Finite Element Analysis of Shielding Composite Enclosures

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Abstract — This paper investigates the electromagnetic behavior of a shielding enclosure built with carbon-fiber composite panels. The numerical model is based on a full wave finite element method taking into account the geometrical details of the walls and avoiding the use of the classical equivalent layer approach. The results demonstrate that the composite material has a significant impact on the wide band frequency response and that the conductivity of the rods strongly modifies the shielding effect. A comparison with the case of a purely metallic enclosure shows that the resonance peaks are significantly shifted.

I. INTRODUCTION

Advanced composite materials become widespread in the aerospace and aircraft industries. They are typically composed by a resin matrix reinforced by high strength fibers, such as graphite, boron, glass, or carbon. With respect to metals these materials offer lower weight, higher stiffness and strength, lower corrosion etc. Despite these advantages, composite materials are not as electrically conductive as traditional metallic ones. The shielding effectiveness of composite structures is strongly affected by the fiber-composition fraction or percentage. So these composite materials may have a significant impact on the electromagnetic compatibility constraints.

Generally, electromagnetic modeling studies of composites materials have been carried out concerning the characterization of the reflection, transmission, and shielding properties of such materials, with reference to canonical configurations having either planar or cylindrical symmetries [1-4]. In these analyses the composite is replaced by an equivalent layer model where the composite is an effective medium. This makes easier the electromagnetic modeling with analytical or numerical methods.

For the packaging of practical structures, the performance of a shielding enclosure is quantified by its shielding effectiveness (SE), defined as the ratio of field strength in the presence and absence of the enclosure. The value of SE is closely related to the dimensions of the enclosure and the possible resonance effect for specific frequency ranges. The variation of SE versus frequency can be efficiently evaluated with a convenient modeling technique like the method of moments [5], the FDTD [6] or the finite element method [7]. Most of these studies are devoted to metallic enclosures and do not investigate the impact of new composite materials.

This paper shows with an adequate finite element modeling that composite materials strongly modify the wide band frequency response of the structure when compared to a metallic one. The analysis is performed for a 2D enclosure made of the carbon fiber composite material described in [2]. In order to avoid the classical assumption relevant to the use of an equivalent layer model, the finite element approach takes into account the fine features of the composite. The computational model clearly underlines the influence of the diameter and the electrical conductivity of the rods on the resonances of the SE.

II. ELECTROMAGNETIC PROBLEM

Let consider the 2D scattering of a plane wave by a 2D enclosure whose walls are made with composite medium (Fig.1). The panels include fiber rods $(\mu_0, \sigma_f, \varepsilon_f)$ embedded in a dielectric resin (μ_0, ε_d) (Fig.2). The TM (Transverse Magnetic) case is considered where the incident electric field and scattered electric field have only one component in the z direction denoted u^i and u^s respectively. The total electric field u^t $(u^t = u^i + u^s)$ satisfies:

$$\Delta u^t + k^2 u^t = 0$$

where k is the wave number ($k^2 = \varepsilon\mu_0\omega^2 - i\sigma\mu_0\omega$).

The computational domain is truncated by Perfectly Matched Layers. The goal of the computation is the evaluation of SE. SE is defined as the ratio (in decibel unit) of the total field existing in the presence of the enclosure to the incident field:

