neo Magnequench

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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 history

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

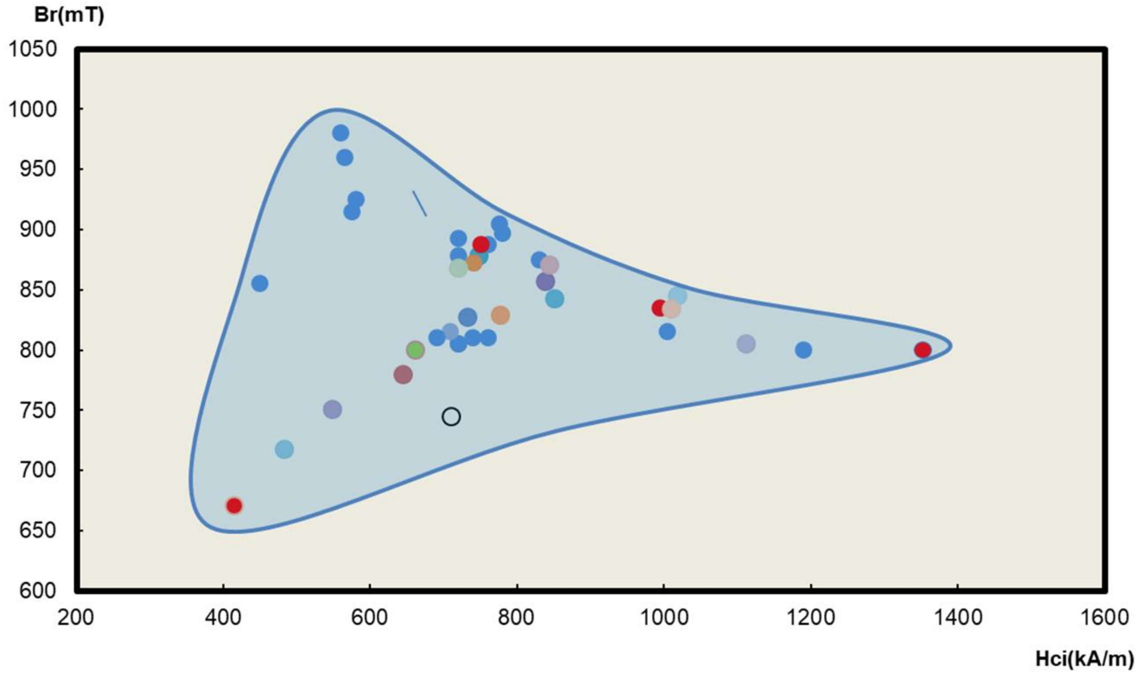
As a result of a financial restructuring of Molycorp, Inc., Neo Performance Materials emerges as a private company.

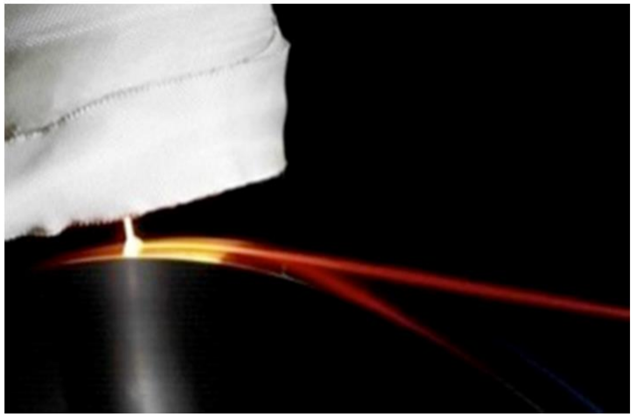
2017

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



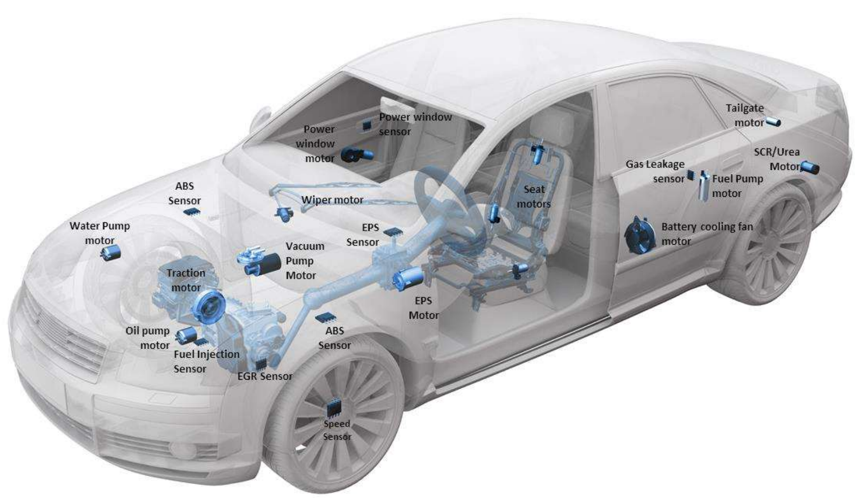


- Technology leader
  - State-of-art jet casting technology
  - Highest powder performance in industry
  - Expanding portfolio of powder grades for individual customers
- Consistency / Quality
  - Narrowest magnetic specifications in industry
  - Former automotive subsidiary with all relevant TS and ISO certifications
- Scale
  - Capacity exceeding combined capacity of all other companies

