Magnetization Fixture Design and Evaluation
Overview

- Introduction

- Salient features of the magnetizing fixture design

- Following aspects have been discussed
  - A. Effect of additional back iron during in-situ magnetization
  - B. Laminated back iron v/s solid back iron
  - C. Effect of conductor location
  - D. Effect of fixture slot shaping
Salient features of the magnetizing fixture design

Factors effecting the distance between conductor and the magnet, ‘A’:

- **Energy required for magnet saturation**
  - Increase in ‘A’ ⇒ Increase in energy for saturation

- **Magnetization flux wave shape**
  - Radial orientation: conductors close to the magnet
  - Halbach orientation: conductors away from the magnet

In-situ magnetization fixture:

- Limited clearance ‘d’ between fixture core and conductor overhang
- Conductor size is limited by the available total space between fixture core and pole housing
### Salient features of the magnetizing fixture design

<table>
<thead>
<tr>
<th>Design parameter</th>
<th>Fixture for Radial orientation</th>
<th>Fixture for Halbach orientation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance between fixture winding and magnet, ‘A’</td>
<td>Closed slot design : ≤ 0.50 mm</td>
<td>Typically more than 1 mm including the sleeve thickness</td>
</tr>
<tr>
<td></td>
<td>Including sleeve thickness, Semi-open slot : ≤ 0.65 mm Fully open slot : ≤ 0.75 mm</td>
<td></td>
</tr>
<tr>
<td>Preferred conductor arrangement</td>
<td>Column</td>
<td>Row</td>
</tr>
<tr>
<td>Conductor size</td>
<td>Depends on the following:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Required magnetizing flux wave shape and</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Current density (MQT, Singapore design limit is &lt;15 kA/mm² to avoid thermal failure mode of fixture)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Ease of handling (bending the wire during fixture winding)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Available overhang space (only for in-situ magnetization)</td>
<td></td>
</tr>
<tr>
<td>Number of turns</td>
<td>Minimum turns required to generate the saturation field of around 3.5 T at the magnet diameter farthest from the fixture winding.</td>
<td>Higher no of turns ⇒ Increased fixture inductance ⇒ Increase time to peak magnetizing current ⇒ Fixture overheating/thermal failure</td>
</tr>
</tbody>
</table>
## Salient features of the magnetizing fixture design

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<th>Design parameter</th>
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<tbody>
<tr>
<td>Slot type</td>
<td>With skew - Open or semi-open No Skew- Closed</td>
<td>Open slot is preferred to obtain sinusoidal magnetizing flux</td>
</tr>
<tr>
<td>Fixture core material</td>
<td>Laminated steel → Prevent eddy current</td>
<td></td>
</tr>
<tr>
<td>Back iron</td>
<td>Required</td>
<td>-N.A.-</td>
</tr>
<tr>
<td>Back iron material</td>
<td>Laminated steel → Avoid secondary transition zones</td>
<td>-N.A.-</td>
</tr>
<tr>
<td>Back iron thickness</td>
<td>Minimum thickness to avoid saturation Rule of thumb - Minimum 10 times the magnet thickness</td>
<td>-N.A.-</td>
</tr>
</tbody>
</table>
| Sleeve thickness for semi-open or fully open slots | • Minimum thickness → Based on structural strength  
• Maximum thickness → Based on the desired magnetizing waveform. Magnetizing energy needed increases with increase in thickness. | Rule of thumb followed by MQT, Singapore:  
Sleeve thickness ≥ 0.3 mm                                                                 |
## Salient aspects of the magnetizing fixture design

<table>
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<th>Design parameter</th>
<th>Fixture for Radial orientation</th>
<th>Fixture for Halbach orientation</th>
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<tr>
<td>Fixture stack length</td>
<td>1.2 - 1.5 times the magnet axial length to limit the fixture resistance</td>
<td></td>
</tr>
<tr>
<td>Magnetizing current</td>
<td>Limited by the Magnetizer system rating</td>
<td>Limited by the Magnetizer system inductance</td>
</tr>
<tr>
<td></td>
<td>(&lt; 50kA for system at MQT, Singapore)</td>
<td>(typical value is &lt; 250 µs for the Magnetizer at MQT, Singapore)</td>
</tr>
<tr>
<td>Time to peak of magnetizing current</td>
<td>Limited by the Magnetizer system inductance</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(typical value is &lt; 250 µs for the Magnetizer at MQT, Singapore)</td>
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![Graph showing magnetizing current over time](image)
Effect of Additional Back Iron during In-situ Magnetization

Fixture with no additional back iron

Applied field at the back of the magnet when additional back iron is absent

Fixture with additional back iron

Applied field at the back of the magnet when the additional back iron is presence
Effect of Additional Back Iron during In-situ Magnetization – Mid Airgap Flux Density

Radial flux is measured at the mid air gap between center core and magnet inner diameter, radius ‘r’ from the magnet center.

Open circuit flux scan set-up

Closed circuit flux scan set-up

Open circuit mid airgap flux density comparison

Closed circuit mid airgap flux density comparison
Effect of Additional Back Iron during In-situ Magnetization - Magnet Surface Flux Density and Saturation Test

- At any applied magnetizing energy, flux per pole is more in case of magnetization with additional back iron due to no saturation in back iron.

