Development of Short-range Frequent-recharging Small Electric Vehicle Equipped with Non-contact Inductive Power Supply System and $LiFePO_4$ Lithium-ion Battery

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***Abstract*- This paper reports on the development of the Waseda Electric Vehicle - 0 Advanced that is equipped with a non-contact inductive power supply (IPS) system and LiFePO4 lithium-ion battery. By using the developed system, rapid charging can be carried out safely, easily, and in a short period. We summarize the vehicle performance evaluation results obtained from related tests.**

I. 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 and LiFePO4 lithium-ion battery with safe, simple, and rapid charging characteristics for short-range frequent-recharging small electric vehicles [2], [3].

This paper discusses a recently developed 6 kW IPS and LiFePO4 lithium-ion battery for small electric vehicles. It also discusses the small electric test vehicle (Waseda Electric Vehicle-0 Advanced (WEV-0Adv.), shown in Fig. 1) that was constructed for evaluation, and summarizes the performance evaluation results obtained from related tests. Like the advanced electric microbus WEB [4] developed previously, WEV-0Adv. is based on a concept that combines a short driving range with frequent recharging. 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.

II. CONSTRUCTING WASEDA ELECTRIC VEHICLE-0 ADVANCED

WEV-0Adv. 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. A $LiFePO_4$ lithium-ion battery was developed as the main battery (Fig. 2(a)). 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. 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 (Fig. 2(b)). For driving power, an induction motor was selected. Table 1 shows the vehicle specifications and Fig. 3 shows the system layout.

III. PERFORMANCE EVALUATION

A. Performance Evaluations Based on Chassis Dynamometer Test

This section summarizes the measured evaluation results for the WEV-0Adv's electricity consumption, reduction in

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CO_2 emissions, driving range and other performance factors taken in chassis dynamometer tests. In these tests, the same conditions were applied to the WEV-0Adv. 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-0Adv. 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. 4(a). Battery voltage and current measurements from the battery installed on the vehicle when driving in this driving mode are shown in Fig. 4(b) for reference. Also for reference, the power consumption attributable to the WEV-0Adv's auxiliary devices was measured as 0.12 kW.

The results from comparatively evaluating both the WEV-0 Adv. and the control vehicle in terms of electricity consumption, fuel consumption and CO_2 emissions are summarized in Table 2. Due to a combination of the low CO_2 emissions characteristics of electric energy [5] and the "well to wheel" overall efficiency of electric cars, analysis of both vehicles' overall efficiency confirmed that the WEV-0 Adv.'s CO_2 emissions were about a half of the control vehicle's CO_2 emissions.

B. Performance Evaluations Based on Road Driving Tests

These tests were carried out to check the WEV-0 Adv.'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.

For this test, inclusive of the weight of the two occupants and the on-board measurement equipment, the full weight of the vehicle was 710 kg. SOC data results are shown in Fig. 5. 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: 1.45 km/approx. 5 min., implemented 5 times)

3) After 50 seconds IPS recharging, the mode driving was implemented once

4) After 70 seconds IPS recharging, the mode driving was implemented once

5) After 100 seconds IPS recharging, the mode driving was implemented once

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 70 seconds.

IV. Conclusion

This paper has discussed the construction of the WEV-0 Adv., 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) WEV-0Adv., 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-0Adv.'s CO_2 emissions were about a half of the CO_2 emissions produced by the normal control vehicle.

b) Road driving tests simulating real-life conditions were carried out and the results confirmed that installation of the developed 6 kW IPS system and LiFePO4 lithium-ion battery brought about safer and easier charging of the electric vehicle. It was shown that by repeating a cycle of 5 minutes driving followed by 70 seconds recharging, endless driving is possible.

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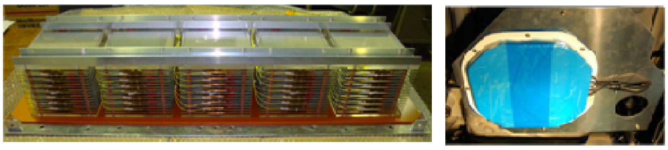
Fig. 1 Waseda Electric Vehicle - 0 Advanced.

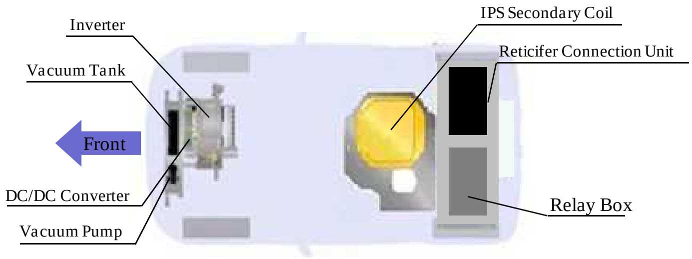


(a) LiFePO4 Battery Module (b) IPS pick up

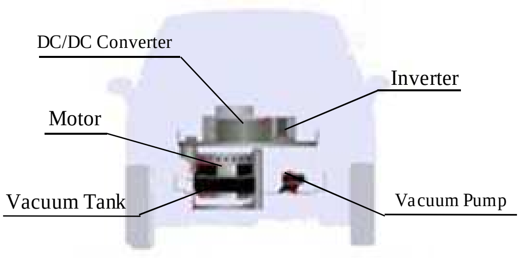
Fig.2 Equipment installed on the WEV-0Adv..

