UK Magnetics Society

one day seminar

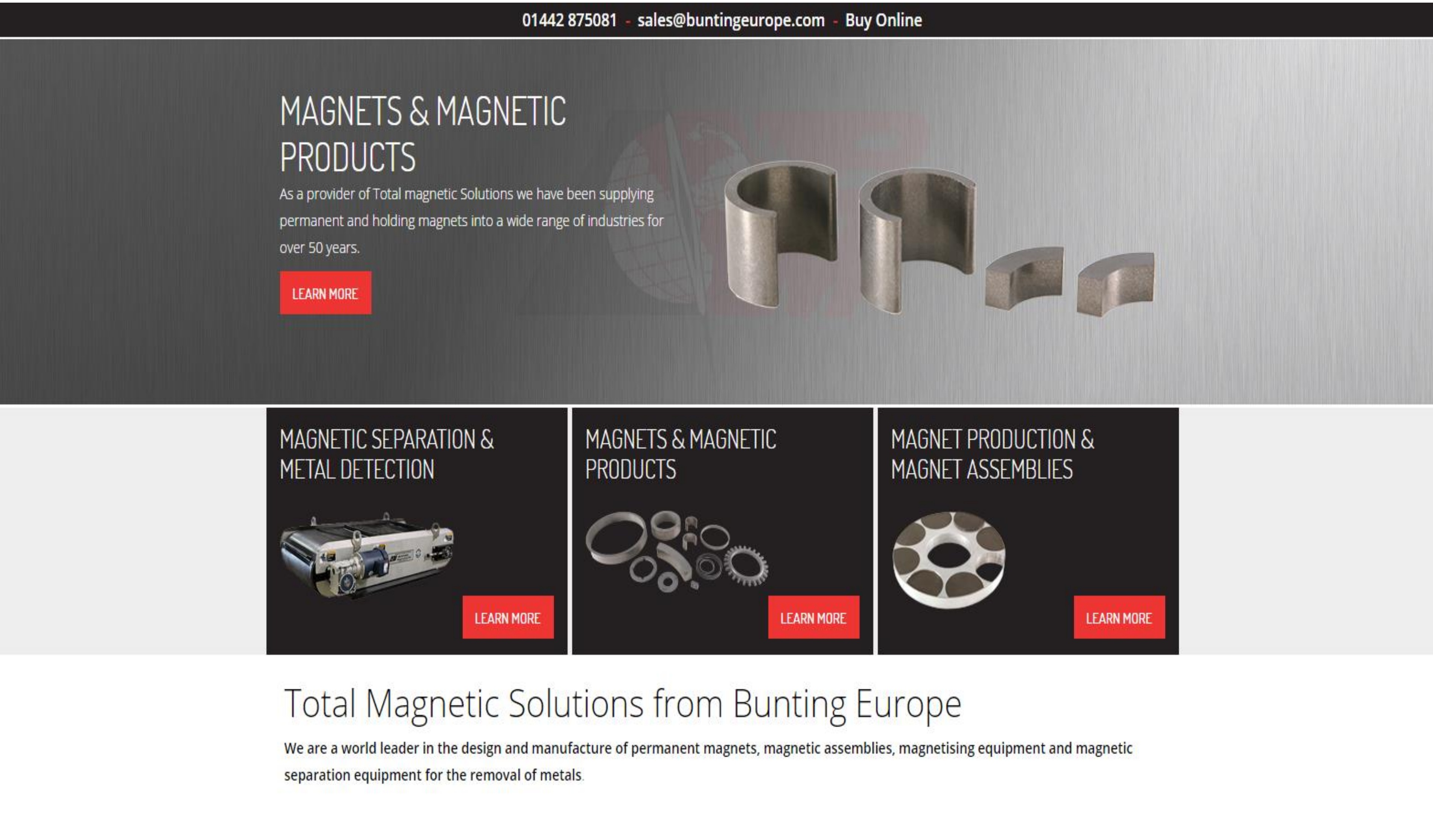
Post Assembly Magnetisation for PM Rotor Manufacture
+
Update on 3D Printed Magnet Work

Dr Chris Riley
Bunting Magnetics Europe Ltd

Held at The University of Sheffield Advanced Manufacturing Research Centre (AMRC)

Presentation Content

1. Introduction - Bunting Magnetics Group
2. Post Assembly Magnetisation – What are the Issues?
3. Magnetising Systems
4. Magnetising Fixture Design
5. Examples
6. Update on 3D Printed Magnets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We are a world leader in the design and manufacture of permanent magnets, magnetic assemblies, magnetising equipment and magnetic separation equipment for the removal of metals.

Post Assembly Magnetisation - Issues

Advantages

- Alleviates problems of handling pre-magnetised magnets
- Speeds up assembly
- Storage of rotors

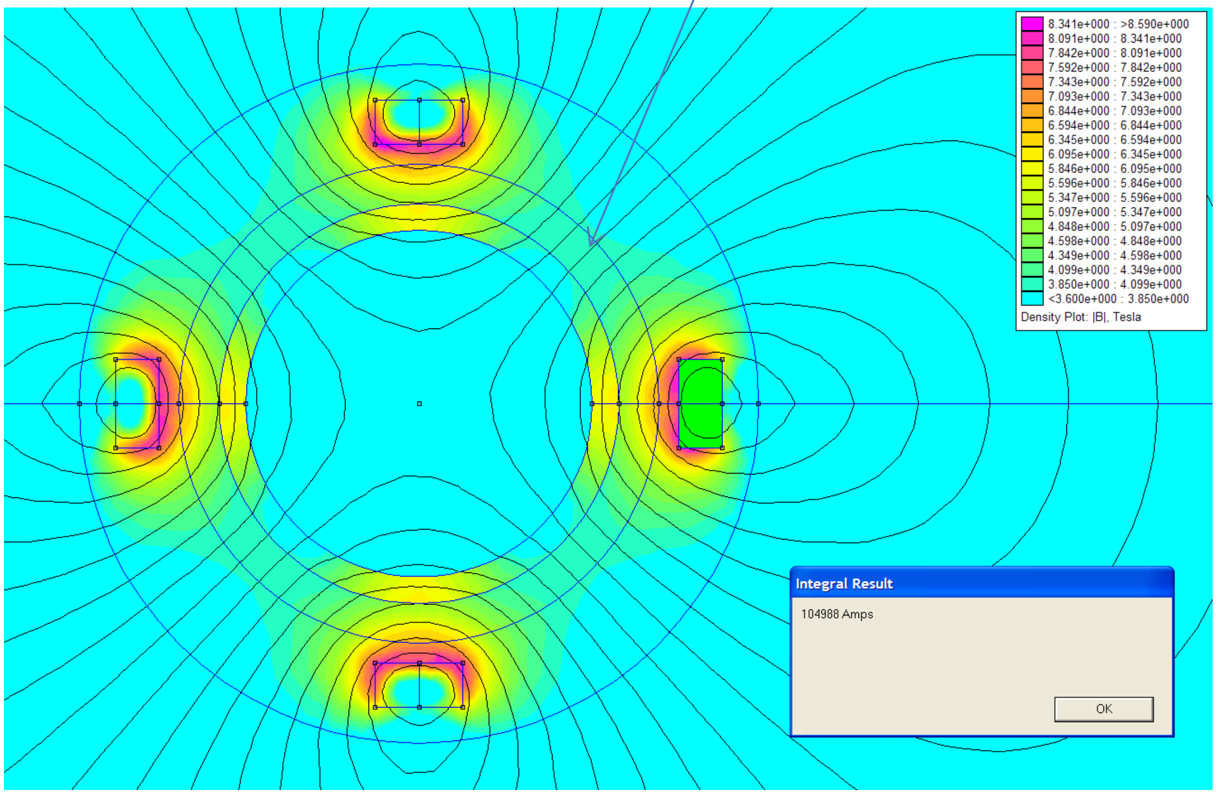
Disadvantages

- Complex Design of Magnetising Fixture
- Many rotor designs not feasible
- High Energies required

Design Issues

Typical 4 pole fixture

Magnet Region



Amp-turns/slot = 105 kA

Current = 13,125A

di/dt = ~300A/µs

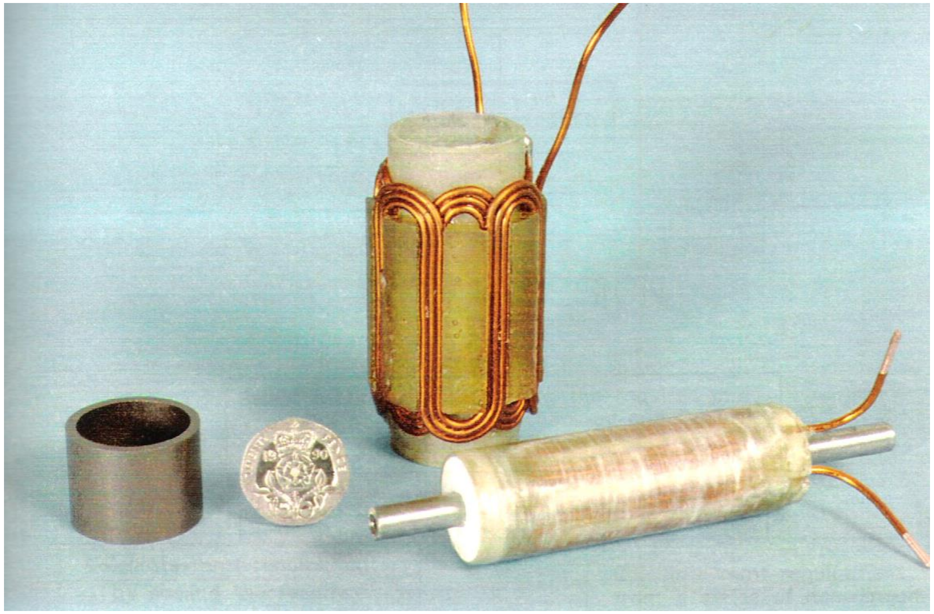
Current Density = 7400 A/mm^2

Lorentz Force = 207 N

Temp. Rise = 40 – 60 ° C (typ)

>1 million deg / sec

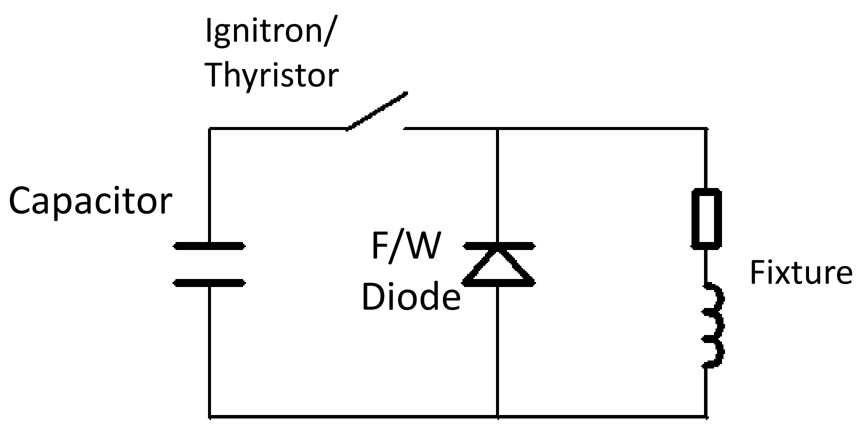
This is what can happen!

