Power coil shield model shielded with aluminum box

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Abstract — the article deals with the problem of shielding the power coil. Such coils are very much a part of power semiconductor transducers. At the same time, however, they are the source of a large electromagnetic radiation, thus degrading the EMC of the whole device.

Keywords — coil, shielding, EMC

I. Introduction

The aim of this paper is to create a model of solenoid coil and visualize magnetic fields created by current passing through the coil. The coil is inserted into aluminum enclosure box which serves as a shielding for alternating magnetic field. For this purpose the software package called COMSOL Multiphysics with AC-DC module was used. COMSOL Multiphysics is software package that solves systems of coupled three-dimensional partial differential equations. This software can be used to model different physical phenomena including electromagnetics. It uses the finite element method of solution and can solve the complex problems, geometries or material properties in 2D or 3D representation for better understanding some phenomena. In this case COMSOL Multiphysics solves the magnetic fields surrounding the coil that is placed in electrical circuit and calculates the inductance of this coil. Design of the coil is created in 3D space dimension. The results are then compared with coil that is not inserted in enclosure.

II. Experimental part and results

Analyzed solenoid coil is made of copper and it is electrically conductive showing an electrical resistance for the direct current. For the alternating current the inductor shows, except the electrical resistance, also a property called inductance, which describes the capability of producing a magnetic field around the inductor. From the electrical point of view the inductance acts as complex impedance being proportional to the frequency of alternating current. The ideal inductor shows only the inductance while its electrical resistance is negligible [1].

The proposed coil inserted in the aluminum enclosure is created in CAD software and is shown in Fig. 1. The coil is physically described by the following parameters: c_h as height of coil [mm], c_{id} is inner diameter [mm] and c_t expresses the width of turns. The die cast aluminum enclosure (by Hammond – type 1590LB) is made from aluminum alloy A380. This enclosure is used as electronic instruments enclosure and provides protection against access of dust and splashing water. Also provides for improved EMI/RFI shielding. The enclosure assembly consists of two parts; lid and box (Fig. 1).
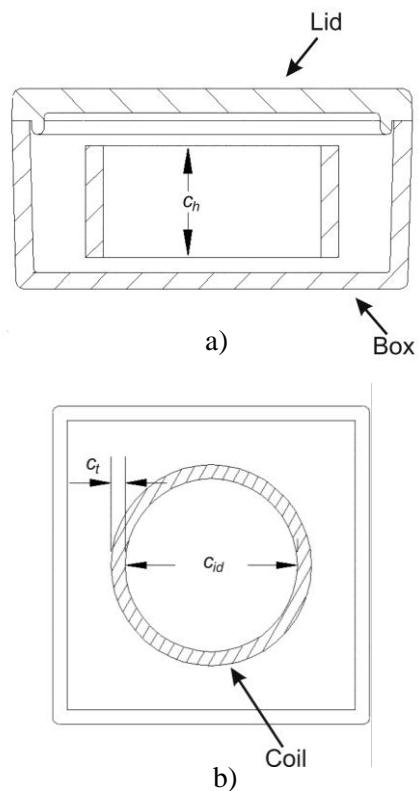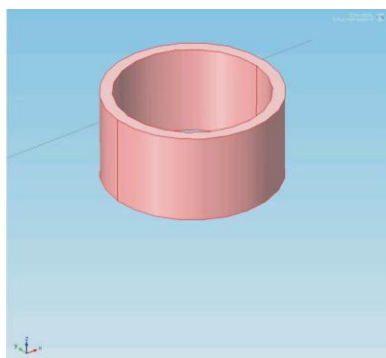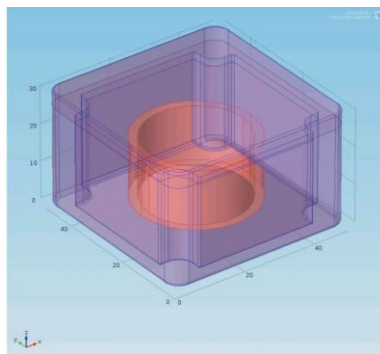
Fig. 1 Aluminum enclosure with inserted coil a) side view of assembly b) top view / inside the box

The geometry of coil and the enclosure is created in CAD software and then imported into COMSOL. The model of system is depicted in Fig. 2. As a material of the coil the copper with conductivity $\sigma = 5.997 \times 10^{-7}$ S.m^{-1} and as a material of enclosure aluminum alloy A380 was selected.


