Optimization of a magnetic structure for wireless power transfer in charge while driving

Vincenzo Cirimele[1], *Student Member, IEEE*, Fabio Freschi[1], *Senior, IEEE*, Luca Giaccone[1], *Senior, IEEE* and Paolo Guglielmi[1], *Member, IEEE*

[1]Politecnico di Torino, Dipartimento Energia, Corso Duca degli Abruzzi 24, 10129, Torino, IT

The electromagnetic design of a wireless power transfer system focuses on the development of coupled inductors. Moreover, the system performance can be improved by a auxiliary magnetic structure. This paper deals with the design of a novel magnetic structure for a light commercial vehicle in charge while driving. The design is carried out through an optimization procedure which aims to solve both EMC and exposure problems.

***Index Terms*—Charge while driving (CWD), optimization, fully electric vehicle, wireless power transfer (WPT), magnetic field exposure.**

I. Introduction

Wireless power transfer (WPT) for the charge of electric vehicles is a main topic for the electric vehicle sector. In fact it seems to represent an effective technology to increase the electric mobility acceptance thanks to the benefits related to the intrinsic safety and the customer comfort in the daily use. Furthermore, charge while driving (CWD) represents a good solution for the reduction of the installed battery capacity on board and the reduction of time travel according to the ideal elimination of the typical long stop periods of recharge requested by plug-in stations or static WPT.

The present work proposes a geometry apt to the CWD dedicated to the light commercial vehicles analyzing the critical aspects related to the exposure during normal and fault operations of the charge process.

II. Basic ideas on the design

WPT is essentially based on the resonance of two magnetically coupled inductors, one placed on the ground, usually named transmitter, and the second one, placed under the vehicle floor, named receiver. The coupling between the two inductors takes place through a large air-gap usually about 20 cm. This means the presence of a high leakage flux near the WPT coils and the consequence necessity of shielding for EMC and human protection. Actually, the presence of a shield helps also the design and the control of the WPT system creating a well known shape of the magnetic field lines independently from the complex geometry of the underside of the vehicle and external metallic object in the ground. On the other hand, the presence of shields implies also the presence of additional losses and the reduction of the coupling of the two coils. To react against this two negative aspects, it is possible to insert a ferromagnetic core that makes it possible to increase the coupling and reduces the losses over the shield by lowering the perpendicular component of the flux that invests the shield.

The best class of materials for this purpose is represented by ferrites for their high permeability and negligible losses at the typical working frequencies of WPT systems for electric vehicles (less than 200 kHz).

III. Proposed solution

Differently from previous works like [1], [2], this solution presents a double side shield composed by an aluminum shield for the receiving side and a second one with a U shape placed under the ground. The use of ferrite cores is limited to the receiver structure in order to limit the cost of the solution and to avoid a huge increase of the self inductance of the transmitting coil causing a not tolerable voltage drop over the resonance capacitor without a comparable benefit in the coupling improvement [3].

The adopted material was the 3C94 ferrite thanks to the good value of relative permeability ($\mu_r = 2300$), stable on a wide range of frequencies (0.1-1 MHz), and the availability in cores of several sizes with a I shape.

The optimization parameters are defined in Fig. 1. They were chosen according to some qualitative observations aimed, firstly, to keep the aluminum far from the coil to avoid a decrease of the leakage flux, and secondly, to constraint the flux lines along a well defined path. Moreover, the optimization parameters allows a contact between the ferrite and the aluminum in order to make the most from this last component using it also as a heat sink.

The dimension in the direction parallel to the movement was selected after the optimization process in order to obtain the desired value of mutual inductance knowing that the shorter this dimension is the greater is the section at constant coupling during the movement of the vehicle.

The goals of the optimization were the maximization of the magnetic coupling k, and the minimization of the losses on the shields P_{loss} considering as negligible the losses in the ferrite cores. Furthermore, the exposure constraints are taken into account with a penalty factor that depends on the magnetic field values on a given volume of interest. In the design stage the field is constrained in a limited (but significant) region, that is the green volume in Fig. 2. If at least one value exceeds the limits of 27 $\mu\mathrm{T}$ [5], a penalty factor is assigned to the objective function causing the rejection of the current configuration. In the full paper further analysis will be performed also for

TABLE I
PARAMETERS FOR THE DE STRATEGY OPTIMIZATION

Parameter	Value
Objective function dimension	12
Population size	50
Mutation ratio	0.8
Crossover ratio	0.5
Max number of iteration	150

