ISSN: 2710-0588

Optimization Design of Shielding Structure for EV-WPT System Based on Whale Optimization Algorithm

Enning Guo[1], Le Gao[2] and Renjie You[1]

[1]Changchun Automotive Test Center Co.,Ltd., Changchun 130011, China

[2]College of Instrumentation and Electrical Engineering, Jilin University, Changchun 130026, China

Abstract

Wireless power transfer (WPT) is a promising charging technology for electric vehicles (EVs). However, electromagnetic exposure and leakage fields raise safety and efficiency concerns. This paper establishes an EV-WPT system model and applies ferrite-based magnetic shielding to reduce leakage fields. A Grey Wolf Optimization (GWO) algorithm is introduced to optimize ferrite design parameters. Simulation results show that ferrite shielding reduces magnetic induction intensity by 27% and improves transmission efficiency from 91.3% to 93.5%, confirming the effectiveness of the proposed optimization approach.

Keywords

Wireless power transfer; Electromagnetic shielding; Grey Wolf Optimization.

1. Introduction

New energy vehicles, as a promising way of utilizing new energy sources, occupy an important strategic position worldwide. Pure electric drive, networking, and intelligence remain the main development directions for them. Wireless charging technology, with its non-contact, mobile, and convenient features, is highly compatible with the application scenarios of electric vehicles and has gradually become a viable charging option. Currently, several wireless charging alliances have been established in various countries and regions, actively participating in the formulation of technical standards for electric vehicle wireless charging (Electric vehicle Wireless Power Transmission, EV-WPT and the competition for the market. As this technology gradually spreads and the demand for higher power and efficiency increases, the electromagnetic compatibility issues of the WPT system have also gradually gained attention. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) has revised the "Guidelines for Limiting Exposure to Time-Varying Electric and Magnetic Fields (1Hz to 100kHz)" in 2010, raising the corresponding electromagnetic radiation limit levels compared to the previous version[1]. However, the increasing power levels and the denser charging equipment will inevitably bring new electromagnetic environmental challenges. Therefore, a more detailed and comprehensive study of electromagnetic protection issues is of great significance for the final deployment of WPT technology in electric vehicles.

The EV-WPT system is shielded electromagnetically using a passive shielding method[2]. Ferrite is used to improve the magnetic circuit and reduce the longitudinal magnetic field distribution of the EV-WPT system. Many researchers have studied the improvement effect of magnetic shielding on the leakage magnetic field of the WPT system. When the system's operating frequency is too high, the magnetic resistance of ferromagnetic materials will significantly increase the resistance of the coil [3, 4]. The influence of the size of the metal shielding plate on the transmission efficiency and shielding effect of the EV-WPT system is studied, and the influence of the offset between the transmitting coil and the receiving coil on

ISSN: 2710-0588

the shielding effect is analyzed[5]. With the development of EV-WPT technology, the increasing power levels have made electromagnetic shielding technology the current research focus. Therefore, conducting research on electromagnetic shielding is of great significance.

The main research contents of this paper are as follows: In the second section, a compensation circuit is established for the SS EV-WPT system and the vehicle model, and the magnetic shielding principle of ferrite is introduced; In the third section, the grey wolf optimization algorithm is introduced; In the fourth section, the grey wolf optimization algorithm is used to optimize the magnetic shielding structure of the EV-WPT system, and the shielding effect of the optimized EV-WPT system is analyzed; In the fifth section, the research contents of the entire paper are summarized.

2. WPT Principles and Modeling

2.1. Modeling of the WPT System

The design of the magnetic shielding structure for the EV-WPT system is commonly carried out by researchers through finite element simulation, which has the advantages of cost savings and high design efficiency. This paper will also conduct the optimization design of the EV-WPT system using the same finite element simulation software. Firstly, an electromagnetic simulation model of the WPT was established, as shown in Fig. 1.

