Radially and tangentially magnetized PMBLDC motor- A comparative analysis using Finite Element Method in COMSOL

Presented By
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Presentation Outline

• Introduction
• Objective
• Literature Survey
• Modeling Using Finite Element Analysis
• Surface Mounted PM Motors (SMPM)
• Tangentially Magnetized PM Motors
• Comparison & Results
• Conclusion
• References
Introduction

• **BLDC Motor does not use brushes for its operation.**

• **Electronic commutation using switches.**

• **Better thermal capability.**

• **Design is focusing on servo application.**

• **Different rotor configurations are possible according to applications.**
  - Surface Mounted PM motor
  - Interior permanent magnet motor

• **Finite element analysis (FEA) using COMSOL Multiphysics.**
Objective

• Familiarize the permanent magnet BLDC motor.

• Design PM BLDC motor with two different rotor configuration.

• Comparison of Surface mounted PM motor and tangentially magnetized PM motor.
Literature review

Permanent magnet Brushless dc motor: (By T. J. E. Miller)

- Electric winding on the stator and PMs on the rotor.
- High efficiency
- Higher speed ranges
- Better speed versus torque characteristics
- Long operating life
- Noiseless operation
- Higher dynamic response

Fig. PMBLDC Motor
Literature review

Permanent magnet BLDC rotor configurations:

- Surface mounted PM
  - Inset PM
  - With external rotor

- Interior PM rotor
  - V shaped buried PM
  - Tangentially magnetized PM

1. Surface mounted PM
2. Inset PM
3. SMPM with outer rotor
4. V shaped buried PM
5. Tangentially magnetized PM
Finite Element Analysis

- The finite element modeling includes the Maxwell’s equation

- Better understanding of the response/behavior of an electromagnetic device

- Virtual prototyping, saving time and cost
## Motor Specifications

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply Voltage</td>
<td>28V</td>
</tr>
<tr>
<td>Magnetic flux density, $B$</td>
<td>0.9 T</td>
</tr>
<tr>
<td>Back EMF constant, $K_b$</td>
<td>0.16</td>
</tr>
<tr>
<td>Torque Constant, $K_t$</td>
<td>0.16</td>
</tr>
<tr>
<td>Outer Diameter</td>
<td>52mm</td>
</tr>
<tr>
<td>Stack length, $L$</td>
<td>45mm</td>
</tr>
<tr>
<td>Rotor Dia.</td>
<td>30mm</td>
</tr>
<tr>
<td>No. of turns, $N_t$</td>
<td>40</td>
</tr>
<tr>
<td>Rated Current, $i$</td>
<td>9.0 A</td>
</tr>
<tr>
<td>Rated Speed</td>
<td>1700 rpm</td>
</tr>
<tr>
<td>Rated torque, $T$</td>
<td>1.45 Nm</td>
</tr>
<tr>
<td>Magnet</td>
<td>SmCo5</td>
</tr>
</tbody>
</table>

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Find the no. of turns:

From Miller’s Torque Equation:

\[ T = (N_{ph} - 1)N_t K_w \alpha rLB_g i = K_t . i \]  ..........(1)

where

\[ \alpha = \text{pole arc coefficient} \]

\[ = \frac{N + 0.14}{N} < 1, \text{ } N \text{ is integer} \]

No. of slot per pole

\[ = 0.697 \]

\( K_w = \text{Winding factor} (= 0.89) \)

Hence, No. of turns, \( N_t = 40 \text{ per slot} \)
Modeling Using Finite Element Analysis

- Slot/pole = 36/8 = 4.5 (take 4)
- Electrical angle = (360*4)/36 = 40°
- Quadrant Operation

Winding Diagram:

<table>
<thead>
<tr>
<th>Phases</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric angle</td>
<td>40°</td>
<td>80°</td>
<td>120°</td>
<td>160°</td>
<td>200°</td>
<td>240°</td>
<td>280°</td>
<td>320°</td>
<td>360°</td>
</tr>
<tr>
<td>A</td>
<td>N</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
<td>N</td>
<td>N</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>S</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>S</td>
<td></td>
<td></td>
<td></td>
<td>N</td>
<td>N</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Surface Mounted PM Motors (SMPM)

- Permanent magnets mounted on the surface of the soft iron material.
- Produce radially directed flux.
- The width of magnet taken to be 8mm.
- Height as 2.5 mm.
Surface Mounted PM Motors (SMPM)

Magnet arrangement

Contour plot

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Excerpt from the Proceedings of the 2014 COMSOL Conference in Bangalore.
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Surface Mounted PM Motors (SMPM)
Tangentially Magnetized PM Motors

• Each permanent magnet is embedded inside the rotor.

