EVTeC 2025
7th International Electric Vehicle Technology Conference 2025

20259014

2 Layers type sheet-coil unit for WPT for EV

- New coil structure saves copper resource -

Sohma Hasegawa [1)] Akane Arakawa [2)] Masato Okabe[3)]

1) Dai Nippon Printing Co., Ltd., Kashiwa, Chiba, Japan

E-mail: hasegawa-s22@mail.dnp.co.jp

2) Dai Nippon Printing Co., Ltd., Kashiwa, Chiba, Japan

E-mail: arakawa-a2@mail.dnp.co.jp

3) Dai Nippon Printing Co., Ltd., Kashiwa, Chiba, Japan

E-mail: okabe-m2@mail.dnp.co.jp

ABSTRACT: With the spread of EVs, the expectation for wireless power transfer (WPT) systems is increasing that can charge EVs easily. The authors have developed a sheet coil for this system that is thinner and lightweight compared to the conventional coil with Litz wire and have reported that it is possible to make the thinner power receiving unit installed in a vehicle by bringing the ferrite and aluminum shield closer together. In this paper, we propose that two-layer copper coil structure which can improve performance and save precious copper resources.

KEY WORDS: Wireless Power Transfer, Sheet-coil, Copper resources

1. INTRODUCTION

Today, motorization of EV has been promoted globally, and there is an increasing interest in wireless charging technology that can charge EVs easily. SAE J-2954[(1)] and other standardization organizations are also examining a magnetic field resonance method in the 85 kHz band. To suppress the temperature, rise of coil and unit in the case of transmitting a high power, 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 should consider the resources on the earth, such as copper. Copper is an important resource, and demand has been increasing rapidly in recent years, raising concerns about resource depletion. Copper prices are also expected to rise, which must be reflected in the product prices. From this perspective, we should also consider reducing the amount of copper used in EVs, which are expected to expand rapidly.

We reported that the leakage magnetic field can be reduced by using a multilayer structure of thin coils: 1st generation (GEN1)[(2)]. Then we have also significantly improved the coil structure to save copper resources. On the other hand, we also developed a structure suitable for automatic and high-speed manufacturing processes: 2nd generation (GEN2)[(3)]. However, GEN2 technology has insufficient performance for safety high-power transmission, and like conventional technology, it is necessary to ensure a distance between the ferrite plates and aluminum shield, and the thickness of the unit is not satisfactory. From this perspective, we made further improvements and succeeded in making the unit ultra-thin: 3rd generation (GEN3)[(4)].

The GEN2 and GEN3 technologies we have reported that both had a single-layer structure, but in this paper, we report that a two-layer structure has the potential for further improved performance and save copper resources. In addition, we will also propose new ideas to reduce the amount of copper used significantly.

2. DESIGN OF COIL UNITS

2.1. Configuration of coil unit

In this paper, the coil patterns and sizes refer to the WPT3/Z1 class VA unit of SAE J-2954. Fig. 1shows an example of the coil pattern and unit structure. GEN2 and GEN3 have different structures, the copper coil in GEN3 is surrounded by a resin layer containing magnetic material (magnetic resin). This magnetic resin is a new additional structure in GEN3, so it is not included in GEN2.

In this paper, a single-layer coil with GEN2 structure (GEN2/1L), a single-layer with GEN3 structure (GEN3/1L), and a two-layer coil with GEN3 structure (GEN3/2L) are used for comparison and discussion.

Coil pitch of coil pattern are noted, respectively. The coil pitch of GEN2/1L and GEN3/1L, which are single-layer coil structures, are both 10 mm, while two-layers coil GEN3/2L is designed at 20 mm. The GEN2/1L and GEN3/1L units have 10 turns, while the GEN3/2L unit has a total of 10 turns in 5 turns x 2 layers. The evaluation was performed with a uniformed number of coil-turns.

Fig. 2 shows a cross-sectional view of the GEN3 coil. The magnetic resin part is shown in light blue, and coil, ferrite plate and aluminum shield in the same color as Fig. 1. The magnetic resin is inserted between the coil lines as shown in Fig. 2(b) and (c) to reduce the proximity effect between the coil lines. The magnetic resin consists of a component positioned between the ferrite coil and a portion that protrudes from between the coil lines; the height of this protrusion is 3 mm, as stated in this paper. The gap between the two layers of the GEN3/2L coil is set to 2 mm to ensure sufficient insulation.

