38th International Electric Vehicle Symposium and Exhibition (EVS38) Göteborg, Sweden, June 15-18, 2025

Heat dissipation performance of a lightweight and thin wireless power receive coil unit for EVs

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Executive Summary

With the spread of EVs, there are increasing expectations for wireless power transfer (WPT) systems that can be easily recharged. The authors have developed a sheet coil unit for WPT that is thinner and lightweight compared to conventional coil unit using Litz wire. For shortening the charging time and/or to charge to large vehicles higher power is expected to be transmitted. The other hand heat generated during power transmission as joule loss should be dissipated from unit to outside. We have investigated dissipate ability of the sheet coil unit and found that heat can be dissipated to outside effectively. In this paper experimental results under various environmental condition are reported.

Keywords: Wireless power transfer, Thermal management, Thinner component, High productivity, Reduce resources

1 Introduction

Today, motorization of EV has been promoted globally, and there is an increasing interest in wireless charging technology that can be easily recharged. SAE-J-2954 [1]and other standardization organizations are also examining a magnetic field resonance method in the 85 kHz band.

As the number of EVs is expected to increase dramatically in the future, there will be a need to supply WPT receiving units for installation in these vehicles. It would be difficult to meet this requirement with conventional hand wound Litz wire coils. We have already proposed a thin WPT receiving unit that can be high speed automatically manufactured. [2] Since installing WPT receiving units on so many EVs means that a large amount of copper will be stored, it is also important to reduce the amount of copper used. We also proposed a significant reduction in the copper used in the receiver coil unit. [3]

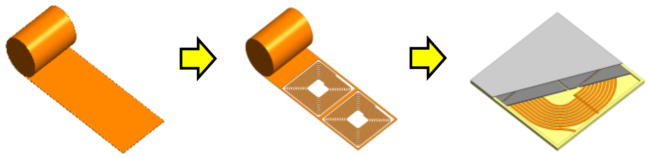
In addition to the supply issues mentioned above, we must also take safety into consideration when designing receiving units. Generally, when receiving large power, the Joule heat generated by the coil current is released to the outside from the receiving unit using a water-cooling system. However, the water-cooling systems occupies space, and the water coolant must be drawn from the vehicle, making the system complicated. From this perspective, heat dissipation through natural cooling is preferable, but to achieve this, heat needs to be released to the outside efficiently. On the other hand, the environmental temperature may be rising due to various factors such as weather conditions, the surrounding road surface temperature, and heat generated by the vehicle itself such as plug in hybrid vehicles.

In this paper, we report the results of measuring the heat dissipation capacity of our thin receiving unit under the worst-case environmental conditions during high power charging.

2 Receiving unit

2.1 Manufacturing process

Fig.1 shows manufacturing process of receiving units. As first step coil patterned by punching process from copper foil. Since optimal width and thickness copper foil is prepared as starting material for product, yield of material can be kept higher, and the remaining copper material can be easily reused. As following step patterned copper coil is fixed in case by molding process with forming case of receiving unit. Then A ferrite plate is placed on the coil and finally closed with an aluminum shield.



(a)Copper foil (b) Patterning (c) Assy

Fig.1 Image of manufacturing process

2.2 Structure of receiving unit

Fig.2 shows cross section of the receiving unit. Patterned thin copper coil is integrated with the case by molding process. There is no material and space to be thermal insulator between copper surface and case. This boundary condition is very important point for capacity of hear release. The other surface of copper coil is covered by thermally conductive material. Similar material is set also between ferrite plates and aluminum shield. Another feature of the receiving unit is that the ferrite plate and aluminum shield can be placed close to each other. In addition, the receiving unit does not use a cooling system, resulting it makes possible an ultra-thin unit.

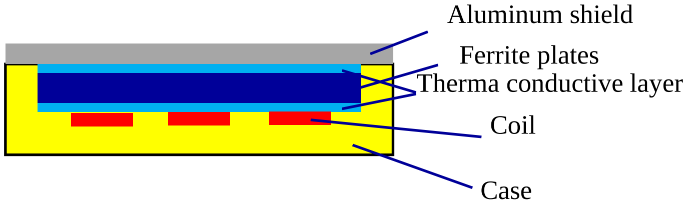


Fig.2 Cross section of unit

3 Experimental

3.1 Test sample

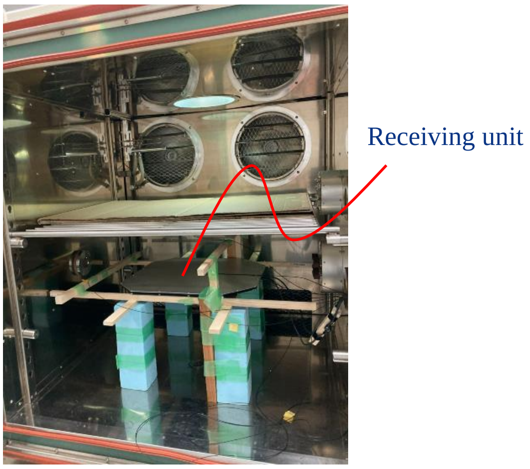
Features of sample unit for this experiment are shown in Table.1 A cooper layer is 1 mm thickness and integrated in the case by molding process and the case is completely sealed by aluminum plate. Total thickness of the unit is 16mm.