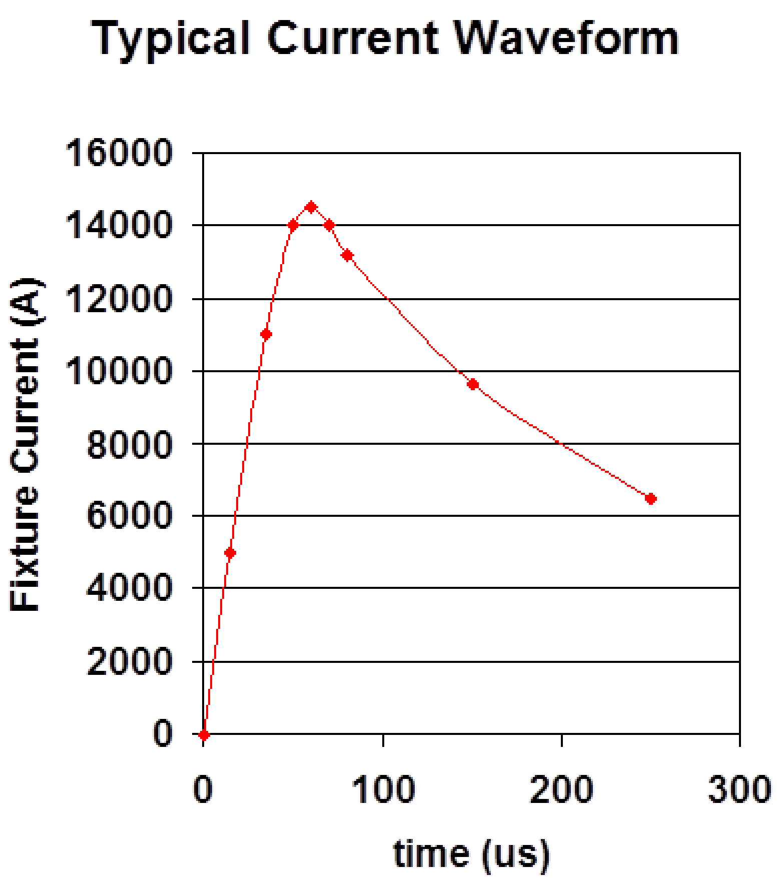


Magnetising Systems

Capacitor Discharge Magnetisation

- A typical magnetising system consists of a magnetiser and a magnetising fixture.
- Magnetising fixtures range from simple solenoids to very complex multi-pole arrangements





Magnetising Equipment

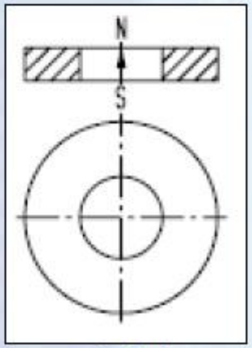
- Low voltage magnetisers
  - Utilise Electrolytic capacitors
  - Maximum voltage typically 800V
  - Standard Energy values usually range from 100J to 24kJ
  - Main applications – solenoid fixtures, multipole ferrite/alnico magnets , some rare-earths

- High voltage magnetisers
  - Utilise oil filled bipolar capacitors
  - Maximum output voltage typically 2500 – 3000V
  - Standard values usually range from 1kJ to 24kJ
  - Main applications - rare-earth magnets – particularly multipole
  - High energy values available for special applications
  - 24kJ unit : 3inch coil with 5Tesla field

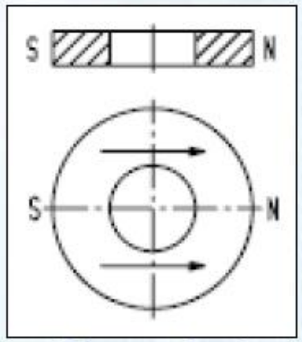
Magnetizing Systems
Fixture

Magnequench® Leading Magnet Innovation™

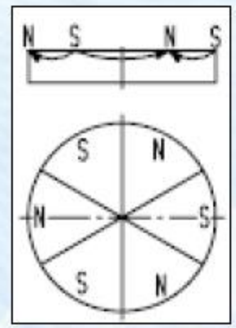
Fixtures can be designed for many types of pole configurations



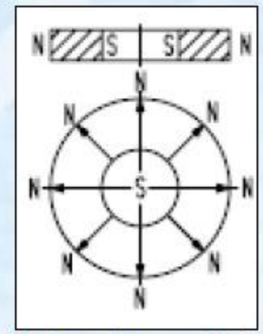
Axial



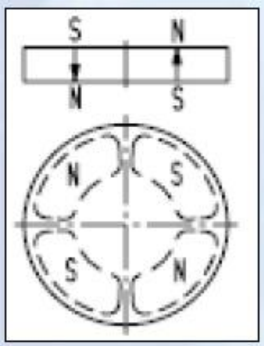
Diametrical



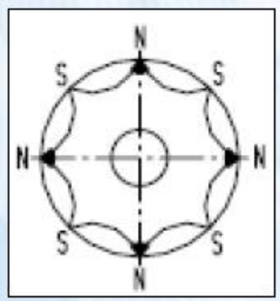
Surface magnetization



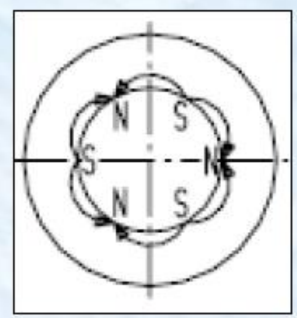
Uni-polar radial



Multi-pole axial



Outer-diameter Halbach



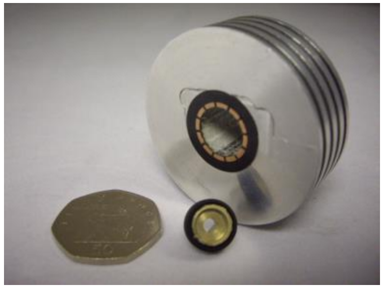
Inner-diameter Halbach

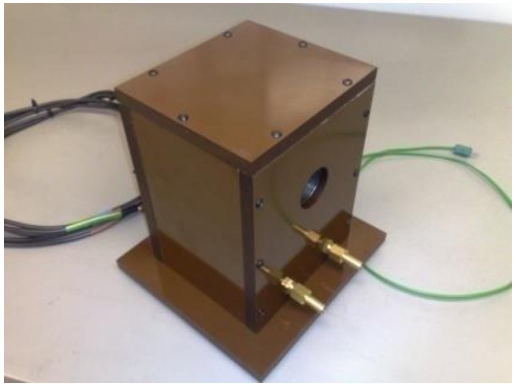
A Division of Neo Material Technologies Inc.

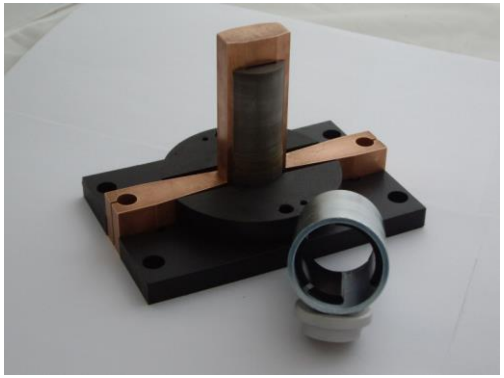
Magnetising Fixtures

Fixtures are generally custom built for each application depending on:

- Magnet material
- Pole Number
- Geometry
- Orientation
- Production rate







Magnetising Fixture Design

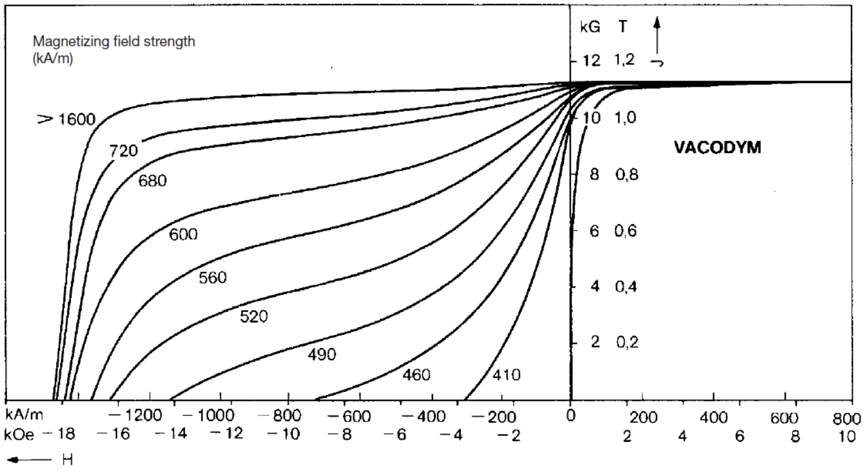
- Field Required to Saturate a Permanent Magnet
- Fixture Design Methodology
- Modelling of Post Assembly Magnetised Components

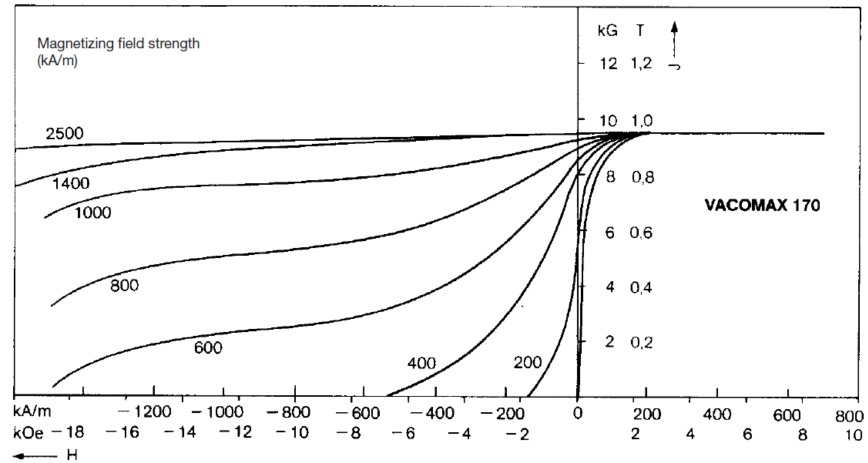
What is the required magnetising field?

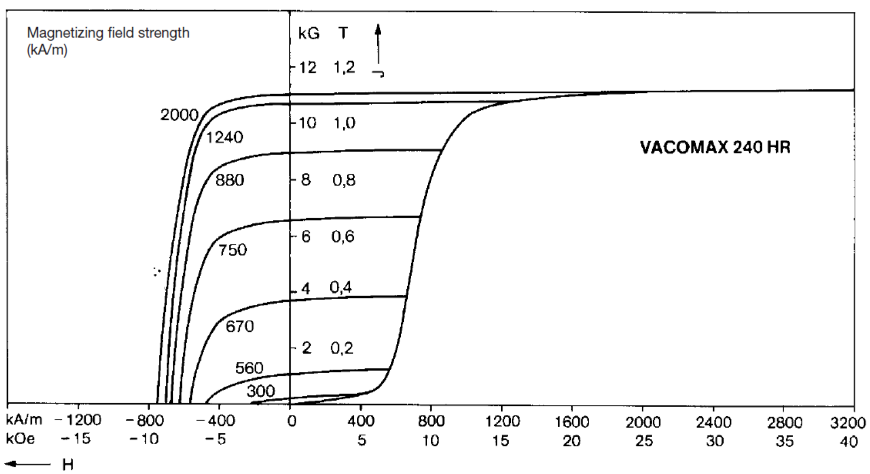
Material	Required Magnetising Field Strength
Cast Alnico	200 – 400 kA/m
Hard Ferrite	500 – 950 kA/m
SmCo	1200 – 4000 kA/m
Standard Sintered Anisotropic NdFeB	1600 – 2500 kA/m
Bonded Isotropic NdFeB	2500 – 3000 kA/m