2.2. Simulation

Electrical characteristics were calculated by electromagnetic field simulation with Murata Software's "Femtet" [5]. For optimization, simulations were performed for various line widths. In this paper, the comparisons and evaluations were carried out based on Q factors obtained from simulations.

2.2.1. Optimization of line width

As sheet coils have different Q factors depending on the line width, the line width needs to be optimized before comparing each coil structure. Fig. 3 shows Q values calculated for various line widths. It can be seen that each coil structure has a peak Q- factor. This is considered that as the line width becomes wider, the coil resistance tends to decrease because the cross-sectional area of the line increases. However, at the same time, the distance between adjacent lines becomes closer and interference due to proximity effects increases. As a result, when the line width increases to the certain dimension, the coil resistance starts to increase, and the Q-factor decreases. From Fig. 3, the line width that maximizes the Q factor in the analysis is the optimum line width. The optimal line width for each coil structure is about 5 mm for GEN2/1L, 8 mm for GEN3/1L, and 12 mm for GEN3/2L. Thereafter, these values are used as the optimum line widths for the analysis.

Compared to the GEN2/1L, the GEN3/1L could improve the Q-factor to 2.2 times by using a magnetic resin and reducing the proximity effect. In addition, the GEN3/2L coil has a Q factor that is 1.4 times higher than that of the GEN3/1L coil.

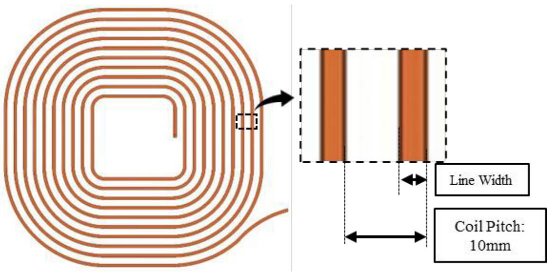

Fig. 1 An example of coil patten and unit (GEN1)

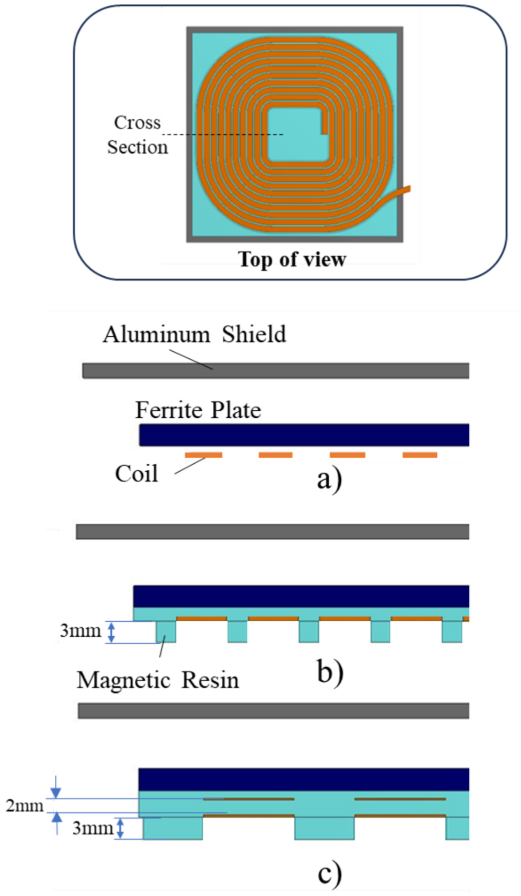

Fig. 2 Part of cross-sectional structure of
a) GEN2/1L b) GEN3/1L c) GEN3/2L

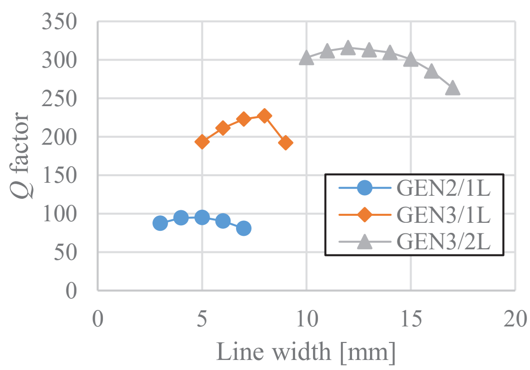

Fig. 3. Q factors calculated for various line widths

2.2.2. Thickness of Copper layers

In this section, the dependence of Q factor on copper thickness is examined. The optimum line widths for each coil structure are from the previously mentioned values.

