

Many-objective optimization of electromagnetic screens for Wireless Power Transfer Systems fostering electric mobility

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In this paper, a Finite Element (FE) analysis for structure optimization of an aluminum screen in a Wireless Power Transfer System (WPTS) for electric vehicles has been performed. The aluminum sheet, located above the receiver coil, plays a significant role in the magnetic field distribution. The geometrical characteristics of the screen affect the power transferred to the load, the screen effectiveness and the weight of the screen itself. In this study, the aluminum plate has 16 equal rectangular holes, whose base and height are geometrical parameters that can vary. An optimization problem is solved to achieve multiple objectives: minimizing the magnetic field 10 cm above the plate, maximizing the power transferred to the receiver, and minimizing the aluminum volume.

Index Terms—Finite Element Analysis, Many-Objective Optimization, Wireless Power Transmission, Electric mobility.

I. INTRODUCTION

The design of electromagnetic screen in WPTSs for electric cars is of paramount importance because it has to fulfil at least a manifold criterion, namely: increase power transferred to the receiver as well as the overall efficiency, decrease the leakage field in the passenger compartment, decrease the screen weight.

In the literature the subject was treated in terms of active shielding [1] or exploiting metamaterials [2], but, in most of the papers, a single-objective or bi-objective optimization is solved or core structural parameters are considered [3].

A key idea is to consider a grid-like structure of the screen, which originates a multiply-connected conductive region. Accordingly, an optimal design method based on Pareto-like approach is here presented, applied to a many-objective problem.

II. FINITE ELEMENT MODEL

A 3D Finite Element model of the WPTS is developed. The model consists of two helix-shaped coils, each one has a ferrite plate (440 mm × 400 mm) as a magnetic concentrator and a thin sheet of aluminum is situated above the receiver part, see Fig. 1. The coils have 15 turns with 75 mm inner radius each. The electrical conductivity of Aluminum is $3.77 \cdot 10^7$ S/m, and for the ferrite it is equal to 0.2 S/m; the relative magnetic permeability μ_r of the ferrite is assumed to be linear [4] and equal to 3000. The aluminum part is considered as a thin 700 mm × 700 mm sheet in which the transition boundary condition is applied with depth $d_s = 1$ mm. The model has 513,630 tetrahedral elements with quadratic variation of potential.

This 3D FE model is connected to electrical circuits in power transmitter and power receiver sides. They consist of a current source (8 Arms, 85 kHz) for transmitter and a 5 Ω resistor as a load. A resonant series 30 nF capacitor is connected in series to the receiver side coil.

The finite element (FE) model consists of the coupled electromagnetic and circuit problem. The magnetic field is

solved in harmonic AC magnetic field problem using the magnetic vector potential (A) formulation.

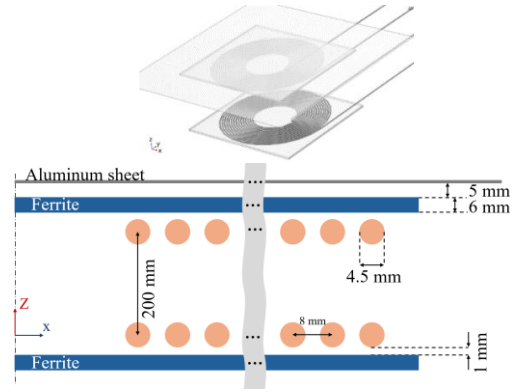


Fig. 1. Model Structure

The Maxwell's equations were solved in frequency domain, where the time varying electromagnetic fields are considered in their steady state behavior at the given field pulsation (ω) in terms of complex vectors:

$$\nabla^2 A - j\omega\mu\sigma A = -\mu J \quad (1)$$

where $\mu = \mu_r\mu_0$ is the magnetic permeability, J is the current density and σ is the electrical conductivity.

III. OPTIMAL DESIGN PROBLEM

The aluminum sheet has 16 holes which are replicated in the specific positions based on the first one, see Fig. 2.

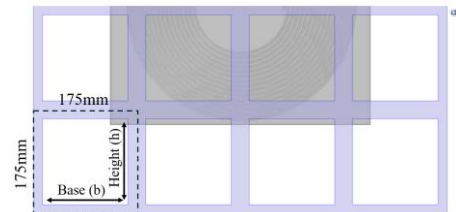


Fig. 2. Aluminum screen with design variables (because of symmetry, only half of the system is shown)

The two design variables are the base (b) and the height (h) of the first rectangle hole in the range of 30 mm to 145 mm for both to ensure that the holes do not interfere.

