Finite Element Processing Methods to Peripheral Flux Leakage in Axial Field Flux-Switching PM Machines

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***Abstract*—In this paper, a finite element(FE) analysis of the peripheral flux leakage in a novel axial field flux-switching permanent magnet (AFFSPM) machine was presented by using energy method. The size of peripheral air cylinders in FE analysis model of AFFSPM machine was determined by the suggested method. Thus, it was possible to optimize between the computational precision and time. The calculation results are coincide with that by permanent magnet (PM) flux method. In addition, the presented method was also used in 2D FE simulation. The investigation shows that this method is useful in the application of machines with PM in stator.**

***Index Terms*—peripheral flux leakage, air cylinder, energy method, AFFSPM machine.**

I. INTRODUCTION

The peak-to-peak values of the PM flux and the induced electromotive force (EMF) computed by FE method are larger than their actual values due to the peripheral flux leakage in a AFFSPM machine with PM in the stator. In order to decrease the computation error, it is necessary to add peripheral air cylinders to the periphery of FE analysis model of machines. However, this increases the workload for meshing, computing and post-processing. Therefore, it's very practical to determine the sizes of air cylinders and to optimize the computation precision and time.

FE simulations of PM machines, including the design, the optimization of machines, the calculation of parameters, have been studied in the literatures. However, how to decide the sizes of peripheral air cylinders in the FE analysis model have rarely been investigated. In this paper, an energy method is suggested to determine the sizes of the air cylinders for a novel AFFSPM machine. The calculated results is compared with that gotten by the PM flux method.

The energy method is discussed in section Ⅱ. In section Ⅲ, PM flux method is introduced and the results are compared. In order to illuminate that the energy method is applicable to 2D FE simulation, a 2D FE example is presented in section Ⅳ.

II. THE ENERGY METHOD

A. The simulation model of AFFSPM machine

The magnetic energy is a sum of the magnetic co-energy in each element. For each one, the magnetic co-energy is calculated as follows:

$$W_c = \int_{-H_c}^{H} \{B\} \cdot \{dH\} \tag{1}$$

where W_c is the stored magnetic co-energy, H_c is the coercive force, B is the flux density vector, and H is the magnetic field intensity vector. For the static magnetic field in the zero-current condition, the interrelated parameters are governed by the following three equations:

$$\begin{cases} \nabla \times H = 0 \\ \nabla \cdot B = 0 \\ B = \mu H \end{cases} \tag{2}$$

where μ is the magnetic permeability. To solve these equations, a magnetic scalar potential is introduced to describe H:

$$H = -\nabla \psi \tag{3}$$

where ψ is the magnetic scalar potential, which could deduce the requisite parameters.

Fig. 1 shows a typical AFFSPM machine of the type to be investigated in this paper. The machine consists of two outer stators and one inner rotor.

There are three peripheral air covers in the FE analysis models of the AFFSPM machine, that is, a radial outer peripheral air cylinder, a radial inner air cylinder and a terminal air cylinder. The three peripheral air cylinders are added in the FE analysis model in turn and their sizes should be determined. Fig.2 shows the 3D FE analysis model of a AFFSPM machine.

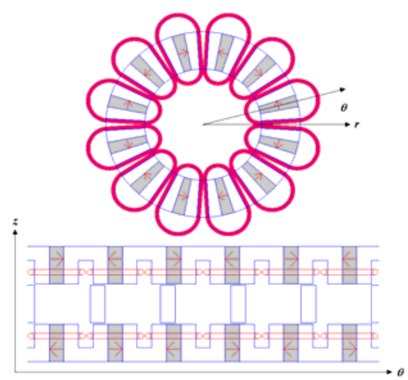
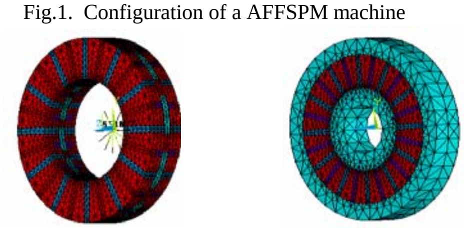


Fig.1. Configuration of a AFFSPM machine



(a) Not considering the peripheral flux leakage (b) Considering the peripheral flux leakage

Fig.2. 3D FE analysis model of AFFSPM machine

B. Determination of radial peripheral air cylinder size

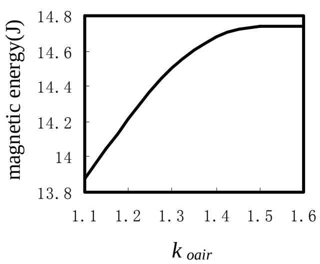
The outer diameter of the radial peripheral air cylinder was calculated. If k_{oair} is defined as a changeable coefficient for the undetermined parameter, and it is

$$k_{oair} = D_{oair} / D_o \quad (4)$$

Where D_{oair} is the outer diameter of the radial peripheral air cylinder, and D_o is the outer diameter of AFFSPM machine. Fig.3 shows the magnetic energy varied with k_{oair} at initial rotor position angle, and the change of magnetic energy in one cycle at different k_{oair} is shown in Fig.4.

