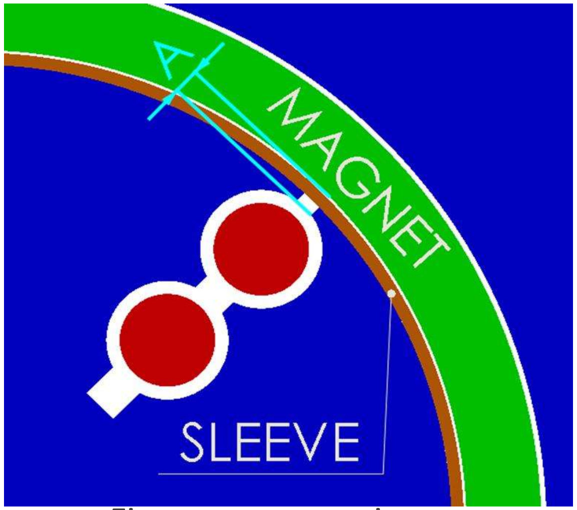
neo Magnequench

Magnetization Fixture Design and Evaluation

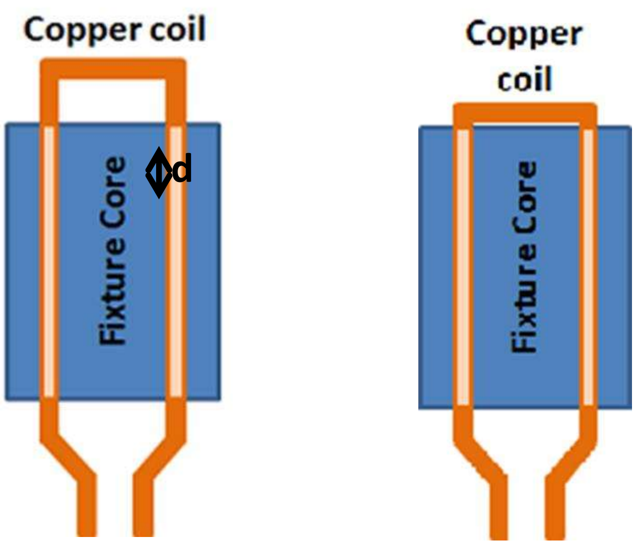
Overview

- 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



Fixture cross-section



Normal overhang In-situ overhang

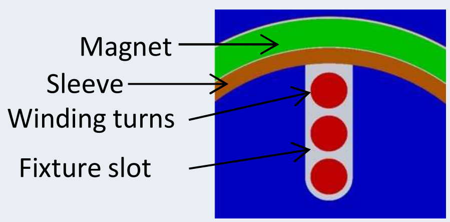
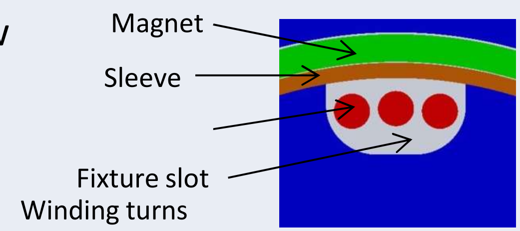
Factors effecting the distance between conductor and the magnet, ‘A’:

- 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

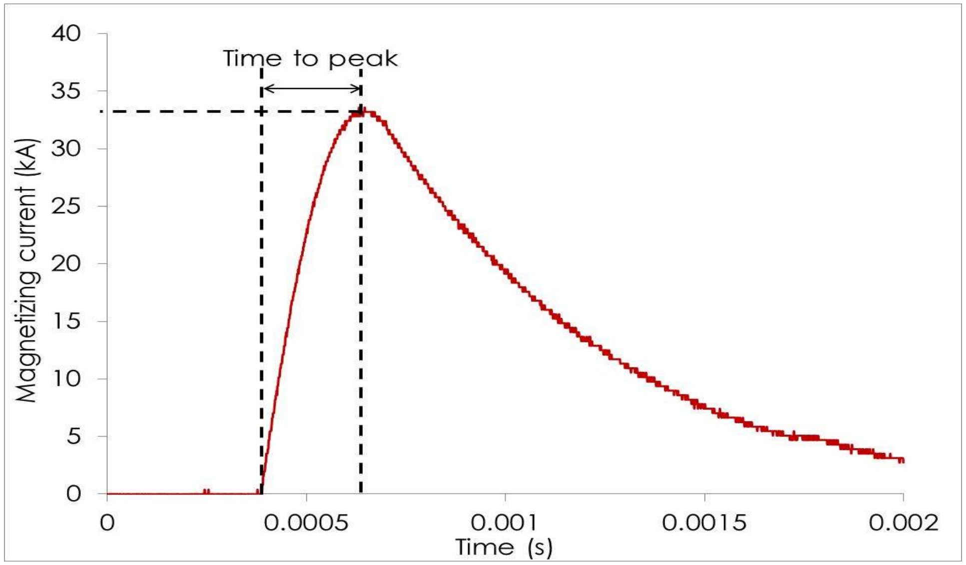
Design parameter	Fixture for Radial orientation	Fixture for Halbach orientation
Distance between fixture winding and magnet, ‘A’	Closed slot design : ≤ 0.50 mm Including sleeve thickness, Semi-open slot : ≤ 0.65 mm Fully open slot : ≤ 0.75 mm	Typically more than 1 mm including the sleeve thickness
Preferred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

Salient features of the magnetizing fixture design

Design parameter	Fixture for Radial orientation	Fixture for Halbach orientation
Slot type	With skew - Open or semi-open No Skew- Closed	Open slot is preferred to obtain sinusoidal magnetizing flux
Fixture core material	Laminated steel→ Prevent eddy current	
Back iron	Required	-N.A-
Back iron material	Laminated steel→ Avoid secondary transition zones	-N.A-
Back iron thickness	Minimum thickness to avoid saturation Rule of thumb - Minimum 10 times the magnet thickness	-N.A-
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	

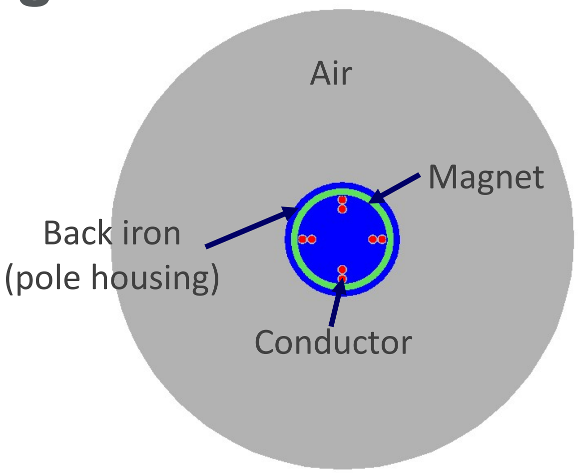
Salient aspects of the magnetizing fixture design