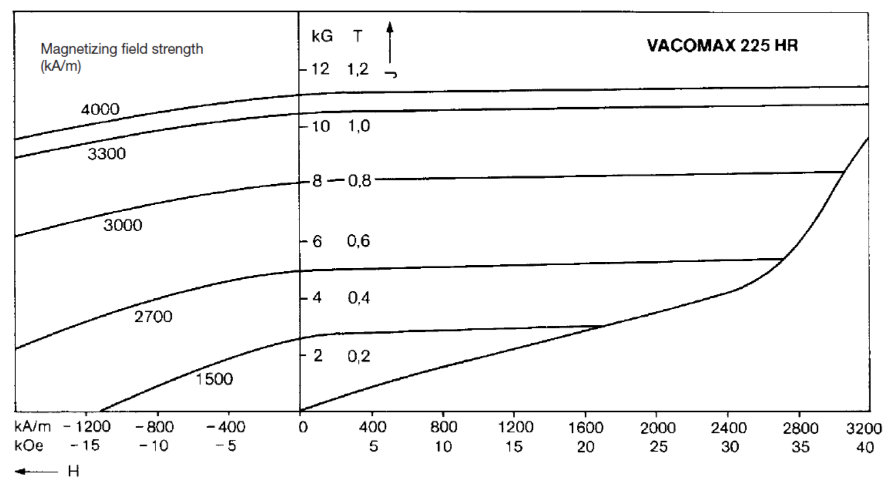
Various Sources

Magnetising fields for Rare Earth Magnets





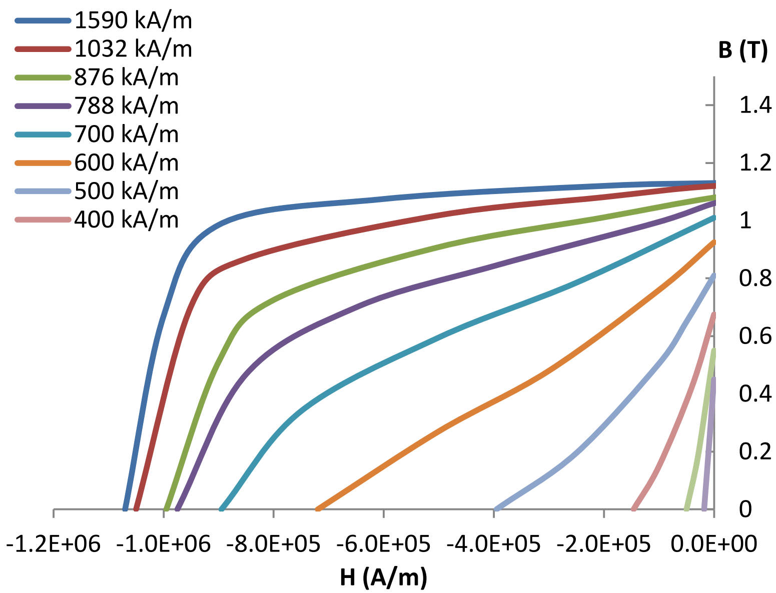


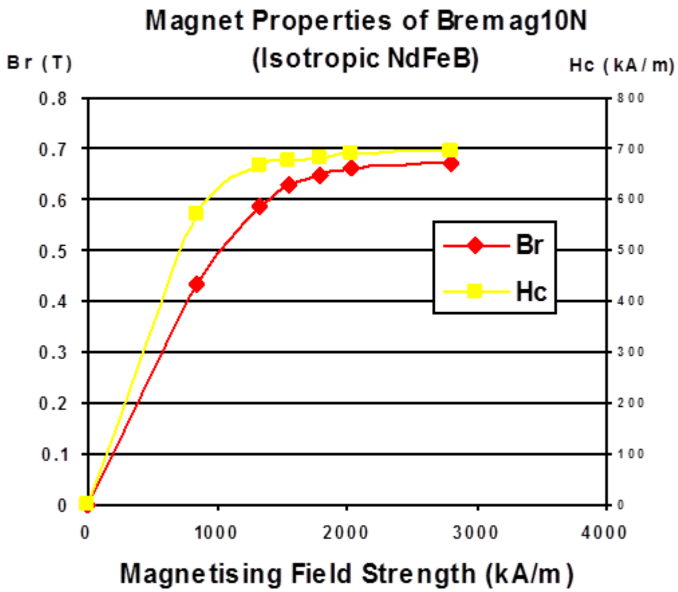


Source: Vacuumschmelze Rare Earth Permanent Magnets Catalogue

Saturation Field of Permanent Magnets

If possible measure the magnet properties!

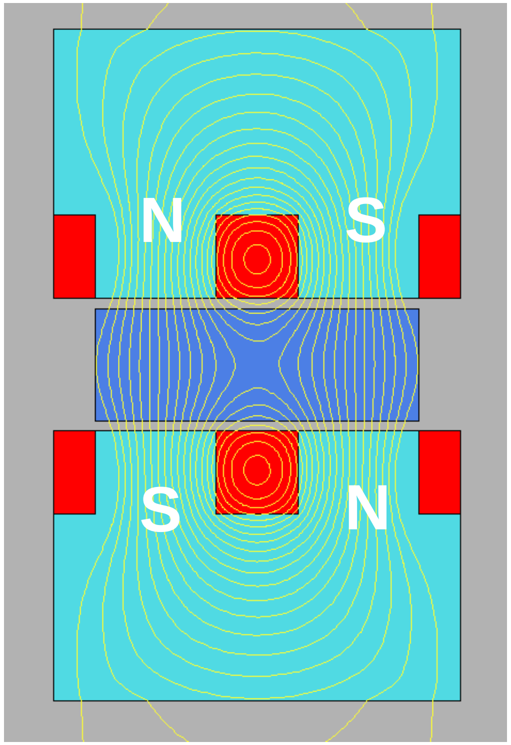


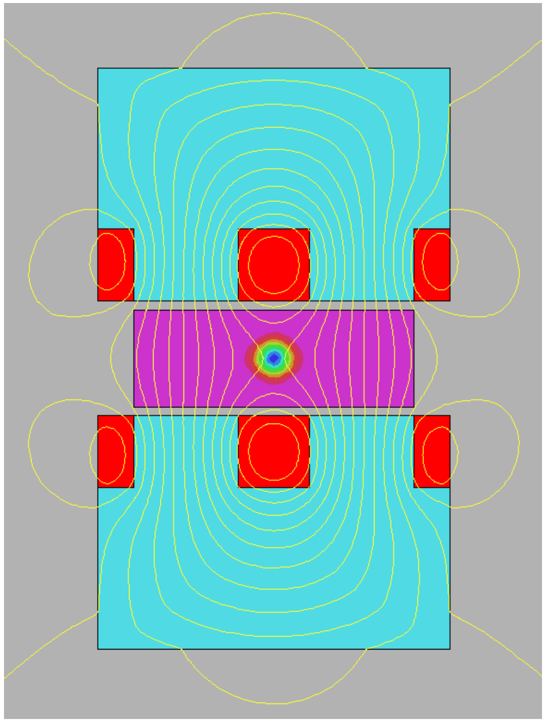


Define Volume Saturation as

$$\frac{1}{V_{mag}}\int \frac{B_r H_c}{B_{rsat} H_{cisat}} d\upsilon \times 100\%$$

Saturation Field of Permanent Magnets





96% by volume

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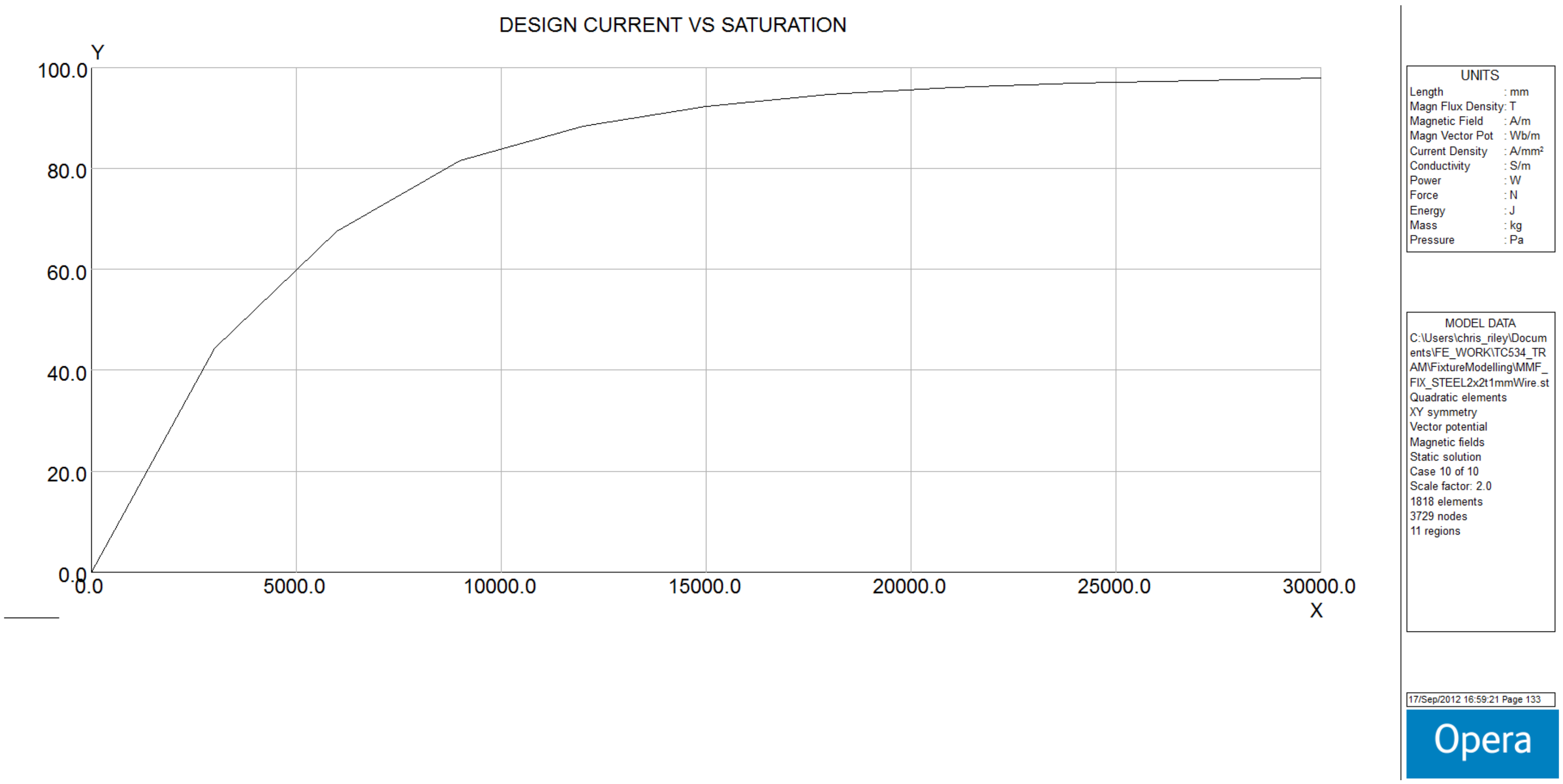
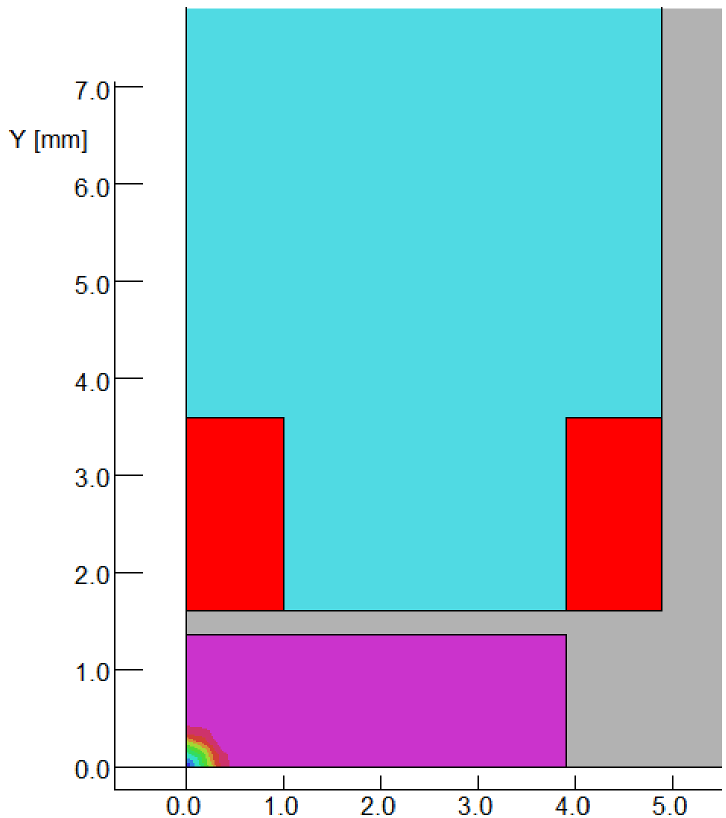
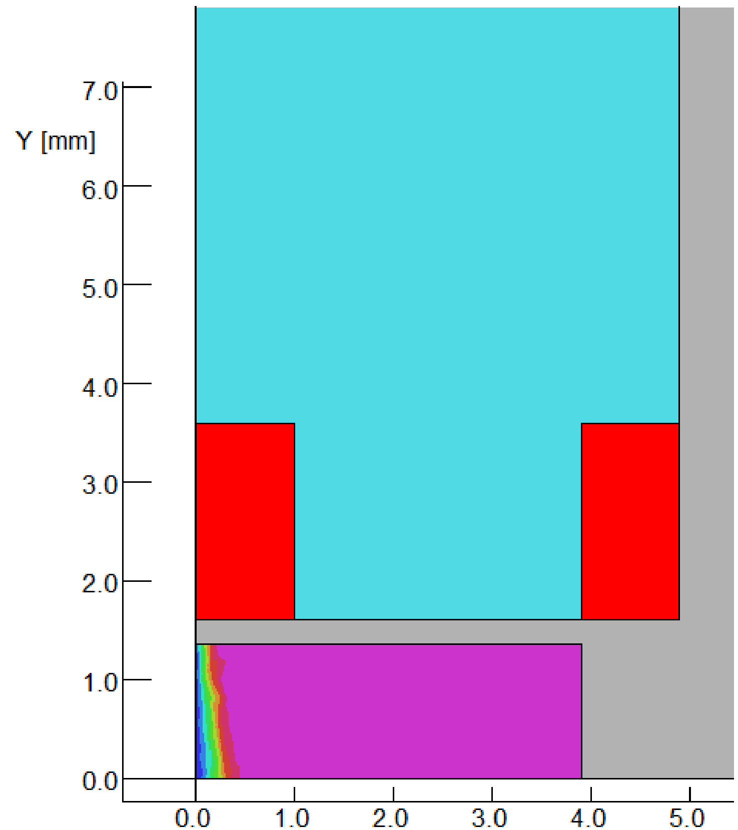
MMF vs Saturation Data