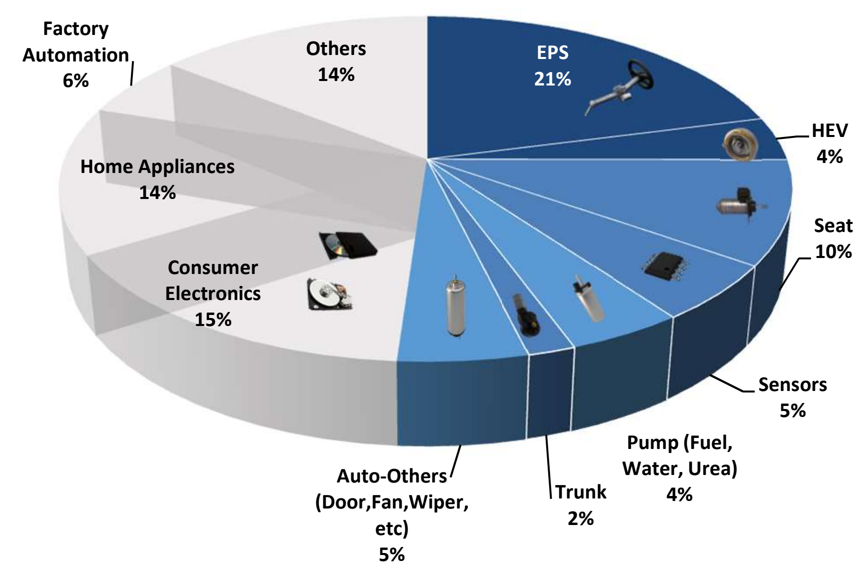
MQ powder products applications

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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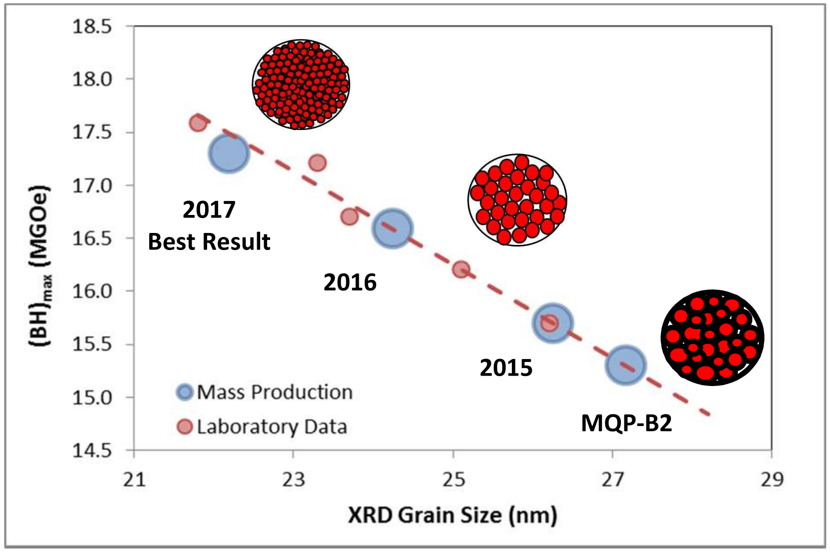
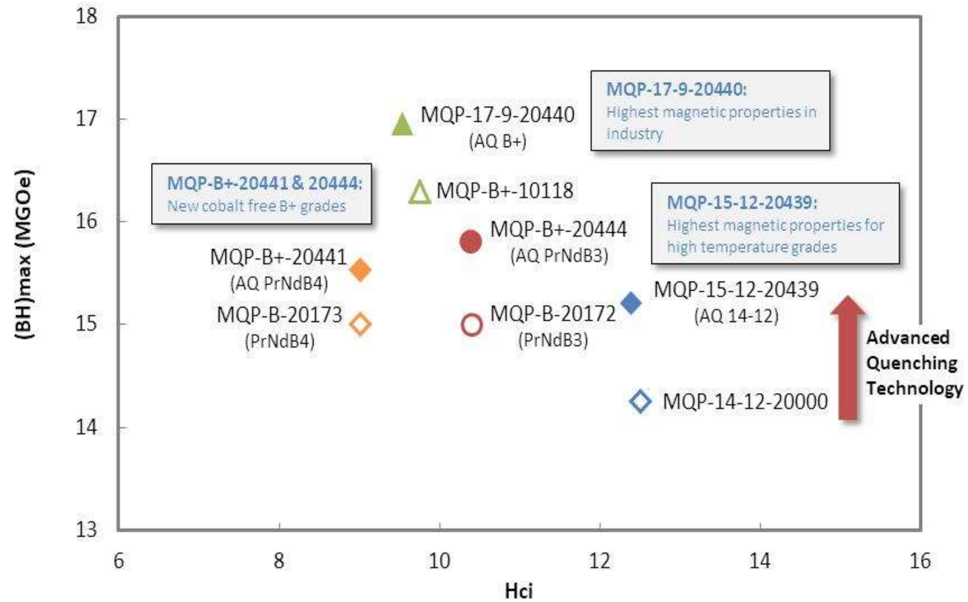
High performance powder by advanced quenching technology (AQ)