Fig. 4 shows the relationships between copper thickness layer and Q factor. Here, the copper thickness of the GEN3/2L coil represents the total thickness of the first and second layers. From Fig. 4, The Q factor gradually improves as the copper thickness increases, and saturates at 0.5 to 0.7 mm. The Q factors for each structure converged to 110 for GEN2/1L, 231 for GEN3/1L, and 330 for GEN3/2L, respectively. The improved Q-factor is considered to result from the thicker coil and the increased surface area, which together contribute to a reduced resistance value. The convergence of Q factors can be explained as follows. When the surface area of the coil is small, the current distribution tends to concentrate in areas smaller than the skin thickness due to proximity effects. However, as the surface area increases, this concentration is reduced, leading to a decrease in the coil's resistance. Despite this, the area through which the current can flow is limited to the skin thickness, causing the resistance to approach a saturation point. As a result, the Q factors tend to converge. Also, focusing on GEN3/2L, the Q factor of 0.3 ~ 0.4 mm copper thickness varied significantly compared to the other two configurations, increasing by 38 %.

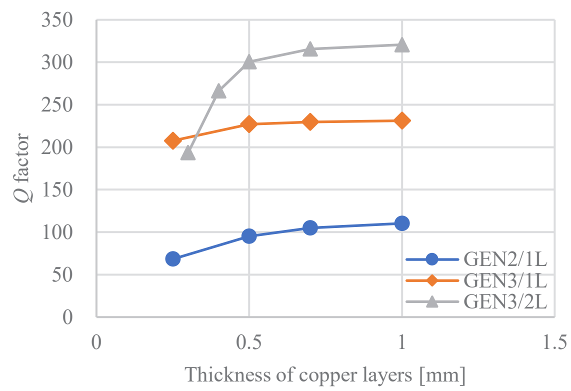

Fig. 4. Copper thickness dependence of Q factors

2.2.3. Evaluation in amount of copper use

This section focuses on the relationships between the copper amount (weight) and the Q factor. It should be required to achieve a high Q factor with a small amount of copper from the point of view of resource conservation and cost. To calculate the volume of copper used, the volume of the copper coil was derived from the analytical model used in the previous section, and its value and the specific gravity of copper were used to approximate the weight of the copper used. The specific gravity of copper is 8.96.

The relationship when the horizontal axis in Fig. 4 is converted to weight is shown in Fig. 5. Fig. 5 shows that the Q factor of GEN3/2L at around 100 g copper weight is almost equal to the GEN3/1L. However, GEN3/2L shows the highest Q factor at higher weights. For example, when 200 g of copper is used, the Q factor of GEN3/2L is about 310, which is about 40 % higher than that of GEN3/1L using the same weight of copper. In other words, when the same weight of copper used, a-two-layer structure (GEN3/2L) will perform better than a single-layer structure.

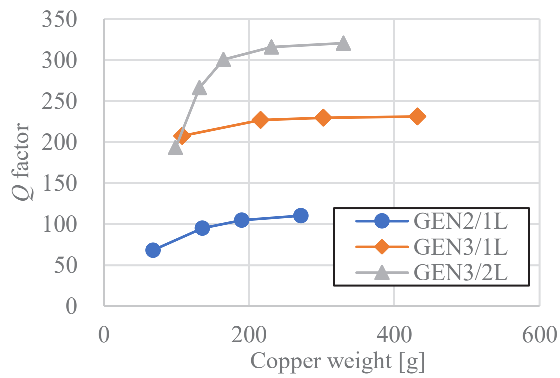

Fig. 5. Copper weight dependence of Q factors

3. AN IDEA TO REDUCE COPPER USAGE

As mentioned in the introduction, copper depletion and rising prices are expected, so we should consider about the amount of copper used. This section studies the impact and effects of replacing from copper to aluminum as a coil metal to reduce the amount of copper used. The coil used for the study is a GEN3/2L structure.