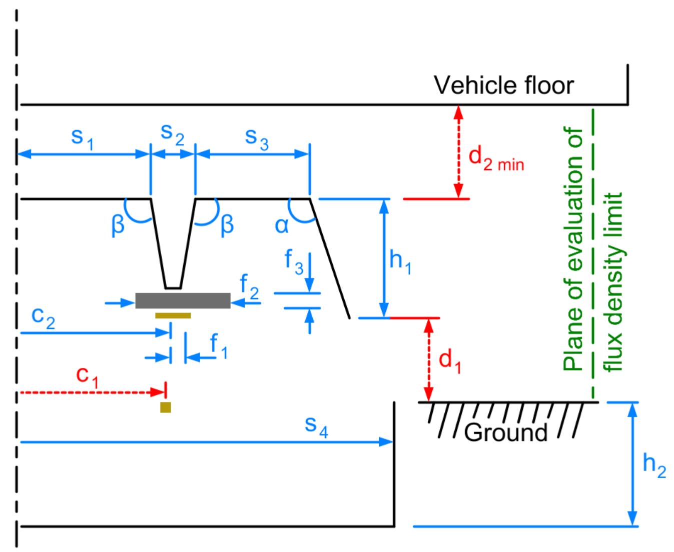

Fig. 1. Scheme of the geometry to be optimized. Fixed parameters in dotted line.

another region, that is the red volume in Fig. 2.

Defining a proper weight P_{max}^{-1} for the losses, it is possible to combine the two goals in a single objective function $f\left(k, P_{\text{loss}}\right)$ defined as (1). The value of the objective function was searched using a differential evolutionary strategy algorithm [4] with the set up parameters of Table I.

$$(k, P_{\text{loss}}) = \min\left[(1-k) + \frac{P_{\text{loss}}}{P_{\text{max}}}\right] \quad (1)$$

IV. RESULTS

The resulting geometry of the magnetic structure is shown in Fig. 2 which principal parameters are reported in Table II.

TABLE II
RESULTING PARAMETERS OF THE OPTIMIZED GEOMETRY

Parameter	Value	Parameter	Value
c_2	0.3 m	s_4	0.9 m
s_1	0.23 m	f_1	0.01 m
s_2	0.03 m	f_2	0.2 m
s_3	0.45 m	f_3	0.025 m
α	92°	h_1	0.15 m
β	94°	h_2	0.3 m

V. CONCLUSION AND FUTURE DEVELOPMENTS

In this paper we presented the main result of the preliminary design of a novel magnetic structure for a light commercial

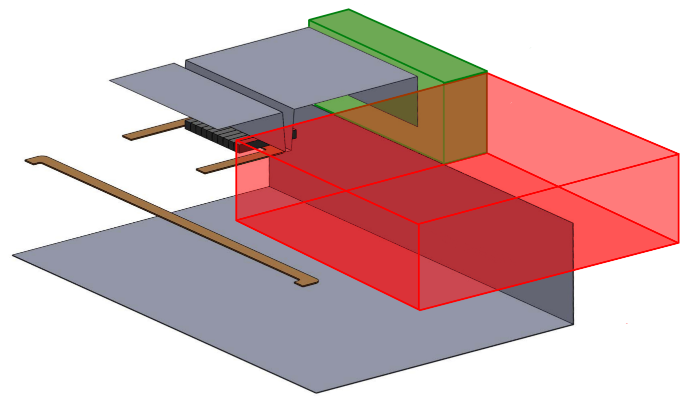

Fig. 2. Resulting geometry of the optimization process and regions of interest for the human exposure.

vehicle in charge while driving. As already pointed out, with relation to the human exposure, there are still some aspects to be analyzed. So far, the optimal design fulfills the ICNIRP requirements in the green volume of Fig. 2. However, the compliance have to be guaranteed also in non-ideal conditions (e.g. misalignment). Moreover, a simpler layout that makes use of a single side shield is under development. In these cases the magnetic field likely exceeds the limit in both green and red volumes.

As claimed by the ICNIRP [5], one should take care that, as a direct consequence of how the *reference levels* (i.e. magnetic flux density) are defined starting from the *basic restrictions* (i.e. induced electric field) the exceeding of the reference levels does not imply the exceeding of the basic restrictions. Hence, in the full paper we will investigate the problem according to this point of view computing the induced electric field in the human body using different phantoms. These values will be compared with the ICNIRP basic restrictions. Several dosimetric analysis will be presented by varying the receptor (male, female, adult, child) at several distances from the source. Moreover, the analysis will be performed under steady state and pulsed condition with the proper methodologies.

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