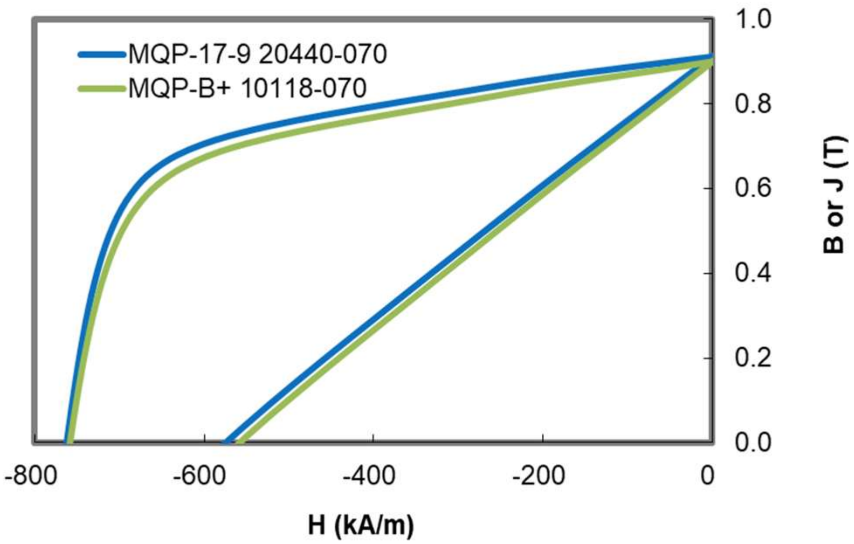


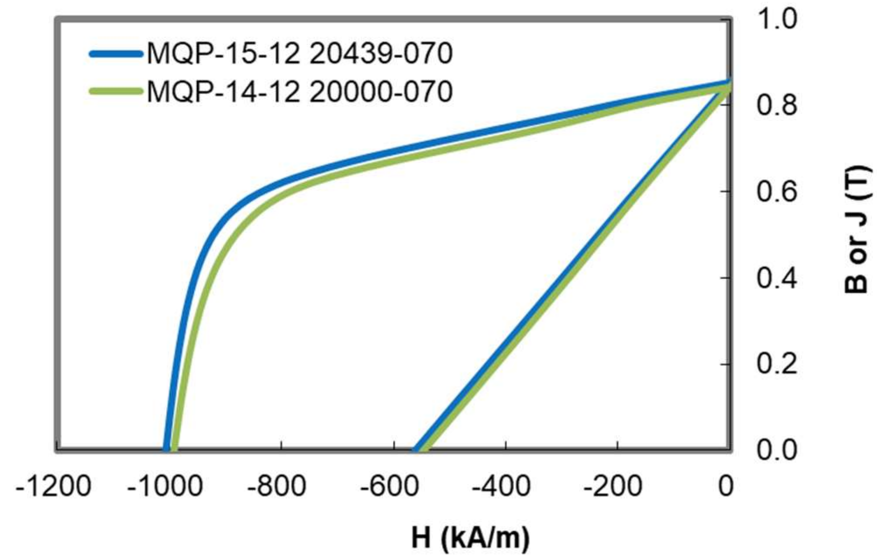


- MQ has been continuously working on improving our product's performance
- AQ technology is the results from our past 3 years R&D efforts
- It brings up to 1 MGOe increase in energy product for existing MQP products

AQ-grade powder example

Powder Grade		Powder Properties: Br mT (kGs)	Powder Properties: Hci kA/m (kOe)	Powder Properties: (BH)max kJ/m³ (MGOe)
Existing Grade	***MQP-B+-10118***	895-915 (8.95-9.15)	716-836 (9.0-10.5)	126-134 (15.8-16.8)
AQ Grade	***MQP-17-9-20440***	905-915 (9.05-9.15)	745-785 (9.4-9.7)	132-138 (16.6-17.3)
Existing Grade	**MQP-14-12- 20000-070**	820 - 850 (8.20 – 8.50)	940 - 1050 (11.8 – 13.2)	107 - 120 (13.4 -15.1)
AQ Grade	**MQP-15-12- 20439-070**	850 - 860 (8.50 - 8.60)	950 - 1030 (11.9 – 12.9)	118 - 124 (14.8 -15.6)





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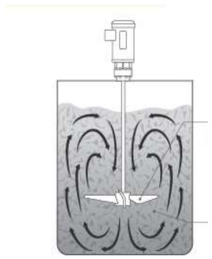
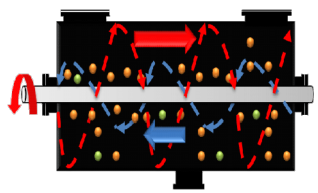
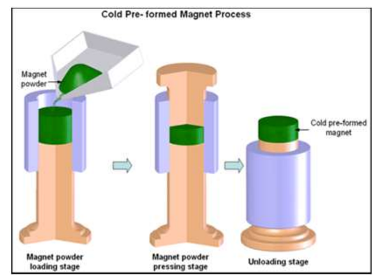
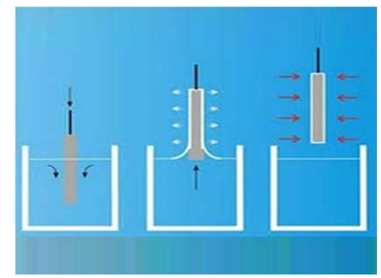
Why powder/magnet surface treatment?