• The magnetic flux density is taken to be at the circumference of the rotor.

• The magnet width of 2.5 mm and depth of 8 mm is taken.
Tangentially Magnetized PM Motors

Magnet arrangement

Contour plot

Excerpt from the Proceedings of the 2014 COMSOL Conference in Bangalore.
Radially and tangentially magnetized PMBLDC motor- A comparative analysis using Finite Element Method in COMSOL

Excerpt from the Proceedings of the 2014 COMSOL Conference in Bangalore.
Vector diagram of magnetic flux density

- **Surface Mounted PM Motors (SMPM):**

\[
\cos \theta = \frac{B \times x}{\sqrt{x^2 + y^2}}
\]
\[
\sin \theta = \frac{B \times y}{\sqrt{x^2 + y^2}}
\]

- **Tangentially Magnetized PM Motors:**

\[
\cos \theta = \frac{B \times y}{\sqrt{x^2 + y^2}}
\]
\[
\sin \theta = \frac{-B \times x}{\sqrt{x^2 + y^2}}
\]
Inductance Calculation

- Magnetic Energy method:

\[ W = \frac{1}{2} LI^2 \]

Where \( W \) = Magnetic Energy density

- Virtual work method:
  - Based on Ohm’s Law

\[ L = \frac{V(\text{induced})}{i \times 2\pi f} \]

\( V(\text{induced}) \) is not produced by magnetic field due to permanent magnet.
Comparison based on inductance

- **Difference in air gap inductance:**

<table>
<thead>
<tr>
<th>Motor type</th>
<th>With 2 phases excited</th>
<th>With R phase excited</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SMPM</strong></td>
<td>Using Energy Method</td>
<td>11.4 mH</td>
</tr>
<tr>
<td></td>
<td>Using Virtual work method</td>
<td>11.4 mH</td>
</tr>
<tr>
<td><strong>Tangentially Magnetized</strong></td>
<td>Using Energy Method</td>
<td>14.5 mH</td>
</tr>
<tr>
<td></td>
<td>Using Virtual work method</td>
<td>14.5 mH</td>
</tr>
</tbody>
</table>
Waveforms

- Magnetic flux density variation at the air gap

<table>
<thead>
<tr>
<th>Magnetic flux density</th>
<th>normB_emqa</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.7</td>
<td>0.005</td>
</tr>
<tr>
<td>0.6</td>
<td>0.01</td>
</tr>
<tr>
<td>0.5</td>
<td>0.015</td>
</tr>
<tr>
<td>0.4</td>
<td>0.02</td>
</tr>
<tr>
<td>0.3</td>
<td>0.025</td>
</tr>
</tbody>
</table>

$B_g$ plot for SMMP motors

$B_g$ plot for tangentially Magnetized PM

Excerpt from the Proceedings of the 2014 COMSOL Conference in Bangalore.
Waveforms

- By Maxwell’s stress tensor method.

\[ \text{Torque, } T = \oint_B (r - r_0) \times (n_1 T_2) dS \]

Where \( r_0 \) is the point on the axis of rotation and \( n \) is unit vector normal to the surface \( S \).

Excerpt from the Proceedings of the 2014 COMSOL Conference in Bangalore.
Cogging Torque, \( T = -\frac{1}{2} \Phi^2 \frac{dR}{dt} \)

Cogging torque variation for SMPM motor

Cogging torque profile for tangentially magnetized PM motor

Excerpt from the Proceedings of the 2014 COMSOL Conference in Bangalore.
Waveforms

Back EMF variation for both rotor configurations

- Induced Voltage, \( V = N \sum \frac{L}{A} \int E_z dA \)

Torque waveforms for estimating the ripple torque
Conclusion

- A three phase 36 slot, 8 pole BLDC motor applied for aero space applications was used for analysis.

- Comparison was done for Surface mounted, radially magnetized motor and tangentially magnetized motor using COMSOL Multiphysics 3.5a.

- Main difference was found in air gap inductance.

- The interior permanent magnet design gave desirably more inductance than surface mounted PM design.
References


References


[9] COMSOL3.5a manual
THANK YOU

Questions???
Winding Pattern

Excerpt from the Proceedings of the 2014 COMSOL Conference in Bangalore.