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3D Dynamic Transient Analysis of Induction Machines using New Equivalent Magnetic Circuit Network Method

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Abstract— **This paper present a new time-stepping 3-D analysis method for dynamic transient analysis of induction machines. The method can analyze induction machines with faster computation time and less memory requirement than conventional numerical methods. Also, this method is capable of modeling the movement of the mover without the need for re-meshing and analyzing the time harmonics for dynamic characteristics. From comparisons between the results of analysis and experiments, it is verified that the proposed method can estimate the torque, harmonic field, and etc. as a function of time with a good accuracy.**

INTRODUCTION

To predict the electromagnetic phenomena is important for improvement of the motor performance due to the design trends in recent years. Of course, 3D analyses are more accurate than 2D analyses. However, they require huge computation time and a large memory. Furthermore, when a machine driven by a PWM inverter is analyzed using time stepping method, the number of time steps required to obtain the precise computational results is formidable. Therefore, the 3D analysis is not a proper method in design stage. In this paper, a new time-stepping method, which combines a magnetic equivalent circuit with a numerical method like FEM is proposed. Additional variables like electric potentials are not needed in the proposed technique. Therefore, this method can analyze the 3D dynamic characteristic of the motor with less computational time than other 3D FEM techniques and it also easily takes into account the rotor movement by changing the MMFs and the reluctances. In this paper, we analyze the dynamic characteristic of an induction machine to estimate the harmonics fields by using the proposed method. The results are compared with the measurements and conclusions are made.

ANALYSIS METHOD

The proposed method is applied to the linear induction motor (LIM) shown in Fig. 1 to clarify the usefulness of the developed technique. In this method, the analysis model is divided into hexahedral element and then equivalent magnetic circuit network is constructed by connecting the node of every elements center. Figure 2 shows the mesh shape of LIM. The MMFs generated by the induced currents are represented as passive sources in the conventional network. Therefore, by using only scalar potential at each node, it is possible to model and analyze induction motors in 3-dimensions.

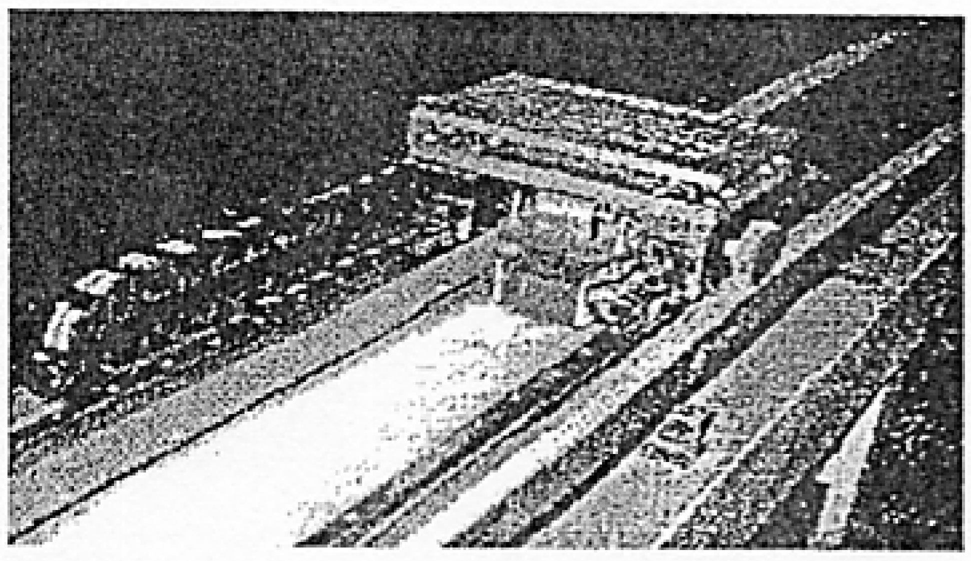

Fig. 1. Prototype of the LIM servo system.

The MMF generated by the induced current can be obtained from the Faraday's law

$$\nabla\times\vec{E}=-\frac{d\vec{B}}{dt},\quad \nabla\times\vec{J}_e=-\sigma\frac{d\vec{B}}{dt} \tag{1}$$

The induced current in the conducting region in response to the time varying magnetic flux linked by the region has x- and z-components. The induced current density may be expressed as follows using Taylor's series.

$$J_{ez}=-\sigma\frac{dB_y}{dt}\Delta x=-\sigma\frac{d\phi_y}{dt}\frac{\Delta x}{S_e} \tag{2}$$

From (1) and (2), the new reluctance and MMF considering the induced current by applying the time difference method can be obtained as follow

$$\phi' R_N = F'_N \tag{3}$$

where, $R_N=(R_m+R_{IND})$, $F'_N=(F_S+F_{IND})$, R_m and F_S are the reluctance and MMF due to input current, and R_{IND} and F_{IND} is the added reluctanc and MMF due to the induced current.