Three objective functions, to be minimized, are defined:

$$f_1 = -P_L (W), f_2 = S_{Al} (m^2), f_3 = \max\{|B|\} (\mu T). \quad (2)$$

Objective function f_1 is responsible for maximizing the power transferred to the receiver coil, f_2 is related to minimizing the aluminum surface (and so the screen weight) and f_3 aims to minimize the maximum value of the magnitude of the magnetic flux density ($|B|$) at a point on a plane located 10 cm above the aluminum sheet, having dimension $2 m \times 2 m$. The position of the point is not prescribed, it varies depending on the screen geometry. Based on ICNIRP regulations, the limit for general public exposure to timevarying magnetic fields at working frequency (85 kHz) is $27 \mu T$ [5].

IV. RESULTS

The many objective optimization problem (2) has been solved, simultaneously considering the three objective functions.

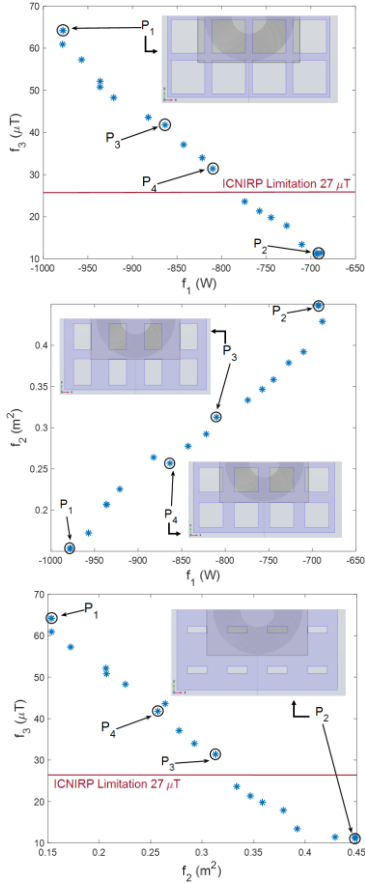


Fig. 3. Pareto front projection into f_3 - f_1 , f_2 - f_1 and f_3 - f_2 planes. Relevant geometries are highlighted.

The NSGA-II algorithm, with 50 generations and 20 individuals, has been utilized. The projections of the Pareto front into 3 different objective function planes are shown in Fig.

3, where four selected solutions, with their relevant screen geometry, are highlighted.

The details of the solutions highlighted in Fig. 3 are reported in Table 1. Fig. 4 shows the magnetic flux density, 10 cm above the aluminum sheet related to each of the four solutions.

TABLE I
MANY OBJECTIVES OPTIMIZATION RESULTS

	b (mm)	h (mm)	f_1 (W)	f_2 (m ²)	f_3 (μT)
P ₁	145	145	-977.918	0.15360	64.206
P ₂	86.44	30	-692.577	0.44851	11.105
P ₃	85.39	129.63	-810.012	0.31291	31.407
P ₄	119.5	121.88	-863.447	0.25695	41.797

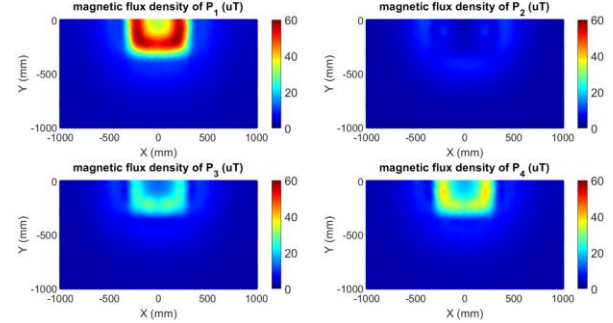


Fig. 4. Magnetic flux density magnitude on a plane located 10 cm above the aluminum sheet relevant to four solutions (see Fig. 3 and Table I).

V. CONCLUSION

The results of the optimization problem show that f_1 is in contrast to f_3 and f_2 is in contrast to f_3 . The designer can choose a screen, e.g. solution P₁, for maximizing the power transferred to the load, resulting in a deterioration of the screen effectiveness but a lighter screen. Otherwise, the maximization of the screen effectiveness leads to a lower power transferred to the load and a heavy screen, like e.g. solution P₂. Several other geometries in between these two end-points are possible, giving flexibility to the designer.

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