- Without any additional back iron, the shape of the mid-air gap flux will shift from radial towards sinusoidal (edges will be rounded).
Laminated back iron v/s Solid back iron
Comparison of magnet pole transition zones

With laminated back iron

- Thinner transition zone
- Primary transition zone

With solid back iron

- Thicker transition zone
- Secondary transition zones

Magnet inner diameter

Magnet outer diameter
Laminated back iron v/s Solid back iron
Flux density comparison on magnet inner diameter

Flux scan set-up
Comparison of magnet radial flux for magnetizations with laminated and solid back iron

<table>
<thead>
<tr>
<th>Type of back yoke during magnetization</th>
<th>Flux integral (T-degree)</th>
<th>Difference in flux integral</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid</td>
<td>74.34</td>
<td>-</td>
</tr>
<tr>
<td>Laminated</td>
<td>89.42</td>
<td>+20.3 %</td>
</tr>
</tbody>
</table>
Effect of Conductor Location

Change in conductor location from magnet surface

Setup for Flux-linkage prediction

Change in flux linkage profile with the change in conductor location from magnet surface
Effect of fixture slot shaping

Flat slot magnetizing fixture system

Curved slot magnetizing fixture system

Motor phase back-emf for magnet orientation achieved using the flat and curved slot magnetizing fixtures

Cogging torque of the motor for magnet magnetized using the flat and curved slot magnetizing fixtures
Magnetization fixture for Automotive Accessory motor magnet

- Back iron and the fixture core: Laminated steel
- Heavy insulated copper wire: AWG 12
- Cooling pipe: Brass (6 mm diameter)
- Connecting terminals: Copper
- Casing: Delrin (Polyoxymethylene)
- Sleeve: Stainless steel

For series production, the magnetization cycle time is determined by the following:
- Energy required for magnetization
- Cooling system
- Magnetizing system rating
Magnetization fixture for Automotive Accessory motor magnets

**Fixture core**

- 4 x Φ 2.50 mm
- M3x0.5 - Ψ 3
- TOP PLATE ONLY

**Fixture core with sleeve**

- Φ 27.775

- 134 pcs. T=0.35mm
- 35A250 LAMINATED STEEL

- BOTTOM PLATE STEEL AISI 1018 T=3mm

**Fixture core with sleeve**

- Φ 28.475

- STACK OF LAMINATED STEEL 35A250 0.35 mm THICK

**Back iron**

- TOP PLATE STEEL AISI 1018 T=3mm

- STACK OF LAMINATED STEEL 35A250 0.35 mm THICK
Magnetization fixture design

- Back iron (Laminated steel)
- Fixture core (Laminated steel)
- Fixture winding (Copper)
- Sleeve (Stainless steel)
- Magnet
- Cooling pipe

Fixture outline

Current density plot @ peak magnetizing current
Magnetization fixture design

Flux distribution @ peak magnetizing current

Flux density plot @ peak magnetizing current
Magnetization Fixture – Structural Design Details

Fixture and back iron structural dimensions

Winding diagram
Core top view

Core bottom view
(Turning right side)

Conductor splicing and soldering joint
Fixture Fabrication

- Fixture casing with cooling pipe installed
- Wound core mounted on the cooling pipe and connected to the terminals
- Completed fixture
- Fixture set-up for magnetization
Magnetization parameters and Flux scan

- **Magnetizing parameters used by MQT**
  - Voltage = 1950 V
  - Capacitance = 4000 µF
  - Cycle time = 15 min
  - Cooling type = Forced water cooling inside the fixture core, Forced air on outer body of the fixture

- **Peak Current** = 33.6 kA

- **Time to peak** = 240 µs

**Note:** A single layer flux scan measurement and does not represent the integrated flux over the entire axial length of the magnet.
Saturation test and Magnetization

- Saturation test is used to identify the energy required to fully saturate the magnet.

- Saturation test procedure:
  - To generate the saturation curve an integral of magnet flux per pole is charted incrementally as magnetizing energy is increased.
  - The magnet is saturated when a significant increase in magnetizing energy results in less than 2% change in magnet flux per pole.
Case Study - Magnetizing of Isotropic Bonded Neo Arc Magnets - Concept

Transition from virgin to demag occurs when the applied field in an element begins to decrease.

\[ a_x H^2 + b_x H + c_x = y_x \]
Case Study – Magnetizing of an Isotropic Bonded Neo Arc Magnets – Magnetizing Fixtures

Laminated steel inner core

Laminated steel outer core

Conductor

Motor housing

Motor Housing & flux ring

Laminated Steel

Magnet poles & flux ring
Case Study – Magnetizing of an Isotropic Bonded Neo Arc Magnets – Magnetizing Fixture and Orientation of Flux
Case Study – Magnetizing of an Isotropic Bonded Neo Arc Magnets- Magnetization Process
Case Study - Magnetizing of an Isotropic Bonded Neo Arc Magnets – Mid Airgap Flux Density

Mid airgap Flux Density

Degrees

Gauss

Measurement
Model
Case Study – Magnetizing of an Isotropic Bonded Neo Arc Magnets – Design Flow

One FEA model solves for magnetization, and…

…the result…

…is used in the application FEA.