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

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Induction

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

- A demagnetization analysis method based on 2D and 3D finite element analysis (FEA) for PMSM in EPS systems is proposed.
- The size of PM is designed considering the demagnetization performance under the condition of minimizing the amount of PM.
- The simulation and experiment results clearly show the effectiveness of the proposed analysis method.

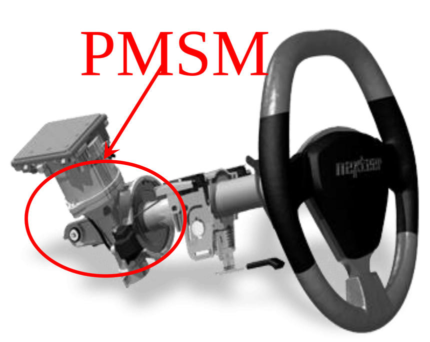

Fig.1 EPS system.

Specifications and main parameters

TABLE I
BRIEF SPECIFICATIONS AND PARAMETERS OF THE PMSM

Parameter	Value	Unit
Phases	3	/
Number of slots	12	/
Number of poles	8	/
Output Power	540	W
Rated Torque	4.3	Nm
Rated Current	80	A
Frequency (Base / Max.)	80/266.7	Hz
Speed (Base / Max.)	1200 / 4000	rpm
Battery Voltage	12	V
Stator Diameter	88	mm
Thickness of PMs	3.0	mm
Width of PMs	17.0	mm
Axial Length	24	mm
Min. / Max. air-gap length	0.5 / 1.8	mm

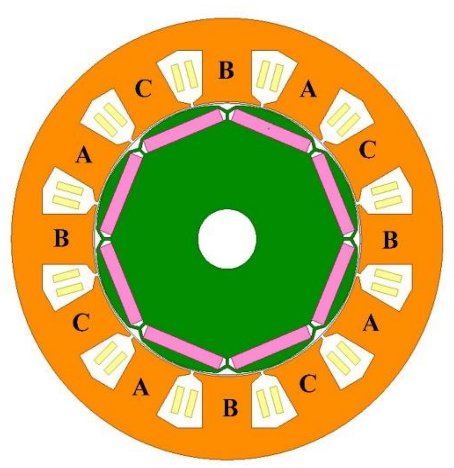

Fig.2. Finite element model of motor.

In the constant torque region up to the rated speed of 1,200 rpm, the required torque is approximately 4.3 Nm while in the flux weakening and constant power region with the maximum speed up to 4,000 rpm, the required torque is about 1.3 Nm.

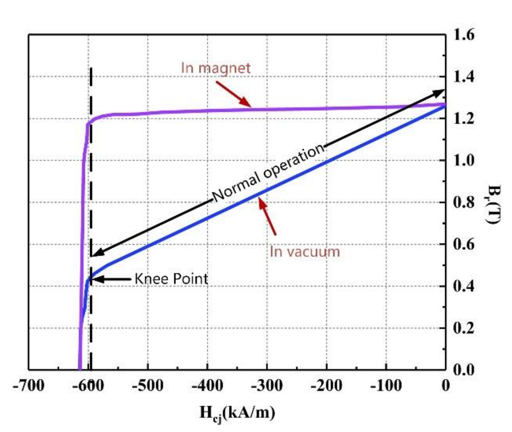

Fig. 3. B-H curve for Magnet N48H material at 120℃.

- Since the rated output torque is 4.3Nm, the electromagnetic torque of the motor should be more than 4.5 Nm.
- Magnet N48H is applied and the operation temperature is predicted at 120C, in which the knee point is 0.45T.

Demagnetization analysis

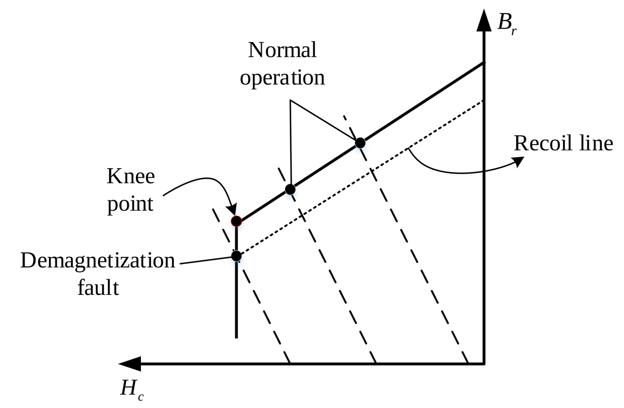

Fig. 4 Normal operation and demagnetization fault

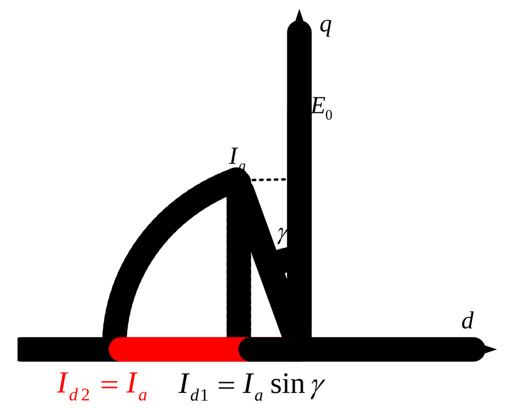

Fig. 5 The largest reverse d-axis current.

