Recent developments in melt-spun Nd-Fe-B bonded magnets for automotive applications

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Outline

• Introduction
  • Magnequench history
  • Recent trend in automotive industry

• Recent developments from MQ
  • High-performance powder by advanced quenching technology
  • Powder/magnet surface treatment for improved heat and corrosion resistance
  • Novel design by optimizing magnet shape and magnetization pattern

• Summary
Magnequench has evolved from a GM business unit into a leader of bonded neo magnetic solutions with a global footprint.

1986
- General Motors (GM) forms Magnequench as a business unit

2006
- Magnequench merges with AMR Technologies, Inc. (AMR). New company is called Neo Material Technologies, Inc.

2012
- Neo Material Technologies, Inc is acquired by Molycorp, Inc., in June

2016
- As a result of a financial restructuring of Molycorp, Inc., Neo Performance Materials emerges as a private company.

2017
- Neo Performance Materials completes its IPO on Toronto Stock Exchange

#1 Global Market Leader of Nd-Fe-B powders for bonded and hot deformed magnets
MQ powder products performance

- Technology leader
  - State-of-art jet casting technology
  - Highest powder performance in industry
  - Expanding portfolio of powder grades for individual customers

- Consistency / Quality
  - Narrowest magnetic specifications in industry
  - Former automotive subsidiary with all relevant TS and ISO certifications

- Scale
  - Capacity exceeding combined capacity of all other companies

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MQ powder products applications
Over 50% of the MQ powder is used in automotive applications

- Greater demand for increased passenger comfort and functionality
- Automotive industry push towards “Electrification”
- Demand for high efficiency, light weight, and compact electric motors in cars

Applications using MQ magnetic materials within a car

Magnequench’s business by application
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MQ has been continuously working on improving our product’s performance

AQ technology is the results from our past 3 years R&D efforts

It brings up to 1 MGOe increase in energy product for existing MQP products
## AQ-grade powder example

<table>
<thead>
<tr>
<th>Powder Grade</th>
<th>MQP-B+-10118</th>
<th>MQP-17-9-20440</th>
<th>Existing Grade</th>
<th>MQP-14-12- 20000-070</th>
<th>Existing Grade</th>
<th>MQP-15-12- 20439-070</th>
<th>AQ Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Existing Grade</strong></td>
<td><strong>895-915</strong></td>
<td><strong>716-836</strong></td>
<td><strong>126-134</strong></td>
<td><strong>905-915</strong></td>
<td><strong>745-785</strong></td>
<td><strong>132-138</strong></td>
<td><strong>850 - 860</strong></td>
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<td>MQP-B+</td>
<td>8.95-9.15</td>
<td>9.0-10.5</td>
<td>15.8-16.8</td>
<td>(9.05-9.15)</td>
<td>(9.4-9.7)</td>
<td>(16.6-17.3)</td>
<td>(8.50 - 8.60)</td>
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<td>13.4 - 15.1</td>
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</table>

**Powder Properties**

- **Br**: Br (kGs)
- **Hci**: Hci (kOe)
- **(BH)max**: (BH)max (kJ/m³ (MGOe))

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### Diagrams

- **Diagram A**: Comparison of B vs. J for MQP-17-9-20440 and MQP-B+ 10118-070.
- **Diagram B**: Comparison of B vs. J for MQP-15-12- 20439-070 and MQP-14-12 20000-070.
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- High-performance powder with uniform microstructure
- Powder/magnet surface treatment for improved heat and corrosion resistance
- Novel design by optimizing magnet shape and magnetization pattern
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Why powder/magnet surface treatment?

**Electronic applications:**
- HDD, ODD, Printer...
- Working temperature less than 80°C
- No requirement on mechanical strength at high-temp
- Less corrosive working environment
- Relatively shorter life span

**Automotive applications:**
- Seat/windows lifting motors, EPS sensor, water/fuel pumps...
- Working temperature up to 150~180°C
- Require high mechanical strength at high temperature
- More corrosive working environment
- Longer life span

- Harsh working environment in automotive applications
- Require magnets with better mechanical strength, thermal stability and corrosion resistance
- Powder/magnet surface coating is necessary to meet the requirements
Process of making compression molded magnets for auto applications

MQP Magnetic Powders → Powder Surface Treatment → Compounding (MQP+binder) → Compression Molding & curing → Magnet Surface Treatment & Coating

- Apply anti-oxidation or corrosion resistant coating on powders.
- Precursors of highly crosslink-able epoxy mixed with MQP powder.
- Apply additional anti-oxidation or corrosion resistant coating on magnets.

