Xiao-yuan WANG, Xiang LI, Chun-peng LI, Si-jia XU, Le-tao LING, 2019. Design of a PCB stator coreless axial flux permanent magnet synchronous motor based on a novel topology Halbach array. *Frontiers of Information Technology & Electronic Engineering*, 20(3):414-424. https://doi.org/10.1631/FITEE.1700345

Design of a PCB stator coreless axial flux permanent magnet synchronous motor based on a novel topology Halbach array

Key words: Axial flux permanent magnet synchronous motor; Printed circuit board; Halbach permanent magnet array; Finite element method

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Introduction (1/2)

1. An axial flux permanent magnet (AFPM) motor is different from a radial flux permanent magnet motor because the air-gap flux is along the axial direction and the air-gap is in-plane. Because its axial dimension and the armature winding inductance are small , AFPM has received increased attention.

2. A printed circuit board (PCB) stator coreless AFPM motor can greatly reduce the weight of the motor with no cogging torque or stator iron loss, and can achieve an accurate position of the coil; thus, the motor servo is good and conducive for batch production.

Introduction (2/2)

A PCB stator coreless AFPM motor

Imperfections:

1. Flux in the stator coils will be reduced because of the coreless stator structure ;

2. Stator winding of the PCB stator is directly printed on the PCB. In a certain area of PCB, the number of turns of the stator winding, the line width, and line distance are different.

Solution:

Using a novel topology for a Halbach permanent magnet array, where the pole diameter and outer diameter of the polar angle parameters are independent , and the main and auxiliary poles are optimized with different central fan shapes.

Innovation

1. Apply a novel type of Halbach permanent magnet array to the design of a PCB axial flux permanent magnet motor.

2. We focus on the influence of the shape of the array on the air-gap magnetic flux density and magnetic flux leakage, especially from the inner and outer diameters of the rotor.

Method (1/4)

1. PCB stator AFPM motor structure

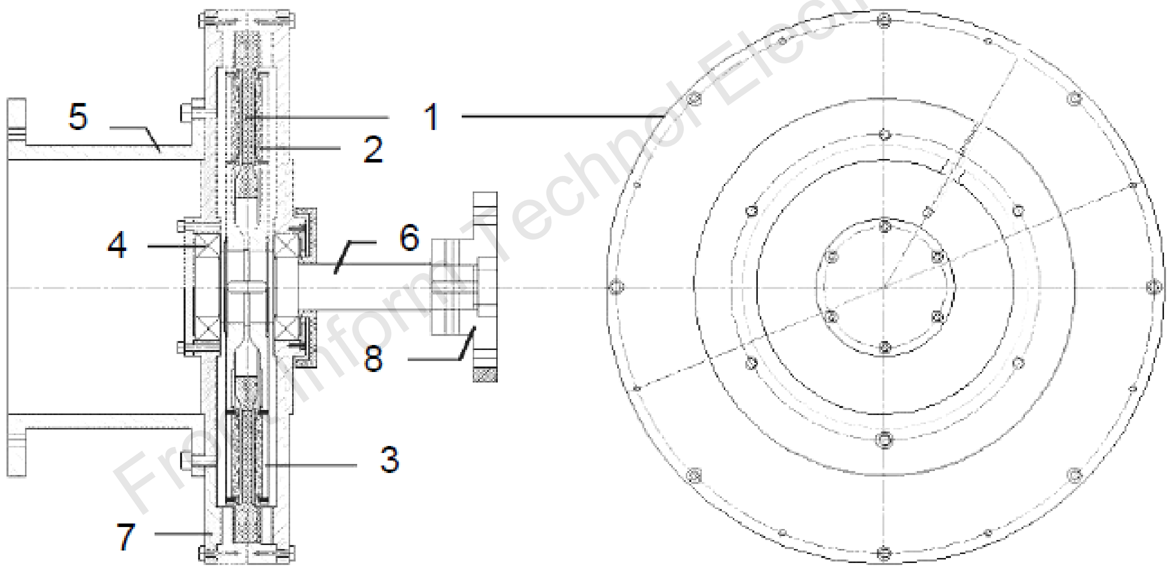

Fig. 1 Schematic of the stator slot

1: stator; 2: permanent magnet; 3: back iron; 4: bearing; 5: supporting member; 6: shaft; 7: shell; 8: prime mover

Method (2/4)

2. Three assumptions are made about the model:

(1) The permanent magnet is uniformly magnetized, the surface is smooth, and the two permanent magnets can perfectly be combined.

(2) Permeabilities of the PCB stator coil and air are approximately equivalent; thus, the PCB stator coil is treated as air when the gap flux density is calculated without load.

