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Experiments and Design Criteria for a High-Speed Permanent Magnet Synchronous Generator with Magnetic Bearing Considering Mechanical Aspects

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Abstract

Many methods for magnetic gear design consider magnetic characteristics only. However, the fixed-pole of a magnetic gear is deformed because of the force of attraction between the two permanent magnets on its inner and outer cores. This deformation leads to increased mechanical damage to the magnetic gear, decreasing its efficiency. To address this problem, this paper presents a method for the design and analysis of a magnetic gear that considers mechanical stress. We first use finite-element analysis and an experimental prototype to demonstrate the damage caused by a magnetic characteristics only design. We then show how the design flaws may be fixed through redesign. In the redesigned gear, the stress on the fixed-pole is reduced by 67.5%.

Structure of Magnetic Gear Analysis Model

Fig. 1. Structure of mechanical gear.

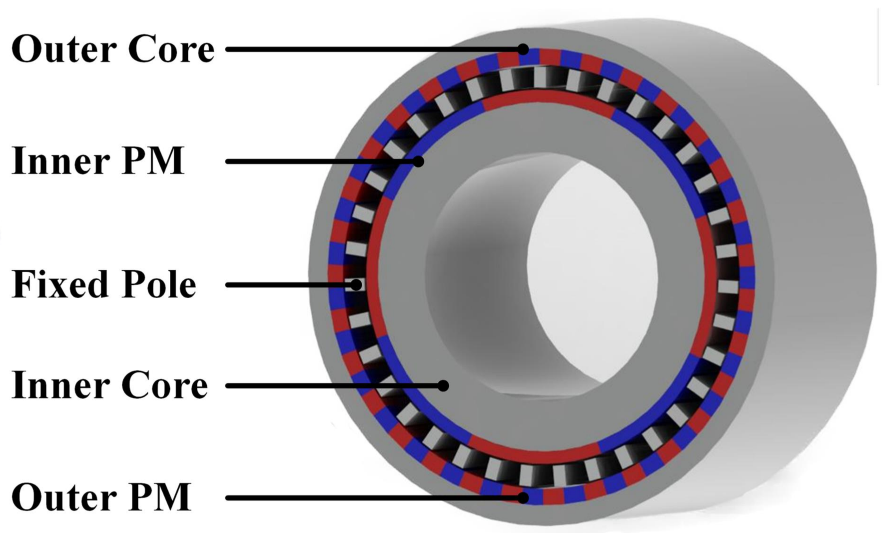

Fig. 2. Structure of magnetic gear.

Table I. Specifications of magnetic gear with excellent magnetic properties.

Parameter	Value	Unit
Outer radius of outer rotor	60	mm
Inner radius of the fixed-pole	46	mm
Outer radius of inner rotor	42	mm
Stack length	70	mm
Inner / Outer Permanent magnet thickness	3 / 3	mm
Inner / Outer Air gap	1 / 1	mm
Inner speed	1000	rpm
Gear ratio	7.75	-

- ❖ Physical contact of mechanical gears causes problems such as noise, vibration and backlash.
- ❖ Unlike mechanical gears, magnetic gears transmit power or rotation using the magnetic forces of the primary and secondary PMs.
- ❖ A fixed-pole is placed between the inner and outer rotors to change the magnetic flux of the PMs.
- ❖ The structure of the magnetic gear used in this study as shown in Fig.2.
- ❖ Table 1. shows the design specifications of the magnetic gear with excellent magnetic properties studied in this paper