Electronic applications:	Automotive applications:
HDD, ODD, Printer…	Seat/windows lifting motors, EPS sensor, water/fuel pumps…
Working temperature less than 80°C	Working temperature up to 150~180°C
No requirement on mechanical strength at high-temp	Require high mechanical strength at high temperature
Less corrosive working environment	More corrosive working environment
Relatively shorter life span	Longer life span

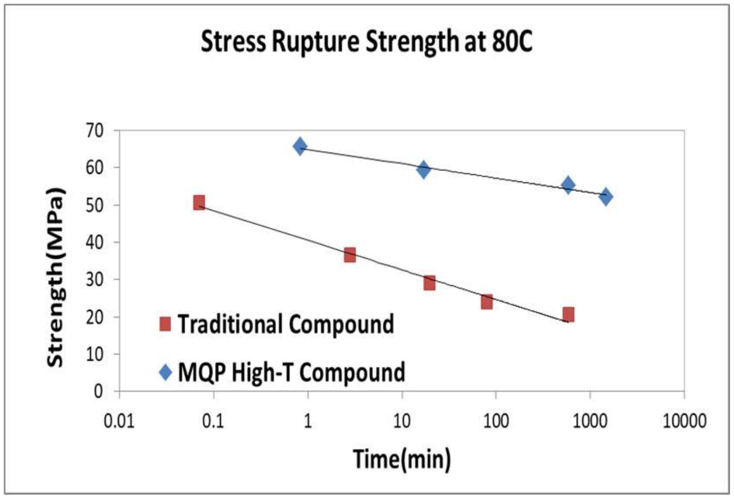
- Harsh working environment in automotive applications
- Require magnets with better mechanical strength, thermal stability and corrosion resistance
- Powder/magnet surface coating is necessary to meet the requirements

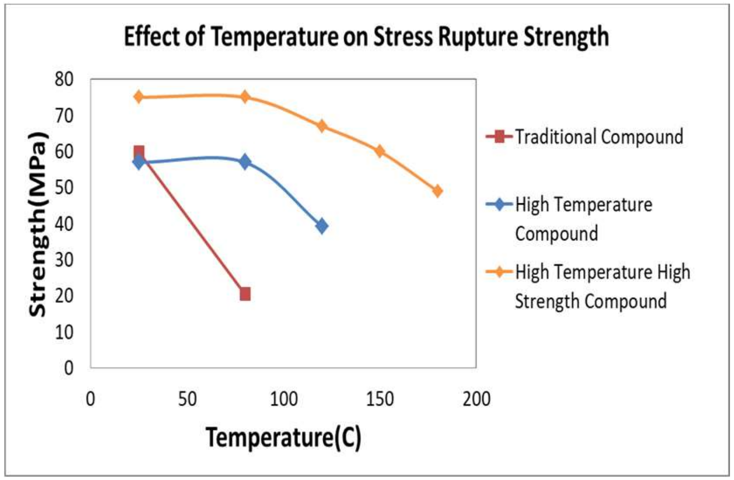
Process of making compression molded magnets for auto applications

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.

High mechanical strength at high temperature

- 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



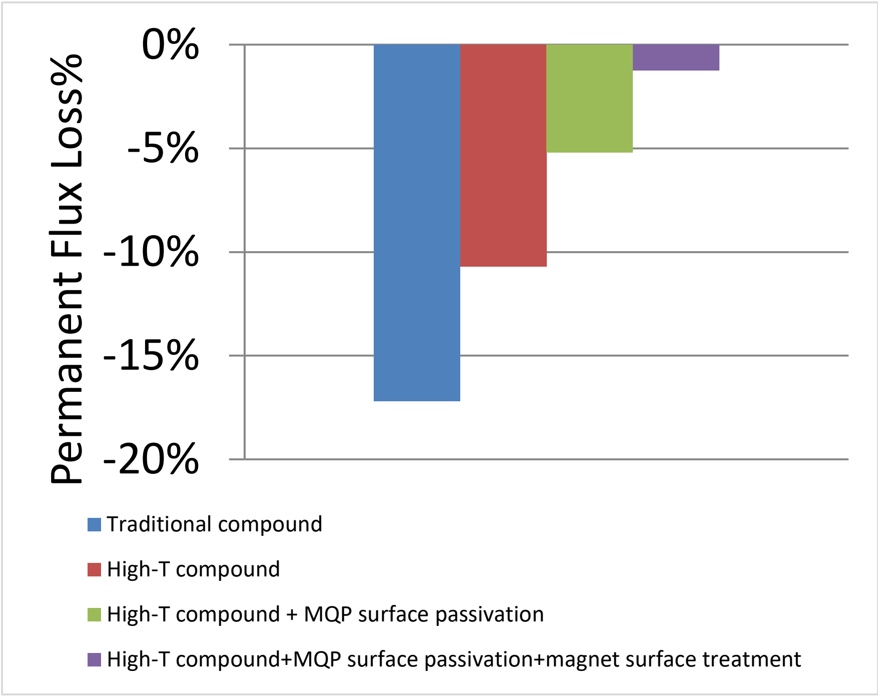


Improved magnet aging at high temperature

- 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)