Design parameter	Fixture for Radial orientation	Fixture for Halbach orientation
Fixture stack length	1.2 -1.5 times the magnet axial length to limit the fixture resistance	
Magnetizing current	Limited by the Magnetizer system rating (< 50kA for system at MQT, Singapore)	
Time to peak of magnetizing current	Limited by the Magnetizer system inductance (typical value is < 250 µs for the Magnetizer at MQT, Singapore)	

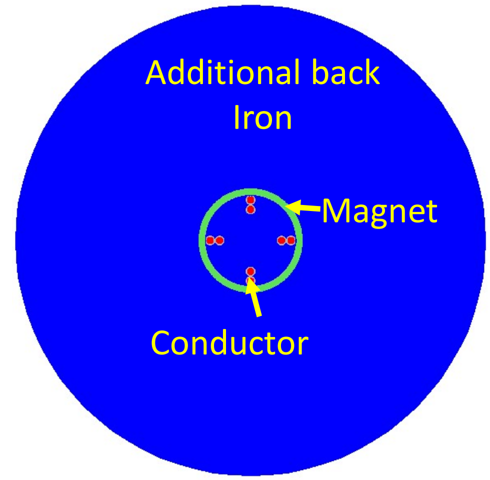


Magnetizing current

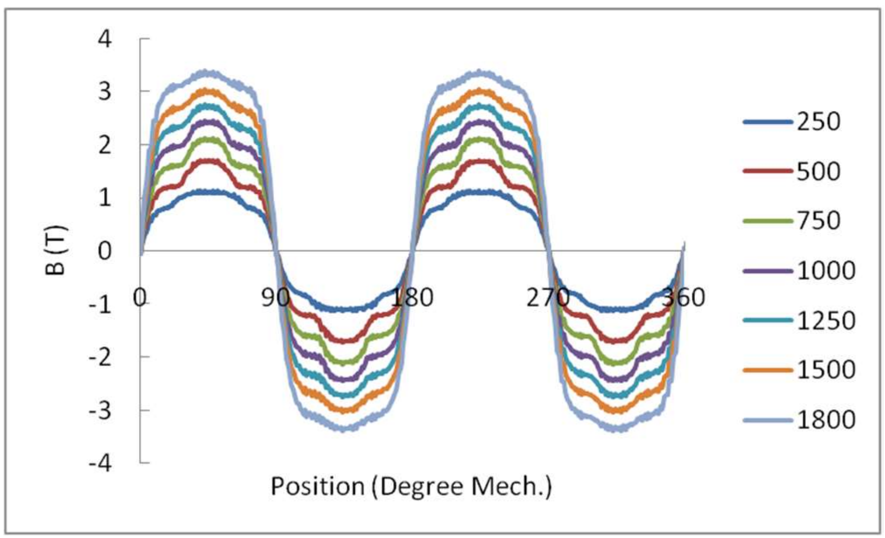
Effect of Additional Back Iron during In-situ Magnetization



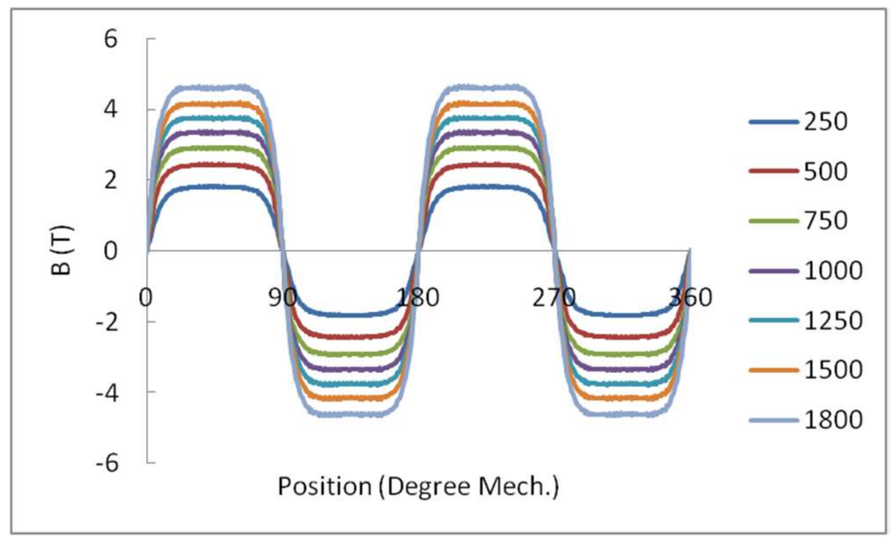
Fixture with no additional back iron



Fixture with additional back iron

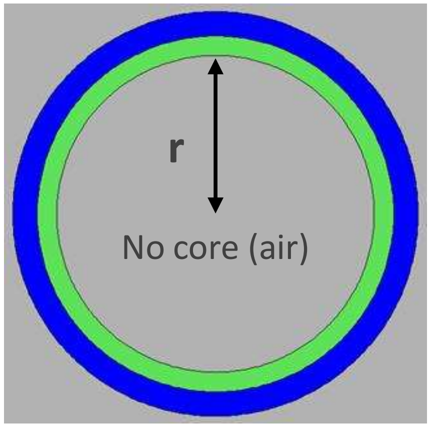


Applied field at the back of the magnet when additional back iron is absent



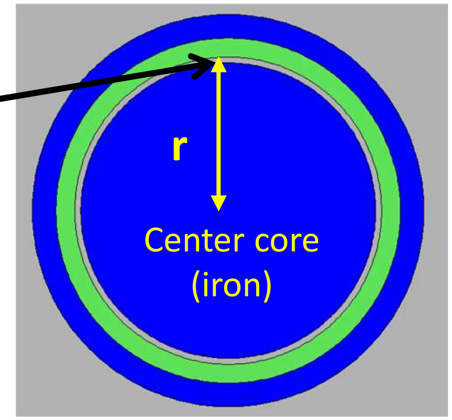
Applied filed at the back of the magnet when the additional back iron is presence

Effect of Additional Back Iron during In-situ Magnetization – Mid Airgap Flux Density

