Paweł JABŁOŃSKI

Częstochowa University of Technology

Approximate BEM analysis of thin electromagnetic shield of variable thickness

Abstract. *The paper concerns an approximate analysis of electromagnetic shield of variable thickness. The method bases on the boundary element method (BEM), but to avoid nearly singular integrals the analysis uses a semi-analytical solution for the shield. Not only it makes the numerical errors smaller, but also reduces the memory used and computation time.*

Streszczenie. *Praca dotyczy przybliżonej analizy ekranu elektromagnetycznego o zmiennej grubości. Proponowana metoda wykorzystuje metodę elementów brzegowych (MEB), ale w celu uniknięcia całek prawie osobliwych w obszarze ekranu stosuje się rozwiązanie półanalityczne. Powoduje to nie tylko zmniejszenie błędów numerycznych, ale także redukuje zapotrzebowania na pamięć operacyjną i czas obliczeń.*

Keywords: boundary element metod, electromagnetic shielding.
Słowa kluczowe: metoda elementów brzegowych, ekranowanie elektromagnetyczne.

Problem description

A closed electromagnetic shield, Ω_1, is placed in free space, Ω_0, and encloses a protected region, Ω_2 – Fig. 1. The external and internal surfaces of the shield are referred to as S_1 and S_2, respectively. The shield region has relative permeability μ_r = const, electric conductivity γ_1 = const, and considered to be very thin, whose thickness, d, can vary from point to point. The protected region and the free space are non-magnetic and non-conductive.

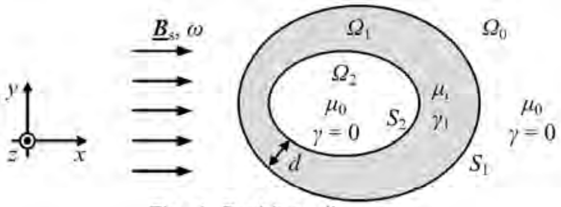

Fig. 1. Problem diagram

The phasor of the z-component of the vector magnetic potential fulfills the following equations corresponding to particular regions:

$$(1)\quad \nabla^2 \underline{A}^{(0)} = 0, \qquad \nabla^2 \underline{A}^{(1)} - \kappa^2 \underline{A}^{(1)} = 0, \qquad \nabla^2 \underline{A}^{(2)} = 0,$$

where $\kappa^2 = \mathrm{j}\omega\mu_r\mu_0\gamma_1$. Field continuity conditions yield $\underline{A}^{(0)} = \underline{A}^{(1)}$ on S_1, $\underline{A}^{(1)} = \underline{A}^{(2)}$ on S_2, and

$$(2)\quad \left.\frac{\partial \underline{A}^{(0)}}{\partial n}\right|_{S_1} = -\frac{1}{\mu_r}\left.\frac{\partial \underline{A}^{(1)}}{\partial n}\right|_{S_1}, \qquad \left.\frac{\partial \underline{A}^{(2)}}{\partial n}\right|_{S_2} = -\frac{1}{\mu_r}\left.\frac{\partial \underline{A}^{(1)}}{\partial n}\right|_{S_2},$$

and $\underline{A}^{(0)} \to \underline{A}_s$ far from the magnetic shield, where $\underline{A}_s$ is the z-th component of the magnetic vector potential of externally applied magnetic field $\underline{\boldsymbol{B}}_s$.

The standard BEM procedure gives the following:

$$(3)\quad \begin{bmatrix} \boldsymbol{H}_1^{(0)} & \frac{1}{\mu_r}\boldsymbol{G}_1^{(0)} & \boldsymbol{0} & \boldsymbol{0} \\ \boldsymbol{H}_1^{(1)} & -\boldsymbol{G}_1^{(1)} & \boldsymbol{H}_2^{(1)} & -\boldsymbol{G}_2^{(1)} \\ \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{H}_2^{(2)} & \frac{1}{\mu_r}\boldsymbol{G}_2^{(2)} \end{bmatrix} \begin{Bmatrix} \boldsymbol{A}_1 \\ \boldsymbol{Q}_1^{(1)} \\ \boldsymbol{A}_2 \\ \boldsymbol{Q}_2^{(1)} \end{Bmatrix} = \begin{Bmatrix} \boldsymbol{A}_s \\ \boldsymbol{0} \\ \boldsymbol{0} \end{Bmatrix},$$