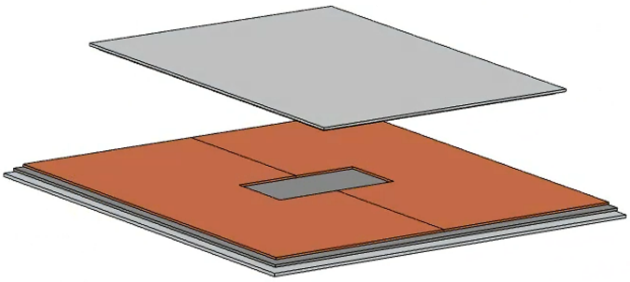


Figure 1. Electromagnetic model of the WPT system

The WPT model established in this paper has a transmitting coil with dimensions of 715mm × 560mm and a receiving coil with dimensions of 418mm × 418mm. The main material of the coils is copper. The size of the aluminum plate in the figure is 725mm × 570mm. The ferrite plate is the main research object in this paper and is only shown as a schematic diagram in Fig. 1. The compensation circuit of the EV-WPT system adopted in this paper is a dual SS type, as shown in Fig. 2. Here, TX represents the transmitting coil, RX represents the receiving coil, CS1 and CS2 represent the compensation inductors, and RL represents the load. This paper will optimize the design of the structure of the ferrite.

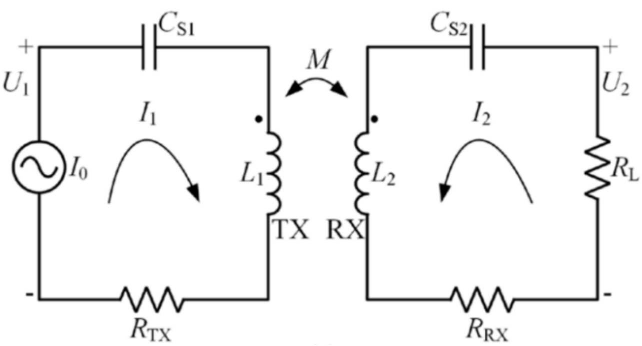


Figure 2. Dual SS compensation circuit

ISSN: 2710-0588

2.2. Ferrite Shielding Principle

The magnetic circuit is a key concept for achieving electromagnetic shielding in ferromagnetic materials. In a static magnetic field, the current flowing through the coil will generate magnetic lines of force in the surrounding space, and the closed path that the magnetic lines of force pass through is the magnetic circuit. The schematic diagram of the principle of ferromagnetic material shielding is shown in Fig. 3.

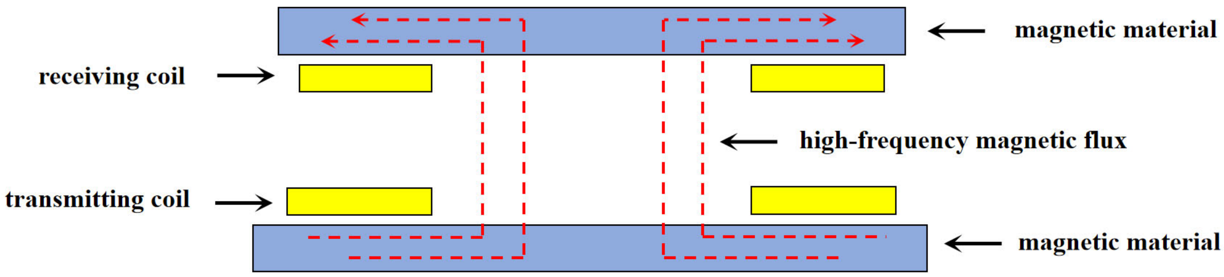


Figure 3. Magnetic circuit diagram

The relationship among the magnetic flux, magnetic potential and magnetic resistance in the magnetic circuit can be described by the Ohm's law in the magnetic circuit. Specifically, it can be expressed as:

$$\Phi = \frac{U_m}{R_m} \tag{1}$$

Among them, Φ represents the magnetic flux in the magnetic circuit, with the unit being Wb. Um represents the magnetic potential between two points in the magnetic circuit, with the unit being A. Rm represents the magnetic resistance between two points in the magnetic circuit, with the unit being 1/H. It can be specifically expressed as:

$$R_m = \frac{\int_l H \cdot dl}{\int_S B \cdot dS} \tag{2}$$

Here, S represents the cross-sectional area of the magnetic circuit, and l represents the length of the magnetic circuit. When the cross-sectional area S of the magnetic circuit is uniform with the magnetic field, the magnetic resistance Rm can be further simplified as:

$$R_m = \frac{Hl}{BS} = \frac{l}{\mu S} \tag{3}$$

3. Whale Optimization Algorithm

The whale optimization algorithm (WOA), proposed in recent years, is an efficient multi-objective optimization algorithm capable of achieving rapid and stable optimization iterative computation, boasting significant advantages. Therefore, in the following sections of this paper, the WOA will be employed to optimize the design of the ferrite structure in the EV-WPT system.

