

A Finite Element - Analytical Method for Electromagnetic Field Analysis of Electric Machines with Free Rotation.

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Introduction:

For electromagnetic field analysis of electric machines, the finite element method (FEM) has been more attractive than analytical approaches [1]-[8]. However, as the machine rotates, the finite elements in the airgap are distorted, leading to deteriorate the accuracy. To solve this problem, the concept of airgap element was introduced [9]. Following this concept, two hybrid methods were presented which combine the analytical solution of airgap and the standard FEM. In [10], the Neumann boundary condition was calculated to couple between the analytical solution and the FEM equations, but involves heavy computational burden. In [11], this condition was inappropriately assumed to be zero. Also, these two hybrid methods were exemplified by using idealized machines. Method:

In this paper, the finite element-analytical method (FEAM) is newly proposed and implemented for analysis of practical machines with free rotation. A new analytical solution of the airgap region will be derived, which can naturally couple with the FEM equations of both the stator and rotor regions. The proposed FEAM will be verified by comparing with both FEM and experimental results based on practical PM brushless DC (PMBDC) machines. The key of the proposed FEAM is to naturally couple the analytical solution with the FEM equations based on the continuity of magnetic vector potentials across their boundaries. Consequently, the modified stiffness matrix is derived as shown in Fig. 1.

Results:

Fig. 2(a) shows the airgap flux density distribution of a practical inner-rotor PMBDC machine resulted from using the FEAM, whereas Fig. 2(b) shows the relevant distribution resulted from using the FEM. The agreement is very good, hence numerically verifying the accuracy of the proposed FEAM. Fig. 3(a) shows the calculated no-load EMF waveform of a practical outer-rotor PMBDC machine resulted from the FEAM, whereas Fig. 3(b) shows the measured waveform. The agreement is also very good, hence confirming that the FEAM can allow for the machine with actual free rotation.

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$$S = \begin{bmatrix} \cdots & s_{L2} + \sum a_{L2}(n) & \cdots & s_{L3} + \sum a_{L3}(n) & \cdots & s_{L4} + \sum a_{L4}(n) & \cdots & s_{L5} + \sum a_{L5}(n) & \cdots \\ \cdots & s_{R2} + \sum a_{R2}(n) & \cdots & s_{R3} + \sum a_{R3}(n) & \cdots & s_{R4} + \sum a_{R4}(n) & \cdots & s_{R5} + \sum a_{R5}(n) & \cdots \\ \cdots & s_{L6} + \sum a_{L6}(n) & \cdots & s_{L7} + \sum a_{L7}(n) & \cdots & s_{L8} + \sum a_{L8}(n) & \cdots & s_{L9} + \sum a_{L9}(n) & \cdots \\ \cdots & s_{R6} + \sum a_{R6}(n) & \cdots & s_{R7} + \sum a_{R7}(n) & \cdots & s_{R8} + \sum a_{R8}(n) & \cdots & s_{R9} + \sum a_{R9}(n) & \cdots \end{bmatrix}$$

Fig. 1 Modified stiffness matrix.

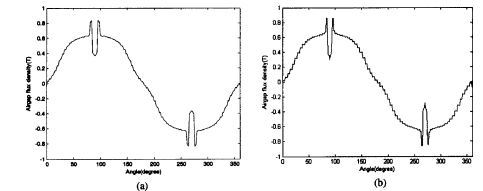


Fig. 2 Airgap flux density distributions. (a) Using FEAM. (b) Using FEM.

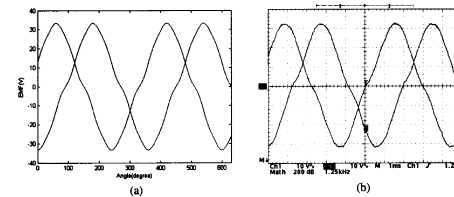


Fig. 3 No-load EMF waveforms. (a) FEAM-calculated. (b) Measured.