Performance evaluation of large-scale high-frequency electromagnetic field simulations using iterative substructuring methods

***†L.J. Liu[1], Masao Ogino[1]**

[1]Information Technology Center, Nagoya University, Japan.

*Presenting author: kellyliu@hpc.itc.nagoya-u.ac.jp
†Corresponding author: kellyliu@hpc.itc.nagoya-u.ac.jp

Abstract

The electromagnetic field simulations are in high demand for industrial and medical applications. However, electromagnetic problems of high frequency up to several gigahertz are much more difficult to solve than low-frequency problems. Finite element method (FEM) with the formulation of the E method has been used to solve the vector wave equations in high-frequency electromagnetic problems, and it yields a large-scale complex symmetric linear system.

The conjugate orthogonal conjugate gradient (COCG) method with the shifted incomplete Cholesky preconditioning can be used to solve the complex symmetric linear system. However, the COCG method shows oscillating residual norm histories since the formulation leads to an ill-conditioned problem, and exhibits slow convergence in the large-scale analysis. With increasing of the size of the problem and complexity of the geometric model, the incomplete Cholesky preconditioner has difficulty obtaining high performance of both parallel efficiency and convergence. As an extension of the conjugate residual method for Hermitian linear systems to complex symmetric linear systems, the conjugate orthogonal conjugate residual (COCR) method is expected to obtain smoothed convergence behavior [2]. The iterative substructuring method based on the COCR method shows faster convergence compared with the COCG method for large-scale electromagnetic field analysis of high frequency, however, the oscillating tendency was still found.

It is a crucial issue to solve large-scale problems efficiently on parallel computers. Both robust convergences for large-scale problems and a scalable parallel efficiency are required. An iterative substructuring method based on a MINRES-like_CS method with Domain Decomposition Method has been proposed [3]. It can solve large-scale complex symmetric systems arising from the formulation of the E method and can improve the convergence performance compared to other methods.

However, by applying the original algorithm of MINRES-like_CS to calculate the residual for checking convergence, we found that even if the residual norm is smaller than the prescribed tolerance, the true residual norm may be bigger depending on the material properties. To fully utilize the advantage of the fast convergence of MINRES-like_CS method and at the same time to assure the precision of solution, we apply a new convergence criterion to the MINRES-like_CS method. And also, we investigate the relation between the convergence criteria and material properties of electromagnetic models. We found that our method could not only provide faster convergence but also achieve high accuracy.

Keywords: Electromagnetic field, Large scale, MINRES-like_CS method, High frequency, Rapid convergence, Parallel analysis

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