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For under-the-hood applications, mechanical strength of magnet needs to be maintained at temperatures up to 150~180°C.

Magnets made from traditional compound can’t operate above 80°C due to their low creep/stress rupture strength.

High temperature compounds using highly crosslinked epoxy as binders has been developed for under-the-hood applications.
Improved magnet aging at high temperature

- Compression molded rare earth magnets are prone to oxidation at temperatures above 120°C (aging) due to their high rare earth content
- Improved magnet aging can be achieved by applying following anti-aging technologies:
  - High temperature compound
  - MQP powder surface passivation
  - Magnet surface treatment

Accelerated Aging Results (equivalent to 1000 hours at 180°C)

- Traditional compound
- High-T compound
- High-T compound + MQP surface passivation
- High-T compound+MQP surface passivation+magnet surface treatment
Magnet coating for auto applications

- Magnets must meet higher standard of corrosion test for certain auto applications than for traditional electronic applications.
- Magnet coating plays the most important role in providing corrosion resistance.
- Parylene coating outperforms traditional E-coating in corrosion test.

<table>
<thead>
<tr>
<th></th>
<th>Electrophoresis coating</th>
<th>Parylene coating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coating material</td>
<td>Epoxy</td>
<td>poly(p-xylene)</td>
</tr>
<tr>
<td>Coating method</td>
<td>Electrophoresis</td>
<td>Vapor deposition</td>
</tr>
<tr>
<td>Coating thickness</td>
<td>~20um</td>
<td>10~30 um</td>
</tr>
<tr>
<td>Corrosion resistance in PCT (120°C, 2atm, 100%RH) test</td>
<td>10~24 hours</td>
<td>~250 hours</td>
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<tr>
<td>Appearance</td>
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Magnet magnetization and motor performance evaluation

Magnetization of MQ1 magnets

Cogging torque measurement

Load characteristics using computer controlled dynamometer

Back-emf measurement
What is magnet shaping?

- In a ring magnet there is a possibility of under-utilizing magnet material.

- Magnet shaping
  - Optimal use of magnet material
  - Reduction in magnet cost

Can we reduce the material in this 18º?
Design considerations and possible magnet shapes

- **Design considerations**
  - Useful for fractional slot/pole combination
  - Magnet is magnetized with radial magnetization profile without any skew
  - Feasibility of shape in mass production and corresponding manufacturing cost penalty if any
  - No demagnetization at the thinnest portion of the magnet
  - Mechanical strength of the magnet is sufficient from assembly point of view
Case study #1: Automotive accessory motor (6-slot / 4-pole motor)

Uniform ring with skew

Shaped ring with eccentric OD

Peak to peak cogging torque ↓ 40%

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Case study #2: automotive accessory motor (14-slot / 4-pole motor)

Uniform ring with skew  
Shaped ring with eccentric ID

- Magnet weight:
  - Uniform magnet with skew: 1
  - Shaped magnet without skew: 0.90

- Motor back-emf:

- Cogging torque:
  - Peak to peak cogging torque ↓ 7%
Magnetization fixture design: effect of slot shape and conductor location

- Moving conductors away from the magnet surface helps in achieving more Halbach flux profile and hence reduced cogging torque

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

Cogging torque of the motor for magnet magnetized using the magnetizing fixture with flat and curved slot
Magnetization fixture design: effect of back iron shape

- The direction for the applied field is changed by shaping the back iron

### Comparison of Back Iron Shapes

<table>
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<th>Back iron shape</th>
<th>Ring</th>
<th>Flower</th>
<th>Change (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cogging torque (mN-m)</strong></td>
<td>14.6</td>
<td>7.7</td>
<td>-47</td>
</tr>
<tr>
<td><strong>Back EMF Integral (V°)</strong></td>
<td>26.78</td>
<td>26.85</td>
<td>-</td>
</tr>
</tbody>
</table>

**Cogging torque**

**Back emf @ 3500 rpm**
Summary

- Higher-performance powders have been produced by AQ technology
  - Applicable to all existing MQP products

- Powder/magnet surface treatment technologies have been developed to meet tough requirements for automotive applications
  - High temperature compounds using highly crosslinked epoxy as binders has been developed to achieve high mechanical strength
  - Improved magnet aging can be achieved by applying anti-aging technologies
  - New parylene coating has been developed for improved corrosion resistance

- Use of bonded magnets can be further optimized by improved design in magnet shape and magnetization pattern