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BLDC Motor Cogging Torque Calculation with the Moving Material Method in the Finite Element Method

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Abstract

Conventionally, when we need to know about the dynamic characteristics of motors, the moving band method has been the first considerable technique. In this paper, we have investigated the moving material method that moves the property of the material in moving area elements of BLDC motors, instead of moving mesh elements of the rotor. From this method, we can reduce the demanded HDD memory for FEM analysis and the calculation time with same results.

Key Words : Moving Band, Finite Element Method(FEM), Brush Less Direct Current(BLDC), Motor, Cogging Torque

1. Introduction

FEM (Finite Element Method) is widely used for the electric machine design and analysis these days and its accuracy and calculation time depends on the mesh-generating and solving processes. In the cogging torque calculation of BLDC motors using FEM, we need to perform series of calculations at each point of angles where the relative position between the stator and rotor continuously varies. To make these processes easy, some researchers adopt the moving band method[1-3].

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This method need to separate whole analysis domain into two regions - the stationary part and the rotational part. Each of them has its own mesh and we need to combine them into one whole area mesh for the FEM analysis after the rotational part is rotated from 0 to the angle which we want to analyze.

In this method, meshes of each rotation angle have to be stored in the HDD memory prior to the calculation and it needs much HDD capacity and calculation times to save and restore those data.

So, we propose a novel moving material method that makes the demand of HDD memory capacity smaller and the calculation time faster not by changing the mesh but by rotating the material properties in the magnet area.

2. Moving band method

The moving band method is widely used for reducing the effort and the time of pre-processing when we need to do FEM analysis considering the rotation of a moving part. If this method is adopted, we can skip similar pre-processing procedures at each rotating position while an armature is moving but the meshes which are constructed at each position should be stored to and retrieved from the HDD memory. This process takes time that can not be negligible.

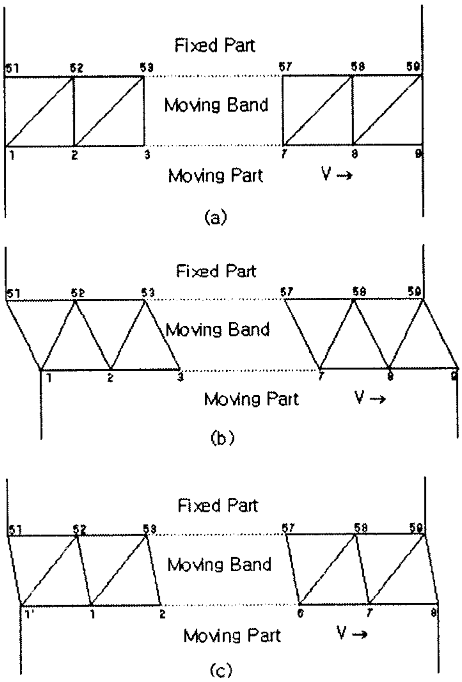


Fig. 1. Moving band method: (a) Initial state (b) Small displacement (c) Displacement is larger than element size

3. Moving material method

Generally, because BLDC motors do not have saliency on the surface of the rotor core, thus this type motors do not have reluctance torque, there is no difference in the rotor core shape with respect to rotating angle except the magnetization magnitudes and angles. Thus, there is a possibility which we can obtain the same results not by rotating the moving part elements but by rotating the material properties in the moving part elements

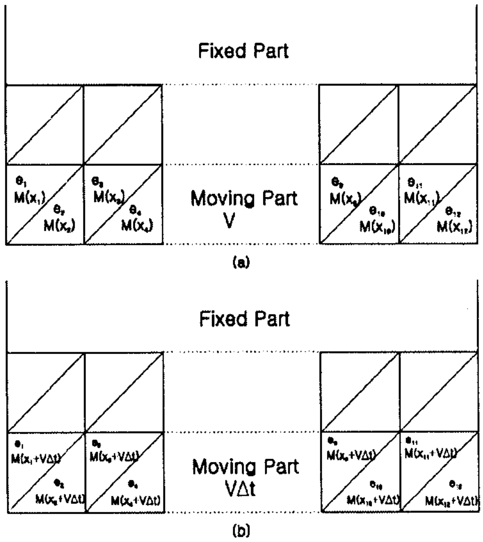


Fig. 2. Moving material method: (a) Initial state (b) Displacement S=VDt

Due to this moving material method, we do not need to store and retrieve the mesh files at each angle, and only just a single whole domain mesh is need to analysis all angles of the motor. This reduces HDD memory capacity and the calculation time significantly.

4. Finite element analysis

Maxwell's equation for this FEM model can be written as follows,

$$\frac{\partial}{\partial x}\left(\frac{1}{\mu}\frac{\partial A}{\partial x}\right)+\frac{\partial}{\partial y}\left(\frac{1}{\mu}\frac{\partial A}{\partial y}\right)=-\frac{1}{\mu}\left(\frac{\partial M_y}{\partial x}-\frac{\partial M_x}{\partial y}\right) \quad (1)$$

where A is the magnetic vector potential, μ is the permeability, M is magnetization of the permanent magnet. In the cogging torque simulation, there is no exciting current, so we do not need to consider exciting currents.

Fig. 3 shows the equivalent distribute magnetization factor of a magnet.