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

	Electrophoresis coating	**Parylene coating**
Coating material	Epoxy	poly(p-xylylene)
Coating method	Electrophoresis	Vapor deposition
Coating thickness	~20um	10~30 um
Corrosion resistance in PCT (120C, 2atm, 100%RH) test	10~24 hours	~250 hours
Appearance		

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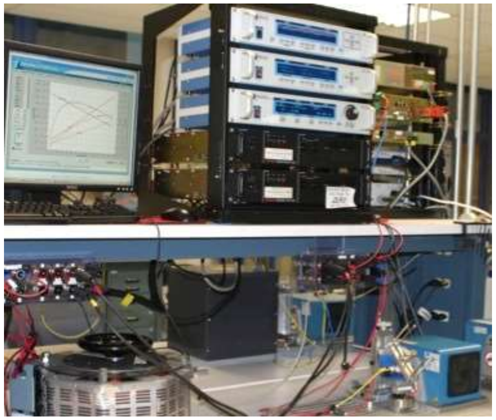
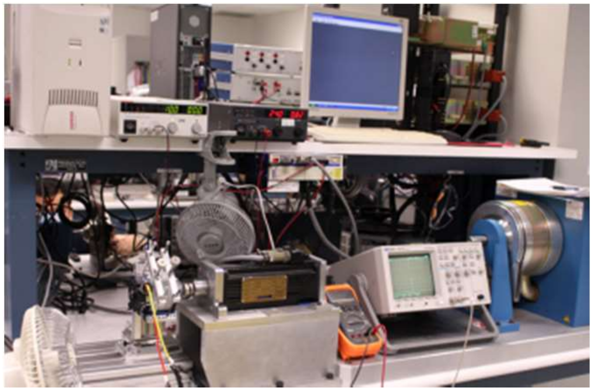
Magnet magnetization and motor performance evaluation

Magnetization of MQ1 magnets

Cogging torque measurement



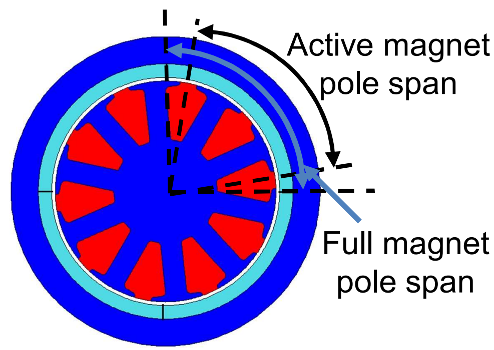
Load characteristics using computer controlled dynamometer

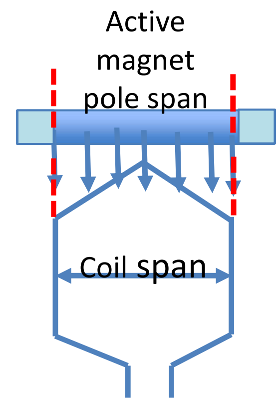


Back-emf measurement

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

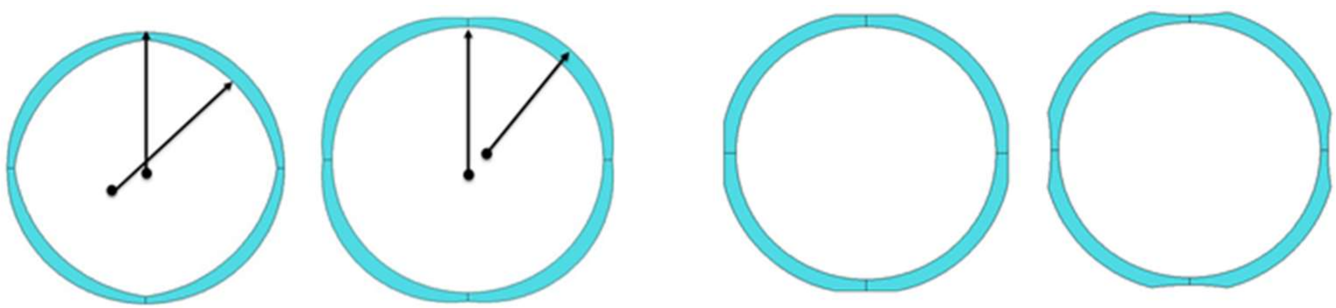




Can we reduce the material in this 18º?