Comparison of Isotropic and Anisotropic Magnets





Fixture Design Methodology

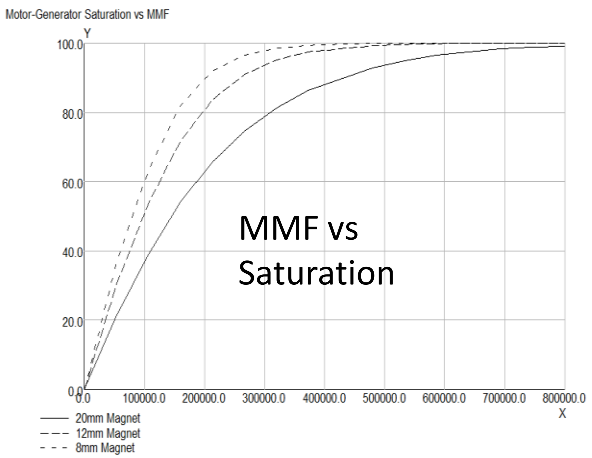
- Scan a wide range of candidate designs using analytical fixture design program
- Manually select best designs according to criteria of saturation, temperature rise, peak current and energy
- Model best designs using a static FEA solver (2D or 3D) to account for any non-linear materials
- If necessary
  - repeat using transient solver
  - Model Performance of magnet after magnetisation

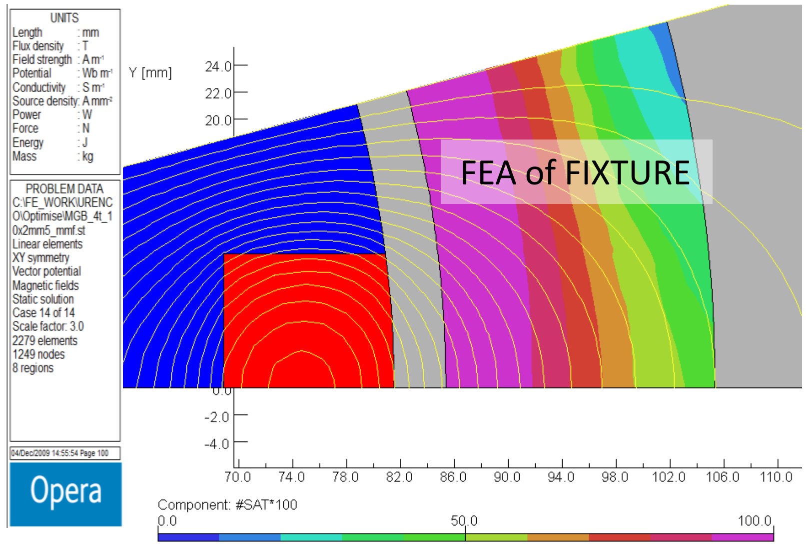
Modelling of Magnetised Magnets

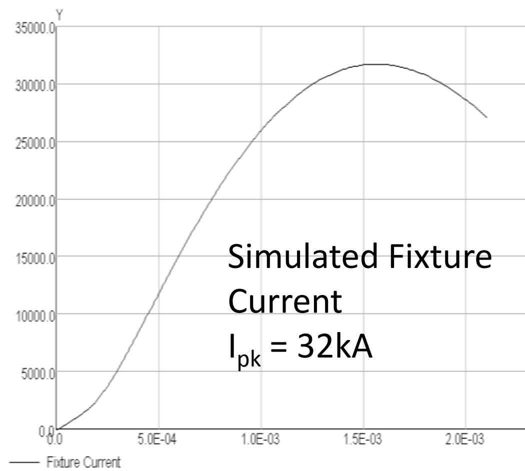
FEA software, designed to not only model the magnetisation process but also the magnets after magnetisation. This is an extremely powerful modelling technique that can be used to:

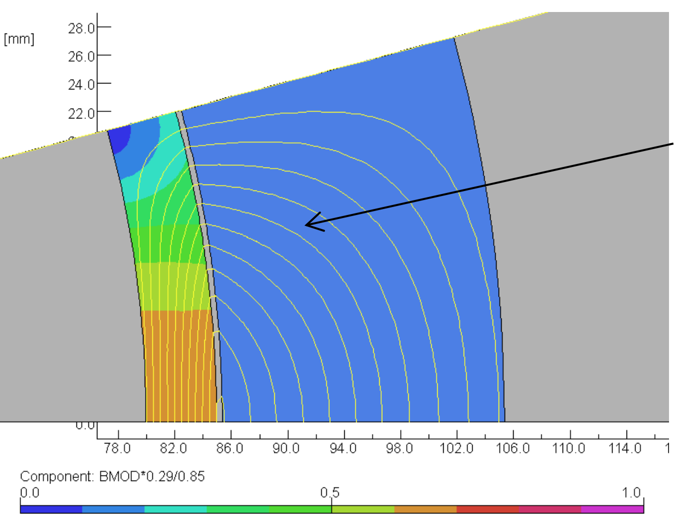
- Simulate motor performances using a true representation of the magnet generated from the actual magnetising fixture
- Design magnets to produce specific profiles (e.g. sinusoidal encoders)
- Optimise permanent magnet rotors (e.g. minimise cogging torque)
- Assess feasibility of post assembly magnetising assemblies

Modelling Magnetised Magnets



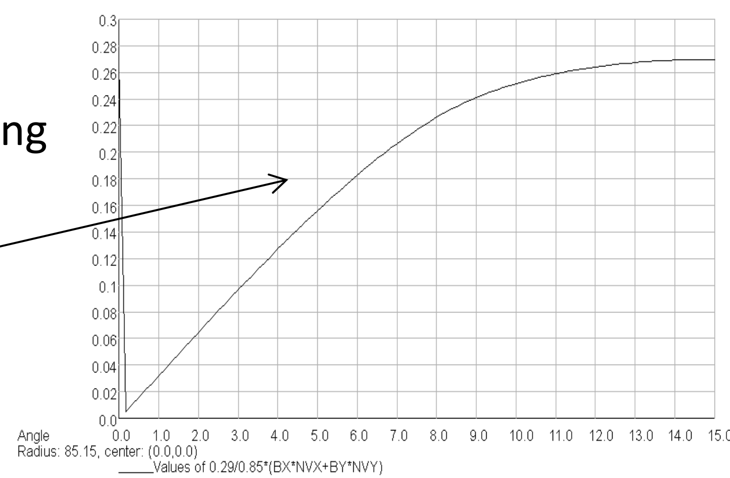






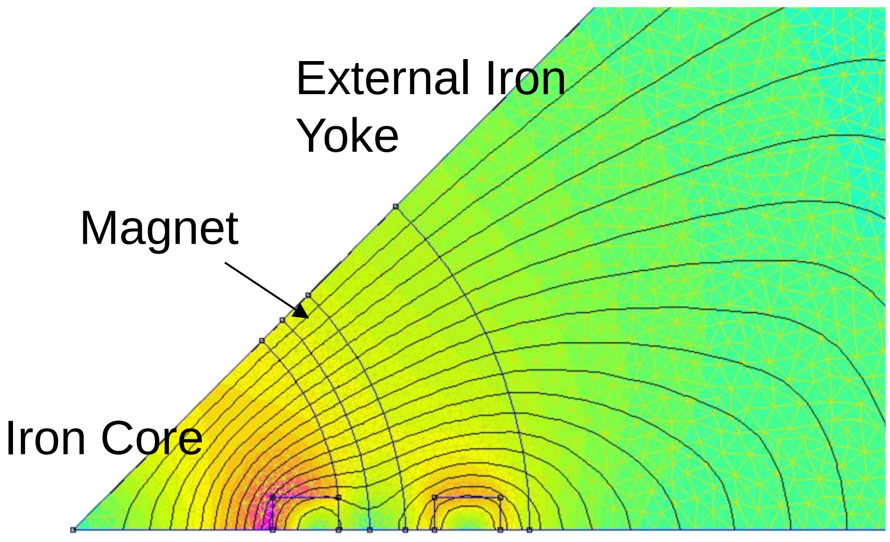
Magnetised Rotor and
0.4m airgap, 5mm steel ring

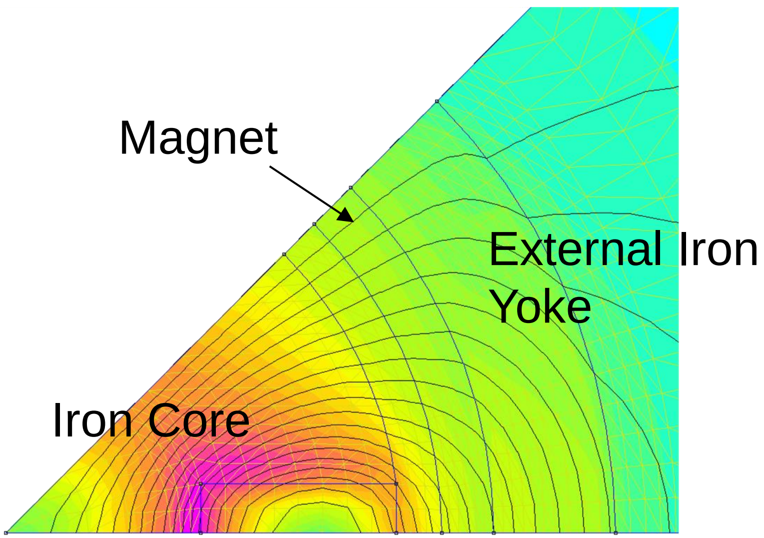
Airgap Flux
Density Waveform
B_{pk} = 0.27T

