Demagnetization Analysis and Design Optimization of Permanent Magnet Synchronous Motor for Electric Power Steering Applications

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Abstract

In this paper, demagnetization characteristics and design optimization of permanent magnet synchronous machines (PMSM) for electric power steering (EPS) systems are studied.

- The thickness of PM in magnetization direction is mainly optimized without irreversible demagnetization under the condition of minimizing the amount of PM.
- A demagnetization analysis method based on 2D and 3D finite element analysis (FEA) for PMSM of EPS system is proposed

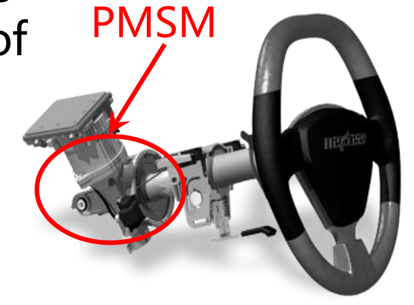

Fig.1 EPS system.

I. Dimensions and FEA model

TABLE I. Main Parameters of IPM Motor Model

Terms	Value
Output power	550 (W)
Rated Torque	4.1 (Nm)
Rated Current	80 (A)
Speed (Base / Max)	1200 / 4000 (rpm)
Battery Voltage	12 (V)
Stator Diameter	88 (mm)
Axial Length	24 (mm)
Min./Max. air-gap length	0.5 / 1.8 (mm)

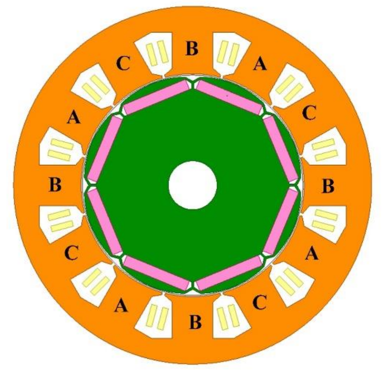

Fig.2 Finite element model of motor.

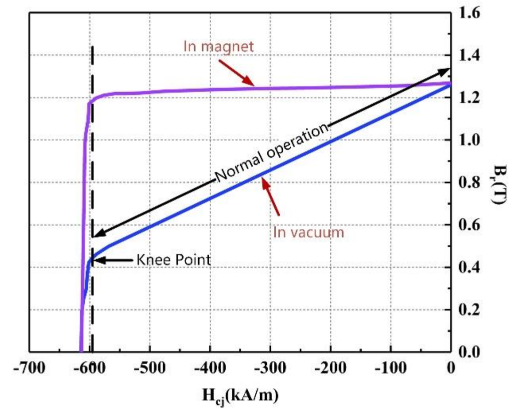

Fig. 3 B-H curve for Magnet N48H material at 120℃.

- ◆ Since the rated output torque is 4.1Nm, the electromagnetic torque of the motor should be more than 4.35Nm.
- ◆ Magnet N48H is applied and the operation temperature is predicted at 120C, in which the knee point is 0.45T.

II. Size Optimization of Permanent Magnet

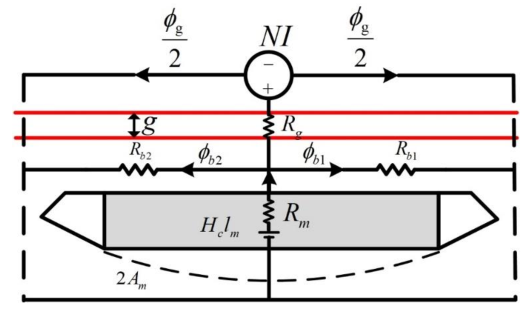

Fig.4 Magnetic equivalent circuit of the I-shaped interior PMSM

Ignoring the reluctances in the silicon steel, the magnetic flux of each permanent magnet can be expressed as:

$$\Phi_m = \frac{H_c l_m + 2R_g\Phi_b - NI}{R_g + R_m} \quad (1)$$

An initial design of thickness and width of PM can be obtained with the Φ_m assumed from (1).