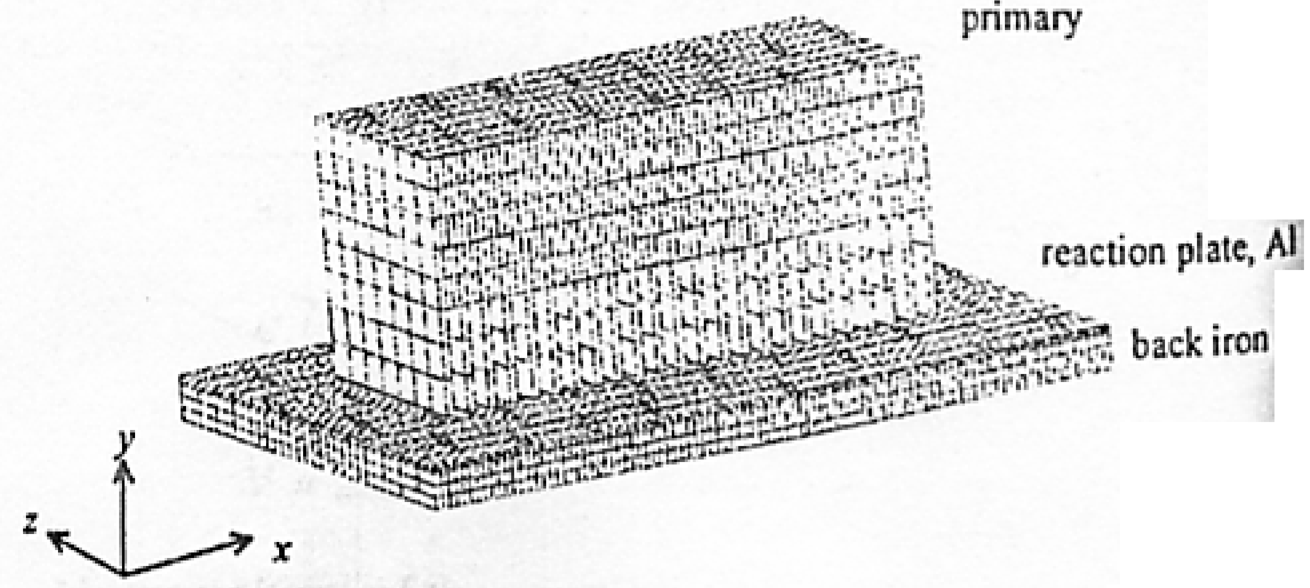

Fig. 2. Mesh shape for EMCN.

The system matrix is constructed by applying the flux continuity condition, which states that the sum of inflow and outflow of magnetic flux at each node is zero The system matrix equation can be obtained as following.

$$[P]_{n\times n}\{U\}_{n\times 1} = \{F\}_{n\times 1} \quad (4)$$

where $[P]_{n\times n}$ is the permeance coefficient matrix which is symmetric and has a good sparsity and bandwidth, $\{U\}_{n\times 1}$ is the matrix of unknown magnetic scalar potential (MSP) at a node, and $\{F\}_{n\times 1}$ is the forcing matrix including MMF due to the induced current.

MOTION EQUATION

The motion of the rotor is governed by the motion equation,

$$F_{Torque} - F_{load} = m(dv/dt) + k_f \cdot v \quad (5)$$

where, F_{Torque} is the electromagnetic torque, m is the mass of mover, v is the mover speed and k_f is the coefficient of viscous friction. When the primary moves from x_1 to x_2, MMF distribution of the primary, $M(x_1)$ and the relative permeability $\mu(x_1)$ of primary changes at each node for $M(x_2)$, $\mu(x_2)$ according to the moving distance of the mover. So, the motion of primary is modeled without a need for re-meshing.

RESULTS AND DISCUSSION

The proposed method has been succesfully applied to the study of a LIM. This motor is fed by a three phase voltage source. The total number of nodes and the element number are 84940. Results with the proposed method are presented in Figures 3 to 5. Figure 3 shows spatial magnetic flux density distribution in z directions, B_z, in the middle of the air gap. This spatial distributions is not uniform in z-direction and can not be calculated in 2D analysis, since it is assumed to be zero. Comparing the proposed method with 2-D FEM with respect to the normal force versus time as shown in Fig. 4, the 2-D analysis overestimates the normal force. This is because it is assumed that the eddy current is constant over the analysis region and the MMF due to the end ring is not included in the model.