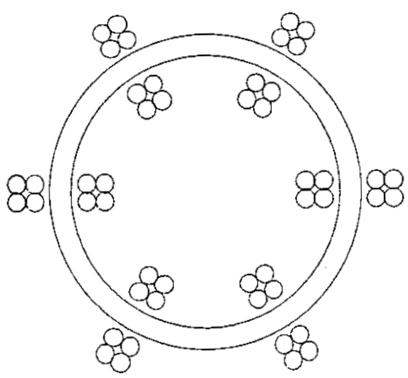


Examples

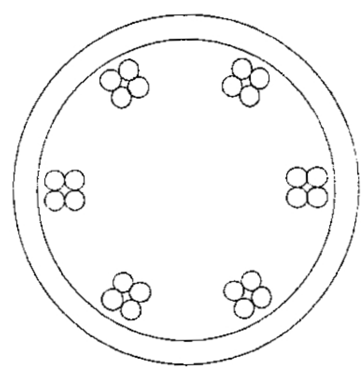
4 Pole Magnet





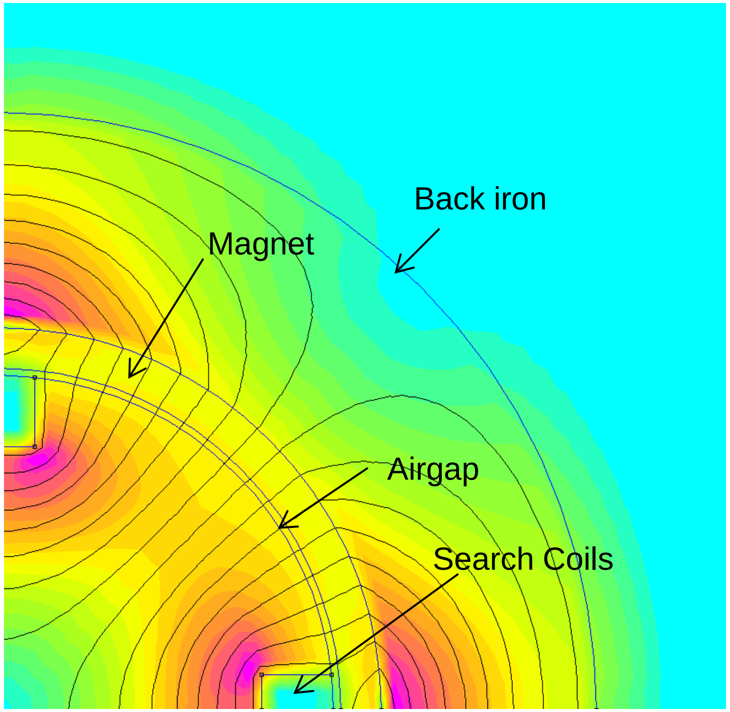


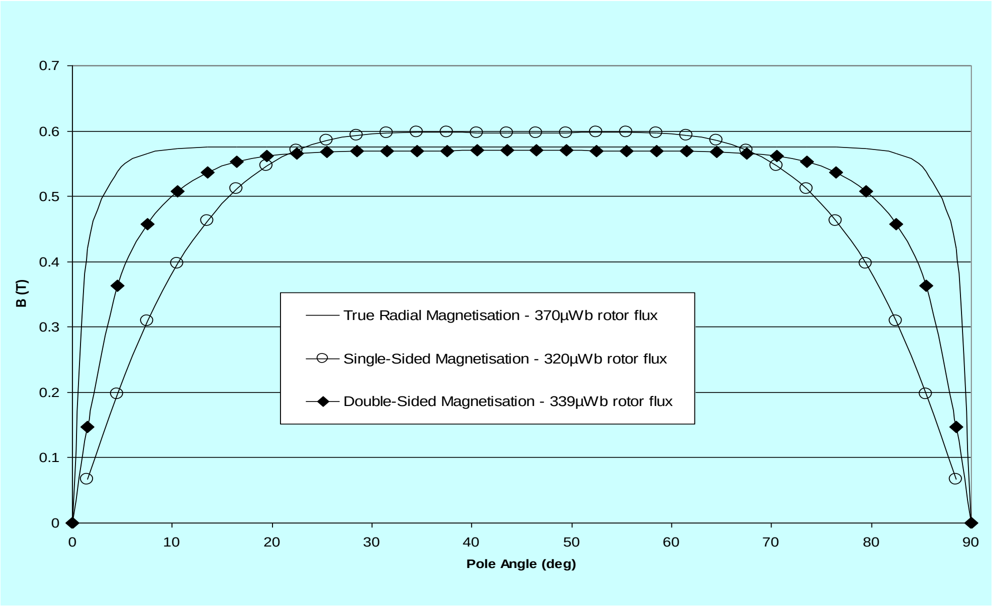
Double-sided
60 kA/slot



Single-sided
144 kA/slot

4 Pole Magnet





Rotor for Power Steering

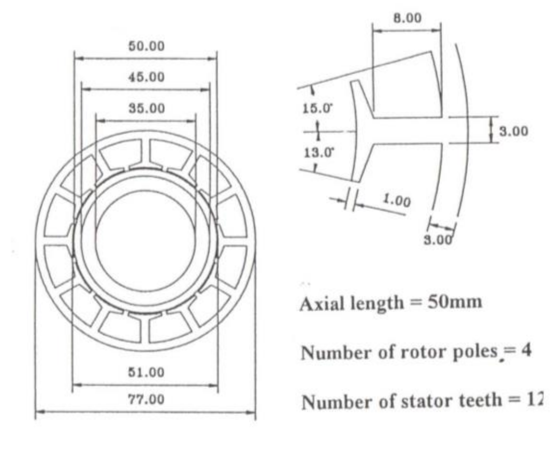
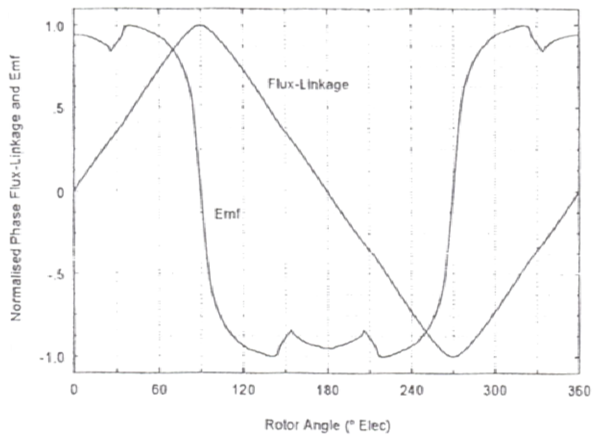
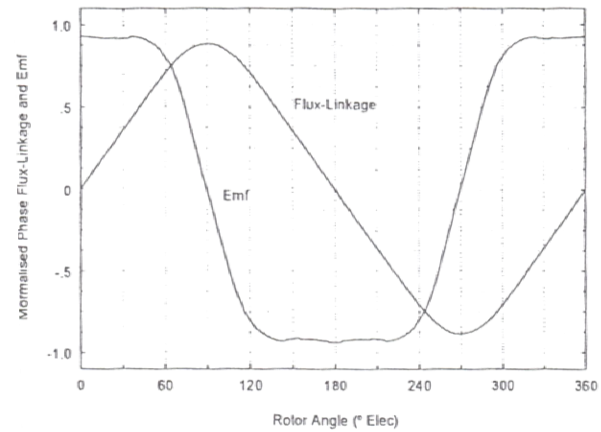
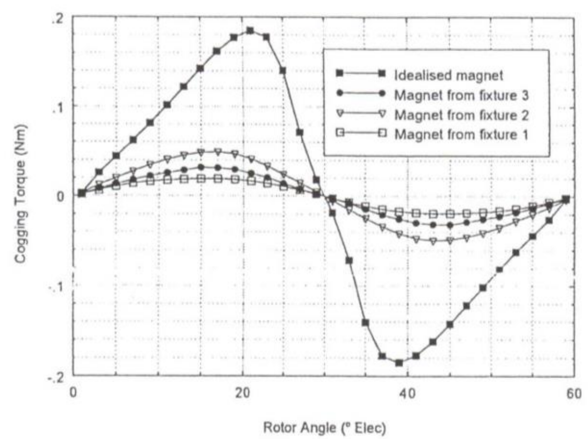


Fig.1. Brushless DC machine dimensions and parameters



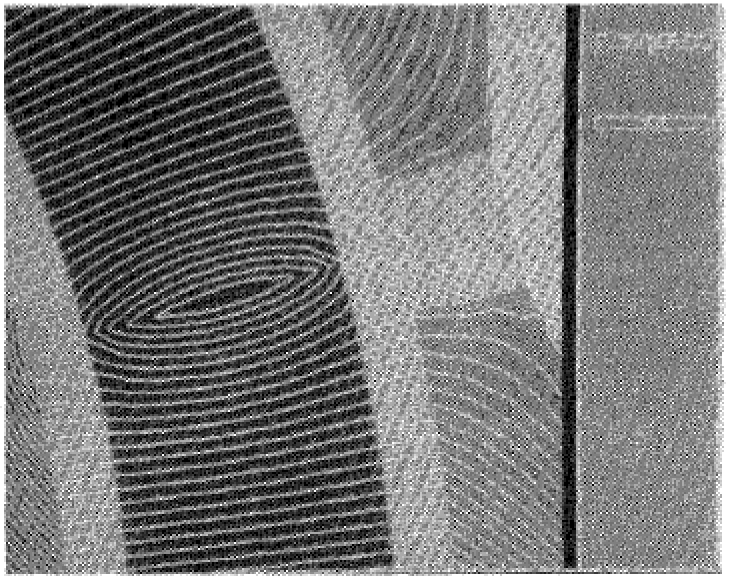


Optimisation of cogging torque

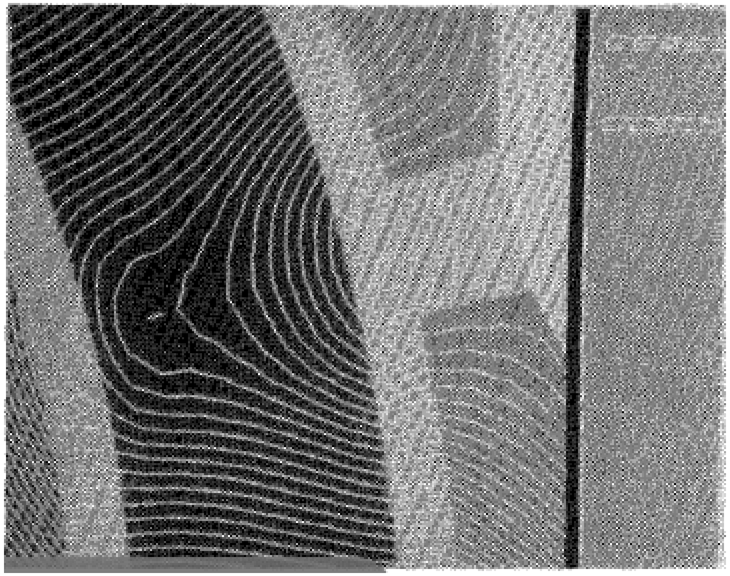


Source: C. D. Riley, "The Design of Magnetising Fixtures and Powder Aligning Systems for Bonded NdFeB Permanent Magnets", October 1996.