Problems with Magnetic Gear of Only Consider Magnetic Characteristics

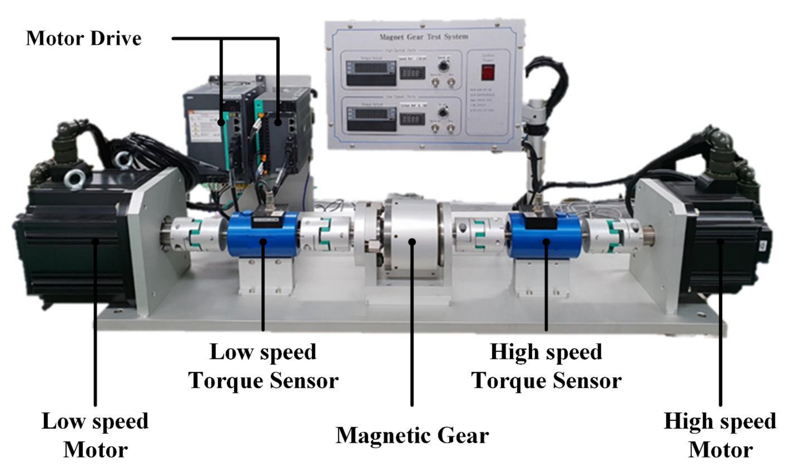

Fig. 3. Magnetic gear test setup

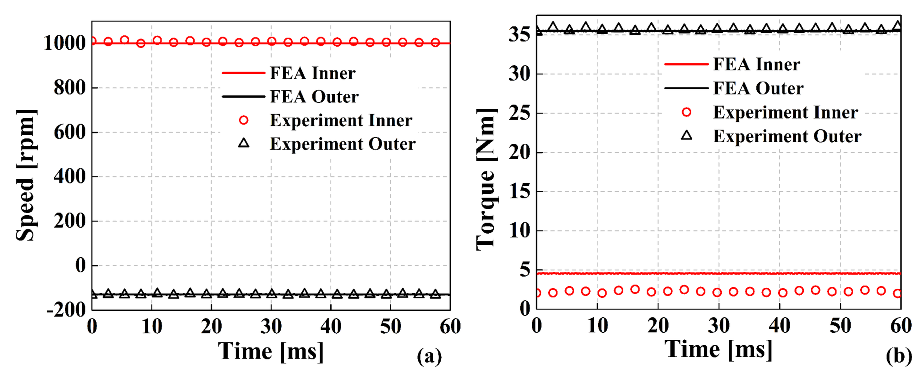

Fig. 4. Comparison of experimental and FEA results (a) Speed (b) Torque.

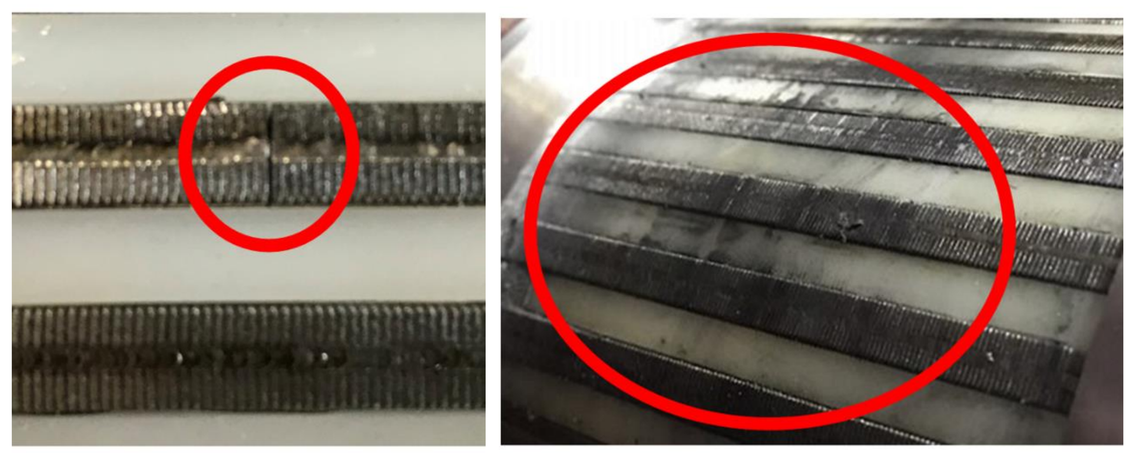

Fig. 5. Structure problems of the fixed-pole.

