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New I-Shaped Core of Induction Heating Coil for Small-Foreign-Metal Particles Detector Using an SiC-MOSFET High-Frequency Inverter

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***Abstract*–A new I-shaped core of Induction heating (IH) coils, which can reduce the iron loss, is proposed for an SiC-MOSFET high-frequency-inverter-based small-foreign-metal particles (SFMPs) detector. Magnetic field analysis results using JSOL JMAG software, a 3D full-wave electromagnetic field simulation software, demonstrate that the iron loss caused by the new I-shaped core for IH coils is decreased by 38.8 % as compared with that of the conventional I-shaped core for IH coils. It is concluded that the stable and continuous operation of the SFMP detector with the newly proposed I-shaped core shape for IH coils can be achieved.**

***Index Terms*–high-performance chemical lms, SiC-MOSFET high-frequency inverter, induction heating, small-foreign-metal particle detection, iron loss**

1 Introduction

High-performance chemical films (HPCFs) are widely used in lithium-ion batteries (LiBs), flat panel displays of notebook computers, notepads, and mobile phones. The HPCFs are used as separators between a positive electrode and negative electrode in LiBs. The material of the HPCFs is plastic, and the required thickness of the HPCFs is less than 0.1 mm. During the manufacturing processes of the HPCFs, small-foreign-metal particles (SFMPs) produced by manufacturing machines are occasionally adhered to the HPCFs. Most SFMPs materials are made of small stainless-steel (SUS304) because the manufacturing machines for the HPCFs are constructed with SUS304. The diameter of adhered on SFMPs is 0.1 mm class. It is well known that overheating LiBs due to the SFMPs adhered on the separators with the HPCFs [1, 2]. Thus, detecting SFMPs adhered on the HPCFs is required for practical continuous production lines of HPCFs in industries.

The present authors proposed an induction heating (IH)-based SFMPs detector with a 400 kHz SiC-MOSFET high-frequency inverter. Fig. 1 shows a block diagram of the IH-based SFMPs detector using an SiC-MOSFET high-frequency-inverter [3, 4]. The IH coils shown in Fig. 1 consist of I- and E-shaped cores. Litz wire is used to construct IH coils on legs of E-shaped core. The turn numbers of coils on each core leg is five turns. The IH coils generate high-frequency magnetic flux in the core gap between E- and I-shaped cores, and the core gap length l_g is 4 mm. Just manufactured HPCFs are carried at the height of 3 mm from the upper-surface of the E-shaped cores. As the IH coils produce a high-frequency magnetic flux in the core gap, the SFMPs on the HPCFs are heated, and then observed by a thermographic camera. In [3] and [4], however, the I-shaped core is heated by the iron loss, and then the HPCF is heated by the I-shaped core. This results in a difficulty to observe the SFMPs adhered to the HPCF. Thus, reducing the iron loss is required for the practical continuous production lines of HPCFs.

This paper proposes a new I-shaped core of IH coils, which can reduce the iron loss, is proposed for an SiC-MOSFET high-frequency-inverter-based SFMPs detector. Magnetic field analysis results using JSOL JMAG software, a 3D full-wave electromagnetic field simulation software, demonstrate that the iron loss caused by the new I-shaped core for IH coils is decreased by 38.8 % as compared with that of the conventional I-shaped core for IH coils.

2 New I-shaped core with reduced iron loss

Fig. 2 shows the core shapes of IH coils for the IH-based SFMPs detector with an SiC-MOSFET high-frequency inverter. Fig. 2(a) shows the conventional I-shaped core used in [3], [4]. Fig. 2(b) shows the newly proposed I-shaped core. The conventional I-shaped core is with three short legs, the length of which is 2 mm in the newly proposed I-shaped core. Generally, the iron loss is inversely proportional to the core thickness in the conventional I-shaped core. Therefore, iron loss can be reduced by changing the core thickness to 20 mm. The thickness of 20 mm was decided with simulation results using JSOL JMAG software. The magnetic flux, generally, passes near the surface in the I-shaped core. This is because the magnetic path length in the I-shaped core for the magnetic flux is the shortest. This results in a larger