The algorithm optimization process can be divided into three stages: initialization, iterative screening, and final convergence. First, several groups of candidate solutions are randomly

ISSN: 2710-0588

generated, and each solution is evaluated by the objective function to determine its quality. The candidate solution with the smallest objective function value is selected as the initial optimal solution. Then, the iterative optimization stage begins. The algorithm simulates the hunting behavior of whales and continuously updates the positions of candidate solutions through two strategies: one is to contract the search range around the current optimal solution and gradually approach the optimal solution; the other is to randomly select other candidate solutions for broader exploration to avoid getting stuck in local optima. In each iteration, all candidate solutions are re-evaluated, and if a better solution is found, the global optimal solution is updated. As the iterations proceed, the algorithm gradually converges to an optimal solution, that is, the Q matrix with the best performance indicators, providing the best parameter settings for the controller.The optimization steps of the Whale Optimization Algorithm (WOA) are (1) Surrounding the Prey; (2) Bubble Net Predation Method; (3) Searching for prey; The principle of the WOA algorithm is illustrated in Fig.4.

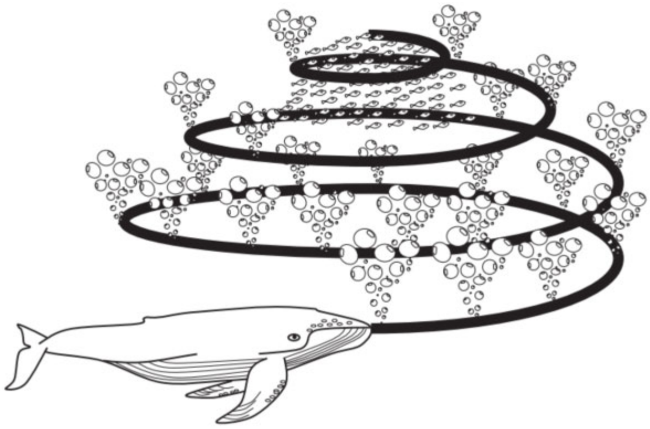


Figure 4. WOA schematic diagram

4. Result Analysis

In order to optimize the overall structural parameters of the ferrite in the EV-WPT system, an observation point was set at a distance of 50 cm from the horizontal center of the WPT system. The length, width and thickness of the ferrite as a whole were taken as the optimization design parameters, and the transmission efficiency and the magnetic induction intensity at the observation point were set as the optimization objectives. The optimized design parameters are shown in Table 1.

Table 1. Overall optimization design parameters of ferrite materials

Optimize design parameters	Parameter range (mm)
Length of ferrite at the transmitting end	[690,710]
Width of ferrite at the transmitting end	[490,510]
Thickness of ferrite at the transmitting end	[5,10]
Length/width of ferrite at the receiving end	[390,410]
Thickness of ferrite at the receiving end	[5,10]

