Cogging Torque Optimization of Flux Concentrated Transverse Flux PM Disk Generator by Skewing PM Poles

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In this paper, a new skewed PM poles structure for reducing the cogging torque for flux concentrated transverse flux PM disk generator (FC-TFPMDG) with soft magnetic composite core is proposed. The frequency spectrum of cogging torque is analyzed to find the dominant component, and then to determine the skew degree of PM poles. The cogging torque and the no-load electromotive force are calculated and analyzed by 3D FEM and further verified by experiment.

***Index Terms*—Cogging torque optimization, finite element method, skew pole, soft magnetic composite, transverse flux machine**

I. Introduction

Transerse flux permanent magnet machines (TFPMMs) and their applications in direct-drive system, especially in direct-drive wind power system, have attracted much interest due to their higher power density, the decoupling between electrical and magnetic circuits, and the modular structure [1, 2]. A novel flux concentrated transverse flux PM disk generator (FC-TFPMDG) with soft magnetic composite (SMC) cores is introduced by authors as shown in Fig. 1 [3]. The prototype of this machine is manufactured as shown in Fig. 2, which has higher space and PM utility than conventional TFPMMs and expands the topology of TFPMMs. However, the cogging torque of the initial design machine is much larger by experimental analysis. This torque can bring more vibration and noise when the machine rotates.

In this paper, a novel FC-TFPMDG with SMC cores is introduced with the merits of the higher power density in traditional TFPMMs and the compact structure at axial direction in disk-type machines. Moreover, the frequency spectrum of cogging torque is analyzed to determine an effective method to minimize the cogging torque of FC-TFPMDG by skewing the PM poles. The cogging torque and the no-load EMF are calculated and analyzed by 3D FEM and then verified by experiment.

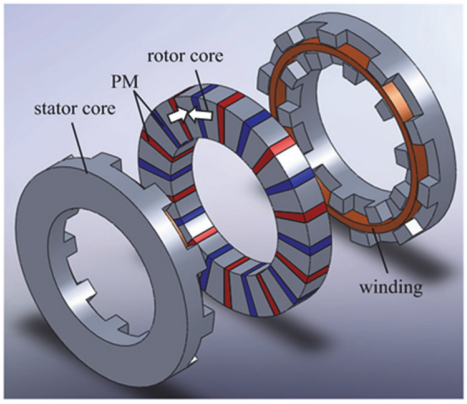


Fig. 1. Structure of single-phase FC-TFPMDG.

II. Cogging Torque Analysis of FC-TFPMDG

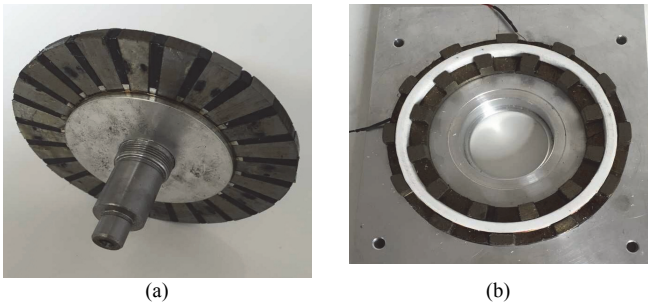
A. Cogging torque

The cogging torque of any permanent magnet machine (PMM) including TFPMMs can be calculated by the total stored co-energy W_{co} and the rotor angle θ of machine, which can be expressed as,

$$T_{cog} = -\frac{\partial W_{co}}{\partial \theta} \tag{1}$$

It is assumed that the stator and rotor cores of machine are ideal without saturation. The co-energy in airgap and PMs are the dominant of the total stored co-energy in PMM. However, the flux density in airgap of this studied machine, FC-TFPMDG is difficult to obtain by using analytical method due to its complex flux path distribution. The 3D FEM software Ansys is adopted to calculate the cogging torque.

The stator cores and the PMs of FC-TFPMDG prototype shown in Fig. 2 are manufactured by SMC and NdFeB respectively. The rated power (single-phase) and the speed of this machine are 50W and 600r/min respectively. The main parameters are listed in Table I.



(a) (b)

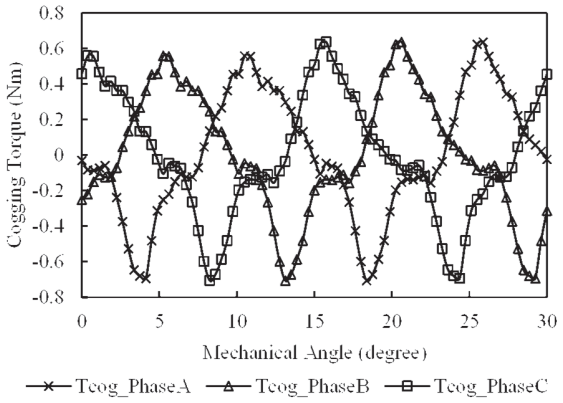
Fig. 2. Prototype of single-phase FC-TFPMDG. (a) rotor. (b) stator (one side).