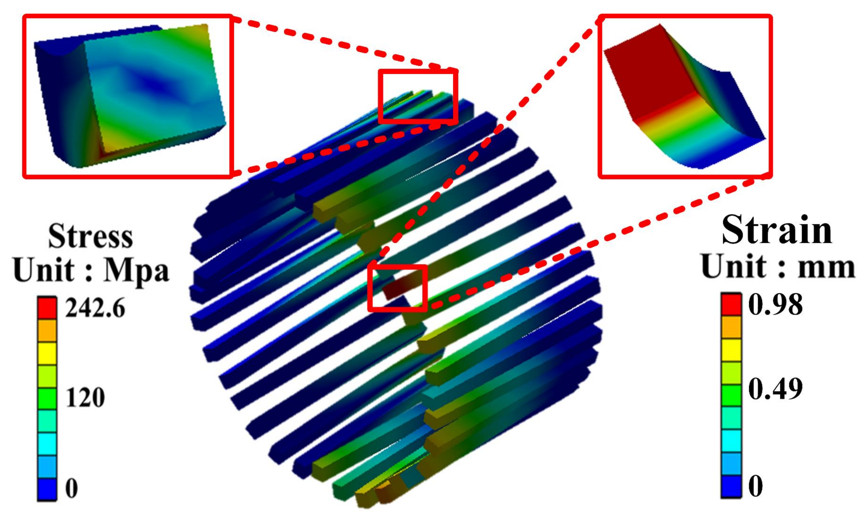

Fig. 6. Stress analysis of initial model.

- ❖ In order to assess the magnetic gear built using magnetic characteristics, a magnetic gear test was setup, as shown in Fig. 3.
- ❖ The results of magnetic gear experiment and its comparison with the FEA analysis are shown in Fig. 4.
- ❖ In contrast, the experiment and FEA results for inner torque have a large difference of about 55%.
- ❖ The reason for this difference is that the PM attraction of the inner and outer cores is accompanied by deformation of the fixed-pole and a broken weld as shown in Fig. 5.
- ❖ The mechanical air-gap between the fixed-pole and the inner and outer rotor is 1mm, Thus the distortion rate of the analysis results and mechanical error must be considered.