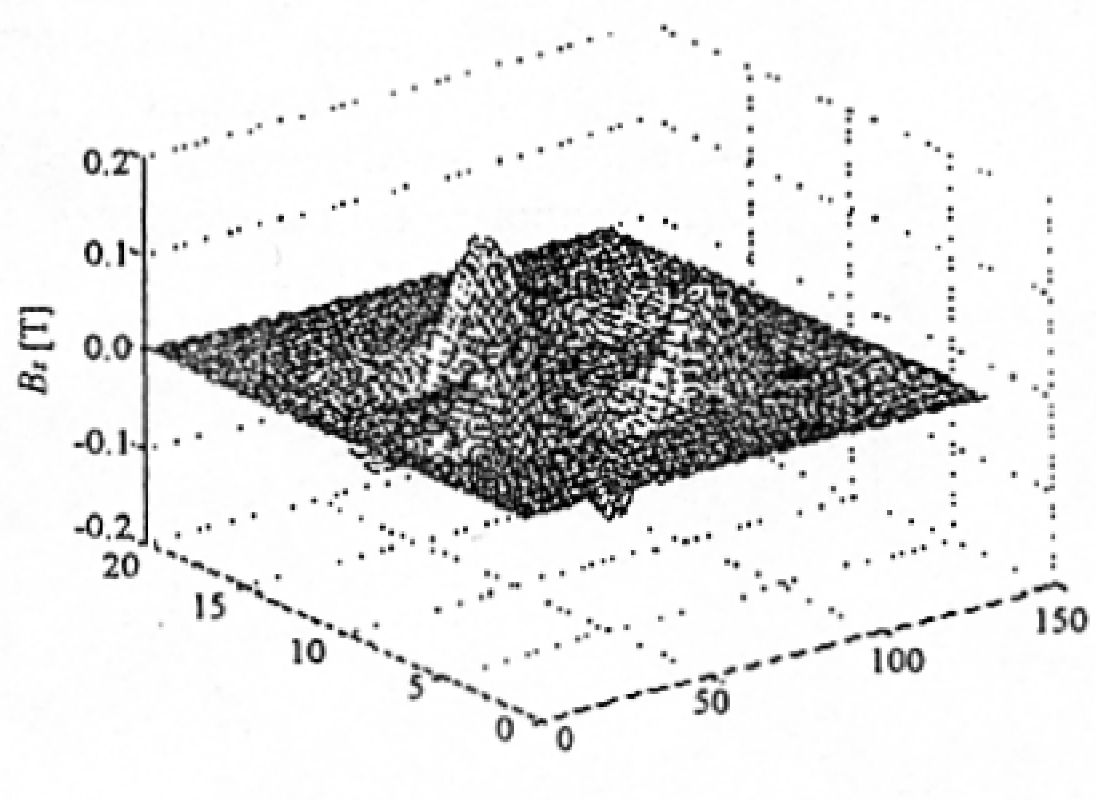

Fig. 3. Spatial distribution of magnetic flux density. B_z

So, the voltage drop of end ring is only considered by modifiying the conductivity σ in the conventional 2-D formulation. The back EMF are shown in Fig 5. References [1]-[3] reported a similar analysis using 3-D FEM which required a long computational time above two hours for just one time step. Also, for transient simulation 3-D FEM requires remeshing at each time step. Therefore, a large computation time is required for time-stepping 3-D analysis.

However, the proposed method in this paper needs only 10 minutes simulation time for each time step. Also, this method do not require remeshing, because the movement is easily modeled by changing the MMF and the reluctance without remeshing. So, this method is an effective method to analyze transient behavior of induction motor in 3-D.

In the final paper, these points plus further results including experimental results and comparison of 3D FEM results and a detailed description of the proposed EMCN method will be given.