Double Airgap PM BLDC Motor



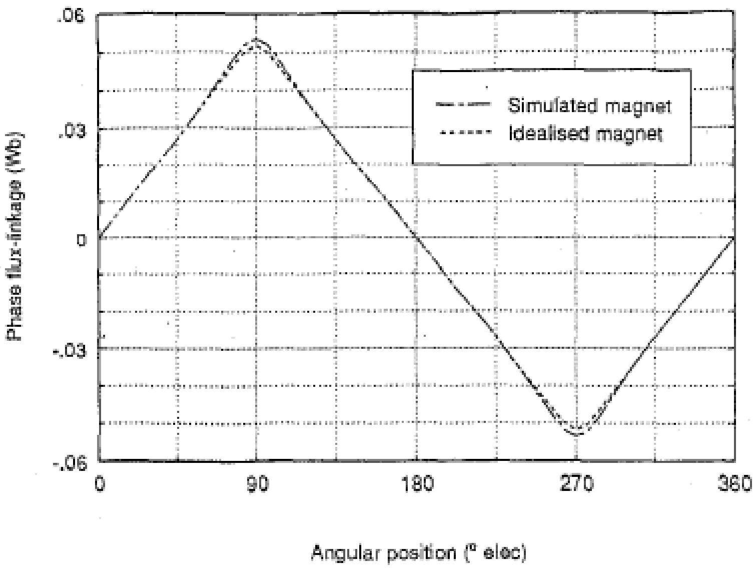
Pole transition of Idealised Magnet

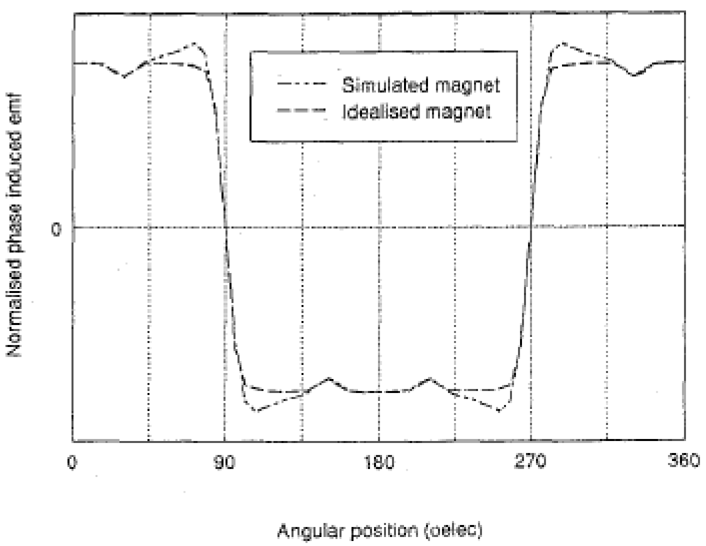


Pole transition of multipole magnetised bonded magnet

Source: Jewell, G.W., Riley, C.D., Howe, D., 'The Design of Radial Field Multipole Impulse Magnetizing Fixtures for Isotropic NdFeB Magnets', IEEE Transactions on Magnetics, Vol MAG33(1), 1997, pp708-722

Double Airgap PM BLDC Motor

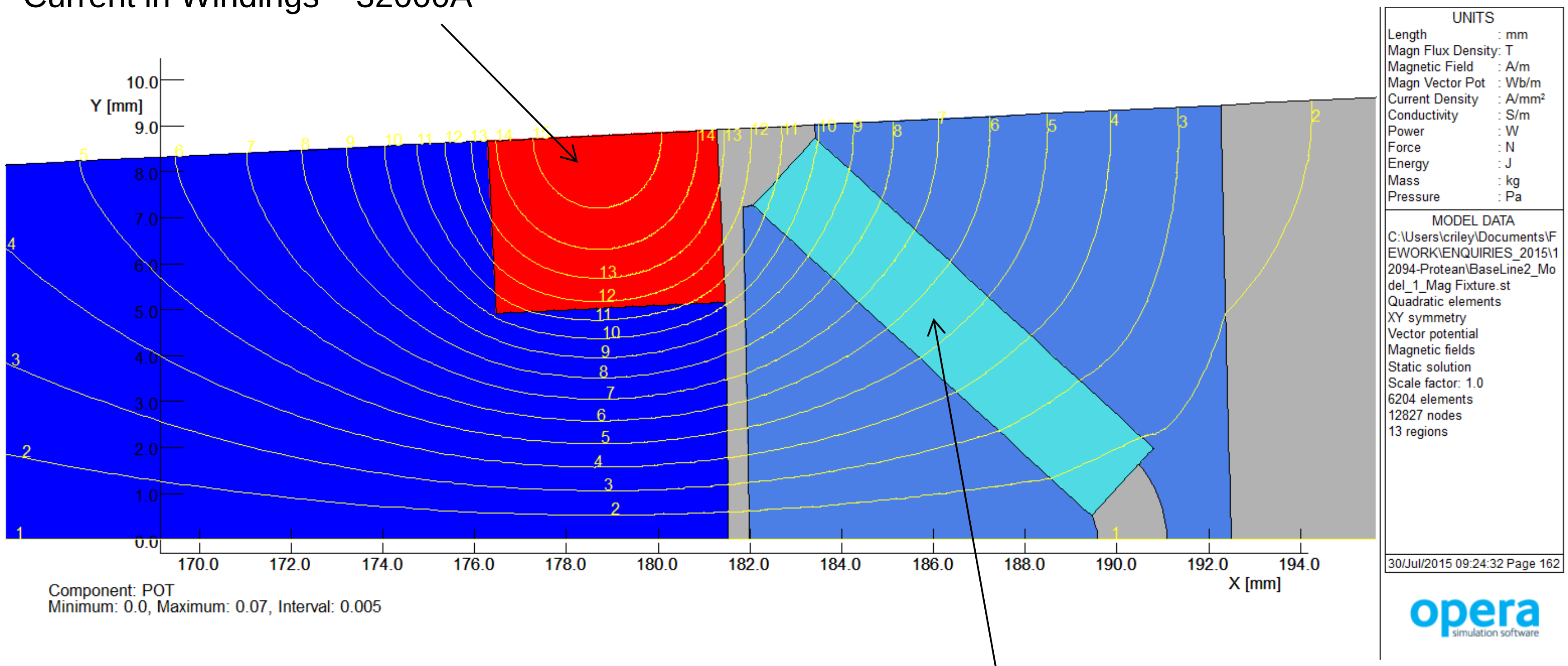




Source: Jewell, G.W., Riley, C.D., Howe, D., 'The Design of Radial Field Multipole Impulse Magnetizing Fixtures for Isotropic NdFeB Magnets', IEEE Transactions on Magnetics, Vol MAG33(1), 1997, pp708-722

Interior PM Rotor

Current in Windings – 32000A

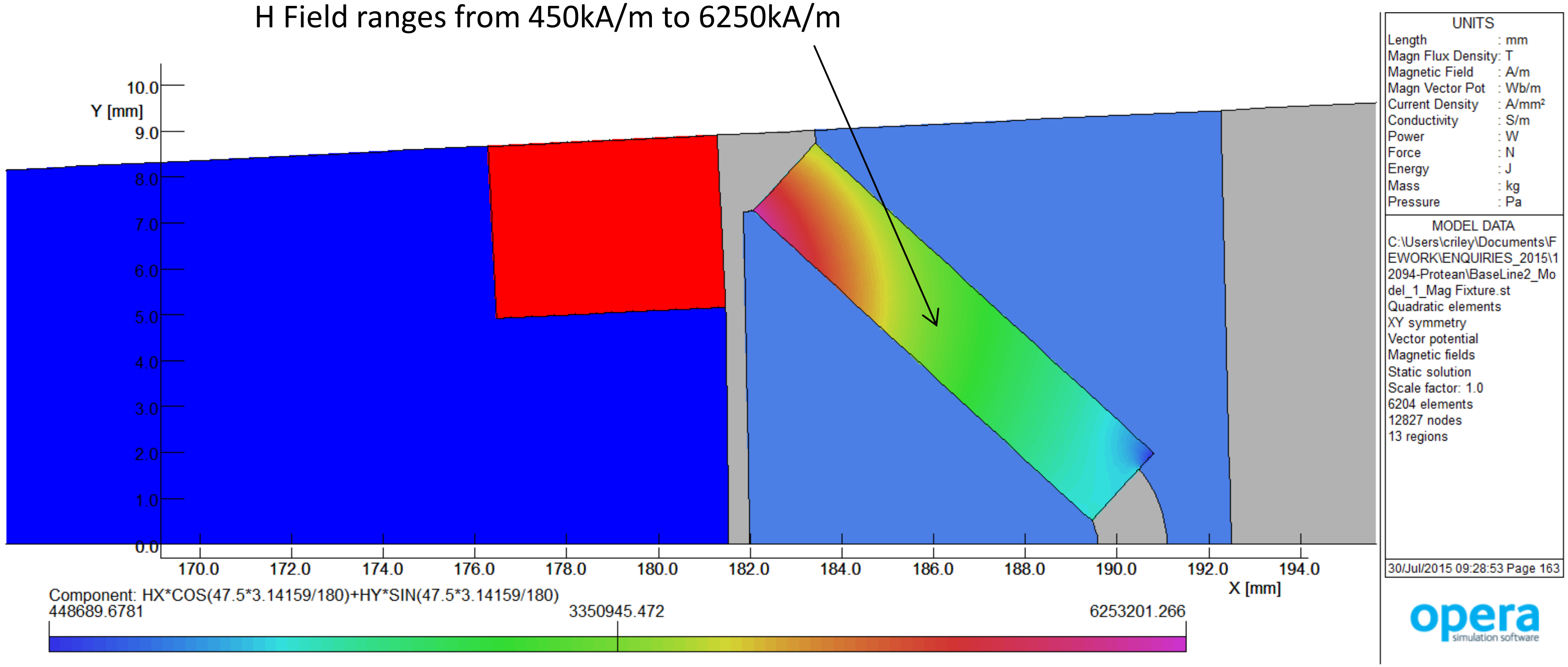


Static FEA Model

Field in magnets reasonably aligned with magnet direction of magnetisation

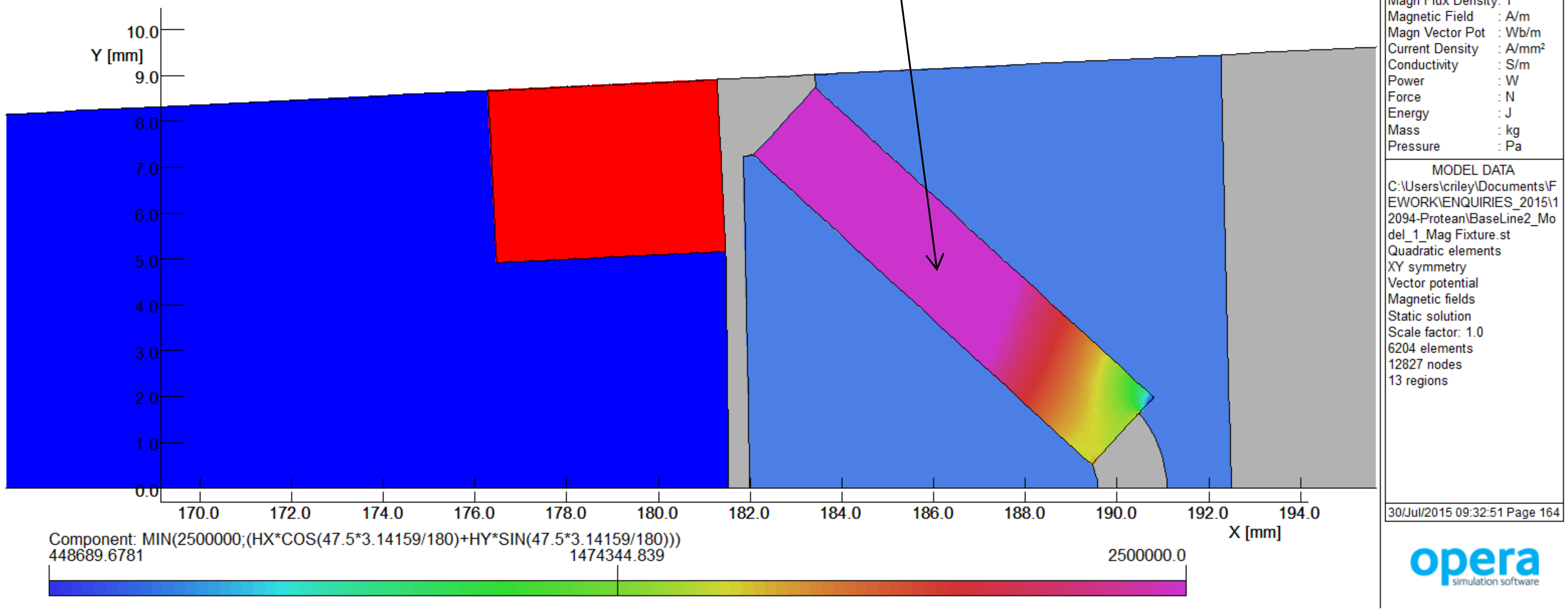
Field Plot of Rotor and Mag Fixture

H Field ranges from 450kA/m to 6250kA/m



Field Plot of Rotor and Mag Fixture

Shows areas of magnet above and below 2500kA/m. The nominal field required to saturate NdFeB