Optimum Design of Magnetic Gear Considering Mechanical Characteristics

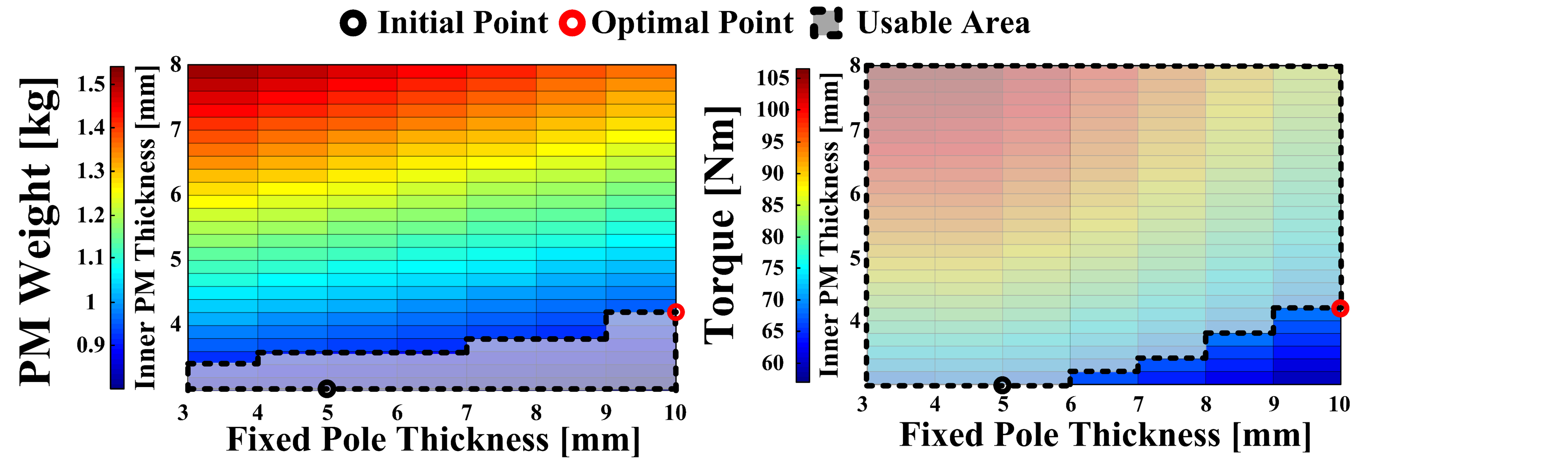

Fig. 7. Optimal point according to inner PM and fixed-pole thickness.

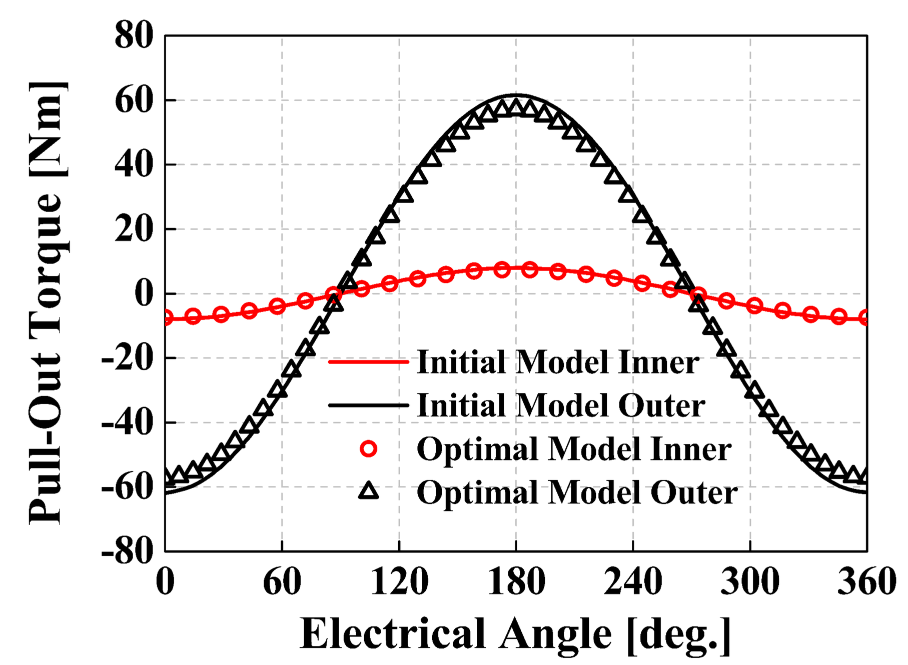

Fig. 8. Comparison of pull-out torque characteristics between an initial and optimal model.