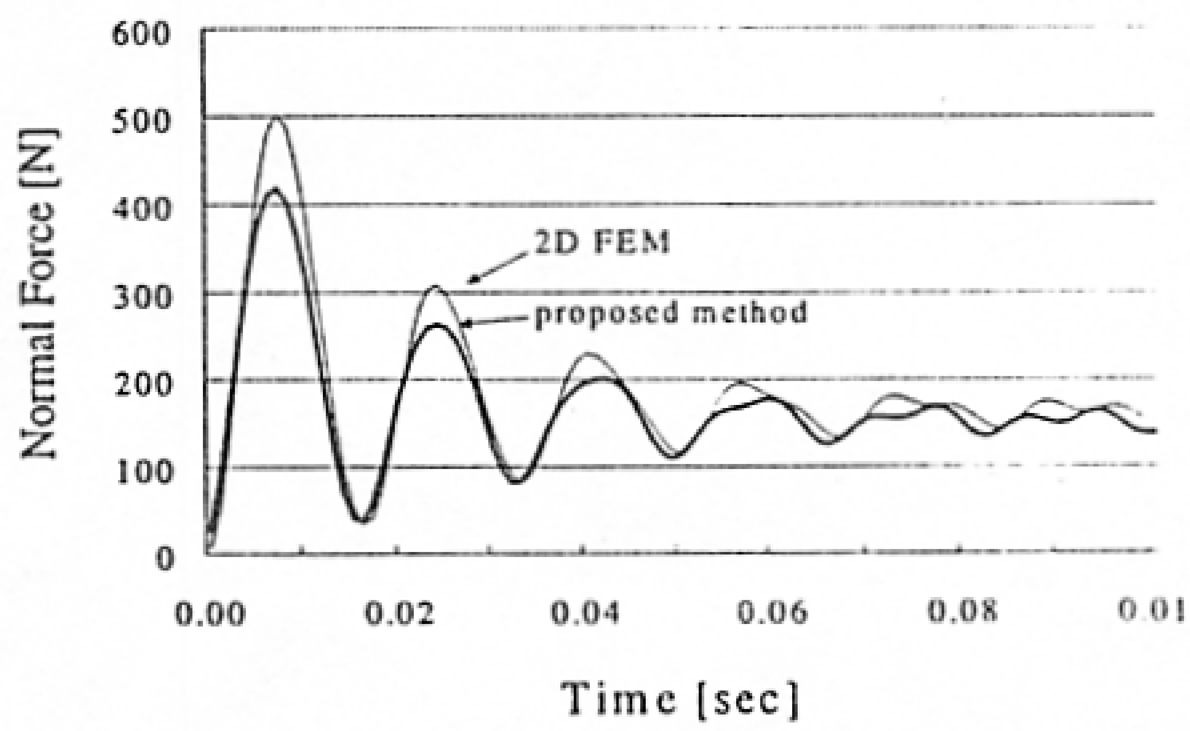

Fig. 4. Comparison of EMCN and FEM for normal force.

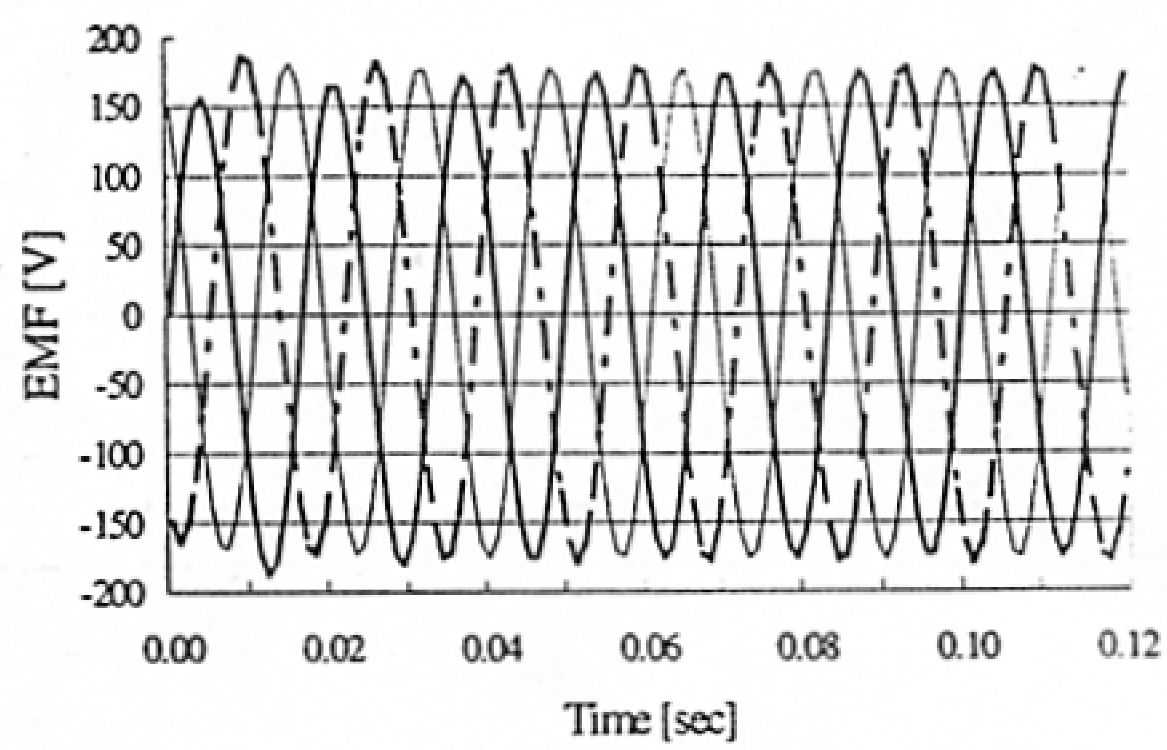

Fig. 5. Back EMF

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