Harmonic balance hybrid finite element-boundary element method including time periodic movement

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Abstract: In this paper, a general method is proposed to include time periodic movement in the hybrid finite-element and boundary-element (FE-BE), each one combined with harmonic balance method. FE method is used for iron and copper parts to deal with nonlinearity and eddy currents, while BE method is used for the air gap between moving parts using free space Green function. This method is especially suitable when linear motion is involved in the electromagnetic devices because the mesh of air is unnecessary. For the particular case of a two-dimensional (2-D) hybrid FE-BE model of linear machines, it only requires elementary manipulations of Green function and its normal derivative in a fundamental period. At the end the efficiency of this approach is illustrated with an example.

Keywords: FEM-BEM coupling, harmonic balance method, linear movement, induction generator.

1. Introduction

Harmonic balance method obviously gives more accurate results as the number of the considered frequencies is increased. It has been introduced in the domain of FE magnetic field computations by Yamada and Bessho [1] in the late 1980s and has since then been improved for adopting Newton-Raphson using differential reluctivity tensor [2]. Harmonic analysis of electromagnetic devices operating at steady state is sometimes preferable to its time domain (time stepping TS) counterpart but is still challenging, especially if nonlinear materials, induced currents and motional effects are involved.

In [3], Gyselinck et al. have introduced position-dependant basis functions in the frequency domain FE modeling of rotating motion. In the present work the authors focus on the motional aspect, and extend the method proposed in [3] to problems with linear periodic movement using Green function in free space. As shown in Fig. 1, mesh movement in FE analysis of linear machines causes some problems such as renumbering the nodes or meshing a large useless space [4,5] and these require dominant changes in the global stiffness matrix at each time step, because of changing geometry. In [6] a hybrid FE and BE method, each one combined with harmonic balance method has been proposed for the numerical simulation of induction heating process. FE method is used for iron and copper parts to deal with nonlinearity and eddy currents, while BE method is used for the air gap between moving parts using free space Green function. This method is especially suitable when linear motion is involved in the electromagnetic devices to uncouple the moving and the stationary meshes. In this paper, this method is extended to consider time periodic movement. For the particular case of a two-dimensional

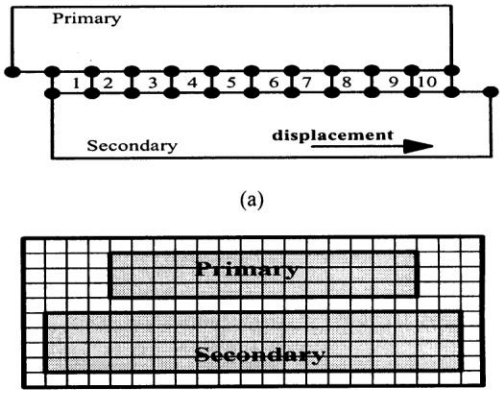

Fig. 1. Mesh movement in linear motion electromagnetic devices.

(2-D) hybrid FE-BE model of linear machine, it only requires elementary manipulations of Green function and its normal derivative in a fundamental period. At the end the efficiency of this approach is illustrated with an example of the particular and restricted case of harmonic analysis of induction machines.

2. Harmonic balance finite element method

The primary and secondary domains were meshed using three-node triangular finite elements as shown in Fig. 2. The equations are obtained using the Galerkin method. If F denotes the finite element region, the element stiffness equation can be expressed in a matrix form as [7,8]