Design, Numerical Analysis and Test of HF Absorber

E. Kadlecová, P. Fiala, M. Zeman, M. Steinbauer, and Z. Szabó
Department of Theoretical and Experimental Electrical Engineering
Brno University of Technology, Kolejní 2906/4, 612 00 Brno, Czech Republic

Abstract—The paper presents numerical analysis of the microwave absorber design. It is possible to use modified concept of the absorber. There were used novel numerical methods (finite element method (FEM)) for thin layers modelling with sandwich non-isotropic electromagnetic materials. Modified absorber has appropriate properties and it is possible to use it in non-reflecting chamber construction. The non-reflecting chamber will be used for open space testing of relativistic microwave pulse generator; $P_{\text{max}} = 500 \text{ MW}$, $t_p = 10 - 100 \text{ ns}$. An experimental testing of the proposed pyramidal absorbers was done in the laboratories at University of Defence Brno, Czech Republic.

DOI: 10.2529/PIERS060901094301

1. INTRODUCTION

It is possible to measure the power supplied by open space impulse by use of the calorimetric converter. The sensor is connected to the measuring device by help of the coaxial line of length approximately $l = 10 \text{ m}$. The closed space has to be realised as a deaden room, see Fig. 1.

The calorimetric sensor has disc design. The carbon with changed crystal lattice is used as one of the thin layers. Combined calorimetric sensors was designed for microwave vircator with output power $P_{\text{max}} = 500 \text{ MW}$, length of pulse $t_p \in <10, 100 > \text{ ns}$.

Usually, two types of the absorber materials (non-reflecting) are used. The polyurethane foam impregnated by graphite is used in high frequency range (more than 1 GHz) — the foam employs heat losses in material. The ferrite absorber is used in low frequency range — the ferrite absorber employs magnetic losses. The mentioned materials are used to prevent reflection of the electromagnetic waves inside the laboratory. The idea is to rebuild the laboratory in Fig. 2 to the shielded non-reflecting chamber for measurements and experiments with power microwave pulse generators $P_{\text{max}} = 500 \text{ MW}$, length of pulse $t_p \in <1, 100 > \text{ ns}$.

2. SHIELDING OF THE WALLS

It is possible to define an electromagnetic shielding by help of shielding coefficient $\tau$. It represents the ratio of the electrical field $E_t$ (magnetic field $H_t$) in the given place of the chamber to the electrical field $E_i$ (magnetic field $H_i$) incoming at the absorber.

$$\tau = \frac{E_t}{E_i}, \quad \tau = \frac{H_t}{H_i}$$ (1)

The metal plate is used to prevent the electromagnetic wave go trough the wall. The damping effect of the metal plate consists of three damping — reflection, absorption and repeatable reflection.
2.1. Effectiveness of the Reflection

Shielding by means of reflection $R$ is caused by partial reflection of the electromagnetic wave on the impedance boundary. The impedance boundary consists of the air — characteristic impedance $Z_0$ and metal plate — characteristic impedance $Z_M$. The characteristic impedances and the amount of the damping from [1] are given

$$Z_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}}, \quad Z_M = \sqrt{\frac{j\omega\mu}{\sigma}}$$

(2)

$$R = 20 \log \left| \frac{Z_0 + Z_M}{2Z_M} - \frac{Z_0 + Z_M}{2Z_0} \right| = R_1 + R_2$$

(3)

2.2. Effectiveness of the Absorption

When electromagnetic wave travels through metal plate it is absorbed and it causes heat losses. Absorption coefficient $A$ of the metal plate is given [1]

$$A = 20 \log |e^{\gamma t}| = 20 \log e^{\frac{\delta}{t}}[\text{dB}],$$

(4)

where $\delta$ is depth of penetration into the metal plate of thickness $t$. The depth of penetration is given

$$\delta = \sqrt{\frac{2}{\omega \mu \sigma}}[\text{m}],$$

(5)

where $\omega$ is frequency, $\sigma$ is electrical conductivity, $\mu$ is the permeability of vacuum. After manipulation of (4) we get the absorption coefficient

$$A = 8.69 \cdot \frac{t}{\delta}[\text{dB}].$$

(6)

2.3. Pyramidal Absorbers

Nowadays, the longitudinal non-homogenous loss environment is made from pyramid or cylinder Fig. 3. It uses dielectric losses and is made from polystyrene or polyurethane that is impregnated by graphite. Linearly increasing cross-section of the pyramid serves as an impedance transformer. The transformer transforms open space impedance to the very low impedance of the absorber. However, the damping maximum takes place in the back side of the absorber. It is necessary to have pyramid with height of $\lambda/4$ on the lowest working frequency.