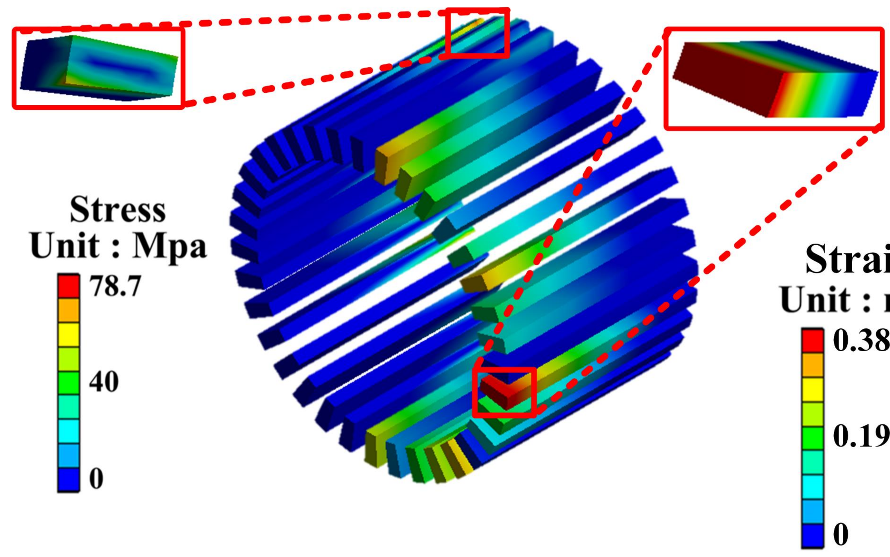

Fig. 9. Stress analysis of optimal model.

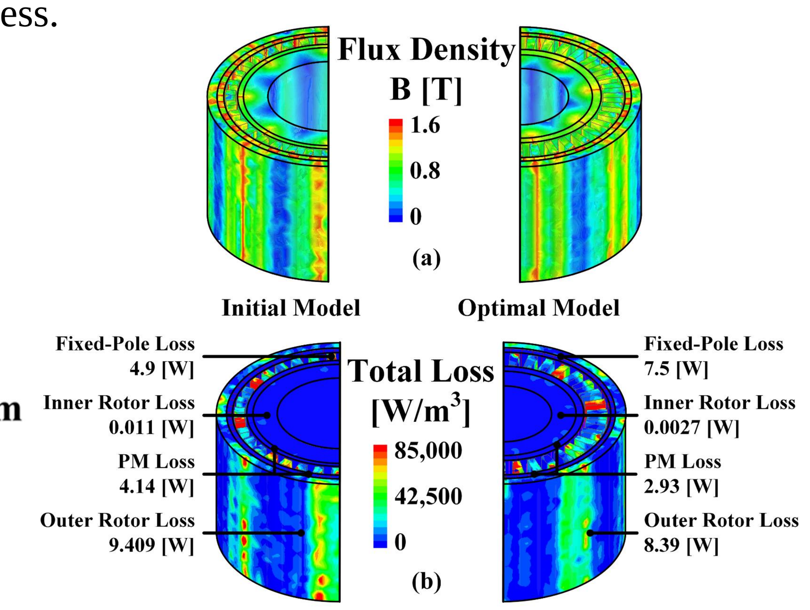

Fig. 10. Comparison of electromagnetic characteristics between an initial model and optimal model. (a) flux density distribution (b) core loss distribution.

- ❖ This paper aimed to build a magnetic gear that satisfies both magnetic and mechanical properties, when compared with the initial model.
- ❖ We derived the design area for which the fixed-pole does not have mechanical problems as shown in Fig. 7.
- ❖ In order to ensure that the optimal model has similar electromagnetic characteristics as the previous model, its total PM weight is increased by about 9.9%.
- ❖ Fig. 8. shows the pull-out torque characteristics of the initial and optimal models.
- ❖ Fig. 10. shows the size comparison and flux density, core loss distribution for each model.
- ❖ As shown in Fig. 9, the stress generated at the fixed electrode of the magnetic gear considering the mechanical characteristics is reduced by about 67.5% from the stress at the fixed electrode of the initial model.

Conclusion

- ❖ Considered if only the magnetic characteristics of the magnetic gear, it has a mechanical problem that the fixed-pole deformation occurs due to the attraction of the permanent magnet located at the inner and outer core.
- ❖ The weight of total permanent magnet increased approximately 9.9%, and its fixed-pole thickness, which has the biggest mechanical problem, increased twice.
- ❖ The optimal model has the increase weight of total permanent magnet and thickness of fixed-pole, but the magnetic properties are similar to each other.
- ❖ Designing a magnetic gear while taking both its mechanical and magnetic characteristics into consideration is better in terms of stability and efficiency.