The flux density provided by PM varies with the armature field.

- In normal operation, the armature current leads the no-load EMF by γ.
- In demagnetization fault, the leading phase angle is π/2 and the PM bears the largest reverse magnetic field.

The largest demagnetization current Id: $$I_d = I_a \quad (1)$$

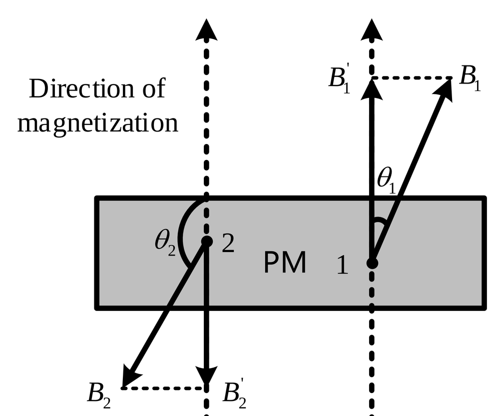

Fig. 6. Projection of the flux density in permanent magnet.

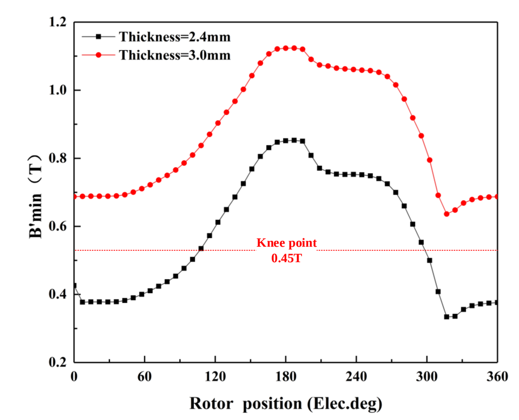

Fig. 7. The minimum operating point values of two schemes.

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

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

The demagnetization performance are analysis when the thickness is 2.4mm and 3.0mm, respectively. The results simulated by the 2D FEM indicate that irreversible demagnetization has occurred when the thickness is 2.4mm while it has not when the thickness is 3mm.

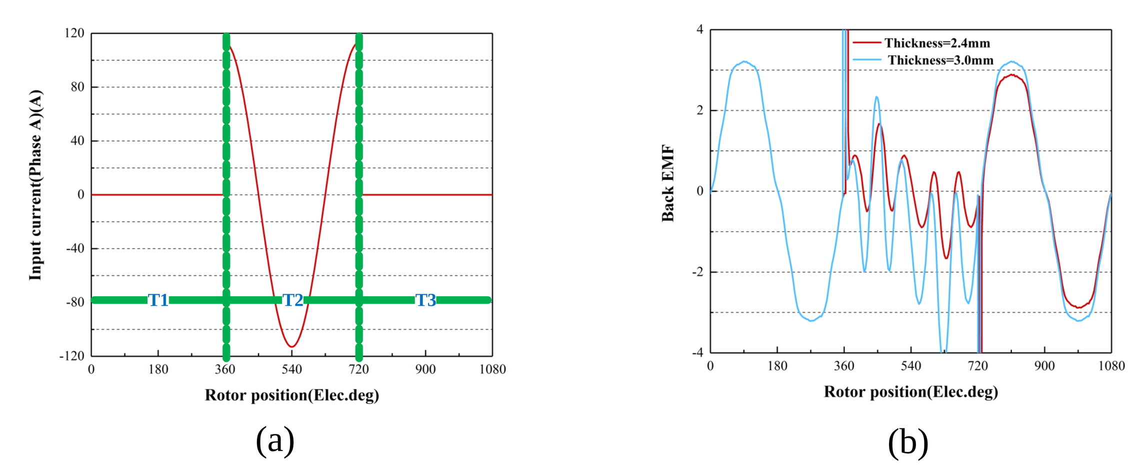

Fig. 8. (a) Current waveform of A-Phase. (b) Demagnetization analysis results of two schemes.

