Title: Efficient analytical and numerical modeling for nondestructive evaluation

**Abstract**:

NDT (nondestructive testing) and NDE (nondestructive evaluation) are the low-cost methods with great reliability, sensitivity and high operational speed which involve the identification and characterization of damages without cutting apart or altering the material. Efficient modeling or simulation can reduce the time cost for experiment with the accurate predictions for practical NDE/T problems.

In the first part, an efficient model is developed to simulate the multilayered biaxial anisotropic material with different orientations, which is a popular structure in composites that are widely used in the aerospace industry, by using the effective medium theory. We analyze the multilayered anisotropic medium with different rotations based on the transmission line theory to derive the reflection and transmission coefficients in the matrix form. An equivalent model is used to extract the effective permittivity, permeability, and orientation angle, for a multilayered biaxial anisotropic medium. Analytical expressions for the effective parameters and orientation angle are derived for the low frequency (LF) limit. The model also gives a non-magnetic effective anisotropic layer if each layer is non-magnetic anisotropic dielectric. A good agreement is achieved by comparing the effective parameters extracted with and without the low frequency approximation. We show that the frequency independent equivalent model is valid for the frequency up to 10 GHz.

In the second part, the adaptive cross approximation (ACA) and multilevel adaptive cross approximation (MLACA) algorithms are presented to accelerate the boundary element method (BEM) for the 3D eddy current NDE problems involving arbitrary shapes. The Stratton-Chu formula, which does not have the low frequency breakdown issue, has been selected for modeling. The equivalent electric and magnetic surface currents are expanded with the Rao-Wilton-Glisson (RWG) vector basis functions while the normal component of the magnetic field is expanded with pulse basis functions. The ACA algorithm has the advantage of purely algebraic and kernel independent. The MLACA algorithm compresses the rank deficient matrices with the ACA and the butterfly algorithm. We improve the efficiency of the MLACA by truncating the integral kernels after a certain distance and applying the multi-stage (level) algorithm adaptively based on the criteria for the different operators to further decrease the memory and CPU time requirements while keeping almost the same accuracy comparing with the traditional MLACA. The proposed method is especially helpful to deal with the large solution domain issue of the BEM for the eddy current problems. Numerical predictions are compared with the analytical, the semi-analytical predictions, and the experimental results for the 3D eddy current NDE problems of practical interests to demonstrate the robustness and efficiency of the proposed method.