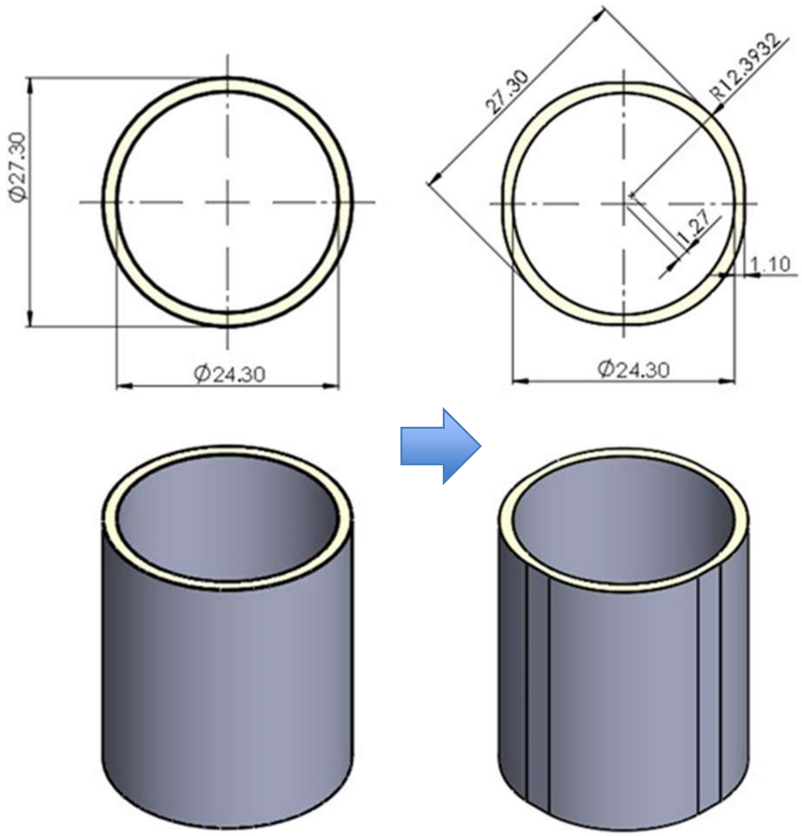
Design considerations and possible magnet shapes

- 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



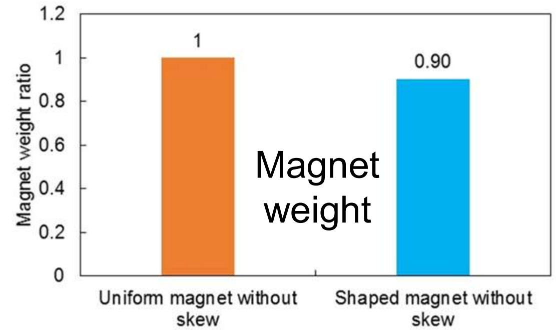
Eccentric ring magnet Non-eccentric ring magnet

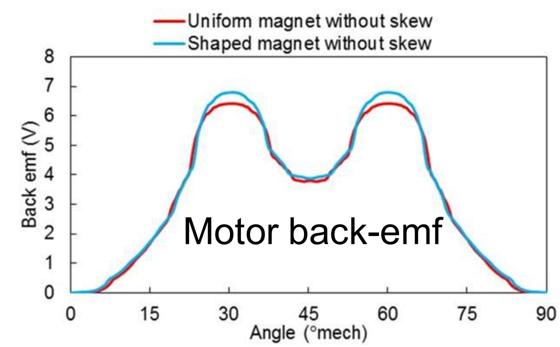
Case study #1: Automotive accessory motor (6-slot / 4-pole motor)

