

Ferrite Reduction in Wireless Power Transfer Pads for Automotive Applications

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This paper investigates the weight and cost reduction of wireless power transfer (WPT) pads used in automotive applications to recharge the onboard battery of an electric vehicle (EV). To achieve this, the design focuses on reducing the ferrite in the pads. Different pad configurations are numerically investigated and the results used to define a ferrite reduction strategy while preserving WPT performance are presented. In the final version experimental prototypes of ferrite layers will be proposed.

Index Terms—Wireless power transfer (WPT); electric vehicle (EV); magnetic field; weight reduction; ferrite reduction.

I. INTRODUCTION

Wireless power transfer (WPT) systems [1]-[2], particularly those based on magnetic resonance coupling (MRC), offer a promising solution for autonomous battery charging without requiring a galvanic connection. In MRC-based WPT systems, inductive coupling occurs between two coils, also referred to as pads. The primary, or transmitter (TX), pad is embedded in the road pavement, while the secondary, or receiver (RX), pad is mounted in the vehicle. Both pads are designed in compliance with the automotive standard SAE J2954 [3], and mainly consist of three layers:

1. A planar winding made of copper litz wire, which minimizes AC losses due to skin and proximity effects.
2. A nickel zinc ferrite layer that reduces magnetic flux leakage and enhances inductance values.
3. An aluminum shield that mitigates EMI/EMF effects in the surrounding area.

Ferrite is heavy and expensive. Reducing its usage not only lowers the weight of components, such as RX and TX wireless charging pads, but also decreases costs, making these systems more accessible and practical [4]. The aim of the work is a study on the possible reduction of the weight of the ferrite in a WPT pad for automotive applications.

II. WPT SYSTEM

The equivalent circuit of a WPT system with series-series (SS) compensation topology is illustrated in Fig. 1 [2], where R_1 and R_2 represent the resistances of the two WPT coils, L_1 and L_2 denote their self-inductances, and M is the mutual inductance. The coupling factor, k , is defined as $k = M / (L_1 L_2)^{1/2}$ and depends on the mutual positioning of the two coils, which can be either aligned or misaligned. At resonance frequency f_0 the excitation can be modeled by a voltage source V_s with a series resistance R_s and the load by a simple resistance R_L .

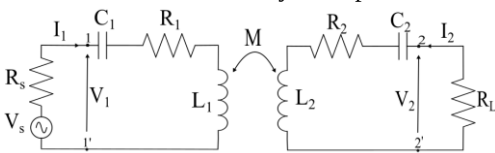


Fig. 1. Equivalent circuit of a WPT system with SS compensation.

The power transfer efficiency η at resonance is given by [3]:

$$\eta = \frac{P_L}{P_s} = \frac{\omega_0^2 k^2 L_1 L_2}{\left(1 + \frac{R_1}{R_L}\right) (R_1 (R_2 + R_L) + \omega_0^2 k^2 L_1 L_2)} \quad (1)$$

where P_L is the output real power transferred to the load and P_s is the real input power. The input power can be expressed also as $P_L + P_{loss}$ where $P_{loss} = P_{cu} + P_{fe} + P_{al}$, being P_{cu} the power loss in the winding, P_{fe} the power loss in the ferrite, and P_{al} the eddy current losses in the aluminum plate..

III. NUMERICAL RESULTS

The WPT-2 power class system [3], rated at 7.7 kVA, operates at the frequency $f_0 = 85$ kHz. The vertical separation between the WPT coils is assumed to be $Z = 200$ mm. The considered transmitting coil consists of $N_1 = 12$ turns and has a rectangular shape with external dimensions 640×540 mm². It is positioned above a ferrite magnetic layer with external dimensions 680×580 mm², and thickness $t_{fe1} = 6$ mm. Additionally, there is an aluminum shield, matching the dimensions of the ferrite layer, of thickness $t_{al1} = 2$ mm. The receiving coil consists of $N_2 = 14$ turns and has a square shape with side length $S_{cu2} = 400$ mm. It is equipped with a square magnetic layer, featuring external dimensions $S_{fe2} = 450$ mm and thickness $t_{fe2} = 6$ mm. Additionally, a conductive aluminum shield with side length $S_{al2} = 440$ mm and thickness $t_{h2} = 2$ mm is included. The fabricated primary coil is depicted in Fig. 2a, while Fig. 2b presents a sketch of the two coupled coil system.

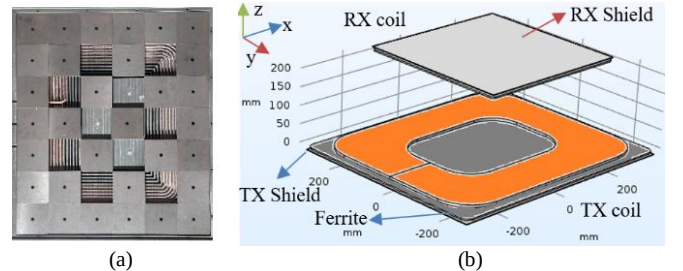


Fig. 2. Fabricated TX pad (a) and a sketch of a WPT coil system (b).

Starting from this configuration, several alternative designs for ferrite layers—referred to as ring-shaped, ring-shaped with a C-section, grid, and cross-shaped (illustrated in Fig. 3)—were explored using COMSOL simulations. These designs aimed to reduce weight while maintaining high WPT performance. The investigation primarily focused on the transmitter pad for simplicity, although the procedure and findings are equally applicable to the receiver pad.

