On-Line Electric Vehicle using Inductive Power Transfer System

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Abstract **– In this paper, 3 generations of OLEV (On-Line Electrical Vehicle) are introduced. The 1st generation of OLEV is conventional E-type structure. The air gap of the 1st generation is 1cm and the input to output power efficiency is 80% with 3 kW output power. The ultra slim U-type mono rail structure is applied to the 2nd generation of OLEV. This structure is applied to the OLEV bus which achieves 52 kW output power with 72% efficiency at 17 cm air gap. SUV (Sports Utility Vehicle) equipped with the 3rd generation of OLEV named ultra slim W-type (dual rail structure) accomplished 15 kW/pick-up and 71% efficiency at 17 cm air gap**

Index Terms **—On-line Electrical Vehicle, ultra slim U-type, ultra slim W-type, 17cm air gap**

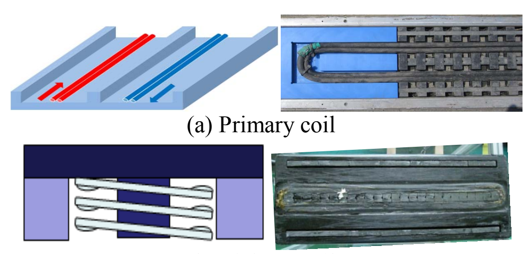
I. INTRODUCTION

The eco-friendly vehicle is the global trend in the automobile industry. The electrical vehicle (EV) is the most suitable alternative of petroleum vehicles. The large capacity, weight, expensive price, short life time, and charging time of battery obstruct the commercialization of EV. Because of the low energy density of battery, battery takes up large space and weight portion in a vehicle. As a result running efficiency of EV is degraded by these negative effects. To solve the problems, contactless power transfer system was proposed by several researchers [1]~[5]. A dual mode electric transportation(DMET) system with 150 cm rail width and 2.5 cm air gap was proposed in [1]. PATH team developed PATH bus with 7.6 cm air-gap and attained 60% efficiency [2]. Recently Waseda Advanced Electric Micro Bus (WEB) project team achieved 92% efficiency with 10cm air-gap at stationary condition [4]. Every air gap of the researches was no more than 10 cm. This value is not feasible for actual road and vehicle suspension condition. Furthermore stationary charging approaches require frequent stop and charging time. The infra structure cost of PATH team is more than 1M$/km. These explain why EV has not been commercialized yet. In this paper, 3 new inductive power transfer systems for moving EV are proposed as the solution.

II. PROPOSED STRUCTURES OF OLEV

A. The 1st generation of OLEV

The 1st generation of OLEV uses E-type core. Basically its structure is similar to E-type cored transformer. Primary core is E-type segmented structure with mechanical supporter, and secondary pick-up is conventional E-type structure. As a transformer, lateral misalignment of both cores severely degrades output power. This misalignment can happen frequently during driving if it were not for our mechanical lateral position control for pick-up with 3mm accuracy.



(a) Primary coil

(b) Pick-up coil

Fig. 1. The 1st generation – E type primary and pick-up coils.

Using these structures, 80% system power efficiency is obtained at 1cm air gap. At primary side, the nominal frequency is 20 kHz and rated current is 100 A. At secondary side, rated load is 2 Ohm and 3kW per pick up is obtained.

B. The 2nd generation of OLEV

In case the air gap or lateral misalignment is large for the 1st generation of OLEV, the power efficiency sharply decreases. Since at least 12 cm air gap is needed for freely driving vehicles, the 1st generation of OLEV is not proper to actual road situations. To overcome this problem, the 2nd generation of OLEV is proposed. Fig. 2(a) shows primary coil and pick-up coil of the 2nd generation of OLEV.