Design of permanent magnet size

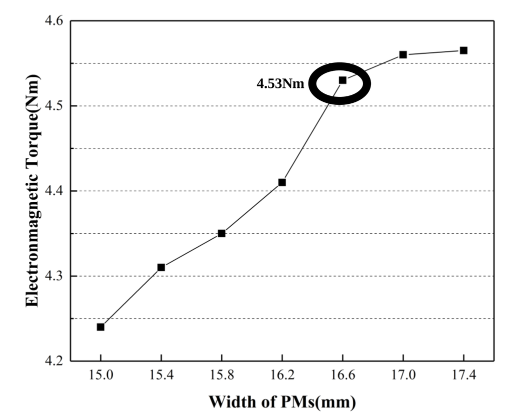

Fig.9 Variation of the electromagnetic torque with different width of PMs.

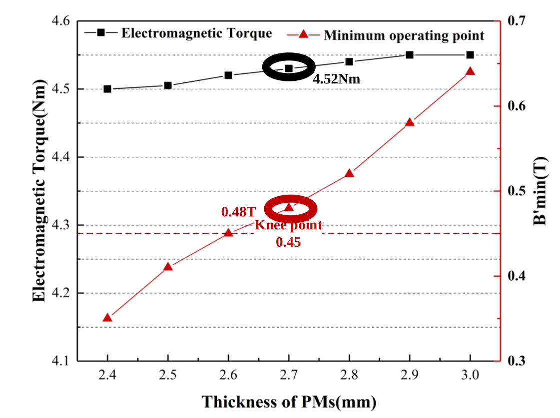

Fig.10 Variation of the electromagnetic torque and minimum operating point with different width of PMs.

Taking the electromagnetic torque, demagnetization characteristics and minimizing the size of magnet into consideration:

- The width of PMs is set as 16.6mm;
- The thickness of PMs is set as 2.7mm.

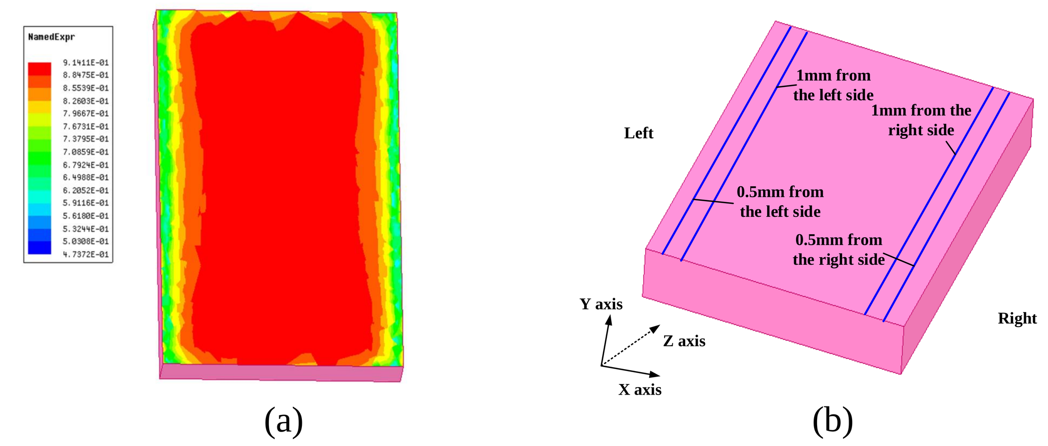

Fig. 11. (a)The distribution of normal magnetic field density on the upper surface and (b) the position of four observation lines.

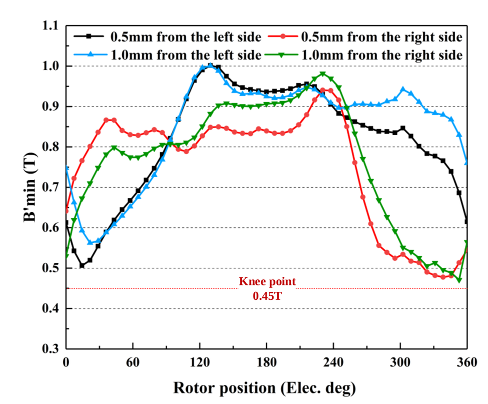

Fig. 12. The value of minimum operating point on the observation lines.

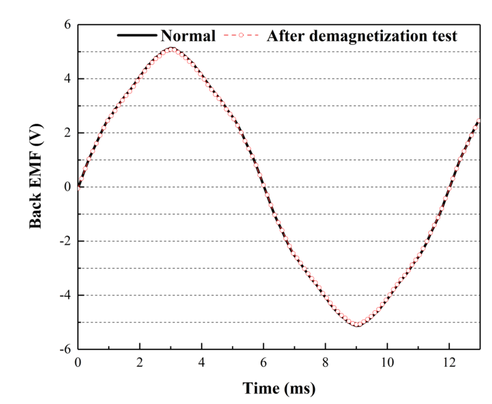

Fig. 13. Waveform of no-load back EMF (line to line, thickness:2.7mm, width: 16.6mm).