Table 1: Features of test unit

Items/unit	Value
Dimensions of unit /mm	470 x 470 x 16
Ferrites plates /mm	420 x 420 x 5
Coil / mm	395 x 395 x 1
Number of turns	14
Inductance / 10^{-6}H	88.0
Impedance/ Ohms	0.23
Q factor	202

3.2 Equipment and test condition

Fig.3 shows pictures of (a) test equipment and (b) set up. A sample receiving unit is set inside of the equipment with enough distance from floor and walls made by metal to care coupling with these metals. Environmental temperature around receiving unit can be controlled by equipment. Resonance capacitor and inverter are connected with coil of receiving unit at outside of the equipment and 85kHz high frequency (HF) current is applied to coil of receiving unit.



(a) Test Equipment (b) Sample set up (Inside)

(b) Fig.3 appearance of equipment

Fig.4 illustrates temperature measurement points of the experiment as cross sectional points. Fig.5 is thermal photo of sample receiving unit when HF current is applied. Horizontal location of measurement points is set by referring to this picture. As shown in the figure most inner turn of coil is temperature highest area of this unit. 8 channels of thermal senser are used for this experiment. Ch1 is set at highest temperature point on the copper coil. This point is assumed highest temperature point of this unit and maximum temperature of this unit is set at 150 °C for safety operation. Ch2, Ch3, Ch4 and Ch7 is horizontally same position as Ch1. Ch2 is measured at on the bottom surface of case and Ch3 is at top surface of aluminum shield plate, Cha 4 is about 10 mm vertically below from Ch2, and Ch7 is about 120mm vertically above from Ch3 respectively. In addition, Ch5 is locating same height as Ch 4 vertically and at the outermost turn of coil reason horizontally and Ch6 is about 100mm distance from the edge of case, Ch8 is on the cooper coil at outermost turn. The IEC 61980-1 standard [4] specifies that the average environmental temperature for testing is 40°C. Referring it 45°C as environmental temperature is set for 1 condition, which is 5 °C higher than suggested level. Furthermore, temperature around the engine of PHEVs is assumed to become very hot, so considering it 80°C is set for another condition.

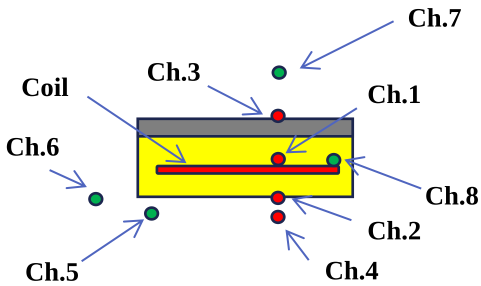


Fig.4 Temperature measurement points

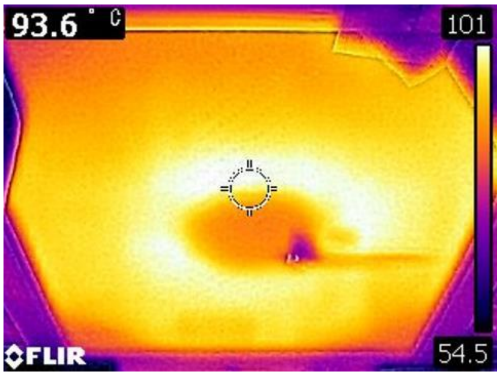


Fig.5 Thermal photo of unit

4 Result and discussion

Fig. 6 shows the measurement results of temperature transitions for Ch1-4. Left half side is result for 45°C as environmental temperature (Condition 1) and right half side is for 80°C (Condition 2). 3 different currents are applied to the coil for each condition, 30-40 arms for condition 1 and 25-35 arms for condition 2. The applied current was changed only after the temperature had nearly saturated. The coil surface temperature (Ch1), which is the heat source, was the highest, followed by the bottom of the case (Ch2) and the aluminum shield surface (Ch3). Here, the temperature of the bottom of the case (Ch2) is higher than Ch3, which means that this heat dissipation path has a lower thermal resistance.

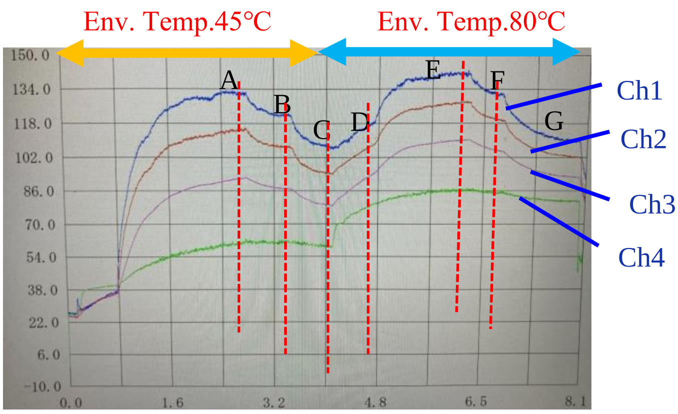


Fig. 6 Measurement results

Table 2 shows lists of saturated temperatures for all channels for various condition.