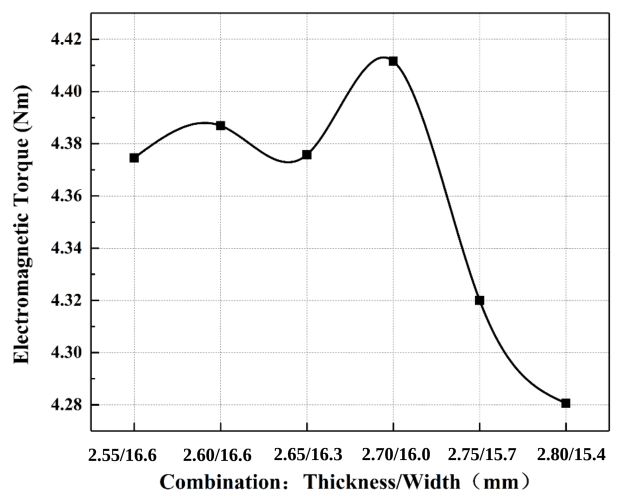

Fig.5 Variation of electromagnetic torque with different combinations.

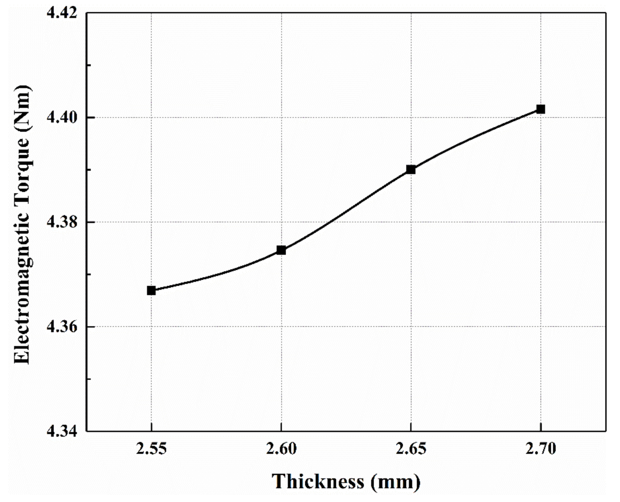

Fig.6 Variation of electromagnetic torque with the thickness when width is 16.0mm.

The value of width is set as 16.0mm while the demagnetization performance need to be considered when select the value of thickness.

III. Demagnetization Analysis

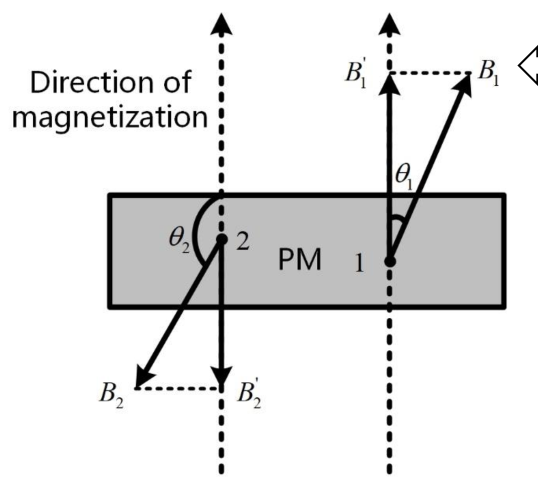

Fig.7 Projection of the flux density in PM.

