Forward Model Computation of Magnetostatic Fields inside Electric Vehicles

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Abstract— An integral formulation is used to analyse magnestatic magnetic field in the interior of an electric vehicle. The developed forward model allows evaluation of the shielding effect of the magnetic chassis and frame, proposes an equivalent model for the power battery and brings a lot of information for further study and new method.

***Index Terms*— Magnetostatics, Magnetic shielding, Magnetic Field Measurement, Electric Vehicle**

I. Introduction

Vehicle electrification is widely promoted to answer environmental issues and reduce the reliance on fossil fuels. However, electric vehicles require a significant number of electrical devices within a quite small space (Electric motor, Power electronics, Power battery, Power cables, etc.). As a consequence, passengers may be exposed to electromagnetic fields due to these components. International Commission on Non-Ionizing Radiation Protection (ICNIRP) gives guidelines to limit exposure to static [1] and time-varying [2] magnetic fields. Recent studies [3] have provided measurement results inside electric vehicles. Nevertheless, few works are dedicated to the identification and evaluation of this electromagnetic exposure trough simulation, which is a great challenge for such a complex system.

II. Vehicle analysis and assumptions

A 3-door-utility electric vehicle from end 90's like in Fig. 1 has been chosen for the study. This car is mainly made with ferromagnetic materials whereas nowadays vehicles may integrate more plastic parts for lightening purpose.

Fig. 1. Studied 3-door-utility electric vehicle

The vehicle ferromagnetic parts acquire a magnetization when subjected to local magnetic fields. This magnetization may produce a shielding effect inside the car with respect to these magnetic fields sources, located outside the vehicle. In this paper, we will mainly focus on static or very low frequency sources: the earth magnetic field (weak field of about 40A/m 50µT in France) and fields created by high currents (few hundreds amperes) flowing inside the power battery and associated cables. As a consequence, the proposed modelling is magnetostatic.

III. Numerical modeling

In our approach, the geometry of the ferromagnetic parts of the vehicle is described by surface meshing. Materials are defined with a constant relative reversible permeability (μ_r=150) and different thicknesses. The problem is solved with the integral formulation in order to accurately compute the magnetic field in air region. The formulation is precisely presented in [4]. Because of the size of the studied object, an adaptive multi-level fast multipole method (AMLFMM) is used to limit memory requirement.

In the following parts, a field applied along the longest dimension is called longitudinal, transverse if along the width and vertical along the height.

A. Induced magnetization due to Earth magnetic field

Earth magnetic field varies on the globe surface but can be assumed homogeneous and constant on the zone where a car is moving. Depending on the car heading evolution, the local magnetic field varies in the interior. Then the shielding effect is characterized for longitudinal and transverse directions (vertical earth field is considered constant and vertical magnetization variations negligible). Even if the Earth magnetic field is weak, it acts on the whole magnetic structure because of its homogeneity. As a consequence, it is far easier to determine a shielding effect, with respect to this magnetic source than a more complex one. By comparing simulation and measurements, we proceed iteratively to determine the influence of the vehicle magnetic parts. Finally, we obtain a model of the car (Fig. 2) that will be useful for the analysis of all other influent magnetostatic sources, such as steady currents flowing inside the power battery.

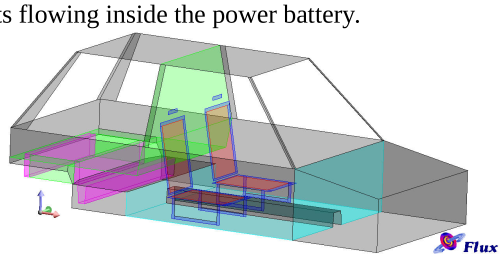

Fig. 2. Numerical model of the vehicle

The chassis frame (in light blue on Fig. 2) is 3mm thick and the body shell (in grey) is 2mm thick. Other additive elements have a local influence and a specific effect on longitudinal or transverse field direction, depending on their shape. In the studied car, there is a vertical grid separating passengers from the rear: modelled (in green on Fig. 2) with a 1mm equivalent thickness, it is only sensitive to a transverse magnetic field. Seats have also a ferromagnetic skeleton that affect locally the magnetic field. They are described by a simple shape (in blue on Fig. 2) and a thin surface of 0.5mm thickness (in red on Fig. 2) to represent the filling part of the seat. The seats add a local sensitivity to both longitudinal and transverse magnetic field, for the body and only to transverse magnetic field for the head. Finally, the battery pack is fixed under the rear plate on transverse spars. These spars are modelled (in magenta on Fig. 2) with a U-shape of 2mm thick and present local sensitivity to transverse magnetic field.

B. Magnetic field created by currents inside the power battery and associated cables

Knowledge and analysis of the cell set-up inside the battery allow us to build an equivalent current model of the battery pack. In this part, the rear battery pack is presented with a part of its external power cabling (blue lines surrounded by the black circle on Fig 4.).

