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

Table 1. Specifications of magnetic gear with excellent magnetic properties.

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

Problems with Magnetic Gear of Only Consider Magnetic Characteristics

In order to assess the magnetic gear built using magnetic characteristics, a magnetic gear test setup was used 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.

Fig. 1. Structure of mechanical gear.
Fig. 2. Structure of magnetic gear.

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.

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.

Conclusion

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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 9.1%.

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.

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