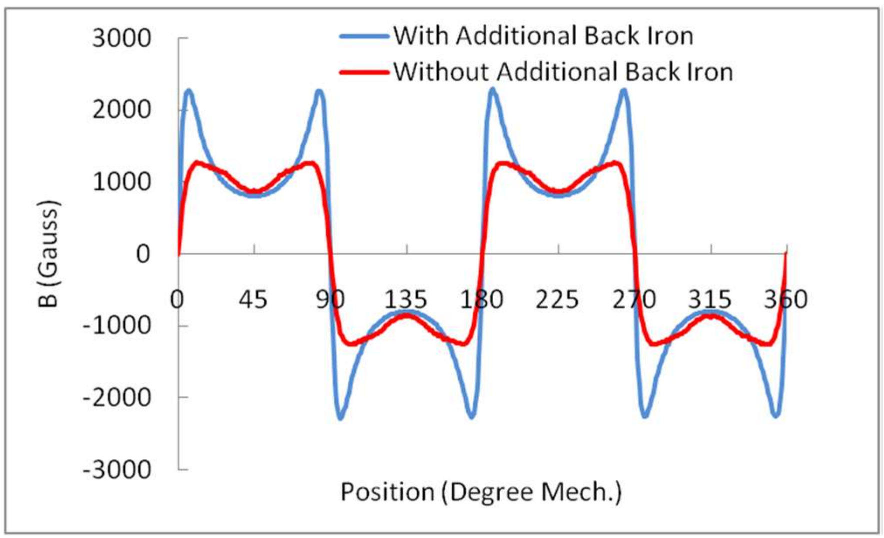


Open circuit flux scan set-up

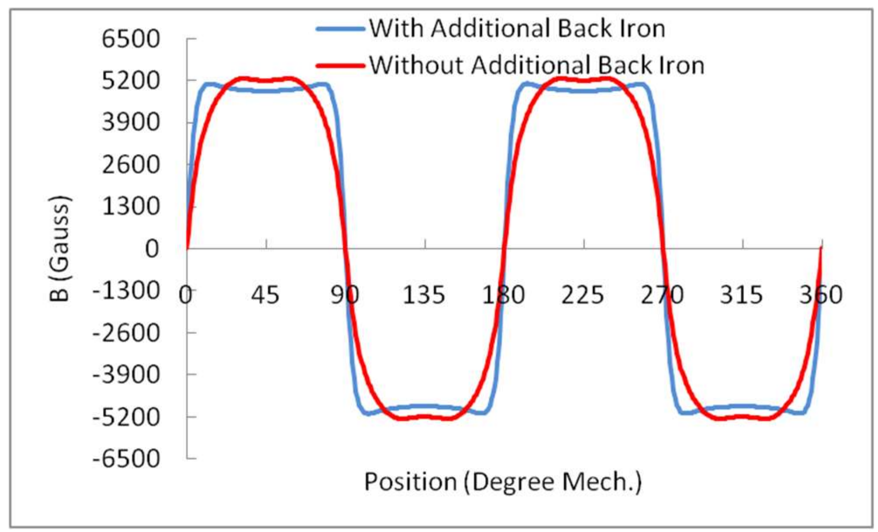
Radial flux is measured at the mid air gap between center core and magnet inner diameter, radius 'r' from the magnet center.



Closed circuit flux scan set-up



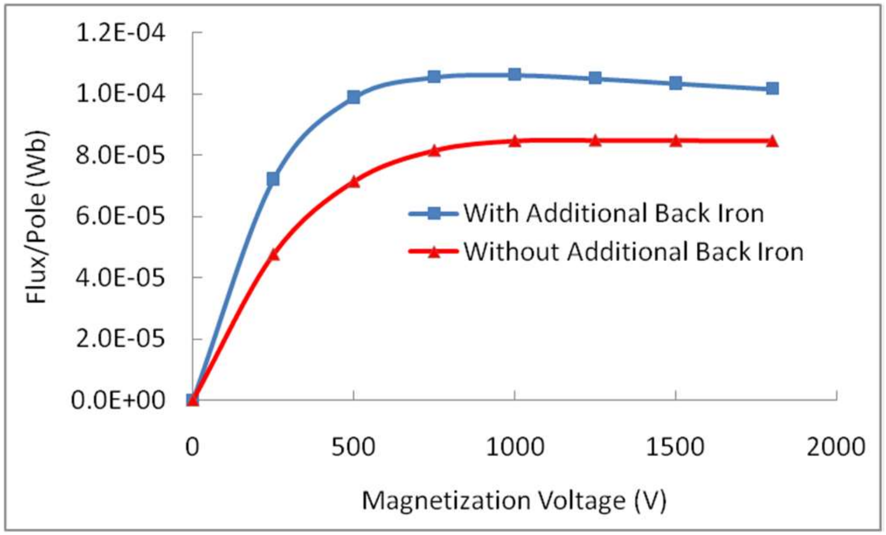
Open circuit mid airgap flux density comparison



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).

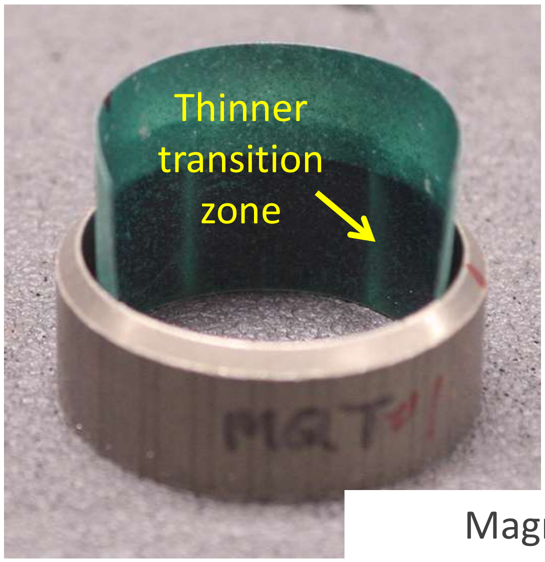


Flux/pole at various applied magnetizing voltages

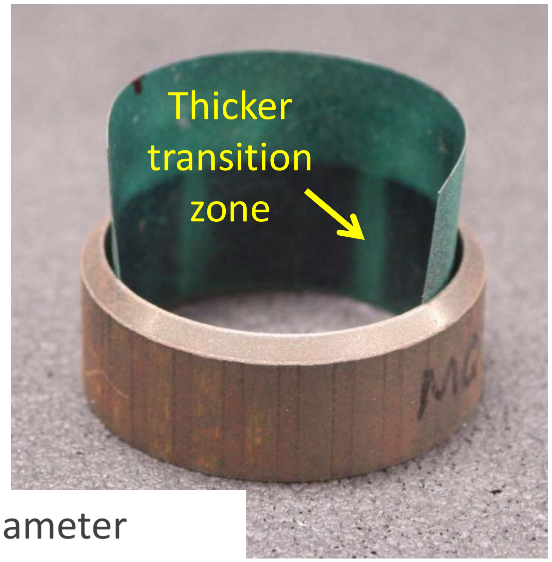
Laminated back iron v/s Solid back iron
Comparison of magnet pole transition zones