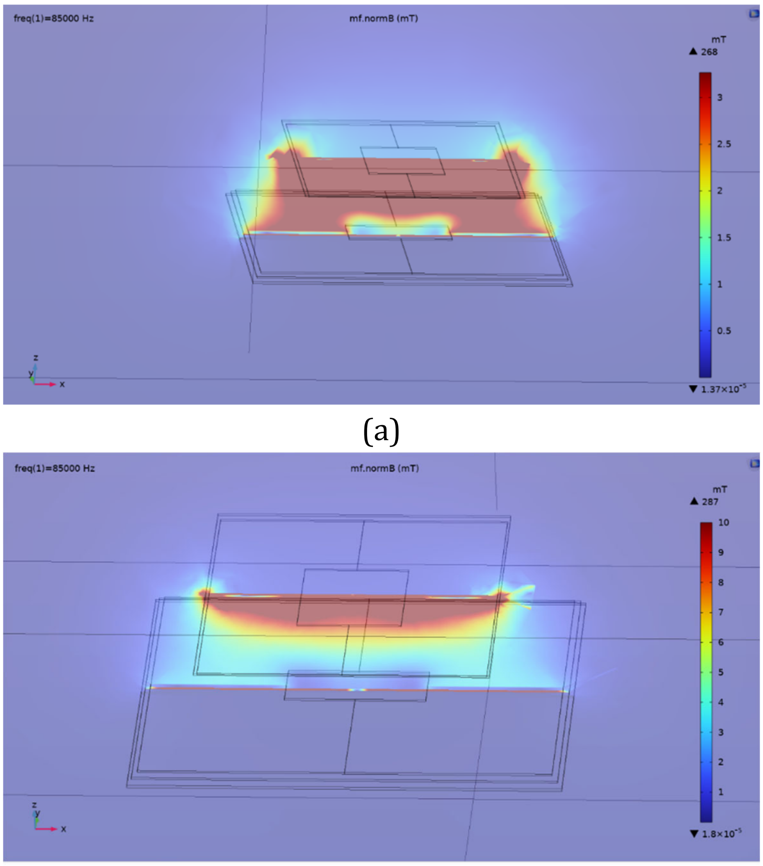
Based on the optimized design parameters in Table 1, the structural parameters of the ferrite were designed as shown in Table 2.

ISSN: 2710-0588

Table 2. Iron oxide structure design parameters

Optimized design parameters	Optimized result (mm)
Length of the ferrite at the transmitting end	704
Width of the ferrite at the transmitting end	505
Thickness of the ferrite at the transmitting end	8
Length/width of the ferrite at the receiving end	408
Thickness of the ferrite at the receiving end	5

The magnetic induction intensity distribution of the EV-WPT system before and after the presence of ferrite plate shielding is compared, as shown in Fig.5.



(a)

(b)

Figure 5. Comparison of magnetic induction intensity before and after ferrite shielding(a)Before being shielded(b)After being shielded

By comparing the magnetic induction intensity before and after shielding, at the observation point before the ferrite shielding, the magnetic induction intensity was 24.8 μT and the transmission efficiency was 91.3%. After adding the ferrite shielding, the magnetic induction intensity was 18.1 μT and the transmission efficiency was 93.5%. The shielding effect reached 27%, and the transmission efficiency also increased. This effectively achieved the shielding of the EV-WPT system and enhanced the transmission performance of the system, proving that the method proposed in this paper is effective.

ISSN: 2710-0588

5. Summary

This work investigates electromagnetic shielding in EV-WPT systems. A finite element model with dual SS compensation was built, and ferrite shielding was applied to suppress magnetic field leakage. The Grey Wolf Optimization algorithm was used to optimize ferrite dimensions, balancing shielding performance and efficiency. Results demonstrate significant reduction in magnetic induction intensity and enhanced transmission efficiency. The findings provide a practical method for improving safety and performance in EV-WPT applications.

Acknowledgements

This work was supported by Jilin Scientific and Technological Development Program under Grant 20230201122GX.

References

[1] International Commission on Non-Ionizing Radiation Protection. Guidelines for limiting exposure to time-varying electric and magnetic fields (1 Hz to 100 kHz)[J]. Health physics, 2010, 99(6): 818-836.

[2] Kim H, Song C, Kim J. Coil design for high efficiency and low magnetic field leakage of wireless charging system for electric vehicle[C]//2015 IEEE wireless power transfer conference (WPTC). IEEE, 2015: 1-3.

[3] Olukotun B, Partridge J S, Bucknall R W G. Loss performance evaluation of ferrite-cored wireless power system with conductive and magnetic shields[C]//2019 IEEE PES Innovative Smart Grid Technologies Europe (ISGT-Europe). IEEE, 2019: 1-5.

[4] Bibirica C, Cristian S, Ene L, et al. Using WEBENCH Coil Designer for wireless power transfer coil generation[C]//2017 10th International Symposium on Advanced Topics in Electrical Engineering (ATEE). IEEE, 2017: 373-377.

[5] Choi S Y, Gu B W, Lee S W, et al. Generalized active EMF cancel methods for wireless electric vehicles[J]. IEEE Transactions on Power Electronics, 2013, 29(11): 5770-5783.