Fig. 2 Model of coil a) without enclosure b) with enclosure

Using AC/DC module in frequency domain the magnetic fields and inductance of coil are calculated. The parameters used in simulation are:

- number of turns of coil - $N = 62$
- inner diameter of coil - $c_{id} = 27.2$ mm
- width of turns of coil - $c_t = 2.2$ mm
- height of turns of coil - $c_h = 15.8$ mm
- coil current - $I = 20$ A
- frequency - $f = 50$ kHz

Important parameter of simulation is a mesh. Proper size and shape of mesh elements influences the accuracy of solution; the finer the mesh elements, the better the solution accuracy. In our case, fine mesh (provided by COMSOL) was selected. Final number of mesh elements for coil inside enclosure was 77 394 and for the coil without enclosure it was 26 360. Both models were surrounded by an air domain. The simulation took 217s and results obtained are shown in Fig. 3.
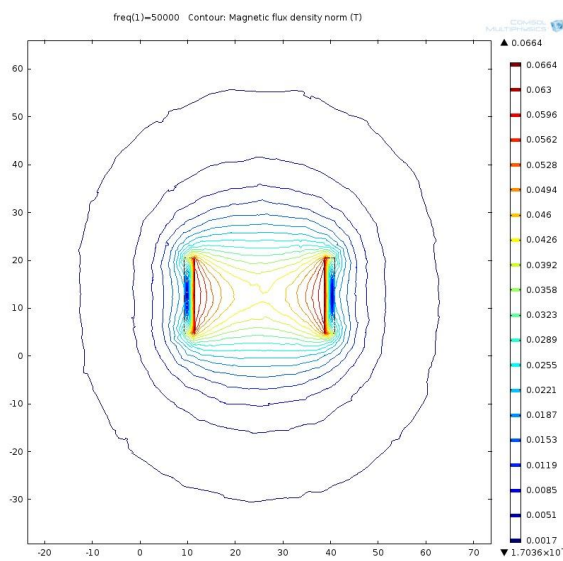
a)
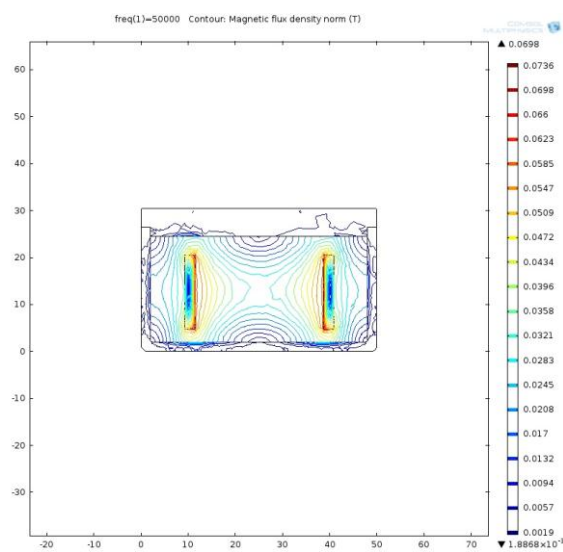
b)

Fig. 3 Magnetic flux density a) coil without enclosure b) coil with enclosure

The inductance of coil calculated by COMSOL is L=88.31 µH. In the Fig. 3 are shown the magnetic fields created by the current passing through the coils. It is obvious, that magnetic field in Fig. 2 b) is enclosed in aluminum box.

Using the basic information obtained from electromagnetic field theory, we can determine the depth of electromagnetic wave penetration for the switching frequency $f = 50$ kHz.

$$\delta = \sqrt{\frac{2}{\omega\mu\gamma}} = \sqrt{\frac{2}{2*\pi*50000*12.566*10^{-7}*3.546*10^{7}}} = 0.00037798\,\text{m} \quad (1)$$

where ω is the circular frequency of current flowing through coil, $\mu = \mu_0 = 12.566\text{x}10^{-7}$ [H/m] is the permeability of the aluminum used as shielding, $\gamma = 3.546\text{x}10^7$ [S/m] is its conductivity.

For the magnitude of the current density vector in a conductive environment, we can write:

$$J = J_m e^{-\beta x} = J_m e^{-\frac{1}{\delta}x} \quad (2)$$

where β is a damping factor of electromagnetic wave. In our case it will be for aluminum $\beta = 2645.622$ mm^{-1}. The ratio of the values of the current densities and the maximum current density (J / J_m) determines the size of the original field in the materials with the thickness x to be reduced. The following table Tab. 1 shows an example of the gradual damping of electromagnetic waves, depending on the thickness of the material for aluminum.

Tab. 1 Wave damping depending on material thickness.

x[mm]	1	2	3	4	5	10
$e^{-\beta.x}$	00709	0.0050	0.0003	2.54e-5	1.8e-6	3.24e-12

From the table, we see that to wipe the magnetic field to one hundred of its original value, we need the magnetic wave to pass through the over 2.0 mm aluminum.

III. CONCLUSION

In this paper the calculation of inductance and visualization of magnetic fields was presented. Calculation was made using COMSOL Multiphysics (AC/DC module) that uses finite elements method of solution. First, the model of coil without the aluminum enclosure and then the simulation of coil with enclosure were made. These enclosures provide improved EMI/RFI shielding and they are used in electronic devices such as power converters. The simulation in this paper showed that this device is suitable as a protection in power converters against EMI/RFI. Future work will be focused on modeling of other electromagnetic phenomena.

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