"Minimum Operating Point", the minimum value of the operating point is used to assess the demagnetization risk, which can be expressed as:

$$B' = B\cos\theta \quad (2)$$

A. Demagnetization Analysis by 2D FEM

When the controller fails, The d-axis demagnetization current I_d can be calculated by:

$$I_d = \sqrt{2}I_a \sin(\gamma + 5^\circ) \quad (2)$$

I_a ——the rated current;
γ —— the leading phase angle, about 65°in field weakening state

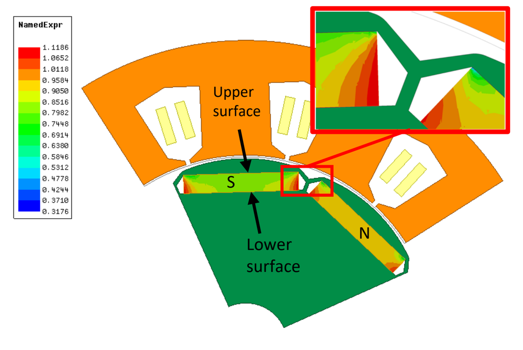

Fig.8 The distribution of the magnetic field in magnetization direction when thickness is 2.70mm.

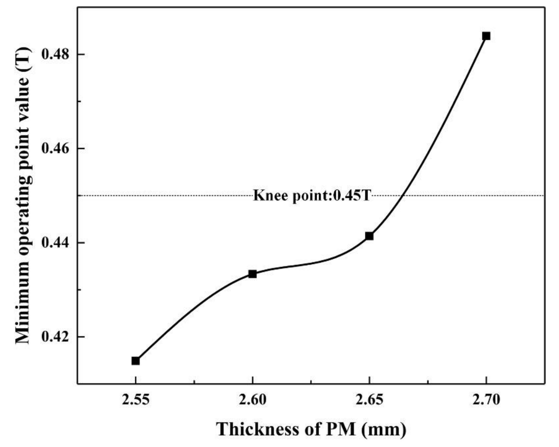

Fig.9 The minimum operating point values on the upper surface of four schemes.

- ◆ Demagnetization is more likely to occur on the upper surface as it is more susceptible to the armature magnetic field.
- ◆ Only when the thickness is 2.70mm, the minimum operating point value is higher than the knee point.

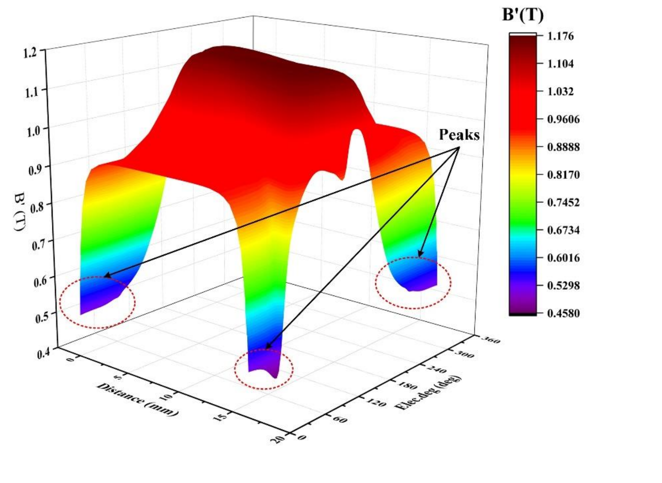

Fig.10 Flux density component in magnetization direction on the upper surface when thickness is 2.70mm.

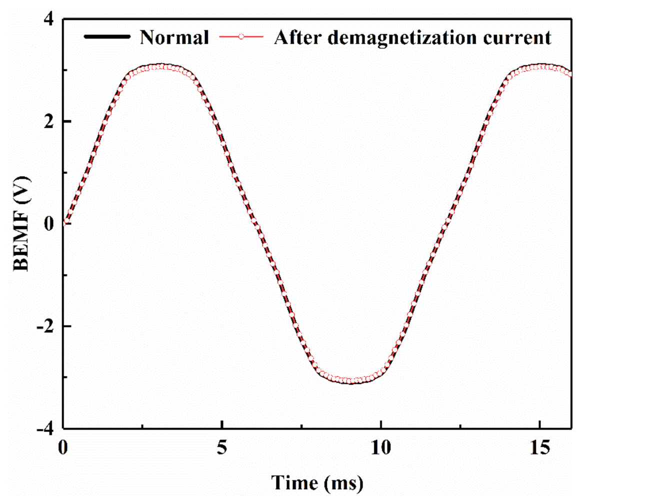

Fig.11 Waveforms of no load back EMF when thickness is 2.70mm

- ■ The no-load back EMF after demagnetized current was maintained, indicating Irreversible demagnetization did not occur.
- ■ In terms of demagnetization risk and reduction of magnet volume, the thickness of the PM is set as 2.70mm.