Table 1 shows the Q factors when coils each layer are replaced with aluminum. In addition, η_{max} is calculated from equation (1). where Q_2 = 300 and k = 0.1 are fixed respectively, and Q_1 is calculated using the values from the simulation results.

$$\eta_{max} = \frac{k^2 Q_1 Q_2}{\left(1 + \sqrt{k^2 Q_1 Q_2}\right)^2} \times 100 \tag{1}$$

The analytical model is a coil taken from the GEN3/2L simulation in the previous chapter, with the copper and aluminum coils connected at the innermost turn. Table 1 shows that if 1st layer is converted to aluminum, the amount of copper used can be reduced by around 70 %, but the Q factor drops by 9 % (i)(ii). The trend is also the same when the coil converted to aluminum is replaced, with a 30 % decrease in copper and a 19 % decrease in Q factor. The differences occurring in (ii) and (iii) are because of the different thicknesses of each layers. Using equation (1) to calculate the maximum transmission efficiency $\eta_{\max}$, it is shown that it is about 1 % different from before the replacement with aluminum. Then, when both layers are converted to aluminum (iv) is simulated, the Q factor decreases by about 25 % compared to a coil of the same structure, and η_{max} decreases by about 1 % as in (ii) and (iii), suggesting that there will be no significant effect on transmission. The simulation results show that switching to aluminum for one of the two layers of coils reduces the usage of copper by 70 %, while reducing the Q factor by 9 %.

In this section, simulations are carried out with coils of the same structure for comparison, but as in the previous chapter, there is a good possibility that the coils of the proposed method can also be optimized. Further performance improvements can be expected by adjusting the coil thickness and pitch as in the previous chapter.

Table 1 Copper reduction and Q factors

	1st Layer	2nd Layer	Q	Q reduction	Copper reduction	η_{max}
(i)	Cu	Cu	316	-	-	94%
(ii)	Cu	AL	286	↓9%	↓70%	93%
(iii)	AL	Cu	255	↓19%	↓30%	93%
(iv)	AL	AL	235	↓25%	↓100%	93%

4. CONCLUSION

This paper discusses the structure, material and weight of the sheet coil and their relationship with the Q factor, based on simulation results.

Some of the coils in the GEN2/1L, GEN3/1L and GEN3/2L structures are included and shown in Table 2. Items #4 and #5 in Table 2 lists coils with adjusted layer thickness and improved Q factors from the previous section. The simulations show that the performance has improved dramatically from GEN2 to GEN3. The Q factor is 2.2 times higher when comparing GEN2/1L (# 1) with GEN3/1L (# 2) and a further 3.0 times higher when comparing GEN2/1L (# 1) with GEN3/2L (# 3). Further performance improvements can be expected by changing from a single-layer to a two-layer structure and the use of magnetic resins.

Comparing # 3 and # 4, the reduction in Q factor is only 7.6 %, although the use of copper is reduced by 72 %. Furthermore, # 5, in which both layers are converted to aluminum, has a Q factor 20 % lower than the other two-layer products, but compared to # 1 and # 2, which are single-layer copper coils, it shows superiority not only in Q factor but also in the weight.

In future, it is considered necessary to evaluate the performance in actual measurements, including transmission performance. In this paper, Q factors and η_{max} were used for the evaluation, but in actual equipment, iron losses, Joule losses, etc. must also be considered. It is important to make a prototype and work out the differences from simulation.

Table 2 Comparison of various coils

#	Coil Tech.	Metal	Metal weight			Q factor
			Cu (g)	Al (g)	Cu+Al (g)	
1	GEN2/1L	Cu	193	0	193	105
2	GEN3/1L	Cu	220	0	220	227
3	GEN3/2L	Cu/Cu	231	0	231	316
4	GEN3/2L	Al/Cu	66	83	149	292
5	GEN3/2L	Al/Al	0	72	72	246

ACKNOWLEDGMENT

I would like to thank all the suppliers who provided materials for this research, as well as Mr. Miyazaki and Mr. Ichikawa for their support.

REFERENCES

(1) SAE International, “Wireless Power Transfer for Light-Duty Plug in/Electric Vehicles and Alignment Methodology J2954," Issued2016-05, Revised 2022-8

(2) M. Okabe, H. Katagiri, N. Ichikawa, “Multilayered thin type lightweight coil for wireless power transmission for EV and leakage magnetic field suppression effect” 32nd Electric Vehicle Symposium (EVS32), Oct. 2016.

(3) M. Okabe, J. Otsuki, K. Miyazaki, H. Hase, H. Katagiri, “Development of thin sheet coil for EV-WPT - Proposal of a new type coil unit -,” 5th International Electric Vehicle Technology Conference (EVTeC2021), May. 2021 unpublished.

(4) A. Arakawa, M. Okabe, J. Otsuki, K. Miyazaki, H. Hase, “Sheet coil and ultra-thinner VA unit used in EV-WPT,” 6th International Electric Vehicle Technology Conference (EVTeC2023), May. 2023. unpublished.

(5) FEMTET,Available:https://www.muratasoftware.com/products/