Multilayered thin type lightweight coil for wireless power transmission for EV and leakage magnetic field suppression effect

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Abstract

The authors are studying a coil with a structure in which a plurality of flat coils is laminated instead of winding a Litz wire. We found the effect of suppressing the leakage magnetic field to the outside by changing the winding pattern of each layer. The multi-layered coil that can be manufactured by a general electronic substrate production process has excellent mass productivity, and can be realized thinner and lightweight, then consequently can save material resources.

Keywords: wireless charging, EV (electric vehicle), PHEV (plug in hybrid electric vehicle), infrastructure, smart charging

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. In the case of transmitting a high power, there is a concern about the harmful influence on peripheral devices and the human bodies due to the leakage magnetic field. And in order to suppress the temperature rise, it is necessary to use a thick electric wire containing a large amount of copper. In the situation of dramatically growing number of electric vehicles and to use the wireless power charging system conveniently, we believe that the system must be safe and we should consider the earth resources such as copper. We have developed a multilayered coil composed of multiple coil-layers made of thin copper foil. And we have also found that by using this multi-layered coil, the leakage magnetic field in power transmission is greatly reduced. In addition, compared with conventional coil using Litz wire, we drastically managed to reduce the consumption of copper and realized a significant reduction in weight of coil and thin shape. The multi-layered coil that can be manufactured by a general electronic substrate production process has excellent mass productivity. In this paper, we will describe the multi-layered coil of new concept.

2 Coil design and fabrication

A part of the sectional structure of a prototyped coil is shown in Fig. 1.Thickness of each three layers of copper (L1, L2, L3) is 0.2 mm. The interval between L1 and L2 is 0.2 mm, while the interval between L2 and L3 is 0.4 mm, which means the total thickness of the coil is 1.2 mm and the planar size of the coil is 300x300mm. We chose Glass epoxy as the material for the

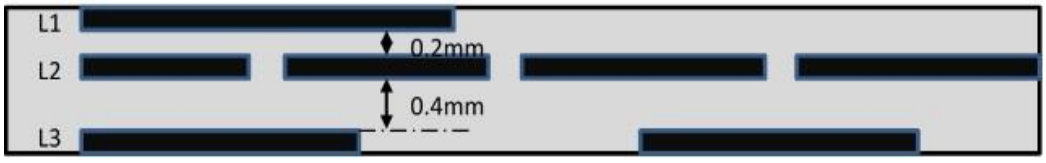

Fig.1 Cross-sectional structure of multi-layered coil

interlayer insulating layers of the copper each other.

In the production process of the coil, the three-layer substrate [copper / Glass epoxy / copper] is etched on both sides to form L1 and L2, followed by heat-setting the copper with the insulating layer interposed therebetween, then etched to form L3. The weight of the coil was around 0.5 kg. This is approximately a quarter of the weight of typical Litz wire[2].

3 Suppression of leakage magnetic field

Simulation result of the leakage magnetic field is shown in Fig.2. The conditions are shown in Table 1

Table 1: Simulation conditions

Coil size (mm)	Transmitter:300x300 Receiver:300x300
Distance between coils(mm)	120
Power(kW)	11
Simulation Area(m)	4 x 4 x 1