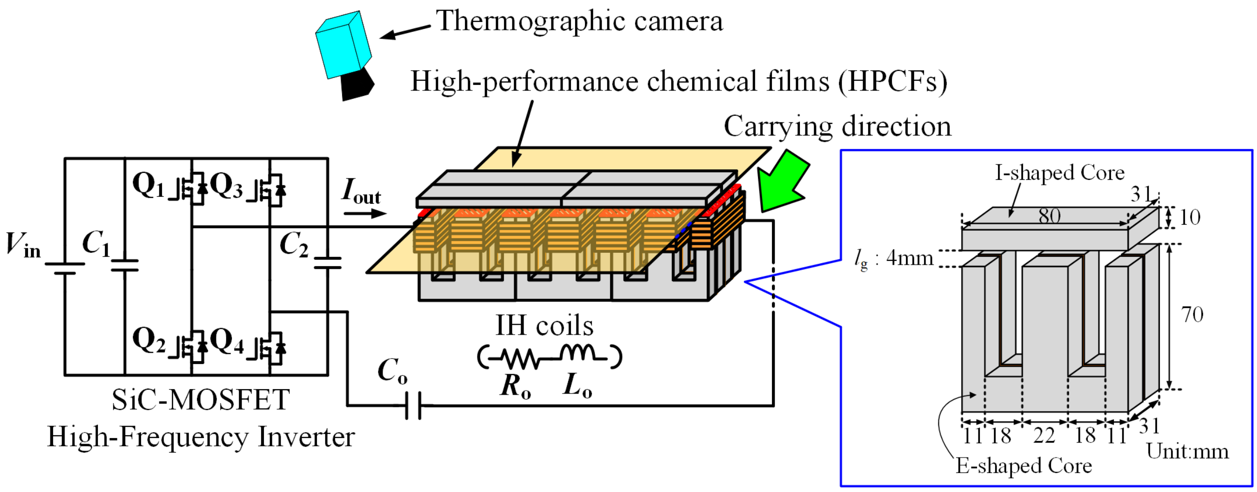
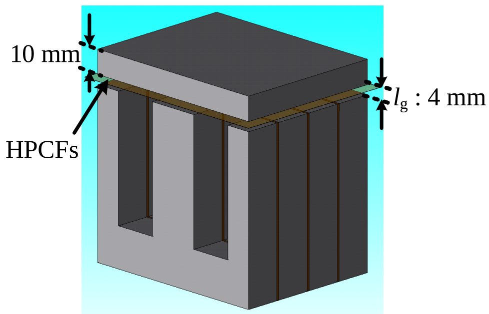
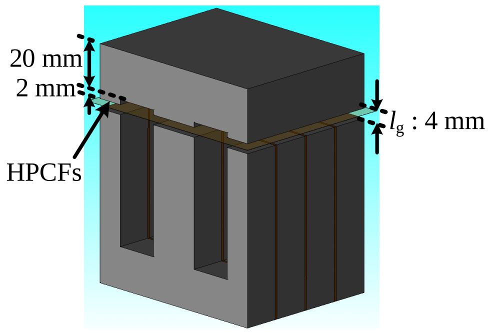


Figure 1: Block diagram of high-frequency-induction-heating-based small-foreign-metal particles detector with 400 kHz SiC-MOSFET high-frequency-inverter.



(a) Conventional I-shaped core.



(b) Newly proposed I-shaped core.

Figure 2: Dimensions of conventional and newly proposed I-shaped cores.

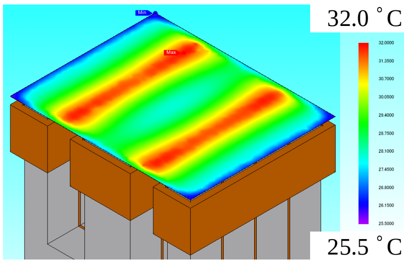
Table 1: Iron-loss comparisons.