TABLE 1. Main parameters and dimensions of FC-TFPMDG

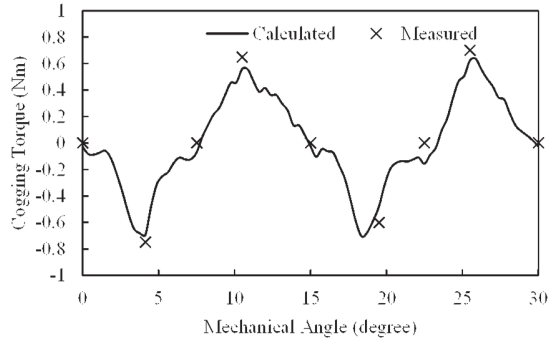
Dimensions	Values
Number of poles	24
Inner radius (mm)	35
Outer radius (mm)	55
Radial length of inner teeth (mm)	7
Radial length of outer teeth (mm)	5
Air-gap (mm)	1
Axial length (mm)	24

Axial length of stator teeth (mm)	6
Number of turns (one side)	210
Circumferential length of PM (mm)	5
Rated voltage (V)	50
Remanence of PM (T)	1.26
Coercivity of PM (kA/m)	865
SMC type	Somaloy 500

The cogging torque of this single-phase module prototype is calculated by 3D FEM as shown in Fig. 3(a). The amplitude of the cogging torque for every phase module is approximately 0.65Nm. For a three-phase one, the entire cogging torque of machine is the superposition of every phase value by shifting 120 electrical degree between each other. The cogging torque amplitude of the three phase machine is about 0.36Nm. Moreover, to verify the calculated results, an experiment is carried out to measure the extreme values of cogging torque by using weight method, as shown in Fig. 3(b). The error between the calculated and measured values is mainly caused by the assembly and experiment tolerance.



(a)



(b)

Fig. 3. Cogging torque versus mechanical angle. (a) Cogging torques of Phase A, B and C respectively. (b) Calculated and measured cogging torque.

B. Frequency harmonic of cogging torque

For this proposed FC-TFPMDG, the electrical period and the cogging torque period are 30 and 15 degree respectively due to its unique core and the PM arrangement. In order to reduce the cogging torque, the Fast Fourier Transformation (FFT) method is adopted to analyze and the find the dominant component of the cogging torque, as shown in Fig. 4.

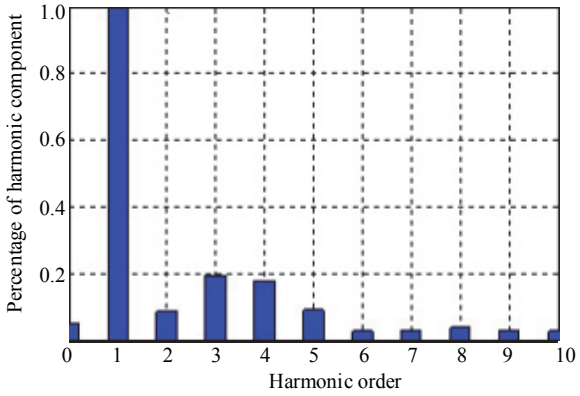


Fig. 4. *n*th order component of cogging torque of single-phase FC-TFPMDG by FEM.

III. COGGING TORQUE REDUCTION BY SKEWING PM POLES

Due to its specific structure of FC-TFPMDG, it can adjust the angle of PM in rotor easily to form the skewing PM poles. In this study, the relation between skewed angle and the frequency harmonic is described to find the selected skewed angle to reduce the cogging torque effectively. The cogging torque of three-phase machine is shown in Fig. 5. The amplitude of the cogging torque after optimized skew poles can reduce to about 0.2Nm, which is smaller than the initial one approximately 0.6Nm.

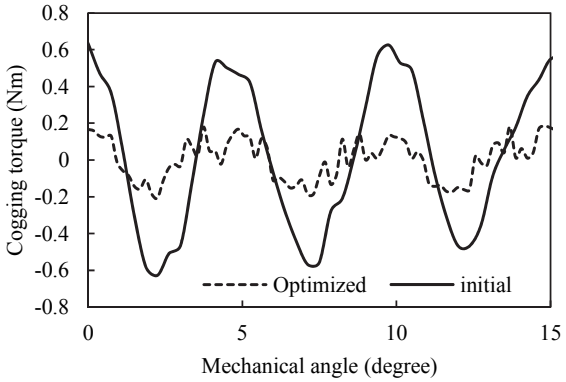


Fig. 5. Three-phase cogging torque without and with PM poles skew.

IV. CONCLUSION

In this paper, a new PM poles skew method to reduce the cogging torque of FC-TFPMDG is proposed. The detailed analysis and calculation will be given in the full text.

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