpm	57 Nm @3500 rpm
Li-ion Battery	Type	Mn type	—
	Capacity	1.93 kWh	—
	Rated Voltage	45 V	—
	Mass	19.1 kg	—
	Size	194x 525 x 116 mm	—

Table 2: CO2 Emissions Performance Comparisons between the WEV-0 and the Base vehicle

	WEV-0	Base Vehicle
Mode	City Area Mode	
Energy Consumption	443 Wh (Electric Energy)	0.334 L (Gasoline)
Energy Consumption Rate	16.9 km/kWh	22.4 km/L
CO_2 Emission (Tank to Wheel)	0 g	776 g*
CO_2 Emission (Well to Tank)	223 g**	63 g***
CO_2 Emission (Total)	223 g	839 g

*2.31kg-CO2/L
**0.375kg-CO2/kWh, Power Transmission Efficiency x IPS Efficiency: 0.92 x 0.81
***Gasoline Fuel (LHV): 34.6MJ/L, 5.45g-CO2/MJ

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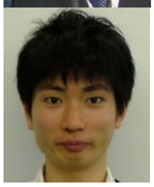
Authors

Yushi Kamiya, Professor, Dr. Eng.
Waseda University.

Y. Kamiya received the B., M. and D. Eng. degrees from Waseda University. He is presently professor at Waseda University.

Shota Nagano, M. Eng.
Waseda University.

S. Nagano received the B. and M. Eng. degrees from Waseda University. He joined Toyota Motor Corporation in 2009.



Mitsutoshi Nabeta, B. Eng.
Waseda University.

M. Nabeta received the B. Eng. degrees from Yokohama City University. He is now a master course student at Waseda University.

Yuuto Ihara, M. Eng.
Waseda University.

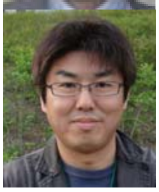
Y. Ihara received the M. Eng. degrees from Waseda University. He is now a doctor course student at Waseda University.

Yasuhiro Daisho, Professor.
Waseda University.

Y. Daisho graduated the doctor's course of Waseda University. He is presently professor at Waseda University.

Shunsuke Takahashi, M. Eng.
Showa Aircraft Industry Co., Ltd..

S. Takahashi received the B. and M. Eng. degrees from Waseda University. He is executive officer at Showa Aircraft Industry Co., Ltd.



Takeshi Sato, M. Eng.
Showa Aircraft Industry Co., Ltd..

T. Sato received the M. Eng. degrees from Waseda University. He is researcher at Showa Aircraft Industry Co., Ltd.