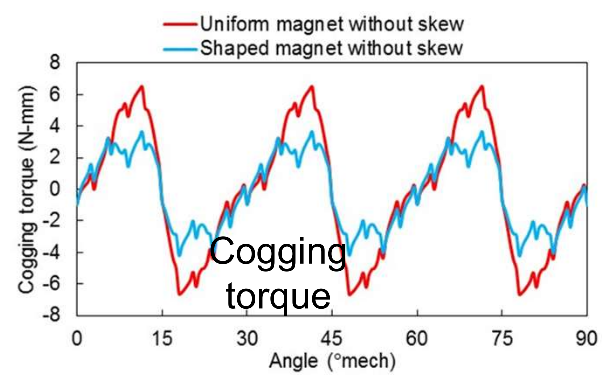


Uniform ring with skew

Shaped ring with eccentric OD

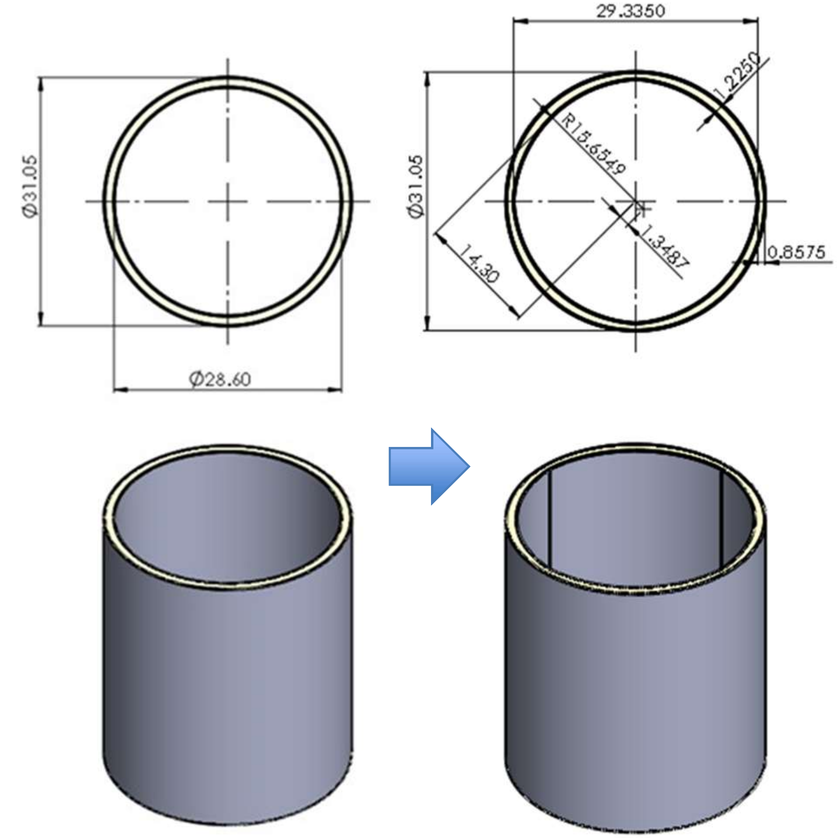






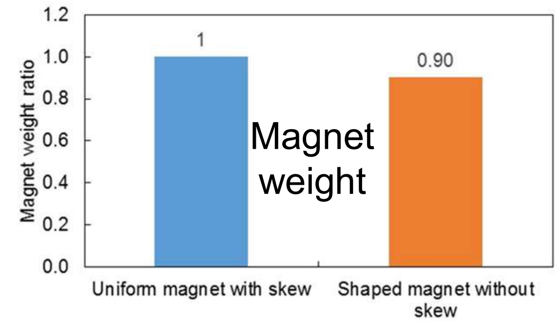
Peak to peak cogging torque ↓ 40%

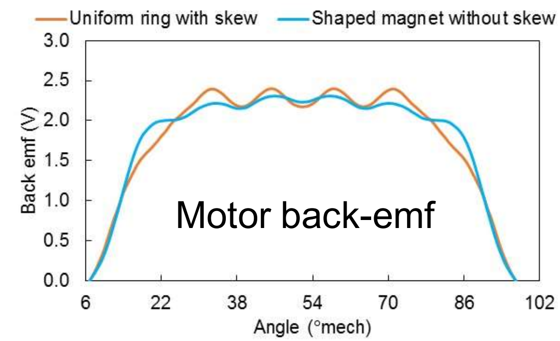
Case study #2: automotive accessory motor (14-slot / 4-pole motor)

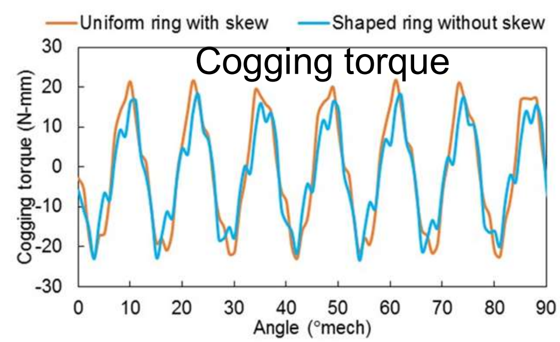


Uniform ring with skew

Shaped ring with eccentric ID

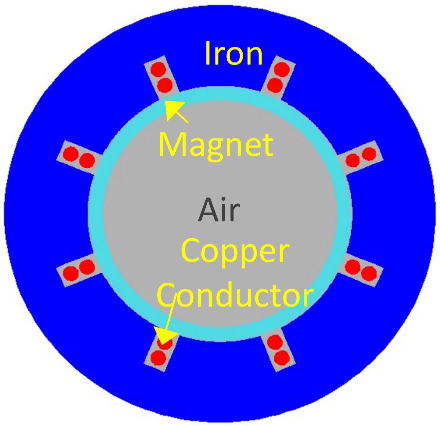




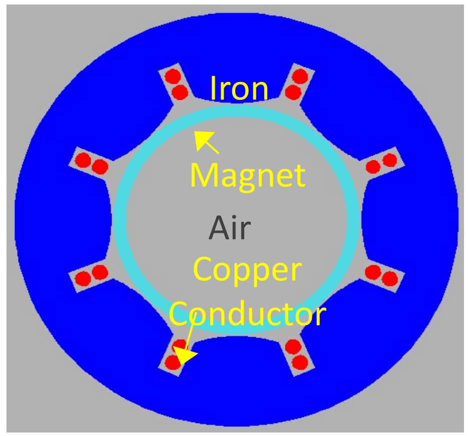


Peak to peak cogging torque ↓ 7%

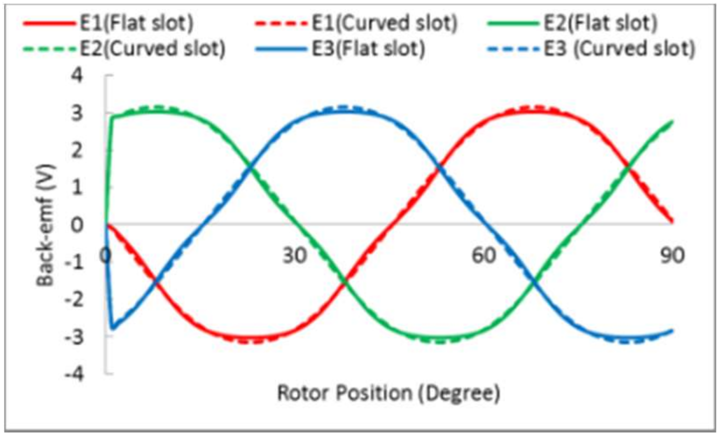
Magnetization fixture design: effect of slot shape and conductor location