Magnequench

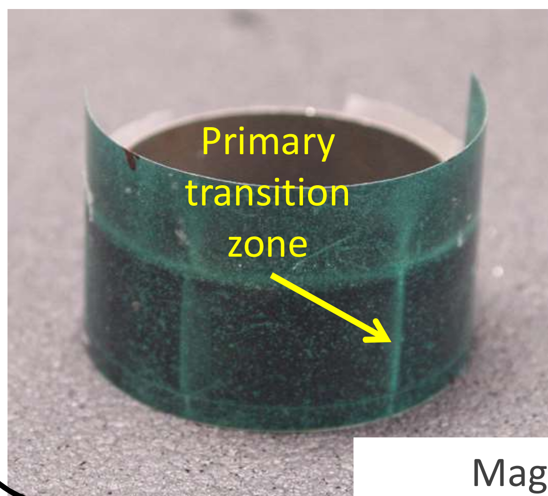
With laminated back iron

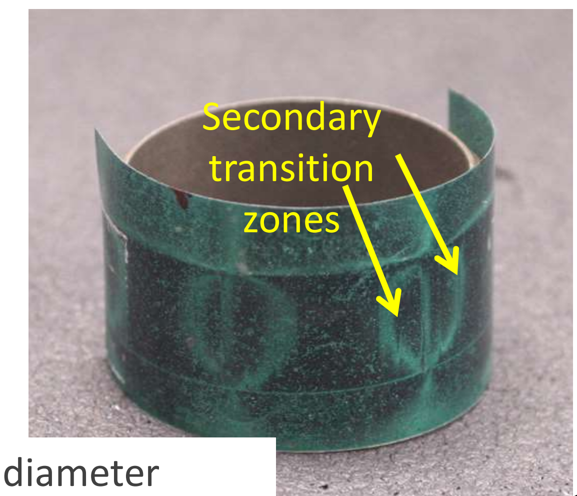


With solid back iron



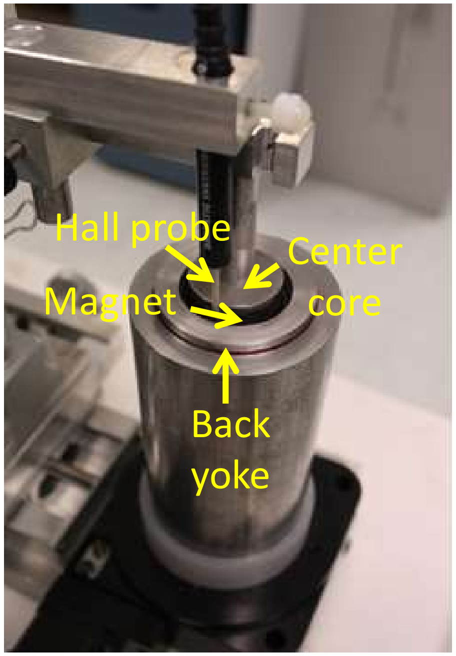
Magnet inner diameter



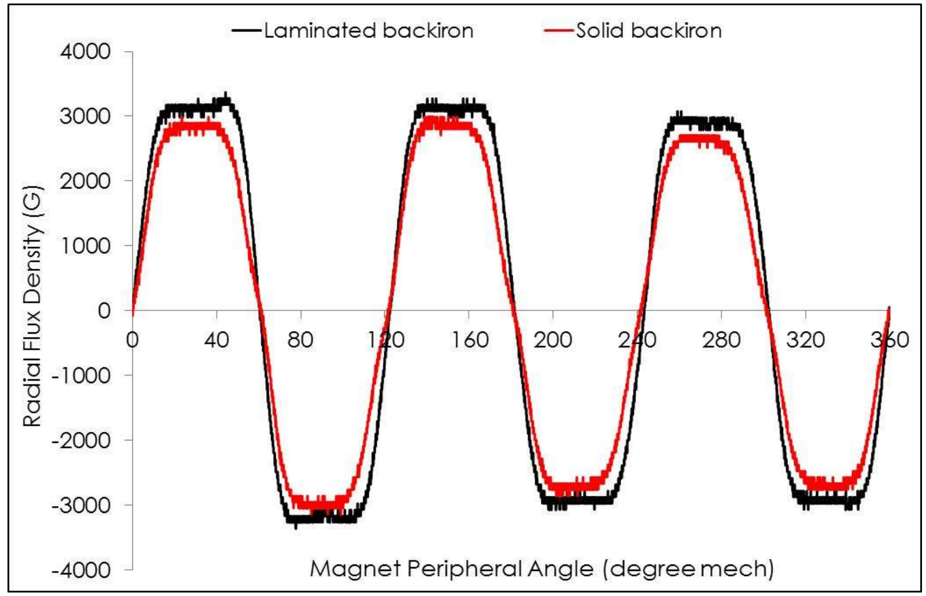


Magnet outer diameter

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



Flux scan set-up

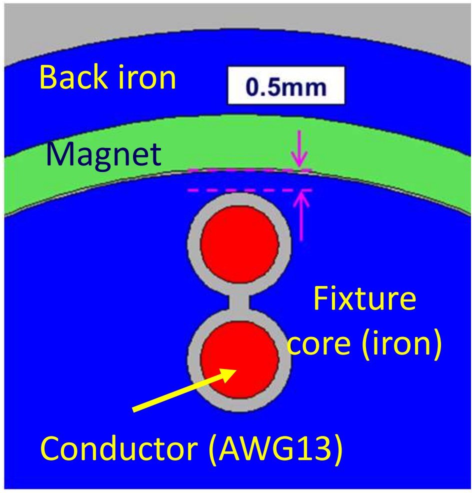


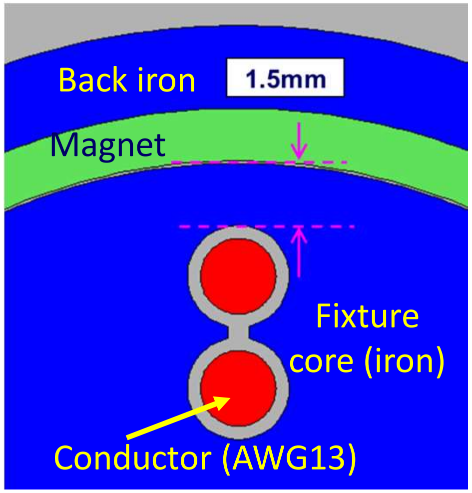
Flux scan of magnet inner diameter

Comparison of magnet radial flux for magnetizations with laminated and solid back iron

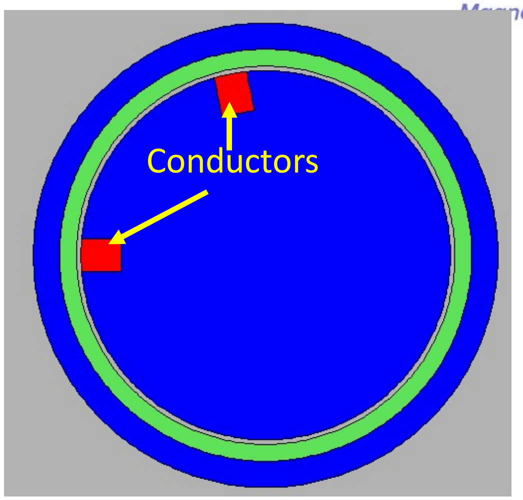
Type of back yoke during magnetization	Flux integral (T-degree)	Difference in flux integral
Solid	74.34	-
Laminated	89.42	+20.3 %