The magnetic energy is constant when k_{oair} is larger than 1.5(Fig.3), which is also demonstrated by the results in Fig.4. Therefore, 1.5D_o is determined as the outer diameter of the radial periphery air cylinder.

The sizes of radial inner air cylinder and terminal air cylinder are also determined according to the above analysis. 0.5D_i *is* selected as the inner diameter of radial inner air cylinder, and 1.1h_s is the axial depth of the terminal air cylinder, where D_i is the inner diameter of AFFSPM machine, and h_s is the axial length of the stator.



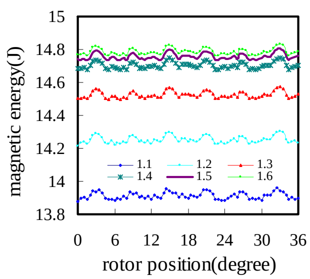


Fig.3. Magnetic energy at the initial position angle

Fig.4. Magnetic energy in one cycle

III. The PM Flux Method

The PM flux is one of most important parameters in the design and optimization of PM machines. The relationship between the peak-to-peak value of the PM flux and the k_{oair} in one phase is shown in the Fig.5. The peak-to-peak value of the PM flux is constant when the k_{oair} value is larger than 1.5, and this is coincide with that obtained from the energy method.

The relations of PM flux peak-to-peak with the sizes of the radial inner air cylinder in one phase and the terminal cylinder are also obtained by the same method. The inner diameter of the radial inner air cylinder is determined as 0.5D_i, and the axial length of the terminal air cylinder is 1.1h_s. These are coincide with those obtained by the energy method.

IV. 2D FE Analysis

In the 2D FE analysis model of a radial field flux-switching PM machine, a circle was added to the periphery of the stator to simulate the air condition. Fig.6 shows the FE analysis model of the machine. The outer diameter of the peripheral air circle is determined. The calculated results based on the energy method are shown in Fig.7 and Fig.8, where k_{airso} is the proportion of the outer diameter of the air circle to the outer diameter of the stator. According to the calculation of the magnetic energy, 1.5D_{so} is determined as the outer diameter of air circle, where D_{so} is the outer diameter of the stator. This result can also be obtained by using the PM flux method.

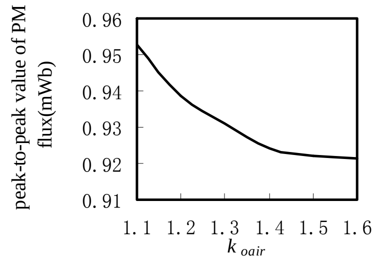


Fig.5. PM flux peak- to-peak value

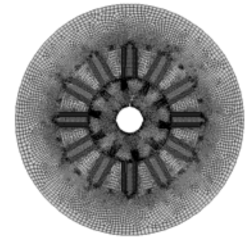
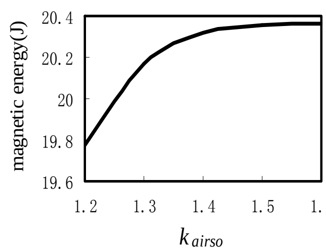


Fig.6. 2D FE analysis model of a radial field flux-switching PM machine



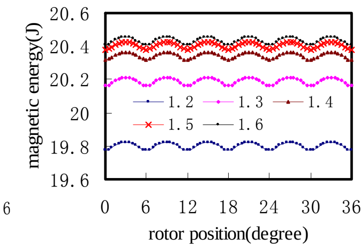


Fig.7. Magnetic energy at the initial rotor position.

Fig.8. Magnetic energy in one cycle

V. Conclusions

In this paper, an energy method is presented and used to determine the sizes of peripheral air cylinders in the FE analysis models of the flux-switching machines. The simulation results are confirmed by the PM flux method in the 3D and the 2D FE simulation. In additional, the peak-to-peak values of the PM flux and the induced EMF computed by the FE method are larger than their actual values, which is caused by the difference of the PM flux at different air cylinder sizes. The determination of the sizes of peripheral air cylinders on the FE analysis models of flux-switching machines is important to obtain the balance between the computation precision and the time. Therefore, it's useful to determine the air cylinder sizes by the energy method in the FE simulation of machines with PM in the stator.

VI. References

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