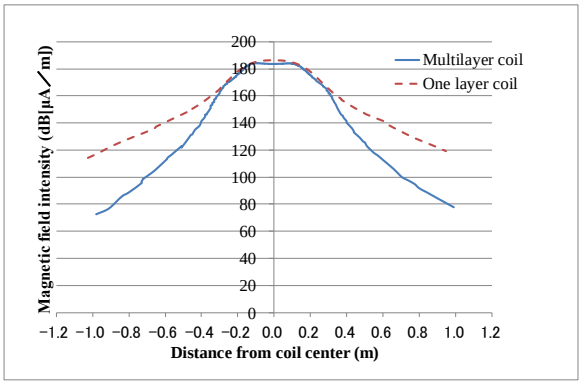

Fig.2 Leakage magnetic field intensity

The leakage magnetic field attenuated significantly. At the position of only 1 m from coil centre it declined to the vicinity of 68.4 dB which is considered as the recommended value of CISPR. And at the position of 10 m, it can be expected that it attenuates to a value considerably smaller than this value. The dotted line is the result for a coil of one layer structure for comparison. A difference of about 40 dB can be seen in the magnetic field intensity at 1 m. Fig.3 shows attenuation of magnetic flux density distribution. Here, a 0.9 x 0.9 m square aluminium plate is installed on the vehicle side coil to protect the passengers. And the vehicle body is assumed to be composed of CFRP. Since the area where the magnetic flux density exceeds the safety guideline for medical equipment[3] is inside the radius of about 400 mm, it is sufficient to care only this narrow area. CFRP is more permeable to magnetic fields than metals, but cabin space is also kept safe

The principle of suppressing the leakage magnetic field to be low is described below. Fig.4 shows directions of currents flowing in L1 and L2 layer. While the current in the L1 layer is in the clockwise direction, the current in L2 flows counter-clockwise and the mutual phase is inverted. In this way, it is presumed that the leakage magnetic field is suppressed by the action of cancelling the magnetic fields respectively.

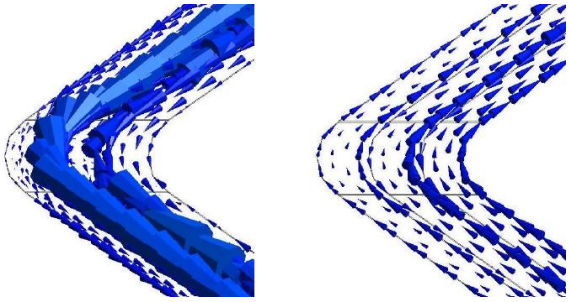

Fig.4 Current directions in cupper layers (a) Current direction of L1 (b) Current direction of L2