![Figure 3: Geometrical model of pyramidal absorber.](image)

3. MATHEMATICAL MODEL

It is possible to carry out analysis of a MG model as a numerical solution by help of Finite element method (FEM). The electromagnetic part of the model is based on the solution of full Maxwell’s equations.

$$\text{rot } E = -\frac{\partial B}{\partial t}, \quad \text{rot } H = \sigma E + \frac{\partial D}{\partial t} + J_s, \quad \text{div } D = \rho, \quad \text{div } B = 0 \quad \text{in region } \Omega$$

(7)
where $E$ and $H$ is the electrical field intensity vector and the magnetic field intensity vector, $D$ and $B$ are the electrical field density vector and the magnetic flux density vector, $J_S$ is the current density vector of the sources, $\rho$ is the density of free electrical charge and $\gamma$ is the conductivity of the material, $\Omega$ is definition area of the model. The relationships between electrical and magnetic field intensities and densities are given by material relationships

$$D = \varepsilon E, \quad B = \mu H.$$  (8)

The permittivity $\varepsilon$, the permeability $\mu$ and the conductivity $\gamma$ in HFM are generally tensors with main axes in the direction of the Cartesian co-ordinates $x$, $y$, $z$. When all the field vectors perform rotation with the same angular frequency $\omega$, it is possible to rewrite the first Maxwell equations

$$\nabla \times E = -j\omega \mu H, \quad \nabla \times H = (\sigma + j\omega \varepsilon) E + J_S \quad \text{in region } \Omega$$  (9)

where $E, H, J_S$ are field complex vectors. Taking into account boundary conditions given in (7) and after rearranging (9) we get

$$(j\omega)^2 \varepsilon E + \sigma E + \nabla \times \mu^{-1} \nabla \times E = -j\omega J_S.$$  (10)

We apply Galerkin’s method with vector approximation functions $W_i$. We use vector form of the Green theorem on the double rotation element [3]. After discretisation we get the expression

$$-k_0[M]\{E\} + jk_0[C]\{E\} + [K]\{E\} = \{F\},$$  (11)

where $\{E\}$ is column matrix of electrical intensity complex vectors. The matrices $[K]$, $[C]$ and $[M]$ are in the form that is given in manual [4] and vector $\{F\}$ is evaluated from expression

$$\{F\} = -jk_0 Z_0 \int_{\Omega} [W_i]\{J_S\} d\Omega + jk_0 Z_0 \int_{\Gamma_0+\Gamma_1} [W_i]\{n \times H\} d\Gamma.$$  (12)

Vector approximation functions $W$ are given in manual [4], $k_0$ is wave number for vacuum, $Z_0$ is impedance of the free space. The set of equation (5) is independent of time and it gives $\mathbf{E}$. For transient vector $\mathbf{E}$ we can write

$$\mathbf{E} = \text{Re} \left\{ \mathbf{E}_0 e^{j\omega t} \right\}.$$  (13)

Figure 4: Evaluation of modules of magnetic intensity $H$ and electric intensity $E$. 

(a) $H$ 
(b) $E$
4. GEOMETRICAL MODEL

The geometrical model was created with standard tools in FEM system ANSYS with help of automated mesh and nodes generators. After that the mathematical model was formed. The applied element is HF120. The geometrical model of HF absorber is shown in Fig. 3. The initial frequency was taken \( f = 1, 2, 3, 4, 5 \) GHz. The concept of the absorber uses special properties of the pyrographite and ferrite dust. These are placed on the pyramid walls with appropriate densities. By means of this concept it is possible to achieve appropriate damping of the incoming electromagnetic wave.

![Figure 5: Experiments with HF absorber-attenuation tests in UO laboratories, (a) \( l = 2 \) m distance between absorbers and measuring antenna, (b) testing absorbers.](image)

![Figure 6: Experiments with HF absorber-attenuation tests in UO laboratories, (a) computer controlled microwave generator, (b) \( l = 10 \) cm distance between absorbers and measuring antenna.](image)

5. RESULTS OF THE ANALYSIS

In the Fig. 4, there is shown module of vector functions of magnetic intensity \( H \) and electric intensity \( E \). There are results for initial \( TE \) plane wave with frequency \( f = 3 \) GHz, \( E_x = 100 \) V/m. We can see the quality of electromagnetic absorber in one numerical solution in Fig. 4. One can see good absorption of specific power. The adaptive numerical model of the absorber was created in the ANSYS program with APDL. It is possible to change the absorber geometry and to perform the optimization according to given parameters. The results of the model was used in construction of the prototype. The prototype was measured according to (1) to (6) in the laboratories at UD Brno. There were used generator and horn antenna with frequency \( f = 10 \) GHz. There were tested HF absorber with \( l = 100 \) mm and 2000 mm inside of receiving antenna, see Figs. 5–7. Measured attenuation was from 16.09 to 20.8 dB. It depends on number of used absorption plates. The testing room and apparatus were calibrated with standard absorbers and result was compared with experimental model. The design of HF absorber was made with special low-cost material.
Figure 7: Experiments with HF absorber-attenuation tests in UO laboratories, (a) testing measurement (calibration) with classical HF absorber, (b) testing experimental absorbers.

6. CONCLUSION

Presented work is a part of the project conducted in co-operation with VTUPV Vyskov, PROTOTYPA a.s. and TESLA Vrsovice Praha. The shielded non-reflecting laboratory for microwave pulse generators is being built. In order to perform the tests of Vircator pulsed generator it is necessary to have a laboratory with shielding up to the frequency of RTG and the laboratory has to eliminate the reflections of the EMG wave in the rage $f > 10 \text{MHz}$. It is necessary to have absorption coefficient of the EMG wave $A_{\text{min}} > 16.5 \text{dB}$ for $f = 1 \text{GHz}$. The HF absorbers were discussed and the analysis of the basic properties was performed for chosen pyramidal absorber. The absorption coefficient resulting from numerical analysis is compared with experimental measurement.

ACKNOWLEDGMENT

The research described in the paper were financially supported by FRVŠ by research plan No. MSM 0021630513 ELCOM and grant GAAV No. B208130603.

REFERENCES