(3) The influence of the rise of temperature on the magnetism of the permanent magnet and performance of the motor is ignored.

Method (3/4)

3. Schematic of a novel type of Halbach permanent magnet array magnet steel

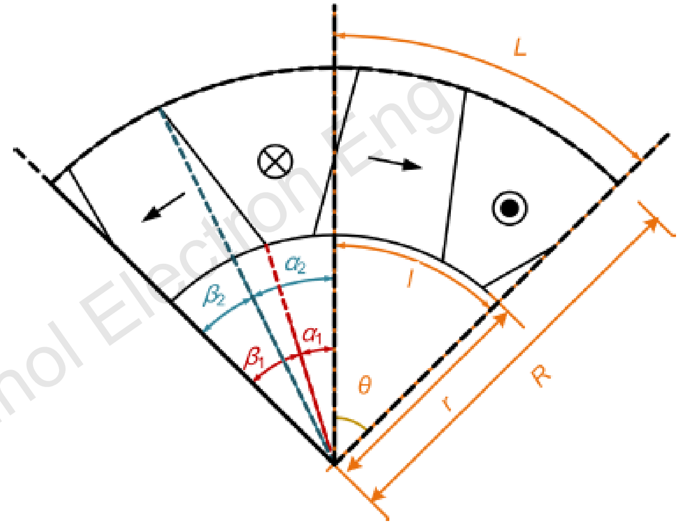

Fig. 6 Schematic of a novel Halbach permanent magnet array magnet steel
L and *l* are the length of the arc of the outer and inner diameters between two central lines of the magnet steel, respectively. *R* and *r* are the outer and inner diameters of the magnet steel, respectively. α_1 and α_2 are the angles between the inner magnetic pole and the outer diameter between the central line, respectively

Method (4/4)

4. PCB stator AFPM motor model

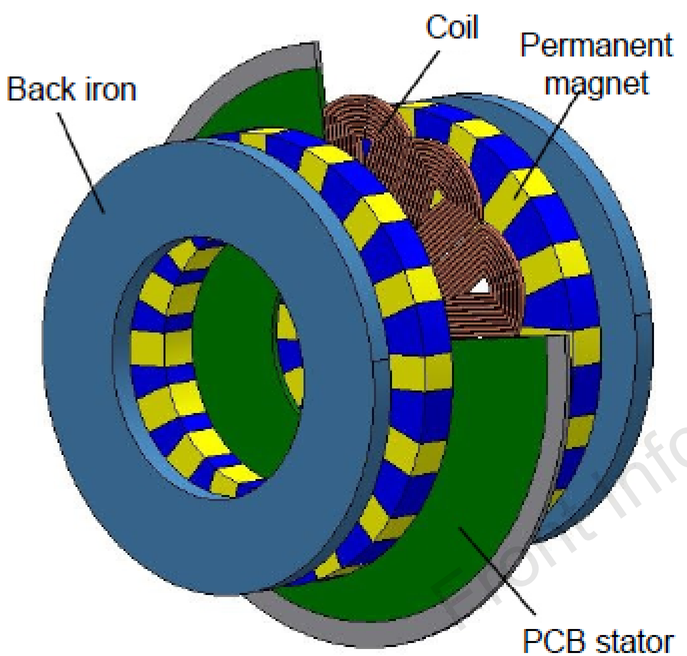

Fig. 3 PCB stator AFPM motor model

Table 1 Basic parameters and design requirements of the motor

Parameter	Value
Rated power	200 W
Permanent magnet material model	45 H
Thickness of the permanent magnet	8 mm
Thickness of theback iron	5 mm
Rotor outer diameter	90 mm
Rotor inner diameter	52 mm
Air-gap length	5 mm
Number of turns	8
Number of slots	12
Number of pole pairs	8

Results of finite element simulation (1/3)

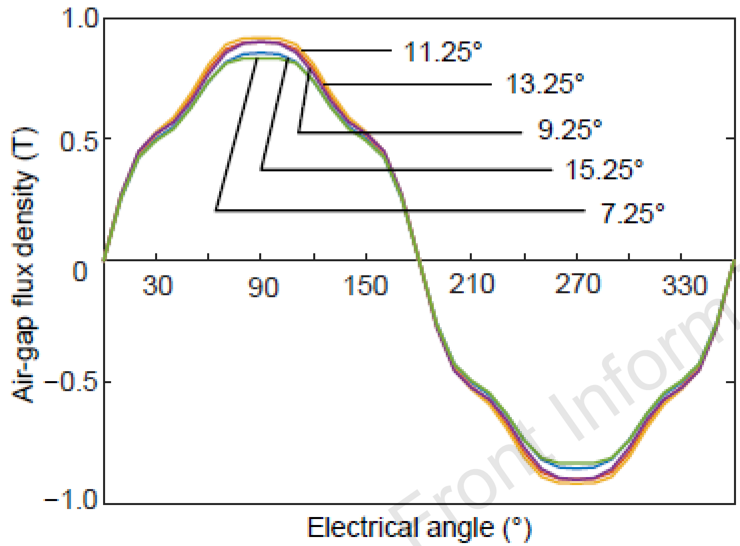

Fig. 7 Distribution of air-gap magnetic density at the mean radius of different α