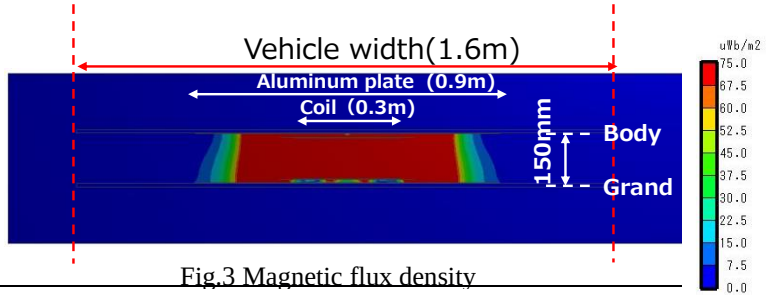

Fig.3 Magnetic flux density

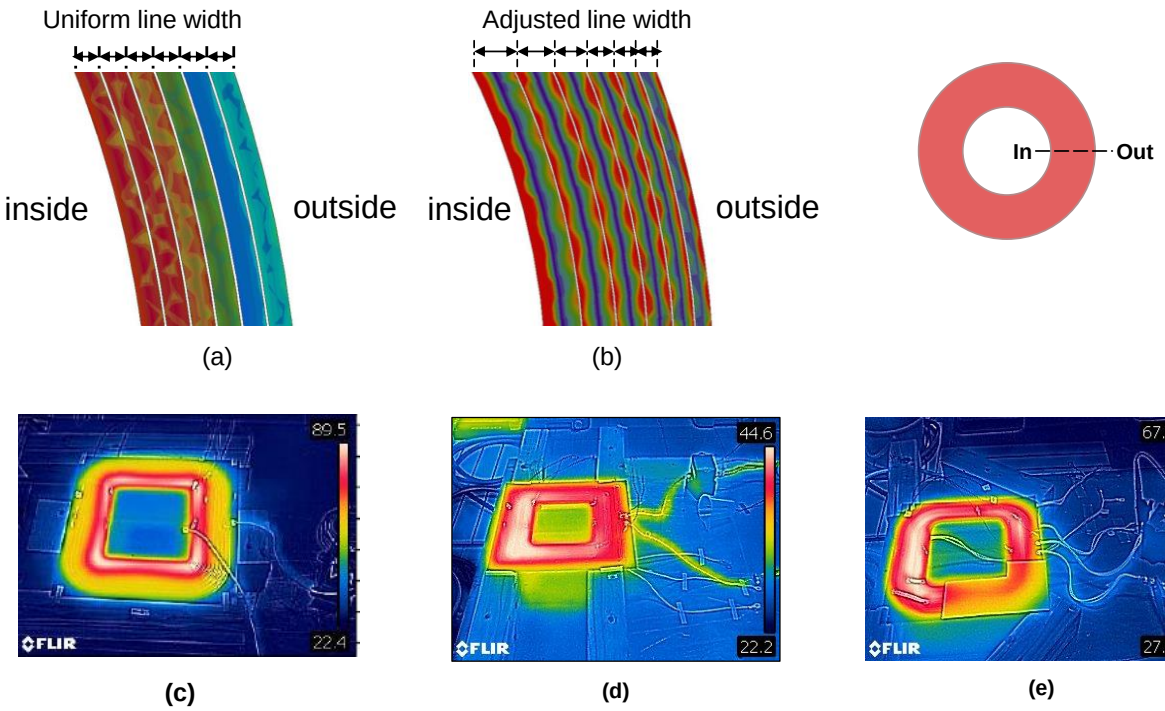

Fig.5 Thermographic images of coil surface when current of 20 A is flowing

4 Control of Joule's heat

Since the conventional coil is surrounded by a member made of a material with high thermal insulation properties, the heat radiation is low. In order to suppress Joule's heat, it is necessary to use a low resistance Litz wire, which causes the increase of its weight as well as its cost. In this section, we will explain control of Joule's heat and how to reduce consumption of copper material as follows.

Generally, during power transmission, the magnetic field density is higher at the centre of the coil and lower at the periphery of the coil. The results of simulating the current density are shown in (a) and (b) of FIG. 5 when the wire width is made uniform and when the wire width is changed. Wire width is made uniform, the current density closer to the coil centre becomes higher. Fig. 5 (c) and (d) shows thermographic images of the surface temperature when a current of 20 A is applied to a coil having a uniform line width and a coil having a wider central portion and a narrower end. While the temperature rises near the centre of the coil of uniform width to about 90 ° C., the coil whose width is adjusted is kept at 45 ° C. or less overall. As described above, in the coil manufactured by etching copper foil, since the line width can be designed freely, the amount of copper can be reduced to the optimum amount.

Keeping the surface temperature of the coil low is effective to reduce the risk of an accident such as ignition which occurs when foreign matter such as metal is heated by electric current. An example of the cooling effect of the coil surface by a heat dissipation sheet is shown in Fig.5 (e).

Fig. 6 shows temperature rise process on the highest temperature position on the coil and on the cooling sheet. Cooling effect of 15 degrees or more was confirmed by cooling sheet. By installing it on the car body etc. via the cooling sheet, further heat radiation effect can be expected.

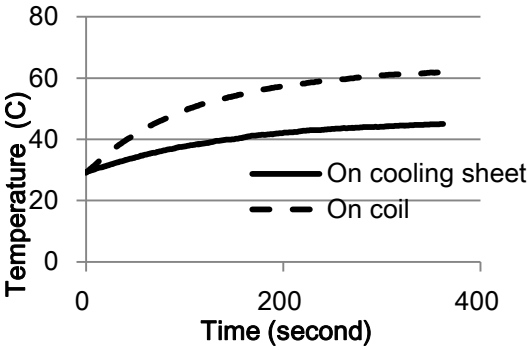

Fig.6 Heat radiation experiment using a cooling sheet

As for the cooling sheet, general products can be widely applied.

5 Conclusion

This paper presents a new concept multilayer coil made of copper foil. This coil has the following advantages. (1) The leakage magnetic field is small, and high power can be safely transmitted. (2) Thin and lightweight. By optimizing the wiring pattern such as layer configuration and adjusting the line width, efficient current flow and Joule heat reduction are realized. Furthermore, it was also shown that the coil surface temperature can be kept low due to the effect of the heat dissipation sheet. (3) It is excellent in mass productivity and can reduce the amount of copper used.

References

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[3]*https://www.iso.org/obp/ui/#iso:std:iso:14117:ed-1:v1:en* 06

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Currently in charge, development of wireless power transmission coil for EV.