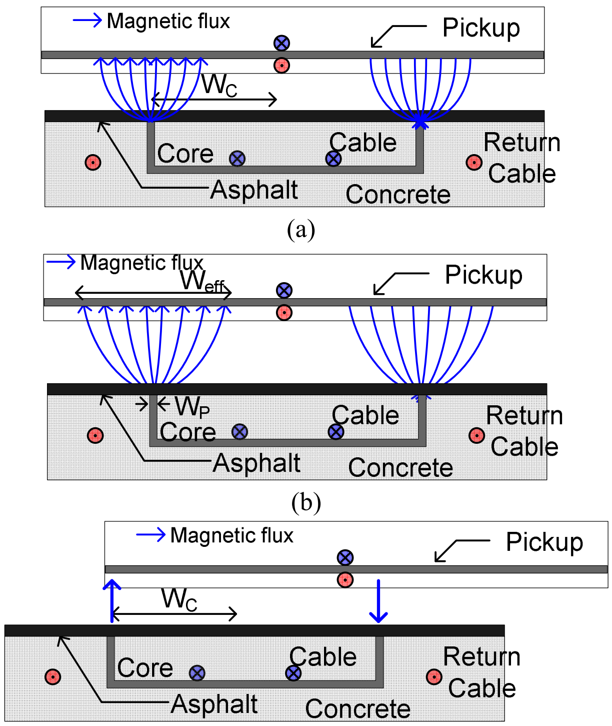
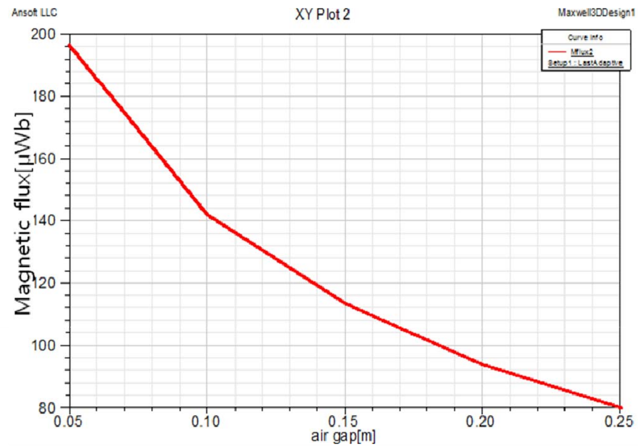


Fig. 2 (a) The 2nd generation: Ultra slim U-type primary coil and pick-up coil
(b) The increased effective pick-up area with lager air gap
(c) Maximum allowable lateral misalignment

The distinction of the 2nd generation of OLEV is the direction of magnetic flux. For the proposed ultra slim U-type mono rail structure the direction of magnetic flux at center position is parallel to the ground, and that at each end position has lots of fringe effect. As shown in Fig. 2(b) the pole width of primary core (W_P) is much smaller than the length of pick-up coil. So the effective pick-up width (W_{eff}) increases as the air gap increases. Therefore the magnetic flux transferred from primary coil to pick-up coil is proportional to the root of the air gap. Fig. 3 shows the transferred magnetic flux, which is approximately proportional to the root of air gap. These effects make it possible to increase air gap from 1cm to 17cm.



(a)

Fig. 3 The simulated magnetic flux transferred from primary coil to pick-up coil for air gap variation

The big difference between the width of primary core (W_P) and the length of pick-up coil desensitizes to the misalignment of primary coil and pick-up coil. As shown in Fig. 2(c), the maximum allowable lateral misalignment is roughly the half of the length of primary core (W_C). The proposed core structure makes it possible about 50% power transfer from primary coil to pick-up coil with 20cm misalignment as shown in Fig. 4. So the 2nd generation of OLEV needs no mechanical control apparatus.

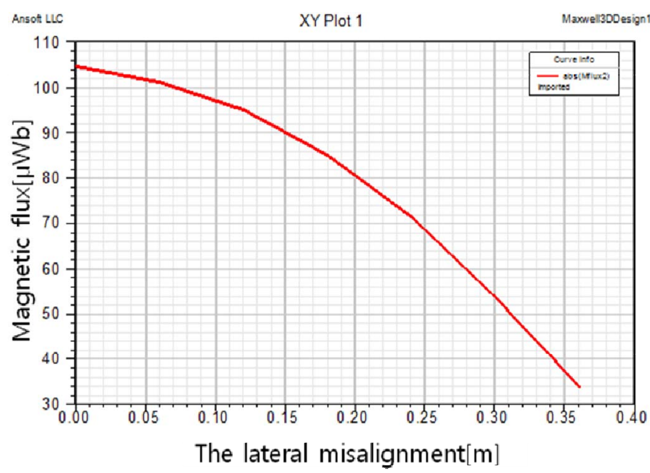
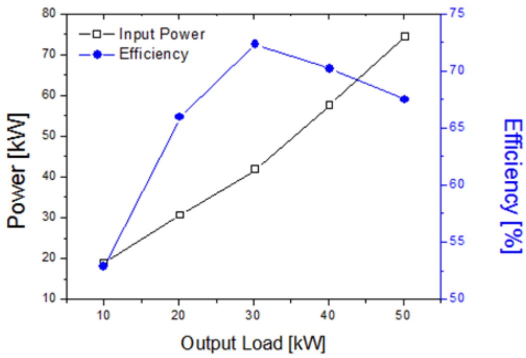
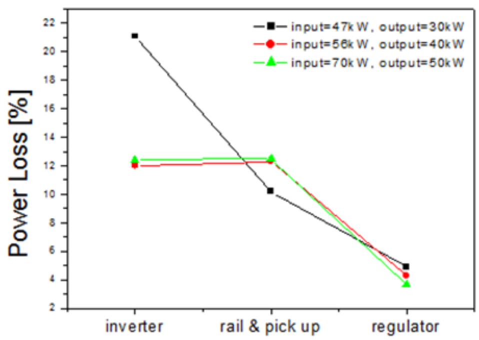