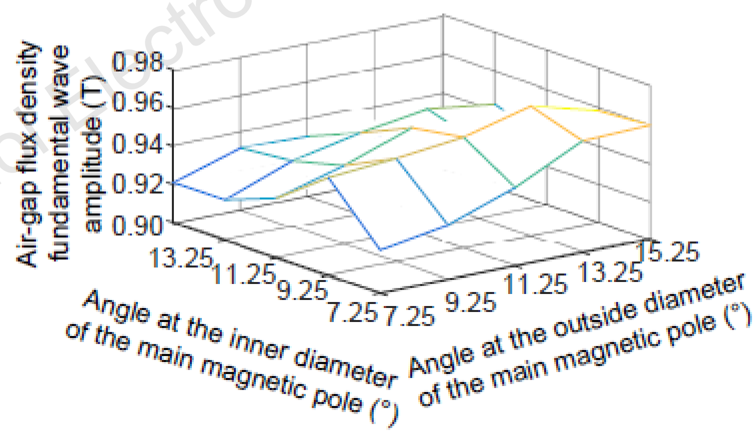

Fig. 11 Fundamental amplitude of the air-gap flux density with the center angle

Results of finite element simulation (2/3)

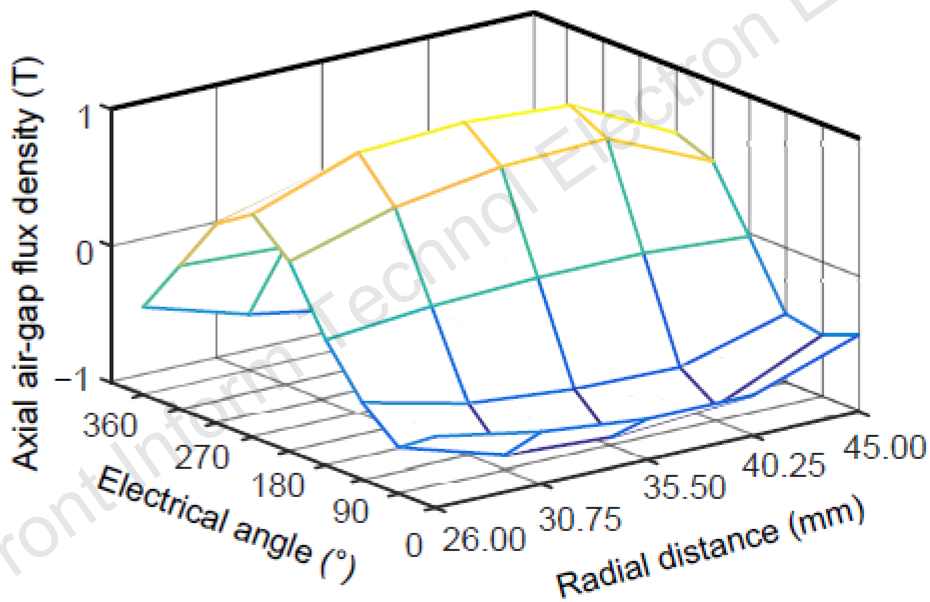

Fig. 12 Air-gap flux density at different radial positions and electrical angles

Results of finite element simulation (3/3)