The 3D finite element model is established when the width and thickness of the PM are set as 16.6mm and 2.7mm respectively and four observation lines are set on each side in order to explore the state of PMs. The results show that the minimum operating points of each observation line are all higher than the knee point of the PM. The normal no-load back EMF (line to line) is about 3.8Vrms and it is maintained after the demagnetization current.

Experimental verification

A prototype is manufactured to verify the proposed motor.

- The temperature of the prototype is heated to 120℃ by the oven.
- Then the normal no-load back EMF is recorded by the oscilloscope when the speed of prototype is 1200rmp.
- Then the current source is used to simulate the d-axis demagnetization current for a period of time.
- Finally, the no-load back EMF is measured again and it is about 3.6 V_{rms}, and it is maintained compared with the normal no-load back EMF.

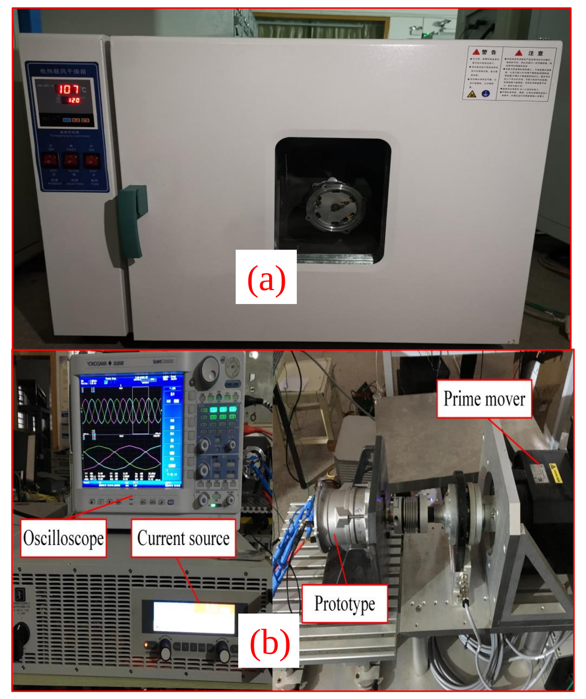

Fig.14. (a) The oven and the prototype. (b) Experimental platform and set up.

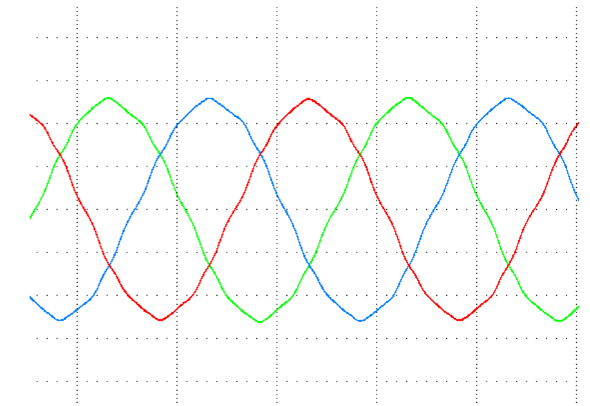

Fig. 15. Normal no-load back EMF of experimental result (line to line) .

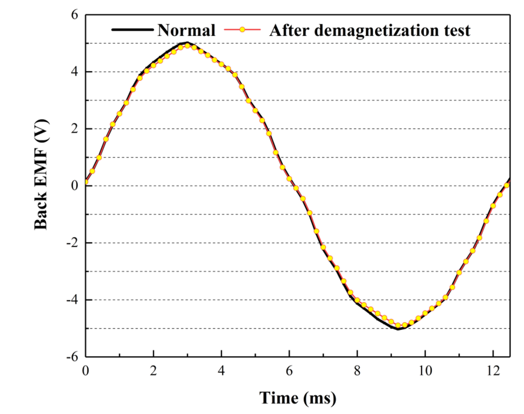

Fig. 16. Waveform of no-load back EMF (line to line) , got by experiment.

Conclusion

In this paper, a demagnetization analysis method based on 2D and 3D FEM is proposed to analyze the demagnetization of the motor when the inverter fails.

- The demagnetization mechanism of PM with different thickness in the proposed PM motor is analyzed by the 2D FEM.
- The optimal size design of PMs of a PMSM applied in EPS systems considering volume limitation and demagnetization characteristics is investigated.
- Through simulation and experiment results, the effectiveness of the proposed analysis method is proved.

Acknowledgement

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