Effect of Conductor Location

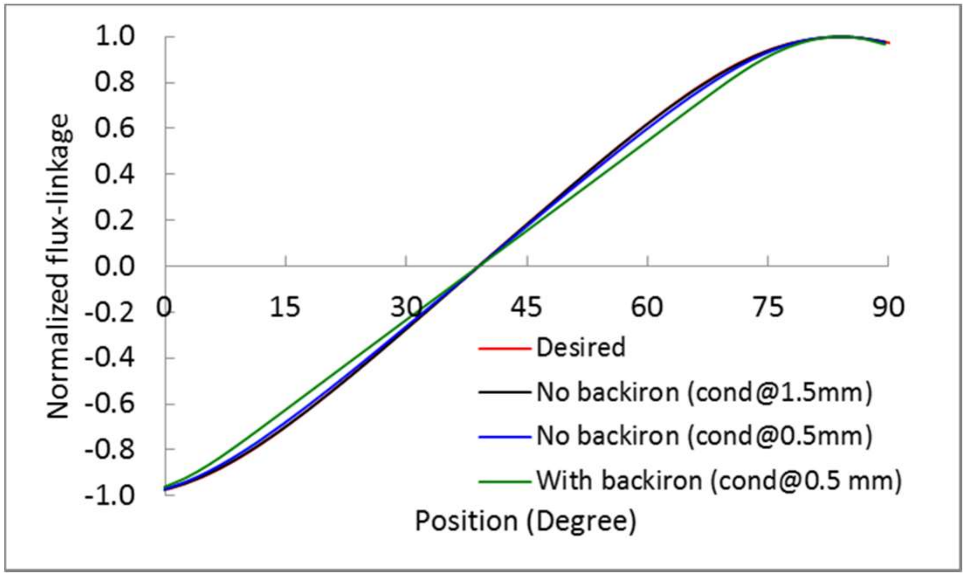




Change in conductor location from magnet surface

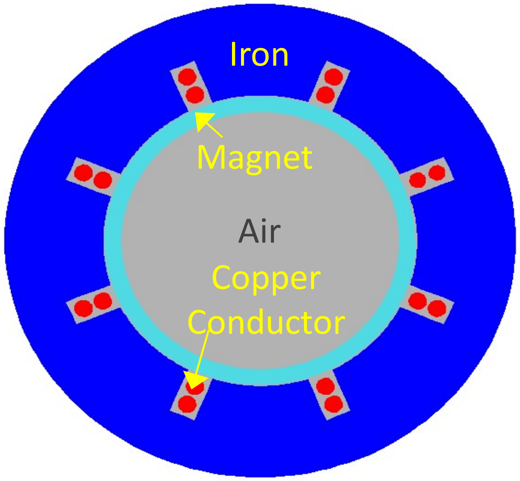


Setup for Flux-linkage prediction

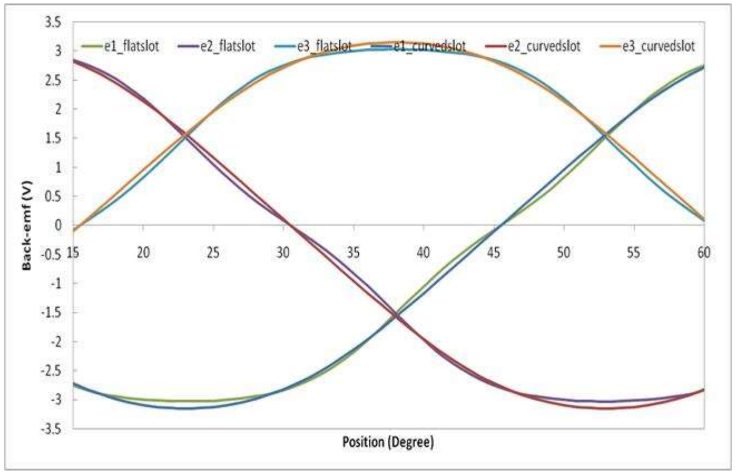


Change in flux linkage profile with the change in conductor location from magnet surface

