L'ÉNERGIE AU CŒUR DES ONDES
RESSOURCES ET ENVIRONNEMENT :
GESTION "INTELLIGENTE"

Design and optimization of inductive power transfer systems by metamodeling techniques
Conception et optimisation de systèmes de transfert de puissance inductifs par des techniques de métamodélisation

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Résumé/Abstract

Ce papier présente une méthode de métamodélisation afin d'optimiser un système de transfert de puissance inductif résonant et de gérer les contraintes de compatibilité électromagnétique (CEM) dans les véhicules électriques. La méthode inclut simultanément différents aspects du problème électromagnétique : la forme des bobines, les caractéristiques géométriques du système (ferrites, châssis du véhicule, plaques de blindage), le désalignement entre l'émetteur et le récepteur. Cette méthodologie repose sur la combinaison de la méthode des éléments finis (MEF) avec des techniques de métamodélisation et des algorithmes d'optimisation.

This paper presents a metamodeling method in order to optimize a resonant inductive power transfer system and to manage electromagnetic compatibility (EMC) constraints in electric vehicles. The method simultaneously includes various aspects of the electromagnetic problem: the shape of the coils, geometrical characteristics of the system (ferrites, chassis of vehicle, shielding plates), and possible misalignment between transmitter and receiver while charging. This methodology relies on the combination of the finite element method (FEM) with metamodeling techniques and optimization algorithms.

1 Introduction

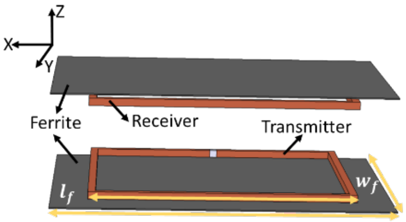
The use of a resonant inductive power transfer (RIPT) system seems an effective technology for the growth of electric vehicles (EVs). Moreover, its application for the charge during the motion of the vehicle (dynamic RIPT) is promising to overcome the barriers represented by the heavy onboard battery storage and the long recharging time. RIPT is essentially based on the resonance of two magnetically coupled inductors (constituting the coupler): The transmitter, placed on the ground, and the receiver, placed under the vehicle floor. The operating frequency typically ranges from 20 kHz to 100 kHz. The coupling between the two inductors takes place through an air gap, usually about 10~25 cm.

Although RIPT systems are now widely studied, there are still several challenges in designing the coupler. Up to now, there is no comprehensive methodology allowing a fast, reliable, and efficient design and optimization of a coil system for RIPT systems. Adequate methodologies have to take into account the environment of the system, including the impact of the car chassis and the presence of the human body since it is needed to evaluate the level of exposure in order to be compliant with international standards. Recently, 3D finite element methods (FEMs) have been studied and applied to solve the electromagnetic problem involving the RIPT system. Such a computational approach gives reliable results about the electrical parameters (mutual inductance, transmission efficiency) and the magnetic parameters (magnetic flux density leakage) around the system, but it may lead to heavy computations that have to be repeated for each new configuration that is highly dependent on various parameters: the size of coils, geometrical characteristics of the system (e.g., ferrite plates, shielding plates), possible misalignment between transmitter and receiver while charging.

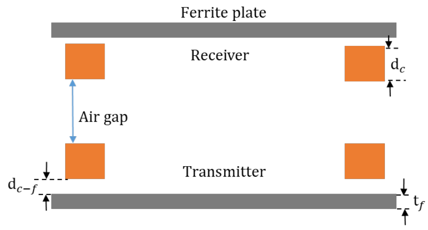
So, the goal of the paper is to propose a fast and efficient modeling methodology in order to assess the efficiency of RIPT systems and manage EMC constraints in EVs. The introduction of metamodeling techniques allows to manage the variability of design variables describing the electromagnetic problem and to quantitatively determine the contribution of each design variable to the observed output. Next, it combines multiobjective optimization algorithms to find the best dimensions of a practical RIPT system.

2 Fast general design and optimization of a standard RIPT system

In general, a RIPT system uses a rectangular or square ferrite plate, just as shown in Figure 1. However, finding the proper dimensions of the ferrite plate (length, width, and thickness) is a difficult task. In such a configuration, combining a standard optimization algorithm with a 3D numerical tool is very time consuming. To accelerate the design procedure, building a metamodel before the optimization loop provides a fast and efficient approach [1, 2]. The ranges of structural variables are displayed in Table 1. This coil size (468 mm) corresponds to a case previously developed in the GeePs laboratory [3, 4]. A multiobjective optimization algorithm involving both the mutual inductance of the coupling system and the ferrite volume allows to find the corresponding Pareto front at low cost (Figure 2.). Different designs may be chosen depending on additional constraints, related for example to the stray field. The proposed metamodel may save around 50 times the computational time (including the time to calculate the training samples and the test samples) compared to a standard approach based on the combination of 3D FEM with an optimization algorithm.



(a) General view



(b) Cross-sectional view

Figure 1: General RIPT with ferrite plates

Structural Variables	Min [mm]	Max [mm]	Probability density distribution
Ferrite length l_f	468	936	Uniform
Ferrite width l_w	468	936	
Ferrite thickness t_f	2	10	
Distance between coil and ferrite d_{c-f}	1	10	

Table 1. Structural variables of the ferrite plate

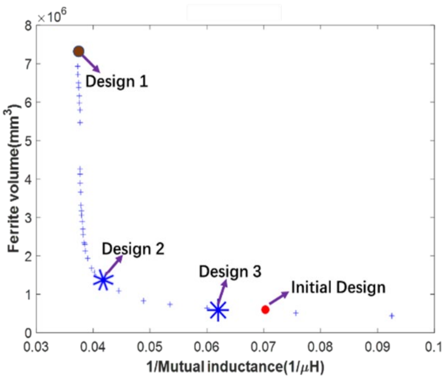


Figure 2. Pareto front between 1/Mutual inductance and ferrite volume

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