For each simulated configuration, coil losses and electrical performance are analyzed to identify the design that provides the best balance between weight reduction and WPT performance.

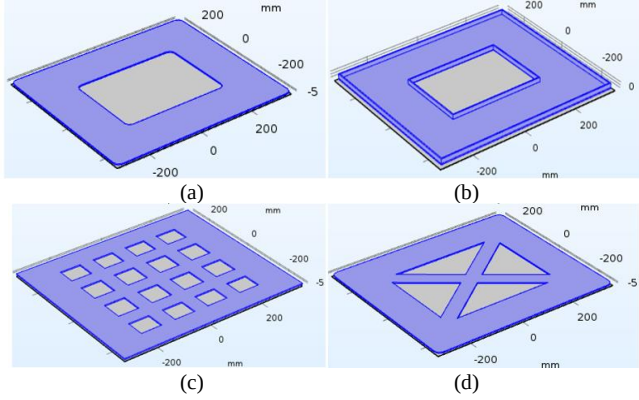


Fig. 3. Ferrite layer configurations: (a) ring-shaped; (b) ring-shaped with a C-section; (c) grid; (d) cross-shaped ferrites.

To simplify the analysis, only the primary pad is considered, and the total power loss on the primary pad, P_{loss} , can be calculated. However, since COMSOL cannot accurately model litz wires, the winding power loss is calculated as $P_{cu} = R_{1,meas} I_1^2$, where $R_{1,meas} = 128 \text{ m}\Omega$ is the resistance measured using an LCR meter for the standard prototype, and I_1 is the primary current derived from the analysis of the equivalent circuit shown in Fig.1.

For each configuration, a 3D FEM simulation was conducted by COMSOL using a tetrahedral mesh consisting of second-order finite elements. The simulation output included the self and mutual inductances of the coils (L_1 , L_2 and M), which were imported into a circuit simulator to evaluate the power transfer efficiency η .

The input voltage source V_s was adjusted to achieve a constant output power of 7.7 kW. The resulting coil currents, I_1 and I_2 , were then imposed as source currents in a second COMSOL simulation to calculate the losses. The magnetic field distribution within the ferrite layer, obtained from these simulations, is illustrated in Fig. 4.

The results, including power losses and ferrite weight, are summarized in Table I. Additionally, the calculated circuit parameters of the coils and the system's electrical performance, in terms of power transfer efficiency η and primary coil current I_1 are presented in Table II. By comparing Tables I and II it is possible to select the best configuration of the ferrite layer.

Based on the simulation results new configurations of ferrite layer will be fabricated and tested in the next future and included in the extended version of the paper.

IV. CONCLUSION

The results show that the entire ferrite layer can be replaced with alternative configurations, achieving comparable electrical performance while reducing both cost and weight. Preliminary findings indicate that employing a grid-shaped ferrite configuration offers the best trade-off between performance and weight savings. Additionally, this approach is straightforward to implement using commercially available square ferrite tiles.

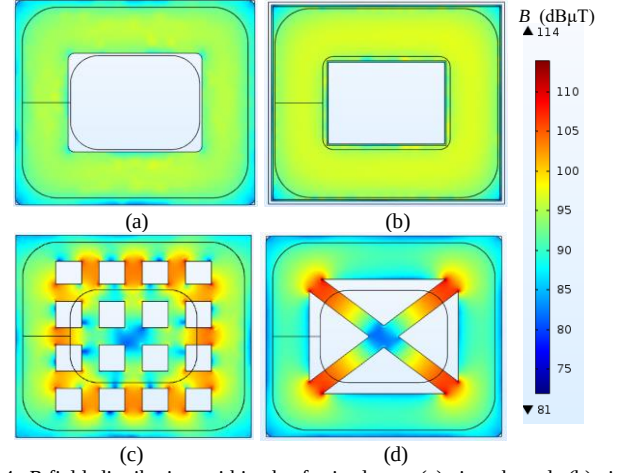


Fig.4. B-field distribution within the ferrite layer: (a) ring-shaped; (b) ring-shaped with a C-section; (c) grid; (d) cross-shaped ferrites.

TABLE I –POWER LOSSES VS. FERRITE LAYER CONFIGURATIONS.

Test case	$P_{cu,meas}$ (W)	P_{al} (W)	P_{fe} (W)	P_{loss1} (W)	Ferrite weight (kg)
standard	94.2	74.43	44.1	212.7	7.56
ring-shaped	191.2	92.19	27.5	310.9	5.52
C-section	138.4	66.57	53.4	258.4	6.58
grid	108.0	72.3	70.2	250.5	5.96
cross-shaped	116.1	89.6	65.2	270.9	5.78

TABLE II –CIRCUIT PARAMETERS OF THE WPT COILS @ 85 KHz.

Test case	L_1 (μH)	L_2 (μH)	k	I_1 (A)	η
standard	198.39	160.06	0.158	27.1	96.67%
ring-shaped	156.05	156.93	0.126	38.7	95.42%
C-section	191.79	157.62	0.133	33.0	96.07%
grid shaped	192.70	158.92	0.157	29.1	96.20%
cross-shaped	177.19	159.15	0.151	30.1	95.93%

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