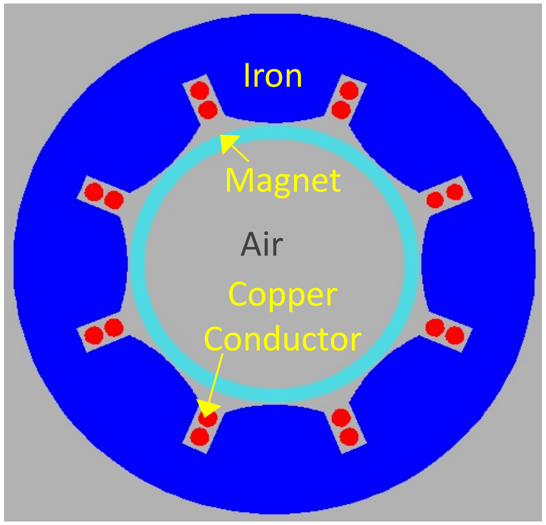
Effect of fixture slot shaping



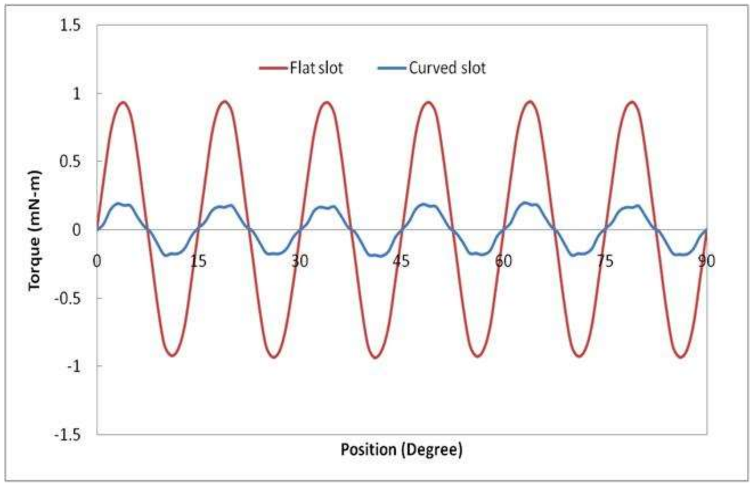
Flat slot magnetizing fixture System



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

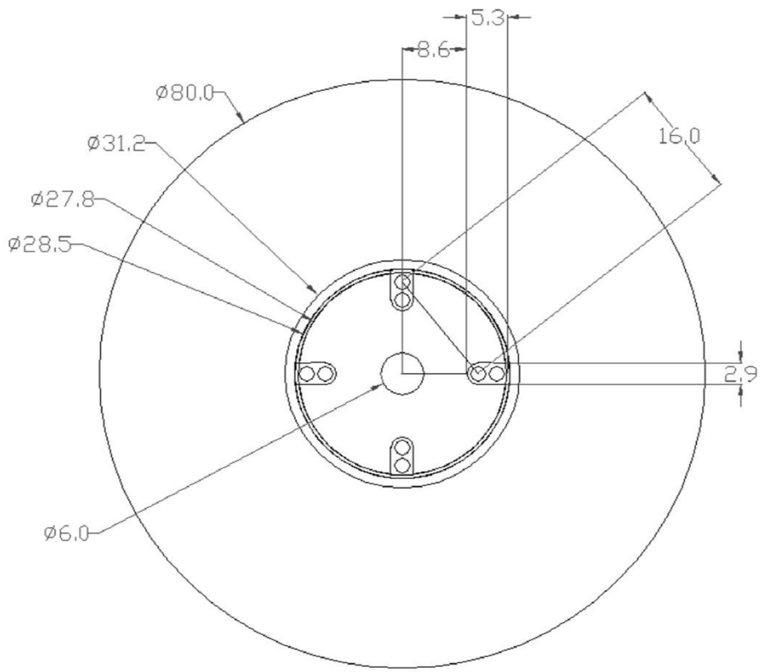


Curved slot magnetizing fixture system



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

Magnetization fixture for Automotive Accessory motor magnet

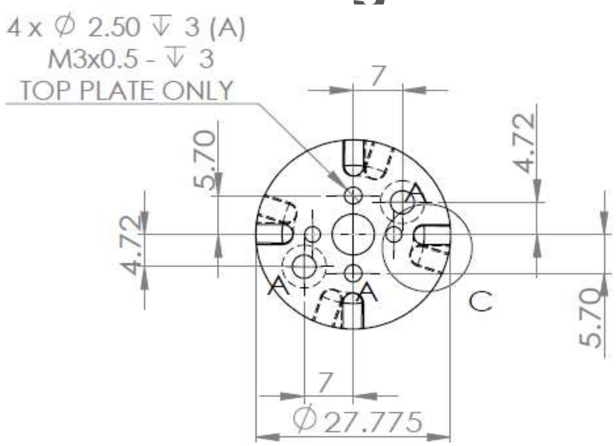


Fixture cross-section with dimensions

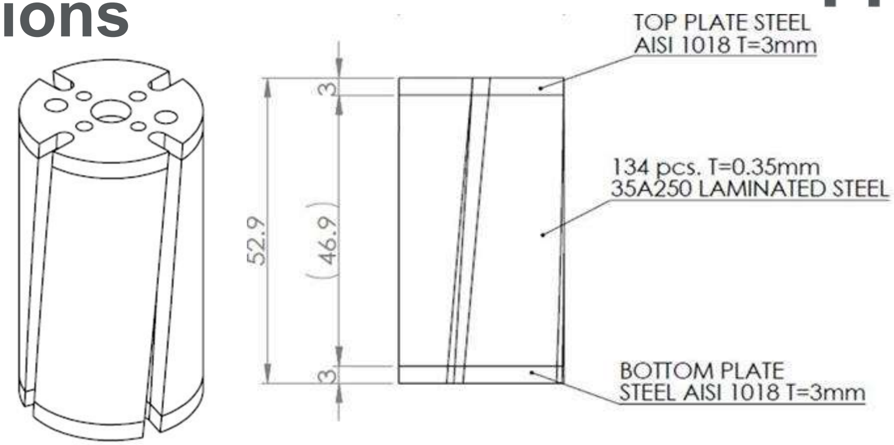
- Back iron and the fixture core: Laminated steel
- Heavy insulated copper wire: AWG 12
- Cooling pipe: Brass (6 mm diameter)
- Connecting terminals: Copper
- Casing: Delrin (Polyoxymethylene)
- Sleeve: Stainless steel

- For series production, the magnetization cycle time is determined by the following:
  - Energy required for magnetization
  - Cooling system
  - Magnetizing system rating

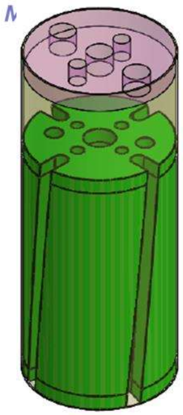
Magnetization fixture for Automotive Accessory motor magnetimensions