Table 2 shows lists of saturated temperatures for various conditions.

Env. Temp./ °C	Coil Current /Arms	Ch1	Ch2	Ch3	Ch4	Ch5	Ch6	Ch7	Ch8
45	40	133	115	92	60	64	54	54	104
	35	122	107	87	61	64	55	55	97
	30	107	94	79	59	62	55	55	87
80	35	142	1128	110	86	89	78	81	119
	30	132	119	105	85	88	81	81	114
	25	110	102	93	81	83	80	80	99

Ch6 and Ch7 are locating with distance from the unit and temperature level are almost independent on applied current values. The results showed that the heat generated by the unit had little impact on the surrounding area. Conversely, the coil temperature was affected by the ambient temperature, and when compared at the same coil current, it showed a temperature difference of 20-25°C, but this was smaller than the ambient temperature difference of 35°C.

Important measured values are shown in Fig.7. in this figure horizontal axis is represented as power loss that is calculated from impedance and applied current value This result showed that coil temperature, which is highest in the unit, does not increase linearly with increasing losses and showed that this coil unit can more than 300W of heat release to outside without any additional cooling system even if under severe environmental temperature conditions of 80°C. The amount of power that can be received varies depending on conditions such as coupling, but if the loss rate of this unit is 2%, it can receive 15kW of power.

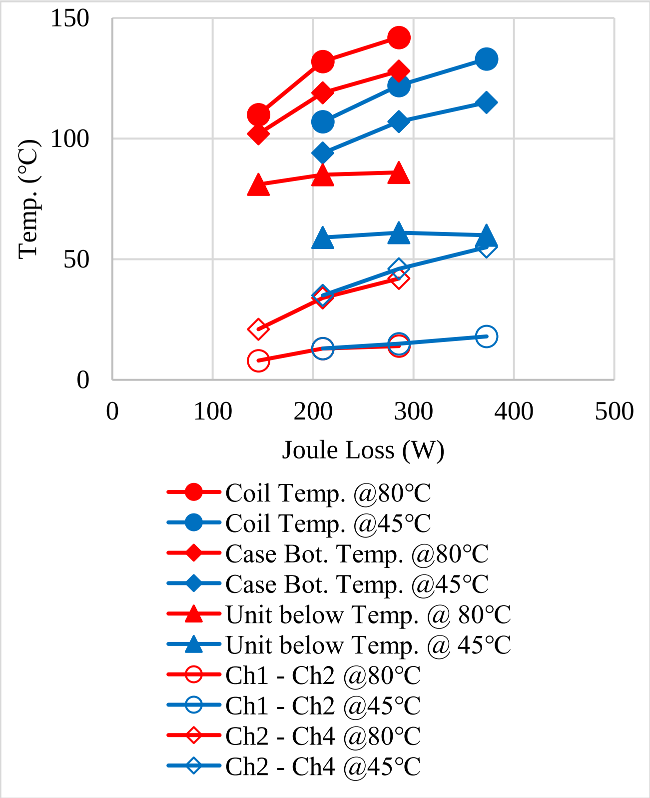


Fig.7 Important measured values

We have considered the reason why heat dissipation capacity of the unit showed high performance is mentioned as below by this figure. We are focusing the temperature difference between Ch1 and Ch2 level is kept small for all conditions. This means that heat resistivity of this pass is small. Resulting, temperature difference between Ch2 and Ch4 is increase relate to increase of coil temperature. Heat dissipation capacity depends on temperature difference at boundary, so this unit is assumed high performance for heat dissipation. The low thermal resistance between the coil and the case surface is assumed because the coil is integrated into the case, creating an ideal interface.

Here, back to table 2, this unit is before optimization of coil pattern, and sill remaining temperature difference between in coil temperature (see Ch1 and Ch8). this technology can design coil pattern to uniform heat generate density then it makes possible to improve heat dissipate capacity higher than current level.

Acknowledgments

I would like to thank all the suppliers who provided the materials for this research and to Mr. Miyazaki, Mr. Tominaga, Mr. Kanayama and Mr. Ichikawa who supported this research.

References

[1] https://www.sae.org/standards.

[2] https://www.evtec.jp/2021/, Dai Nippon Printing

[3] https://www.evtec.jp/2023/, Dai Nippon Printing

[4] IEC61980-1

Presenter Biography

Master's degree in nuclear engineering at Tokyo Institute of Technology in 1989 and joined Dai Nippon Printing.
Currently in charge, development of wireless power transmission coil for EVs.