TABLE I
VEHICLE SPECIFICATIONS COMPARISONS
BETWEEN THE DEVELOPED VEHICLE AND THE BASE VEHICLE

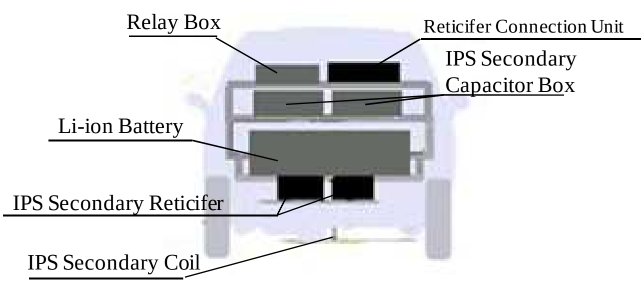
		WEV-0Adv.	Base Vehicle
Vehicle	Weight	710 kg	615 kg
	Size	L2.73 x W1.47 x H1.45 m	
On-Board Unit	Type	Induction Motor (Nippon Yusoki)	Gasoline Engine L3-0.66 L
	Max. Power	6.4 kW	32 kW @5500 rpm
	Max. Torque	68 Nm @0-1000 rpm	57 Nm @3500 rpm
Li-ion Battery	Type	LiFePO4	—
	Capacity	1.56 kWh	—
	Rated Voltage	51.2 V	—
	Mass	60.3 kg	—
	Size	250 x 925 x 390 mm	—



(a) Top view

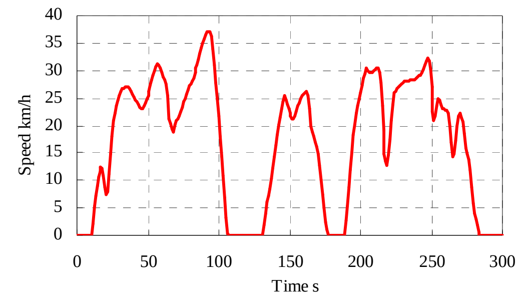


(b) Front view

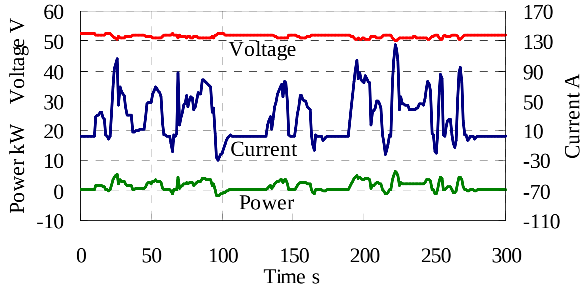


(c) Rear view

Fig.3 WEV-0Adv. system layout.



(a) Speed Pattern
(Distance: 1.4 km, vmax: 37.2 km/h, vave: 17 km/h)



(b) Battery Voltage and Current

Fig.4 Result of the manufacturing facility driving mode test.

TABLE 2
CO_2 EMISSIONS PERFORMANCE COMPARISON
THE DEVELOPED VEHICLE AND THE BASE VEHICLE

	WEV-0Adv.	Base Vehicle
Mode	Manufacturing facility driving mode	
Energy Consumption	115 Wh (Electric Energy)	0.334 L (Gasoline)
Energy Consumption Rate	12.7 km/kWh	22.4 km/L
CO_2 Emission (Tank to Wheel)	0 g	776 g*
CO_2 Emission (Well to Tank)	430 g**	63 g***
CO_2 Emission (Total)	430 g	839 g

*2.31 kg-CO_2/L

**0.375kg-CO_2/kWh, Power transmission Efficiency x IPS Efficiency: 0.92 x 0.81

***Gasoline Fuel (LHV): 34.6 MJ/L, 5.45 g-CO_2/MJ

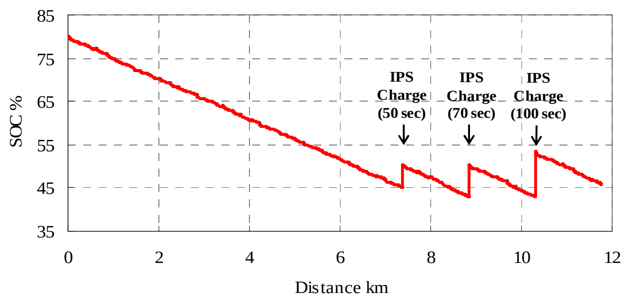


Fig.5 SOC Data from the manufacturing facility driving mode test.