$$SE = -20\log_{10}\left(\frac{|u^t|}{|u^i|}\right)$$

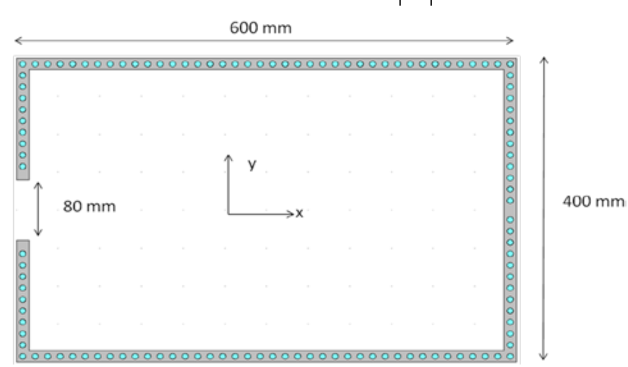

Fig. 1. 2D enclosure with composite walls

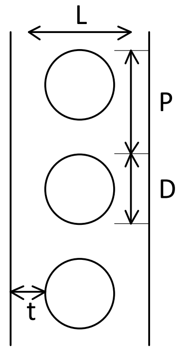

Fig. 2. Composite panel

III. NUMERICAL RESULTS

The shielding effectiveness was computed in the middle of the enclosure when the incident plane wave is x-directed and for $L = 15\,\text{mm}$, $D = 7.5\,\text{mm}$, $P = 15\,\text{mm}$, $t = 3{,}75\,\text{mm}$. Figure 3 shows the variation of SE versus the conductivity of the rods up to 1.2 GHz. For high values of conductivities the resonance peaks correspond to the theoretical values obtained in the case of a closed cavity. It can be pointed out that the negative shielding (field enhancement) near the resonances disappears for a conductivity lower than 10 S/m. Also SE is significantly reduced for those values.

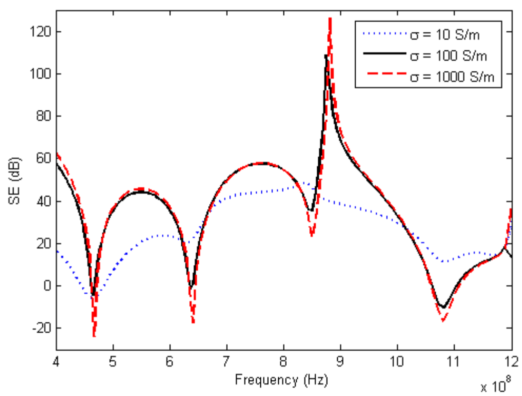

Fig. 3. Variation of SE considering different conductivities of the rods

One of the main advantages of composite materials is their low weight. The impact of the rod diameter on the SE while keeping the same weight (i.e. at constant volumic ratio) was investigated.

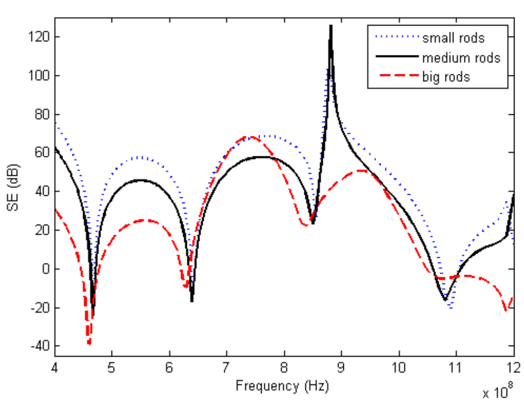

Fig. 4. Variation of SE for various diameters of the rods

Figure 4 clearly shows that SE is significantly reduced when using rods with small diameter. In this case the shielding effect is mainly governed by the ratio between the period of the rods and the wavelength. Also, among other consequences, the use of double panels composites clearly modify the position of the resonance peaks and slightly improves SE when one of the two set of fibers is shifted (Fig. 5).

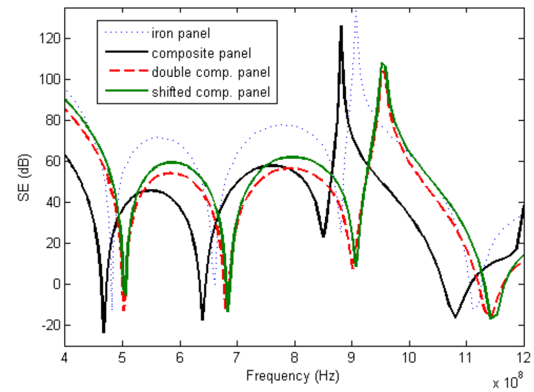

Fig. 5. Variation of SE for different walls

IV. CONCLUSION

The Shielding Effectiveness of an enclosure with composite panels was evaluated. Numerical results show that the behavior of the wide band response is strongly affected by the conductivity of the fiber rods. Additional results involving the influence of the angle of incidence of the exciting wave and the impact of the size of the aperture will be presented in the conference.

V. REFERENCES

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