Volume of magnet above 2500kA/m – 92%

Post Assembly Magnetisation Conclusions

- Post assembly magnetisation can result in considerable savings in assembly time
- The ability to model magnets after magnetisation is an invaluable tool in assessing the feasibility of post assembly magnetisation
- Bonded Isotropic PM Rotors are ideal for post assembly magnetisation
- The key issues with magnetising sintered NdFeB rotors are:
  - Saturating the pole transition regions
  - The energy required to saturate the whole rotor
- In order to post assemble some compromise in performance is likely
- The method of magnetisation should be considered as early as possible in the design phase

3D Printed Magnets

Additive Manufacturing of NdFeB Bonded Magnets

- Aim – to demonstrate the feasibility of fabricating near net shape NdFeB magnet using additive manufacturing techniques
- Additive manufacturing (3D Printing) is the fabrication of geometrically complex 3D objects directly from a CAD model with little or no tooling or post processing, thus reducing waste
- Looked at two methods of additive manufacturing
  - Binder Jetting
  - Material Extrusion

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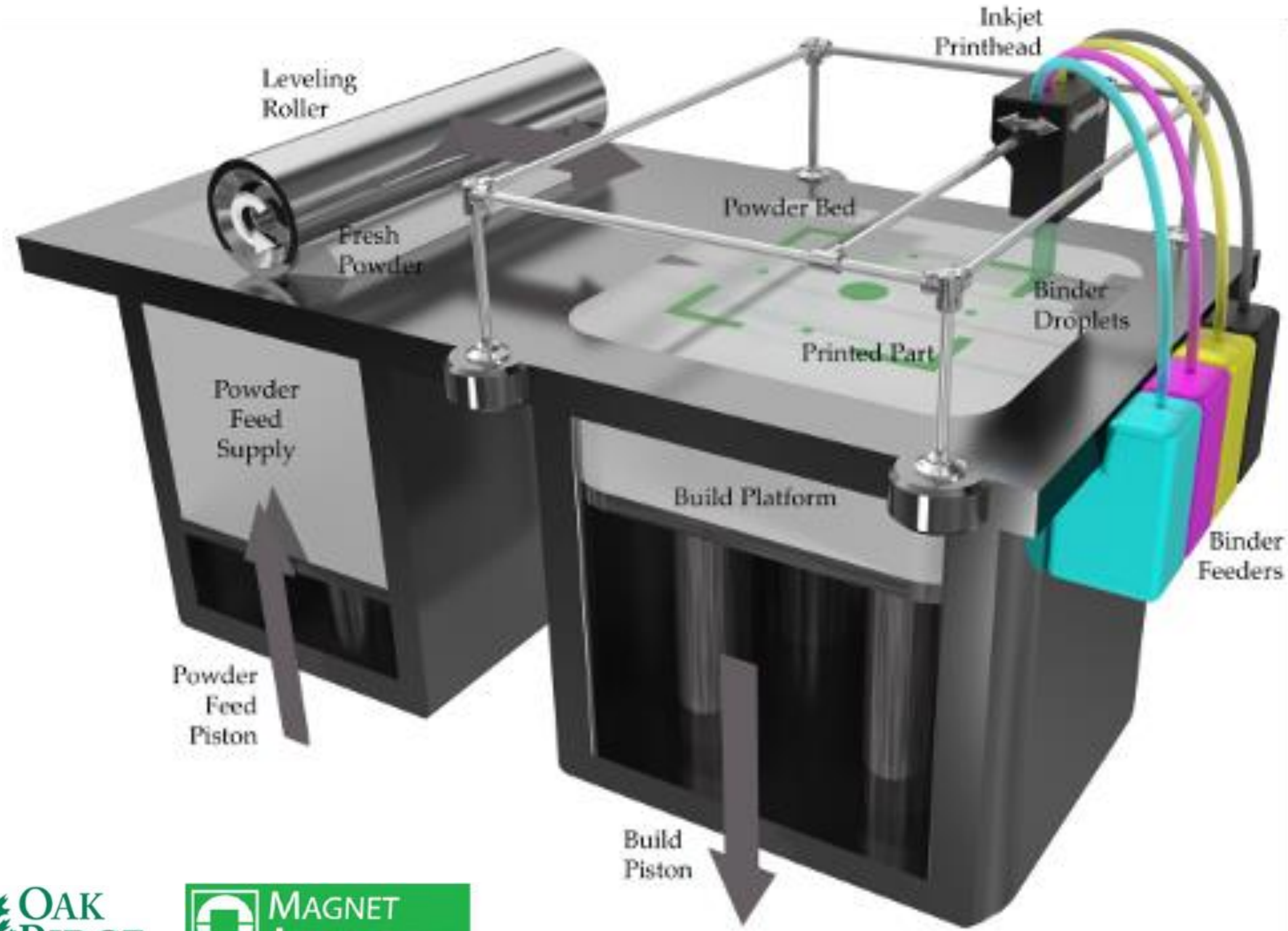
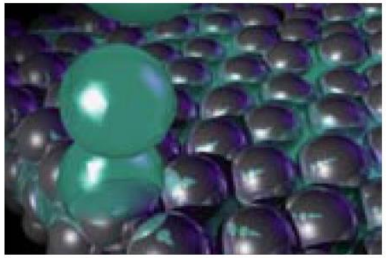
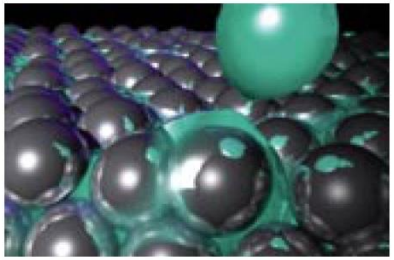
This work was supported by the Critical Materials Institute, an Energy Innovation Hub funded by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Advanced Manufacturing Office

Metals – Indirect 3D Printing (Binder Jetting)







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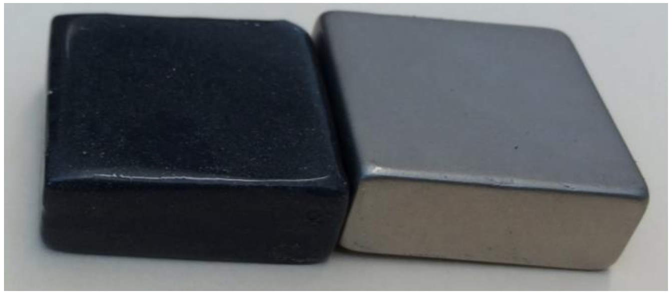
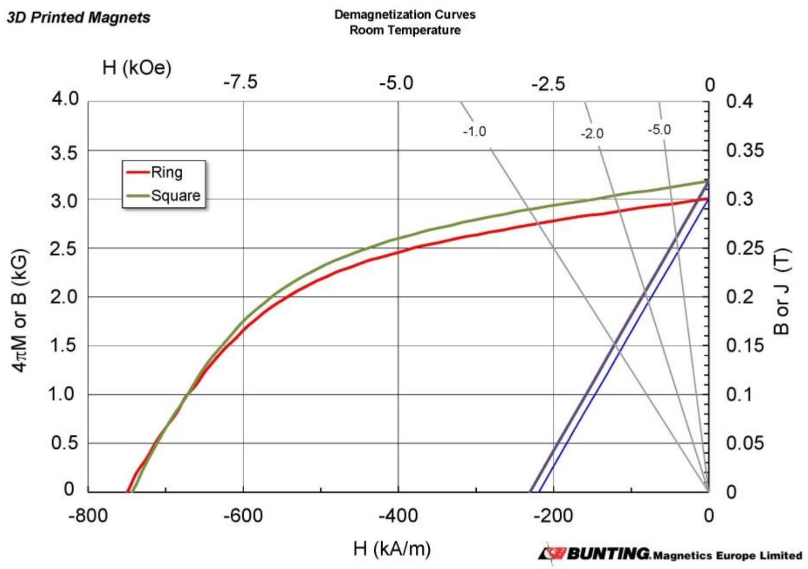
Binder Jet printed magnets



1 x 1" Neo square/ring magnets
(bonded magnet; sintered magnet)



Successfully printed several near-net shape magnets followed by a polyurethane clear coat to achieve a smooth surface with no magnetic property degradation

Bonded magnets produced through this additive process are 46 vol %. Efforts are being made to improve the magnet loading and alignment.

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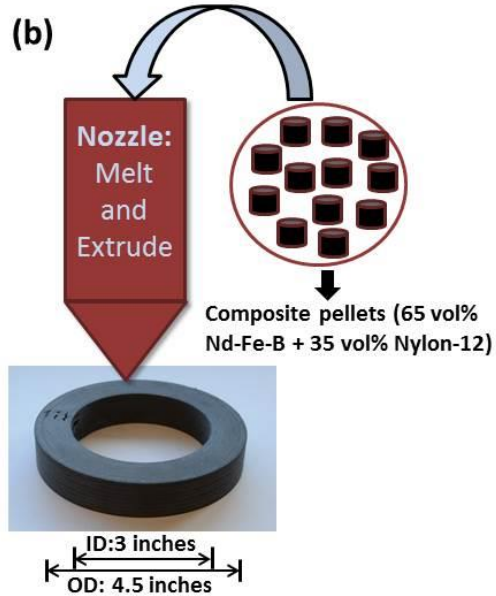
Big Area Additive Manufacturing (BAAM) of NdFeB Bonded Magnets

(a)

(b)



- Feedstock supplied by Magnet Application Inc. : 65%vol MQP B+ powder mixed with Nylon 12
- The temperature at the orifice exit of the extruder was approximately 270 °C