B. Demagnetization Analysis by 3D FEM

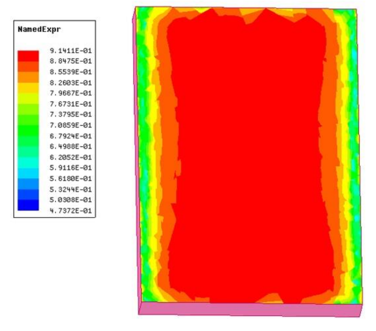

Fig.11 The distribution of the magnetic field in magnetization direction

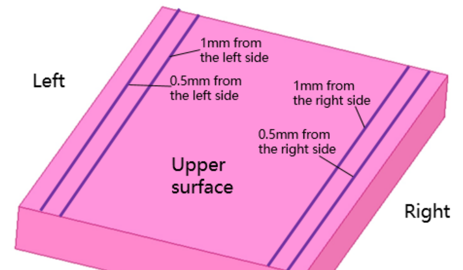

Fig.12 The position of four observation lines

The 3D FEM is used to calculate the demagnetization performance considering the fringing effects in axial direction. The minimum operating points of four lines are all higher than the knee point.

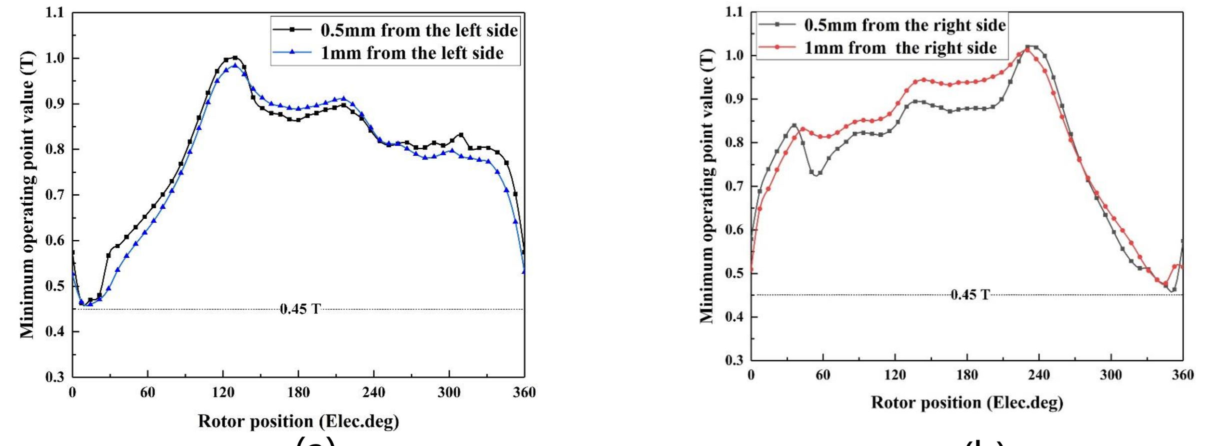

Fig.13 The amplitudes of minimum operating point on the observation lines. (a) left side. (b) right side.

Conclusion

This paper investigates the demagnetization performance of a 550W PMSM with I-shaped rotor applied in EPS system. Ensuring the performance of the motor, the size of the PM, mainly the thickness in the magnetization direction is optimized to reduce the amount of magnet and thus reduce the cost. The 2D and 3D finite element models are used to calculate the magnetic field distribution of PMs. Through simulation results, it was verified that magnets can avoid irreversible demagnetization when the fault current occurs in the winding.