where $\boldsymbol{H}_l^{(m)}$ and $\boldsymbol{G}_l^{(m)}$ – the BEM matrices corresponding to S_l of Ω_m, $\boldsymbol{A}_l$ – nodal values of potential $\underline{A}$ on S_l, $\boldsymbol{Q}_l^{(m)}$ – nodal values of $\partial_n\underline{A}$ on S_l of Ω_m, $\boldsymbol{A}_s$ – nodal values of $\underline{A}_s$ on S_1.

Approximate solution

The problem with the above equations is not only that some elements of matrices $\boldsymbol{H}_1^{(1)}$ and $\boldsymbol{G}_1^{(1)}$ can be numerically very inaccurate (due to nearly singular integrals appearing because of small values of d), but also that they form a relatively large system. To avoid this, an approximate approach is proposed. Within suitable BEM discretization and thickness of the shell smooth enough, the shell between two corresponding boundary elements on S_1 and S_2 can be approximately regarded as a fragment of infinite plate. Therefore, the following approximate relationships can be established:

$$(4)\quad \underline{Q}_{1i}^{(1)} \approx \alpha_i \underline{A}_{1i} - \beta_i \underline{A}_{2i}, \qquad \underline{Q}_{2i}^{(1)} \approx -\beta_i \underline{A}_{1i} + \alpha_i \underline{A}_{2i},$$

$$(5)\quad \alpha_i = \frac{\kappa \cosh \kappa d_i}{\sinh \kappa d_i}, \qquad \beta_i = \frac{\kappa}{\sinh \kappa d_i},$$

where d_i is the magnetic shield's thickness at node i. Such an approximation leads to the following system of equations:

$$(6)\quad \begin{bmatrix} \boldsymbol{H}_1^{(0)} + \frac{1}{\mu_r}\boldsymbol{G}_1^{(0)}\boldsymbol{\alpha} & -\frac{1}{\mu_r}\boldsymbol{G}_1^{(0)}\boldsymbol{\beta} \\ -\frac{1}{\mu_r}\boldsymbol{G}_2^{(2)}\boldsymbol{\beta} & \boldsymbol{H}_2^{(2)} + \frac{1}{\mu_r}\boldsymbol{G}_2^{(2)}\boldsymbol{\alpha} \end{bmatrix} \begin{Bmatrix} \boldsymbol{A}_1 \\ \boldsymbol{A}_2 \end{Bmatrix} = \begin{Bmatrix} \boldsymbol{A}_s \\ \boldsymbol{0} \end{Bmatrix},$$

where $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ are diagonal matrices with elements α_i and β_i, respectively. System of Eqs. (6) contains twice less equations and unknowns than Eq. (3), and no nearly singular integrals occur in it (for sufficiently regular boundary). More details and examples of numerical calculations will be present in the full version of the paper.

REFERENCES (selection)

[1] Jabłoński P.: *Metoda elementów brzegowych w analizie pola elektromagnetycznego*, Wyd. Pol. Cz., Częstochowa 2004.
[2] Jabłoński P.: *Approximate BEM analysis of thin electromagnetic shield*, XXXIV IC-SPETO 2011, 18-21.05.2011, Ustroń, (accepted).
[3] Jabłoński P.: *Approximate BEM analysis of thin magnetic shield of variable thickness*, XXI Sympozjum PTZE,5-8.06.2011, Lubliniec (accepted).

Author: *dr inż. Paweł Jabłoński, Częstochowa University of Technology, Electrical Faculty, al. Armii Krajowej 17, 42-200 Częstochowa, E-mail: paweljablonski7@gmail.com.*