	Fig. 2(a)	**Fig. 2(b)**
Total loss W	15.0	9.3
Joule loss W	6.0	5.2
Hysteresis loss W	9.0	4.1

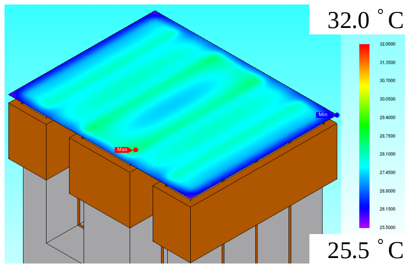
iron loss in the core. This larger iron loss heats the HPCF. Heating of the HPCF results in a difficulty to observe the SFMPs adhered to the HPCF in the practical continuous production lines of HPCFs in [3] and [4] with the I-shaped core of Fig. 2(a). In Fig. 2(b), however, the distance between the surface of the I-shaped core with the thickness of 20 mm and the surface of the HPCFs is longer by 2 mm as compared with that in Fig. 2(a). The thermal transfer from the surface of the I-shaped core to the HPCFs can be avoided in Fig. 2(b). Thus, the IH coils with the newly proposed I-shaped core for the SiC-MOSFET high-frequency-inverter-based SFMPs detector is effective for the practical continuous production lines of HPCFs.

3 Magnetic field analysis results

The validity and high practicability of the newly proposed I-shaped core in Fig. 2(b) are confirmed by magnetic field analysis using JSOL JMAG. Fig. 3 shows magnetic field analysis results for Fig. 2, where the output frequency of the SiC-MOSFET high frequency inverter is 400 kHz, the coil current I is 30 Arms, the gap between the E- and I-shaped cores l_g is 4 mm, the magnetic ux in the core gap between E- and I-shaped cores is 48 mT, the thermal conductivity of the HPCF is 0.29 W/mK, the initial temperature of cores and HPCF are 25.0 °C, and the operation time of the SFMPs detector in Fig. 1 is 60 s, respectively. Fig. 3(a) shows magnetic field analysis results of HPCF with the conventional I-shaped core. This demonstrates that the thermal transfer from the surface of the conventional I-shaped core to the HPCFs occurs. The highest temperature on the surface of HPCFs is 31.9 °C. Fig. 3(b) shows simulation results of HPCF with the newly proposed I-shaped core. The highest temperature on the surface of HPCFs is 28.4 °C. Thus, the thermal transfer from the surface of the newly proposed I-shaped core to



(a) Temperature on surface of HPCFs with conventional I-shaped core.



(b) Temperature on surface of HPCFs with newly proposed I-shaped core.

Figure 3: Thermal analysis results of HPCFs.

the HPCFs is dynamically reduced. Table 1 shows iron-loss comparisons between those in the conventional I-shaped core and those in the newly proposed I-shaped core. As well known that the iron losses in the cores are caused by joule and hysteresis losses. In the conventional I-shaped core, the joule loss is 6.0 W, and the hysteresis loss is 9.0 W, respectively. Thus, the total iron loss is 15.0 W. The total iron loss in the newly proposed I-shaped core is 9.3 W while the joule loss is 5.2 W, and the hysteresis loss is 4.1 W, respectively. The iron loss in the newly proposed I-shaped core is reduced by 38.8 % as compared to that in the conventional I-shaped core.

4 Conclusion

This paper has proposed a new I-shaped core of IH coils, which can reduce the iron loss, is proposed for an SiC-MOSFET high-frequency-inverter-based SFMPs detector. Magnetic field analysis results using JSOL JMAG software have demonstrated that the iron loss caused by the new I-shaped core is decreased by 38.8 % as compared with that of the conventional I-shaped core. Magnetic field analysis results have also demonstrated that the thermal transfer from the surface of the newly proposed I-shaped core to the HPCFs is dynamically reduced. It is thus concluded that the stable and continuous operation of the SFMP detector with the newly proposed I-shaped core shape for IH coils can be achieved.

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