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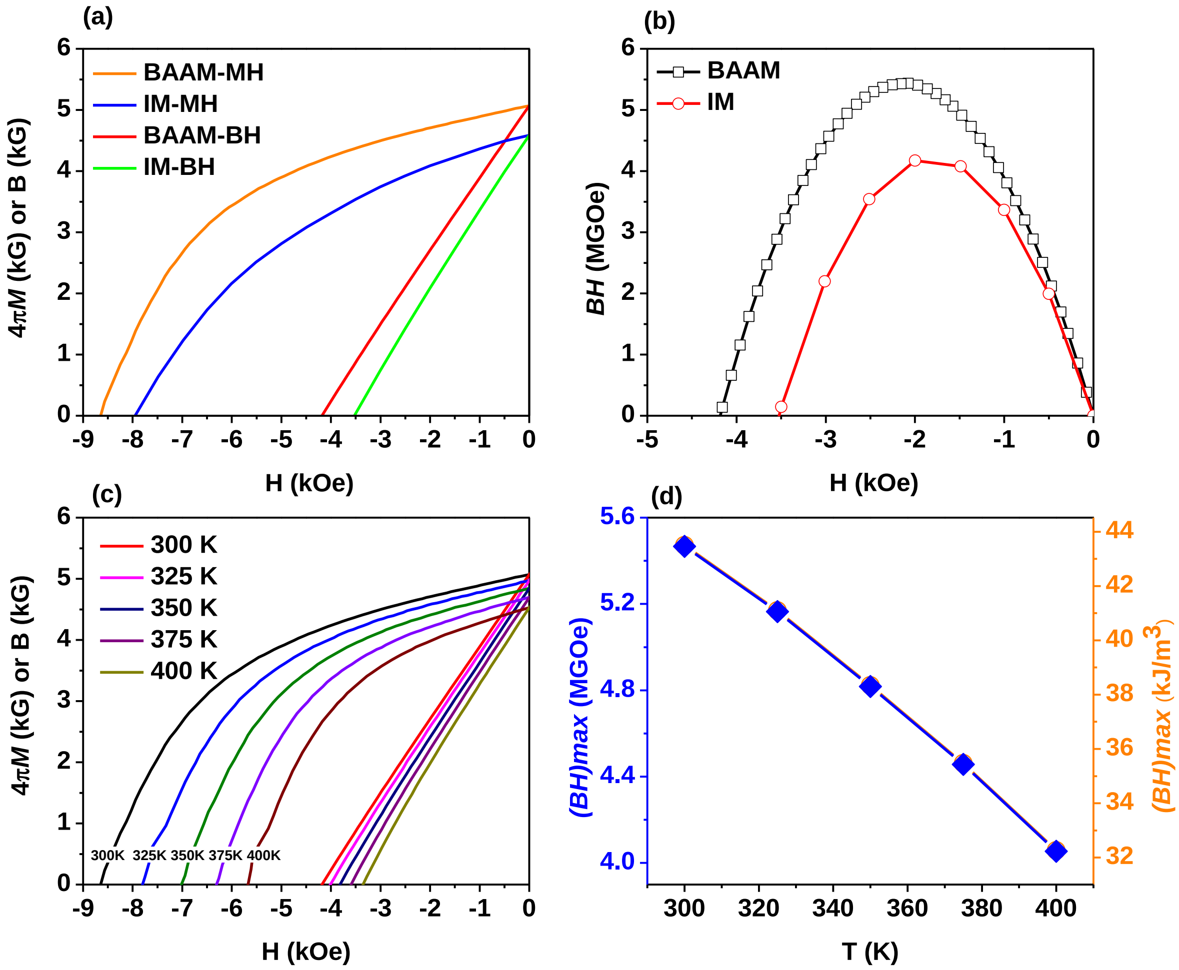
BAAM NdFeB magnets – magnetic properties



a) Hci = 8.65 kOe and 8.64 kOe for BAAM and IM magnets respectively.

b) (BH)max = 5.47 and 4.55 for BAAM and IM magnets respectively.

c) The Hci and Br decreaes with increasing temperature

d) (BH)max decreases with increasing temperature

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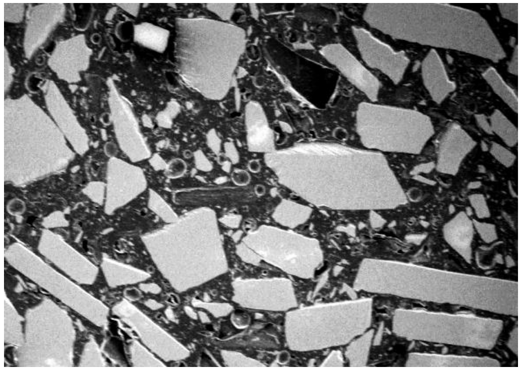
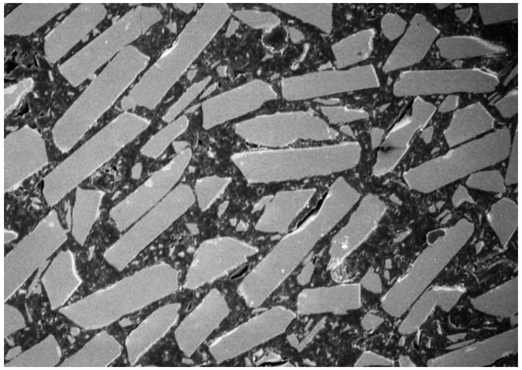
MAGNET APPLICATIONS A Bunting Magnetics Company

BAAM magnets – microstructure



starting pellets



BAAM magnets

- Particles size of the starting pellets ranges from 20µm to 200µm
- Particles are preferentially aligned after printing, which would likely enhance the shape anisotropy

Summary

- The use of additive manufacturing techniques for the fabrication of isotropic near-net-shape NdFeB bonded magnets has been successfully demonstrated with magnetic and mechanical properties comparable or better than those of traditional injection molded magnets.

- 3D printing using anisotropic powder, align while printing. This would increase the coercivity

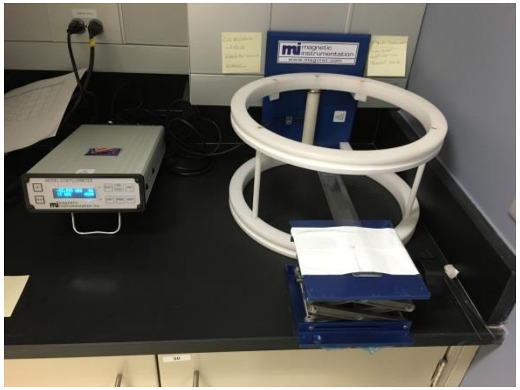
- Coating the starting powder and/or the printed magnets using polymer materials in enhance the thermal stability

THANK YOU

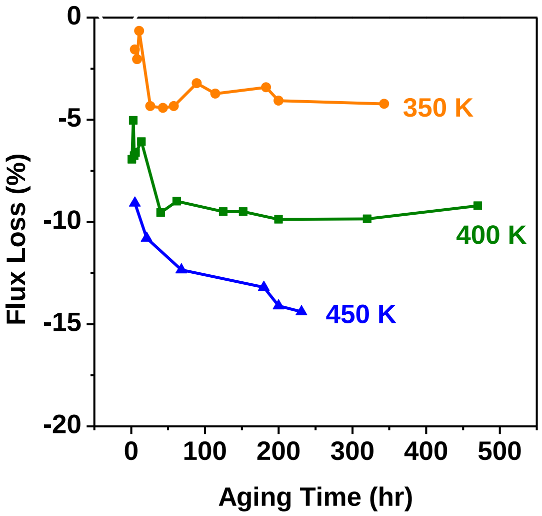
Acknowledgements

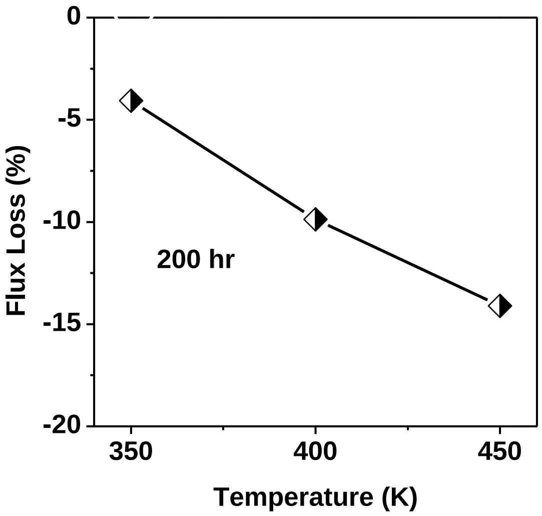
BAAM NdFeB magnets – flux loss

- Stable flux loss value for 350 K and 400 K are approximately -5 % and -9% respectively.
- Maximum operation temperature is below 400 K, coatings are needed to enhance the thermal stability



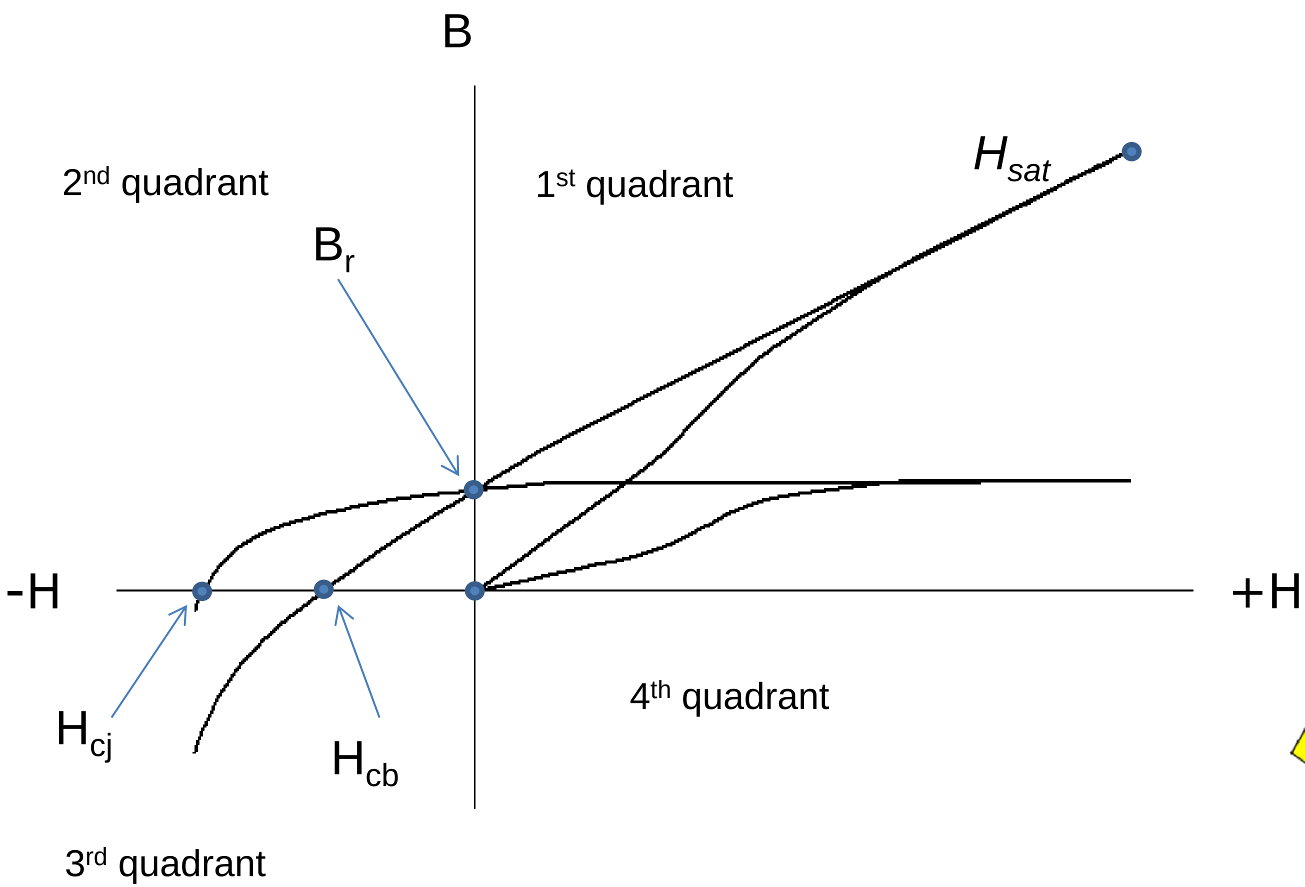
Helmholtz coil and fluxmeter



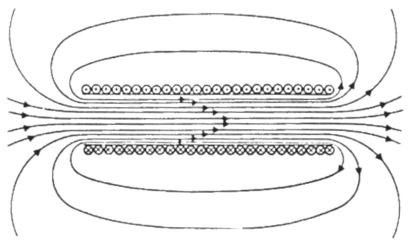


Thermal stability of the BAAM magnets. Flux aging loss for BAAM magnet as a function of (a) Aging Time (0 – 500 h); (b) Temperature (350 K, 400 K, and 450 K) after 200 hours of exposure.

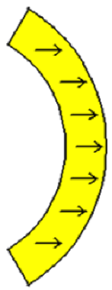
Magnetising a Magnet



Rule of thumb – H_{sat} should be 3 to 5 times H_{ci}



$$H = \frac{Ni}{l}$$



Direction of magnetisation