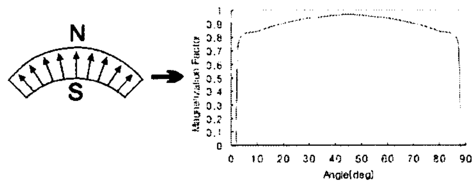
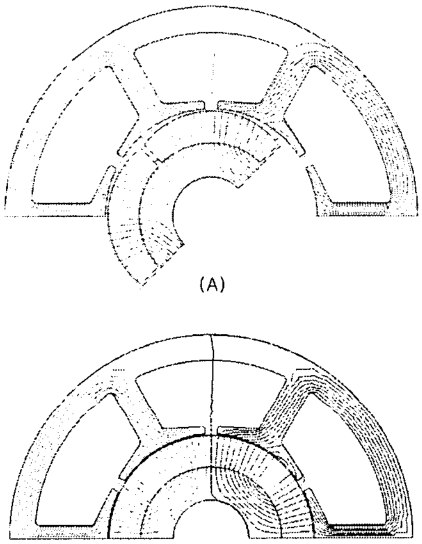


Fig. 3. Distribute magnetization factor



(A)

(B)

Fig. 4. Result fluxlines: (a) Fluxline figure at 45[°] by the moving band method (b) Fluxline figure at 45[°] by the moving material method

We use this factor for the moving material method to make the distributed magnetization data, which is equivalent to the magnet shape in the moving band method.

5. Comparison of two methods

As shown in Fig. 4, there is nearly no difference between fluxline figures if we consider the fact that a periodic boundary condition is applied to both edge of the moving band method model. The flux densities and the torque values of two models are very similar to each other.

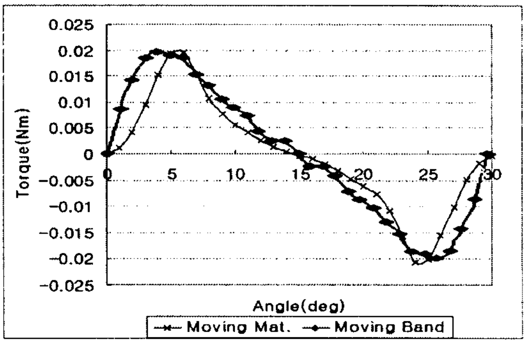


Fig. 5. Comparison of the moving band method and the moving material method

Fig. 5 shows the calculated cogging torque curves of two methods. Considering the cogging torque is relatively small and it is very difficult to simulate exactly, we can conclude that those two methods make sufficiently similar results. There is discrepancy of two simulation results because the moving material method uses the equivalent distribute magnetization factor but this factor seems not enough to consider the magnet shape and magnetization pattern together. But peak values of cogging torque and the positions of peak cogging torque are well matched in the simulation results.

On the other hand, the comparison of performances of two methods are shown in table 1 and table 2. This result means the moving material method is more efficient when it is used properly.

Table 1. Comparison of HDD Memory Demand

Calculation Method	HDD Memory Demand
Moving Band	30,046,104[byte]
Moving Material	2,923,077[byte]
→ About 1/10 of HDD Memory demand	

Table 2. Comparison of Calculation Time

Calculation Method	Calculation Time
Moving Band	6[Min]
Moving Material	2[Min]
Condition : Calculated in 30 angles → About 1/3 of HDD Calculation time	

6. Experiment results

To verify the moving material method is feasible, we measured the BLDC motor cogging torque and compared the measured cogging torque with the simulated cogging torques. Fig. 6 shows the experiment set : the cogging torque meter and BLDC motor.

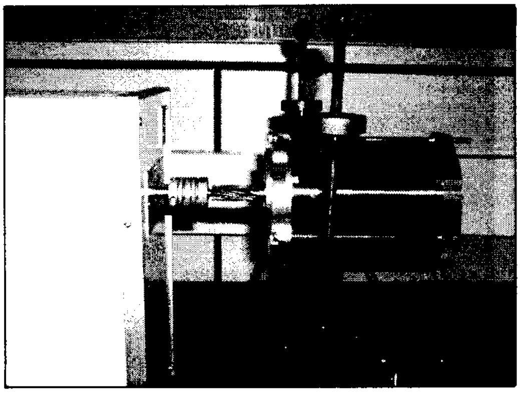


Fig. 6. BLDC motor and cogging torque measurement system

Because the cogging torque value is small, it is not easy to measure it exactly. The measured cogging torque data includes the measurement error caused by the miss-alignment of the motor shaft and the measuring system shaft. Compared with Fig. 5, the cogging torque value in Fig. 7 is well-matched with the calculated data by the moving material method.

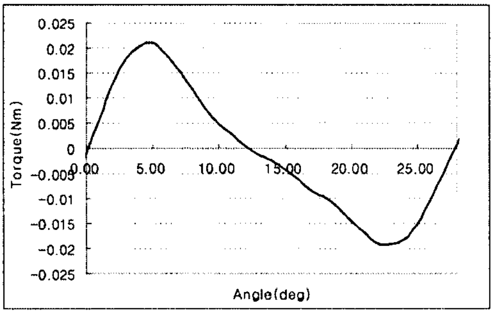


Fig. 7. Measured cogging torque of BLDC motor

7. Conclusions

In this study, we proposed a new method of modeling the rotating machine. Instead of the moving band method, which is widely used when someone want to perform a FEM calculation considering the rotation, we proposed the moving material method.

Usually, when an engineer try to minimize the cogging torque, he have to perform hundreds time of simulations. By using this method, we could reduce the HDD memory demand and the calculation time considerably.

These results are especially useful to researchers who try to analyze the BLDC motor considering the rotation of the rotor comprising magnets and a back-yoke.

Acknowledgement

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Biography

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