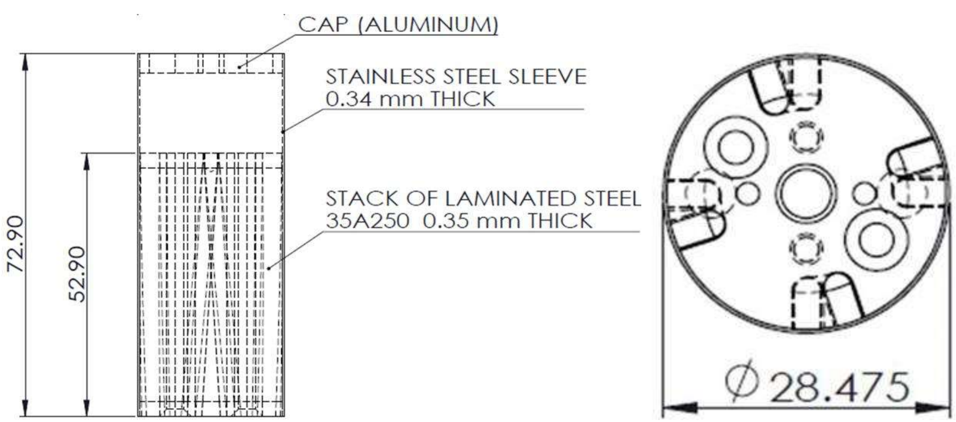
Fixture core



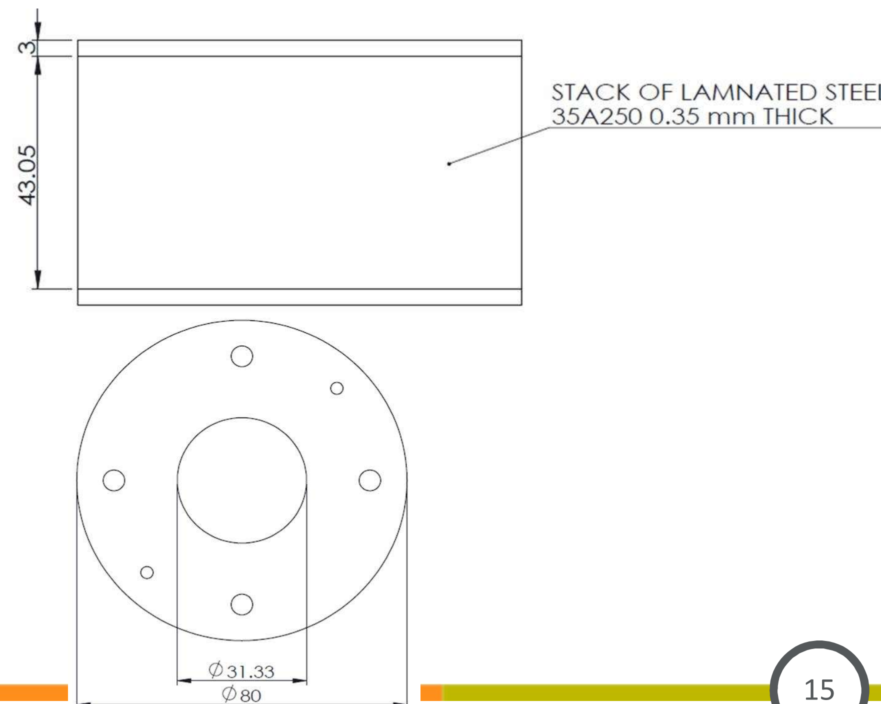
Fixture core



Fixture core with sleeve

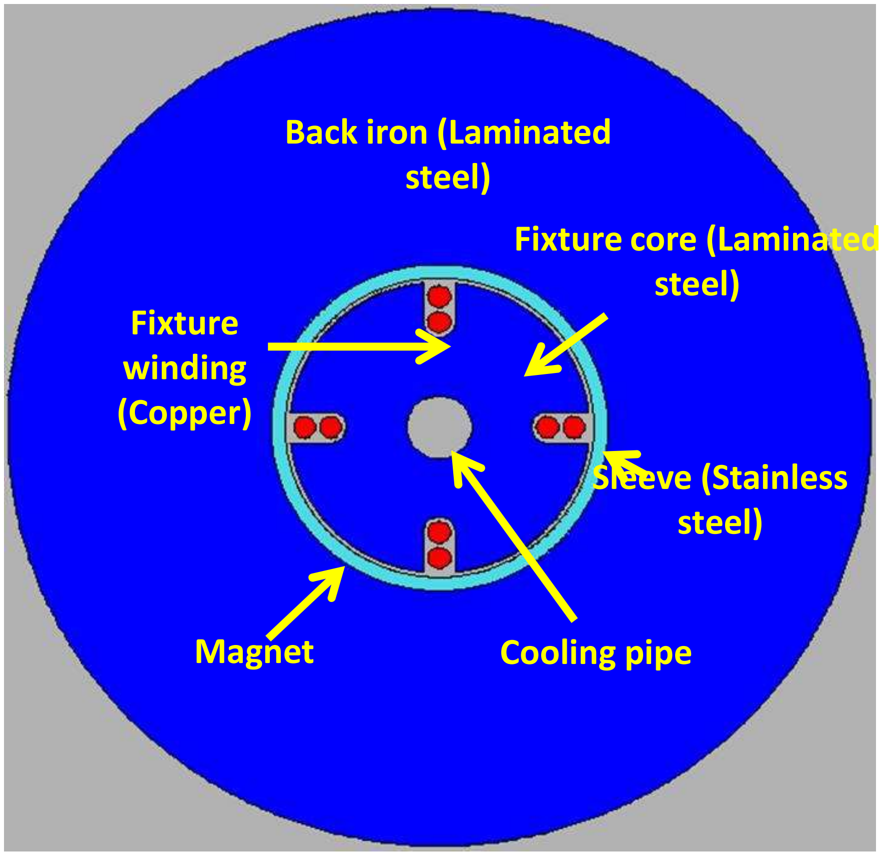


Fixture core with sleeve

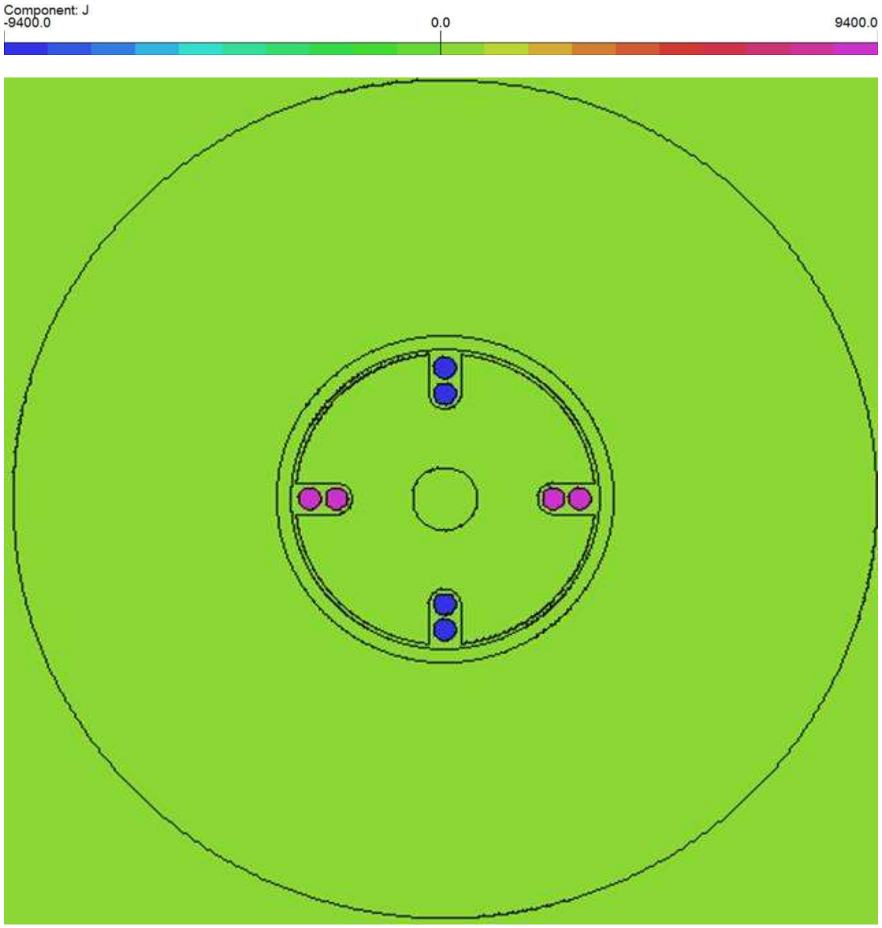


Back iron

Magnetization fixture design

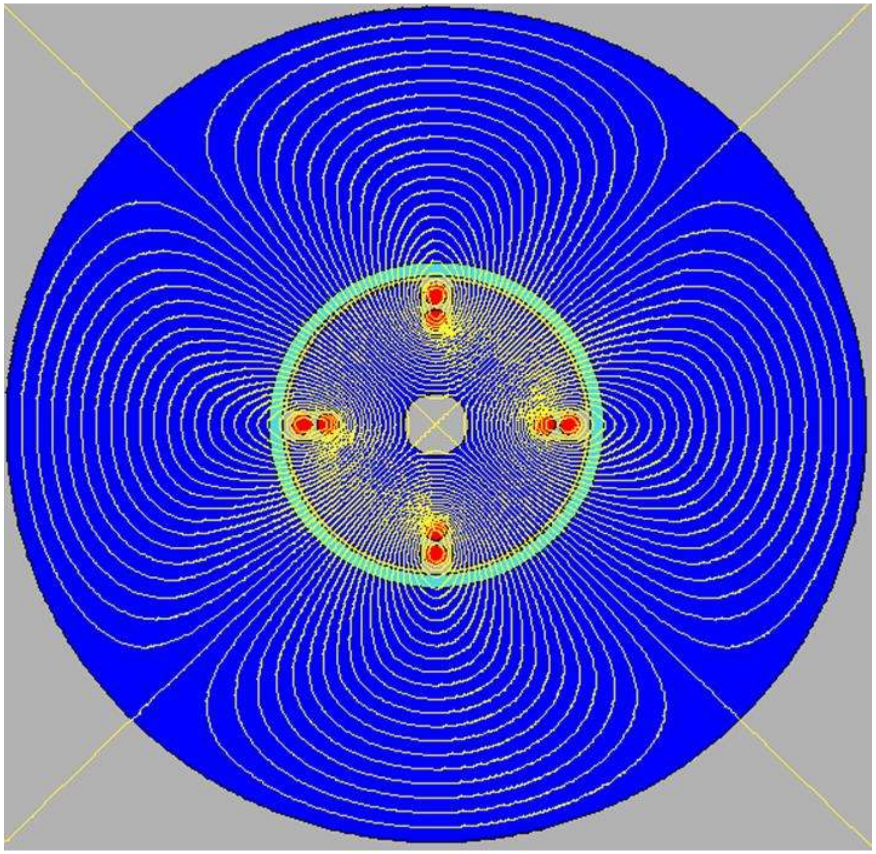


Fixture outline