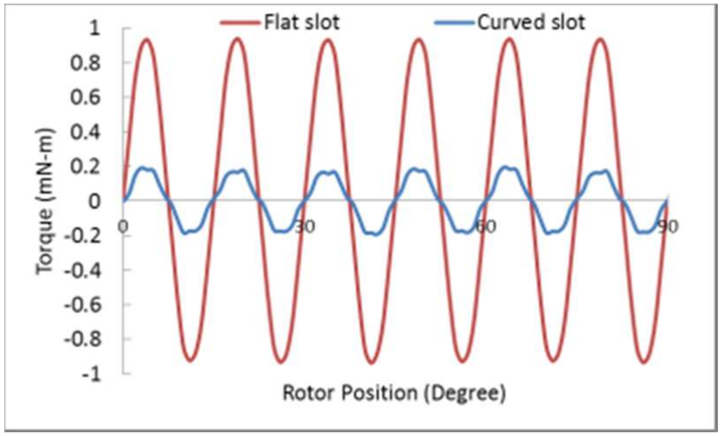
Magnetizing fixture with flat slot



Magnetizing fixture with curved slot



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

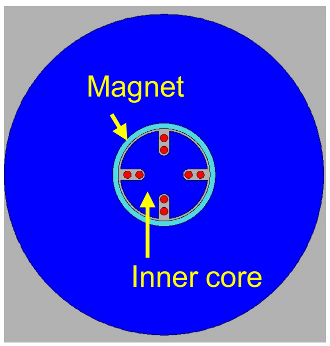


Cogging torque of the motor for magnet magnetized using the magnetizing fixture with flat and curved slot

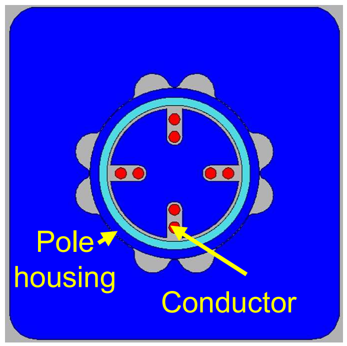
- Moving conductors away from the magnet surface helps in achieving more Halbach flux profile and hence reduced cogging torque

Magnetization fixture design: effect of back iron shape

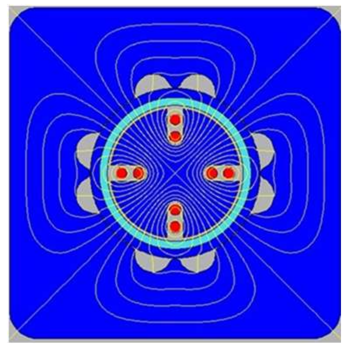
- The direction for the applied field is changed by shaping the back iron



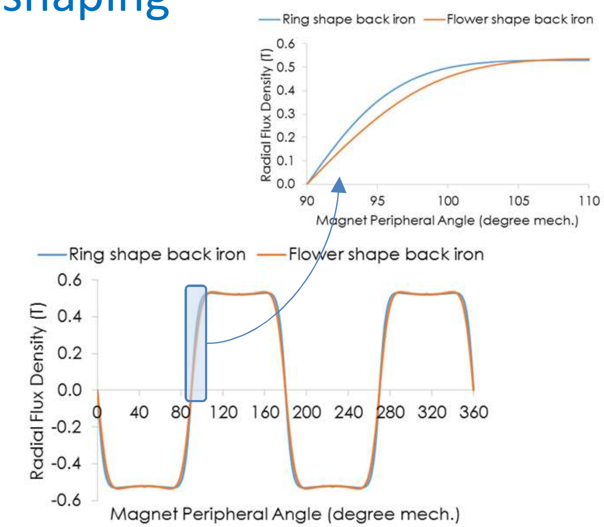
Round shape back iron



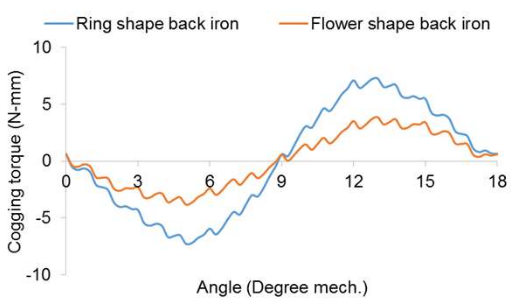
Flower shape back iron



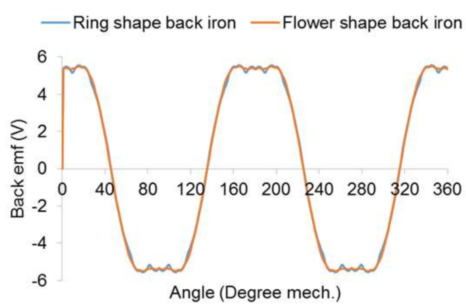
2D FEA of Magnetization



Magnet Magnetization Profile



Cogging torque



Back emf @ 3500 rpm

Back iron shape	Ring	Flower	Change (%)
$T_{cogging\ (pk\text{-}pk)}$ (mN-m)	14.6	7.7	-47
Back EMF Integral (V-º)	26.78	26.85	-

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