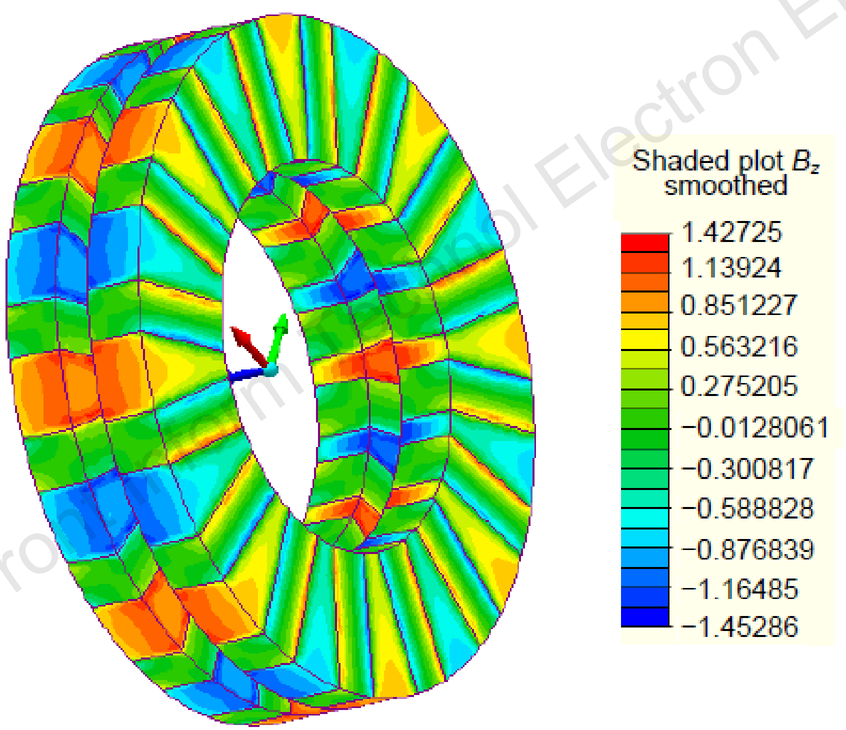

Fig. 14 Magnetic flux density distribution of the novel Halbach permanent magnet array

Experiments (1/2)

1. PCB stator prototype and prime mover with a PCB stator

Fig. 15 PCB stator prototype and prime mover with a PCB stator

Experiments (2/2)

Fig. 16 Experimental platform

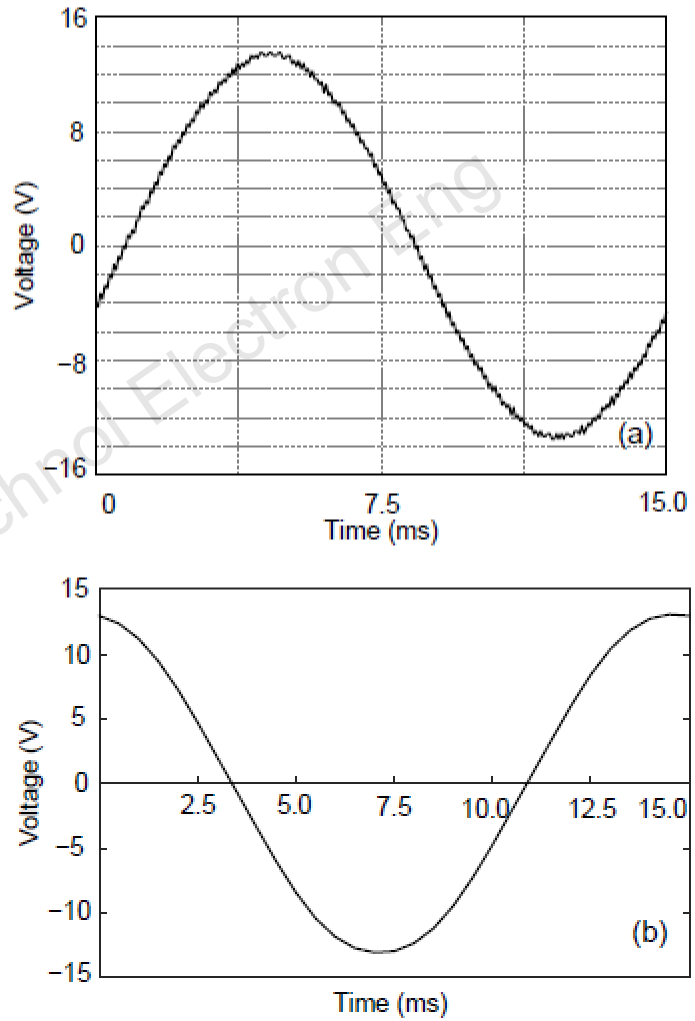

Fig. 18 Comparison of the experimental and simulation results at a speed of 500 r/min: (a) experimental results; (b) simulation results

Conclusions (1/2)

1. For the permanent magnet pole array in the novel Halbach PCB stator AFPM motor, the main and auxiliary poles of the polar angle phase can present a larger air-gap magnetic density under the same condition; compared with conventional AFPM permanent magnet motors, in the PCB stator motor, the magnetic flux density increased by 14.5%.

Conclusions (2/2)

2. In the novel Halbach array, when assuming the magnetic pole's inner and outer diameters and the polar angle as independent variables, it is appropriate to increase the polar angle at outer diameter and decrease the polar angle at the inner diameter of the main pole, which can further increase the air-gap flux density and reduce magnetic leakage. For the PCB stator AFPM motor designed in this study, this amplitude was approximately 2°, and the fundamental amplitude of air-gap flux density was increased by 3%.