Analysis on Design Sensitivity of Permanent Magnet Motor using Lumped Magnetic Circuit Method

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Conclusion

- Considering that air gap flux density of spoke type motor is sensitive to air gap length variance, calculation and analysis was carried out by altering air gap length from 0.8 mm to 1.4mm with increment of 0.2mm.
- When motor is designed under equivalent condition, air gap flux density of spoke type motor was more sensitive compared to that of PMSM when design parameter is adjusted.
- The MEC and FEA result is similar also the linear development for spoke type motor and PMSM is alike in both MEC and FEA analysis.
- As sensitivity of motor can be predicted using MEC, the issue could be avoided in preliminary design stage.

Background

In general, Spoke type Permanent Magnet Synchronous Motor (PMSM) has intense air gap flux density due to its magnet arrangement. However, variation of machine performance is severe due to its design variable which is air gap length. On the other hand, Surface Mounted PMSM (SPMSM) is less sensitive to change of variables that are mentioned above. Therefore, the sensitivity of the SPMSM is shown to be more sensitive due to variation of air-gap is confirmed through a numerical analysis.

Objectives

- The air gap flux density of SPMSM and spoke type PMSM with respect to air-gap length is examined, in order to identify the sensitivity of performance.
- It is analyzed numerically based on Magnetic Equivalent Circuit (MEC) method and it is validated through the comparison with FEA results.

![Diagram of Equivalent magnetic circuit for SPMSM](image1)

- A simple expression of error rate within 1.7% was proposed to confirm the sensitivity according to the change of air-gap length(g).
- It is assumed that there is no saturation occurring in the iron core, so that the reluctances of iron core are neglected (R<sub>core</sub>).
- Air-gap Flux Density Using Proposed Equation
  - In the equivalent circuit, expression of B<sub>g</sub> is as follow.
  \[ B_g = \frac{4B_m}{2\mu_0} \left[ \frac{2L_m}{R_m} \right] \]
  \[ B_g = B_m \frac{2\mu_0}{2\mu_0 + \mu_s} \]
  \[ (\mu_0, \mu_s) \text{ is the area of magnet and air-gap} \]
- Confirmation of Sensitivity through derivative for Air-gap length
  - Through proposed equations, derivative of B<sub>g</sub> for air-gap length is simplified.

![Diagram of Equivalent magnetic circuit for Spoke PMSM](image2)

- Conventional Equations on Reluctance
  - In the equivalent circuit, expression of B<sub>g</sub> is as follow.
  \[ B_g = B_m \frac{2\mu_0}{2\mu_0 + \mu_s} \]
  \[ (\mu_0, \mu_s) \text{ is the area of magnet and air-gap} \]
- Proposed Equations on Reluctance
  - Through proposed equations, derivative of B<sub>g</sub> for air-gap length is simplified.

![FEA Modeling](image3)

- Analyzed SPMSM model (g<sub>gap</sub> = 1 mm)
- Analyzed Spoke PMSM model (g<sub>gap</sub> = 1 mm)
- MRResults

![Magnetic Circuit on SPMSM](image4)

- Error rate of Proposed Reluctance (g<sub>gap</sub> = 1 mm)

![Magnetic Circuit on Spoke PMSM](image5)

- Variation of Air-gap Flux Density (dB<sub>g</sub>) According to Change of Air-gap length(dg)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Conventional</th>
<th>Proposed</th>
<th>Error rate</th>
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<tbody>
<tr>
<td>SPMSM</td>
<td>B&lt;sub&gt;p&lt;/sub&gt;</td>
<td>0.41 [T]</td>
<td>6857E+06</td>
</tr>
<tr>
<td></td>
<td>T&lt;sub&gt;PM&lt;/sub&gt;</td>
<td>5.5 [mm]</td>
<td>6933E+06</td>
</tr>
<tr>
<td></td>
<td>H&lt;sub&gt;PM&lt;/sub&gt;</td>
<td>18.5 [mm]</td>
<td>1.1%</td>
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<tr>
<td></td>
<td>I&lt;sub&gt;core&lt;/sub&gt;</td>
<td>22.17 [mm]</td>
<td>17%</td>
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<tr>
<td></td>
<td>I&lt;sub&gt;g&lt;/sub&gt;</td>
<td>1.5 [mm]</td>
<td>6763E+06</td>
</tr>
<tr>
<td>Spoke PMSM</td>
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<tr>
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<td>T&lt;sub&gt;PM&lt;/sub&gt;</td>
<td>5.5 [mm]</td>
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<td>I&lt;sub&gt;g&lt;/sub&gt;</td>
<td>1.5 [mm]</td>
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![MEC Results](image6)

- Verification of Analysis Result of MEC and FEA

<table>
<thead>
<tr>
<th>dg/mm</th>
<th>SPM dB&lt;sub&gt;g&lt;/sub&gt; [T]</th>
<th>Spoke dB&lt;sub&gt;g&lt;/sub&gt; [T]</th>
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<td>0.4</td>
<td>-0.0276</td>
<td>-0.0673</td>
<td>0.0397</td>
</tr>
</tbody>
</table>

- Variation of Air-gap Flux Density (dB<sub>g</sub>) According to Change of Air-gap length(dg)