Fig. 4 The simulated magnetic flux transferred from primary coil to pick-up coil with lateral misalignment variation

The nominal frequency of power supply is 20kHz and primary rated current is 200A. The rated load is 6kW per pick-up. Total output power of 52kW with 10 pick-ups and 72% power efficiency is accomplished at 17cm air gap. For efficiency calculation, all power losses between input power for inverters and battery stage at vehicles (inverter switching loss, rail & pick-up losses, regulator loss and so on) are considered. Power efficiency is very low when output power is small because of base power consumption, and is at maximum when output power is about 30 kW. The power loss of inverters is relatively large compared with other components.



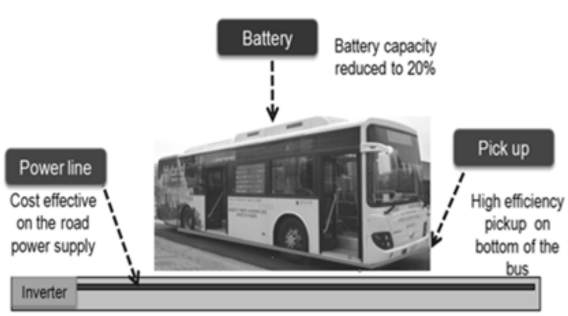
(a)



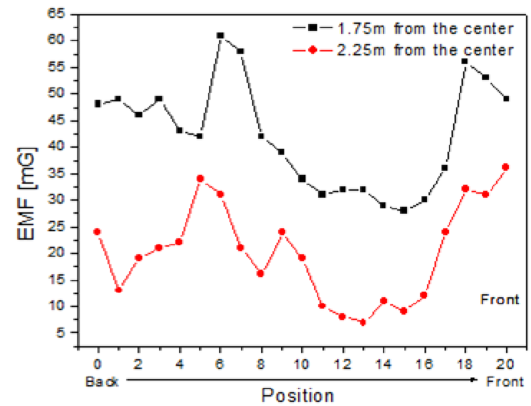
(b)

Fig. 5 (a) The measured efficiency with output load
(b) The power loss of OLEV system

To meet increasing anxiety about the safety of EMF(Electro Magnetic Field) the OLEV system is so designed that the EMF around the OLEV bus(51mG @ 1.75m from the center of road) can satisfy the permitted guideline, 62.5mG@20kHz. An OLEV bus is equipped with the 2nd generation IPTS (Inductive Power Transfer System) technology, and has been successfully demonstrated for more than 12 months at KAIST campus.



(a)

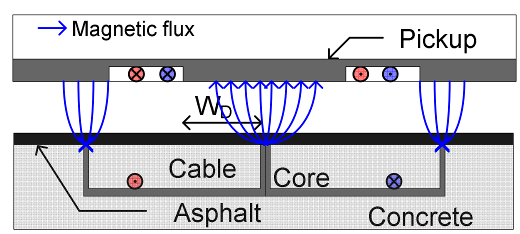


(b)

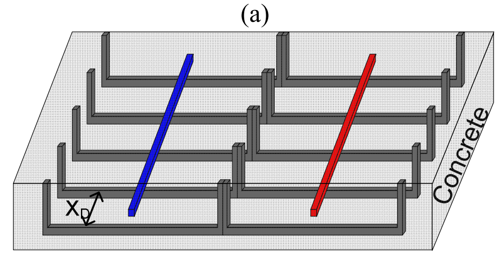
Fig. 6 (a) The 2nd generation of OLEV bus
(b) The measured EMF around the bus