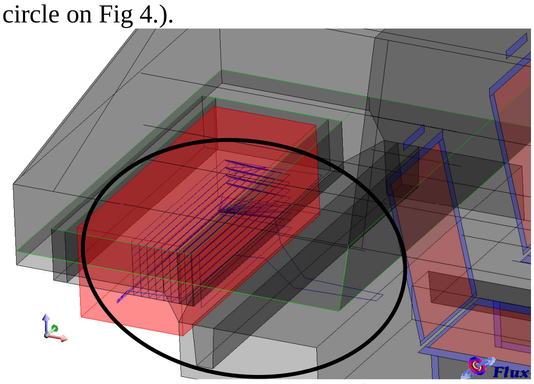

Fig. 4. Equivalent electrical current model of the rear battery pack

The rear battery model is added to the previous vehicle model to evaluate the magnetic field generated inside the car. Module of the magnetic field is computed (fig. 5) along a centred line running from the rear to the front of the vehicle. This line is 150mm above the rear plate (i.e. 160mm above the battery pack) and results are for a total current of 100A. The magnetic field due to the battery pack alone is plotted in blue while the same field attenuated by the car magnetic frame is plotted in pink.

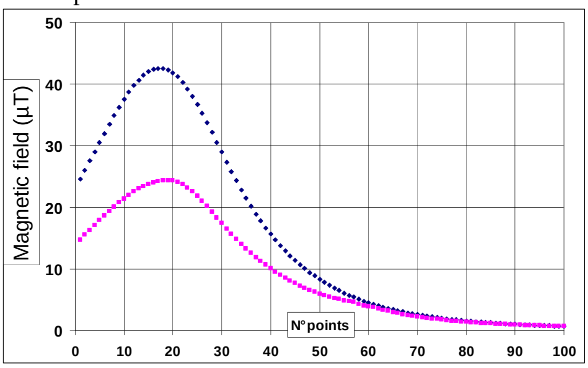

Fig. 5. Magnetic induction created by the rear pack battery

The battery pack and its cabling is between points 5 and 25. As expected, the vehicle acts as a magnetic shield. Peak to peak amplitude is about 42µT when the battery pack is alone and reduced to only 25µT with the vehicle magnetic frame.

Figure 6 illustrates the magnetization of the vehicle frame, only due to a 100A currents flowing in the rear battery pack and external power cables.

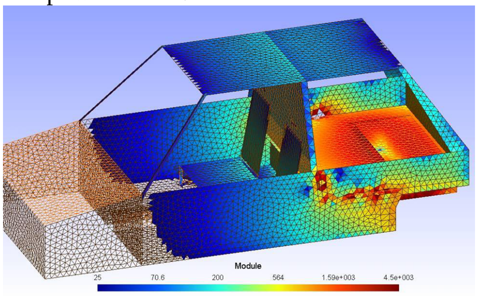

Fig. 6. Magnetization due to 100A inside the rear battery

IV. Comparison to Measurements

As mentioned previously, some measurements have been made onboard the vehicle at different points (passenger location and above the rear battery).

TABLE I
ATTENUATION FACTOR OF THE EARTH MAGNETIC FIELD

	Measurements	Simulations
	Head location	
Longitudinal (X axis)	0.922	0.922
Transversal (Y axis)	0.798	0.830
	Above rear battery	
Longitudinal (X axis)	0.898	0.895
Transversal (Y axis)	0.790	0.745

Table I shows the ratio between the field inside the vehicle and the field applied outside it. Then a good correlation is obtained between model and measurements for the shielding attenuation of the Earth magnetic field (Table I). Magnetic field due to current has also been measured above the rear battery pack and gives a variation of about 460nT/A in module. Simulation gives a 520nT/A variation, which validates our equivalent model of the battery. As a consequence, a first forward model has been built and validated for static magnetic sources inside an electrical vehicle. Besides, this numerical model allows the study of any current repartition (for example inside a battery pack) to minimize its magnetic stray fields inside the vehicle.

V. Acknowledgment

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References

[1] ICNIRP, “ICNIRP guidelines on limits of exposure to static magnetic fields,” HEALTH PHYSICS 96(4):504-514, 2009
[2] ICNIRP, “ICNIRP guidelines for limiting exposure to time-varying electric and magnetic fields,” HEALTH PHYSICS 99(6):818-836, 2010
[3] Karabetsos E., Kalampaliki E., and al., “EMF Measurements in Hybrid Technology Cars,” Greek Atomic Energy Commission, Non-Ionizing Radiation Office, P.O. BOX 60092, 15310 AGIA PARASKEVI, Greece
[4] T.-S. Nguyen, J.-M. Guichon, O. Chadebec, P. Labie, and J.-L. Coulomb, “Ships Magnetic Anomaly Computation With Integral Equation and Fast Multipole Method,” IEEE Trans. on Magn., vol.47, no.5, pp. 1414-1417, 2011