MQ1™ based Redesign of Electric Water Pump Motor

March, 2018
Benchmarking Process

- A water pump motor is procured from the market.

- The motor is benchmarked
  - Physical dimension benchmarking by measuring the following,
    - Weight of active material
    - Key stator and rotor dimensions
    - Winding pattern and conductor details
    - Magnet composition and magnetic characteristics of magnet
  - Performance benchmarking by measuring the following,
    - Closed circuit mid-airgap flux density
    - Cogging torque
    - No-load and load performance
Benchmarked Motor

- End user: Honda automotive
- Motor manufacturer: Aisin
- Part number: 06100-RDC-A00
- Motor type: Brushless (BL) DC motor
- Motor is wet runner
- Application: Inverter cooling
Motor Assembly and Key Weights

- **Stator**
  - No. of turns/coil: 80 turns
  - Conductor diameter: 0.40 mm (AWG 26)
  - Weight of copper = 40.56 g*

- **Magnet**
  - Material: Injection molded Anisotropic NdFeB (similar to HDDR)
  - Number of poles: 4 poles
  - Magnet weight: 20.2 g
  - Density: 5 g/cm³

*The total copper weight is estimated from weight of one coil. Weight of one coil = 6.76 g
Stator and Rotor Dimensions

**Stator**
- No. of laminations = 26
- Lamination thickness = 0.5 mm
- Concentrated winding
- Whole stator is encapsulated with PPS

The motor is wet runner. Stator is encapsulated to prevent water touching the winding.
Magnet Analysis: ICP and B-H Characteristics

- ICP results

<table>
<thead>
<tr>
<th>Nd</th>
<th>Dy</th>
<th>B</th>
<th>Co</th>
<th>Al</th>
<th>Fe</th>
<th>Ga</th>
<th>Si</th>
</tr>
</thead>
<tbody>
<tr>
<td>28.039</td>
<td>0.699</td>
<td>1.038</td>
<td><strong>13.486</strong></td>
<td>0.157</td>
<td>55.622</td>
<td>0.434</td>
<td>0.183</td>
</tr>
</tbody>
</table>

1. High Cobalt content to increase the curie temperature of compound so it can be use to make IM magnet with PPS
2. Cobalt price will fluctuate (increase) with the increased penetration of EV/HEV (Battery).

- B-H Curve

Magnet Characteristics

Halbach orientation on the magnet

<table>
<thead>
<tr>
<th>Magnetics</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_r$</td>
<td>0.62T</td>
</tr>
<tr>
<td>$H_{ci}$</td>
<td>950 kA/m</td>
</tr>
<tr>
<td>$H_c$</td>
<td>405 kA/m</td>
</tr>
<tr>
<td>$(BH)_{max}$</td>
<td>68.5 kJ/m³</td>
</tr>
</tbody>
</table>
Connections to Control Circuit, Closed Circuit Flux Density and Cogging Torque Measurement

- Supply voltage = 12 V
- SWP $\Rightarrow$ Output voltage signal corresponding to motor speed

Cogging torque measurement

Closed circuit mid-airgap flux density measurement

Hall probe

Motor

Torque transducer

$T_{pk-pk_cogging} = 8.21 \text{ mN-m}$
No-Load and Load Performance Measurement

No-load current (A) | No-load speed (rpm)
--- | ---
0.4 | 6108

No-load Measurement

Dynamometer

Load Measurement

Motor

Motor’s load performance

Motor
MQ1 based Redesign
Approach to arrive at MQ1 Based Redesigned Motor

- Using the commercially available motor design software SPEED, a motor is designed with injection molded MQ1 magnet.
  - The MQ1 magnet used is Cobalt free, offering stable and lower price compared to anisotropic NdFeB magnet
- The motor is designed for an optimal active material cost.
- During the design following additional constraints are imposed,
  - The effective airgap for the redesigned motor is same as benchmarked motor (The effective airgap is the actual airgap plus the thickness of PPS overmold on the stator)
  - The conductor current density is similar or lower from the one in benchmarked motor
  - The slot fill is similar or lower from the one in benchmarked motor
MQ1 Based Redesigned Motor: Performance

Motor current at $T=41$ N-mm @ 4803 rpm

Phase back-emf @ 4803 rpm

Cogging torque

$T_{pk-pk_{cogging}} = 0.4$ mN-m

Developed torque @ 4803 rpm
MQ1 Based Redesigned Motor: FEA Validation

- No-load flux density distribution
- Teeth flux-linkage
- Energy loop
- Flux lines
Comparison of Benchmark and Redesigned Motors

Comparison of benchmarked and redesigned motor performance

Comparison of key physical parameters for benchmarked and redesigned motor
Comparison of Key Physical Parameters for Benchmarked and Redesigned Motors

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Benchmarked</th>
<th>Redesigned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnet</td>
<td>Anisotropic NdFeB</td>
<td>IM MQ1</td>
</tr>
<tr>
<td>Magnetization Profile</td>
<td>Halbach</td>
<td>Halbach</td>
</tr>
<tr>
<td>No. of pole</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>No. of slots</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>Outer diameter (mm)</td>
<td>50.90</td>
<td>50.90</td>
</tr>
<tr>
<td>Length (mm)</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Length of airgap (mm)*</td>
<td>1.85</td>
<td>1.85</td>
</tr>
<tr>
<td>Weight of magnet (g)</td>
<td>20.20</td>
<td>22.00</td>
</tr>
<tr>
<td>Weight of copper (g)</td>
<td>40.56</td>
<td>35.00</td>
</tr>
<tr>
<td>No. of turns/coil</td>
<td>80</td>
<td>24</td>
</tr>
<tr>
<td>Coil Wire diameter (mm)</td>
<td>0.40 (AWG 26)</td>
<td>0.64 (AWG 22)</td>
</tr>
<tr>
<td>Current &amp; efficiency (T= 41 N-mm @ 4803 rpm)</td>
<td>2.31 A / 76.20%</td>
<td>2.05 A / 75.91%</td>
</tr>
</tbody>
</table>
Observations

- MQ1 magnet gives relatively stable magnet price as it is **Cobalt free**.

- The cost of active material in IM MQ1 magnet is significantly cheaper compared to benchmarked motor with anisotropic NdFeB magnets.
  - Achieving the Halbach magnetization for an anisotropic NdFeB magnet is challenging while for an MQ1 magnet, it can be achieved by just an appropriate design of the magnetization fixture.
  - The magnet tool cost for the anisotropic magnet is significantly higher due to the need of alignment field.

- For an MQ1 magnet, higher no of poles and appropriate slot no can be used to achieve the cost optimized design.
  - The IM MQ1 based motor is having the same size and volume as the benchmarked HDDR motor.
  - The weight of the MQ1 magnet is 9% more but the copper weight is 14% lower.
Questions? Want to know more? Collaborate with us?

Contact us, research@magnequench.com

Visit our Technical Website www.mqitechnology.com