C. *The 3rd generation of OLEV*

The primary rail length of the 2nd generation of OLEV had to increase to 140cm due to the return cables for reducing EMF. By these return cables, construction cost increases and output power is limited. To solve this problem, the 3rd generation named ultra slim W-type structure is proposed. The proposed structure does not need the return cables. As shown in Fig. 7(a), the ultra slim W-type has narrow primary core pole width and wide pick-up core length. So the ultra slim W-type can transfer power with large air gap. The return path of magnetic flux in the ultra slim W-type is doubled. So the transferred power from primary core to pick-up can be increased. But the maximum allowable lateral misalignment (W_D) is roughly a quarter of the length of primary coil.



(a)



(b)

Fig. 7(a) The 3rd generation : Ultra slim W-type primary coil and pick-up coil
(b) The bone structure of the ultra slim W-type primary coil

In the 3rd generation of OLEV, by adopting fish bone like core structure depicted in Fig. 7(b), the amount of core is reduced to 1/5 compared to the 2nd generation of OLEV, whereas the output power is improved to 17kW per pick-up. By adopting bone core structure, the concrete pouring method is now applicable. It means that the mechanical durability of primary coil is substantially increased.

The decrease of magnetic flux transferred from primary coil to pick-up coil due to the bone structure is negligible as shown in Fig. 8. For the gap of bone structure is 7cm, the decrease of the magnetic flux is only 16%.

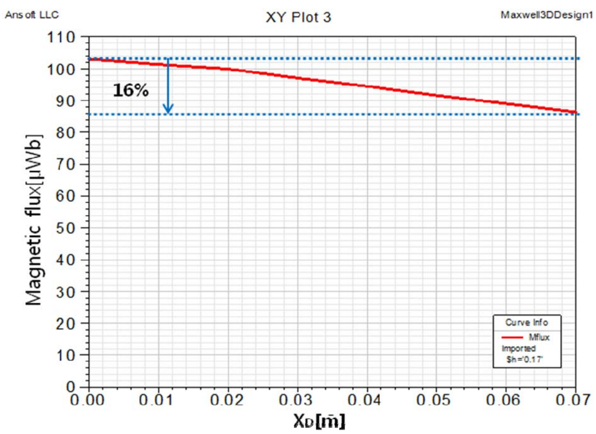


Fig. 8 The simulated magnetic flux transferred from primary coil to pick-up coil with the primary core gap (X_D) variation

The measured power efficiency for an OLEV SUV with the 3rd generation IPT system is 71% at 17cm air gap. The nominal primary frequency and current are the same as the 2nd generation case, respectively. The OLEV SUV has been successfully demonstrated for more than 10 months.

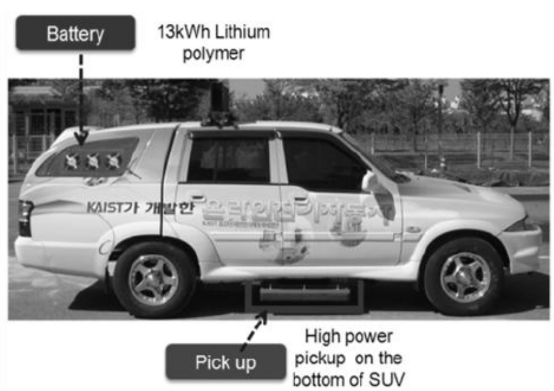


Fig. 9 The 3rd generation of OLEV SUV

III. Conclusion

The OLEV is not only the most promising alternative of the gasoline vehicle but also the most practical approach to the EV. Our three generations of OLEV using the new concept of primary and pick-up coil structures can be applicable to the IPTS of EV. Especially the 2nd and the 3rd generations of OLEV show more than 70% efficiency at 17 cm air gap. These two generations of OLEV have been successfully demonstrated by a bus and an SUV in 2009.

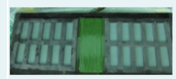
	1G	2G	3G
Open Date	2009. 2. 27	2009. 7. 14	2009. 8. 14
Vehicle			
Pick-up			
Air gap	1cm	17cm	17cm
Efficiency	80%	72%	71%
EMF@1.75m	< 10mG	51mG	50mG
Unit power	3kW	6kW	17kW
Weight	10kg	80kg	110kg

Fig. 10 The three generations of KAIST OLEV

Acknowledgment

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