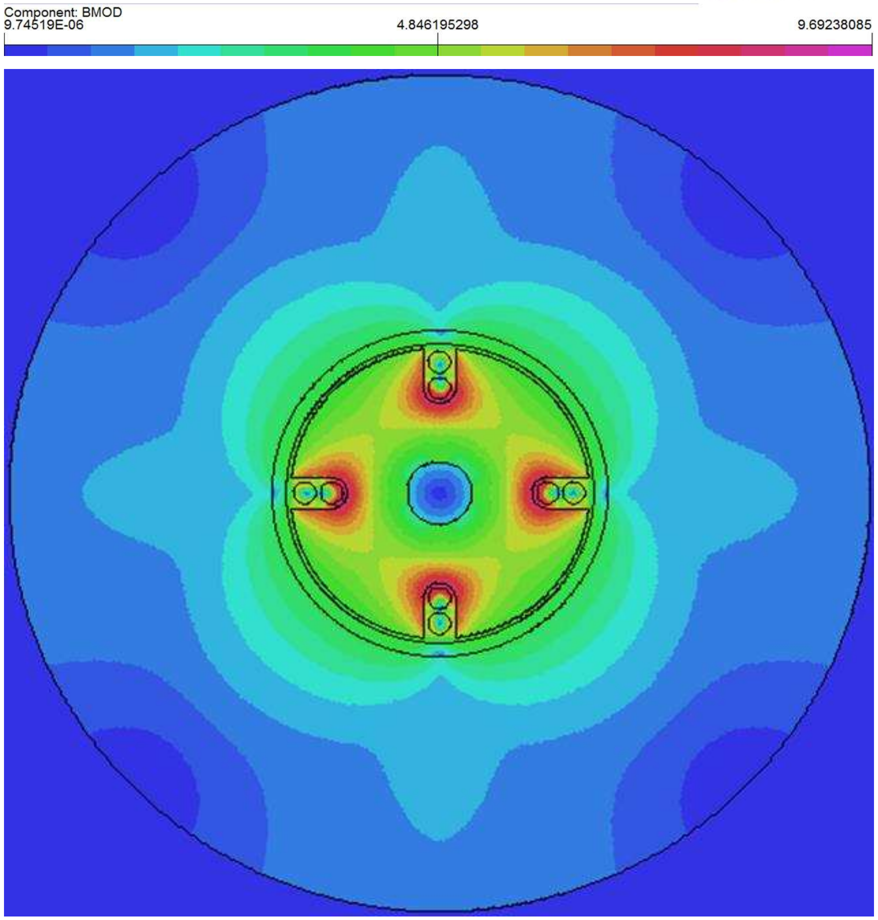


Current density plot @ peak magnetizing current

Magnetization fixture design

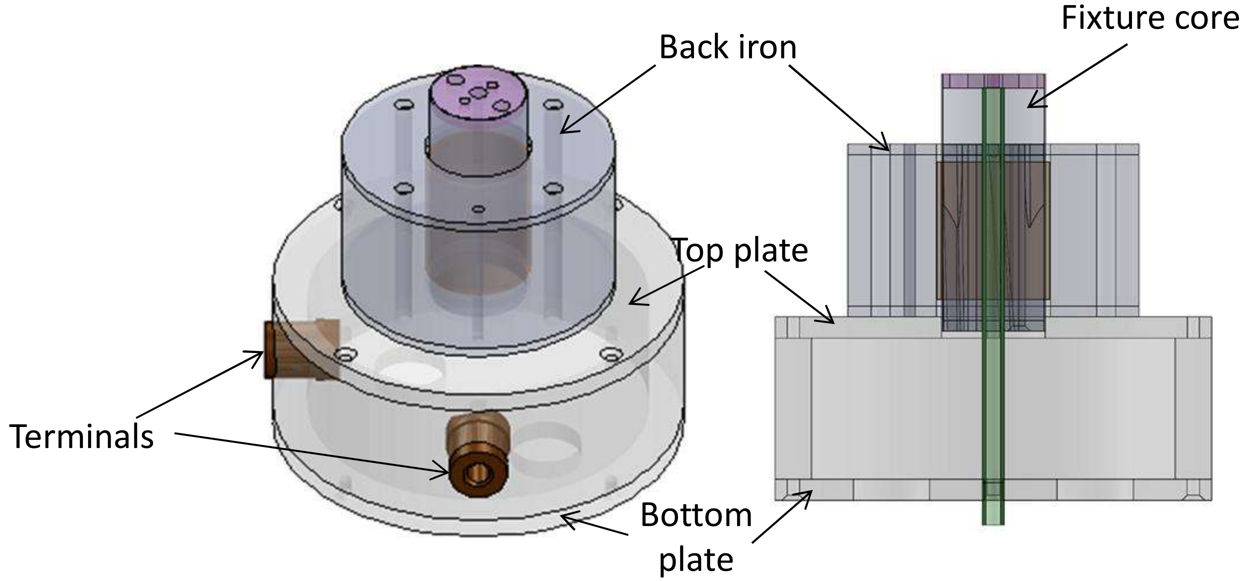


Flux distribution @ peak magnetizing current

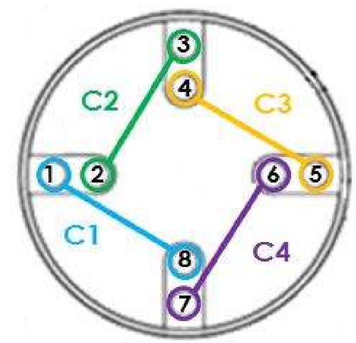


Flux density plot @ peak magnetizing current

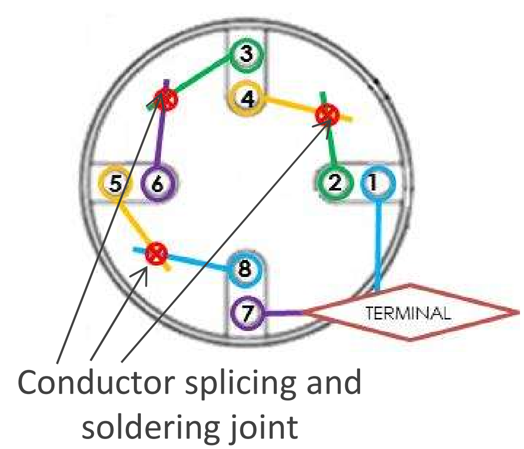
Magnetization Fixture – Structural Design Details

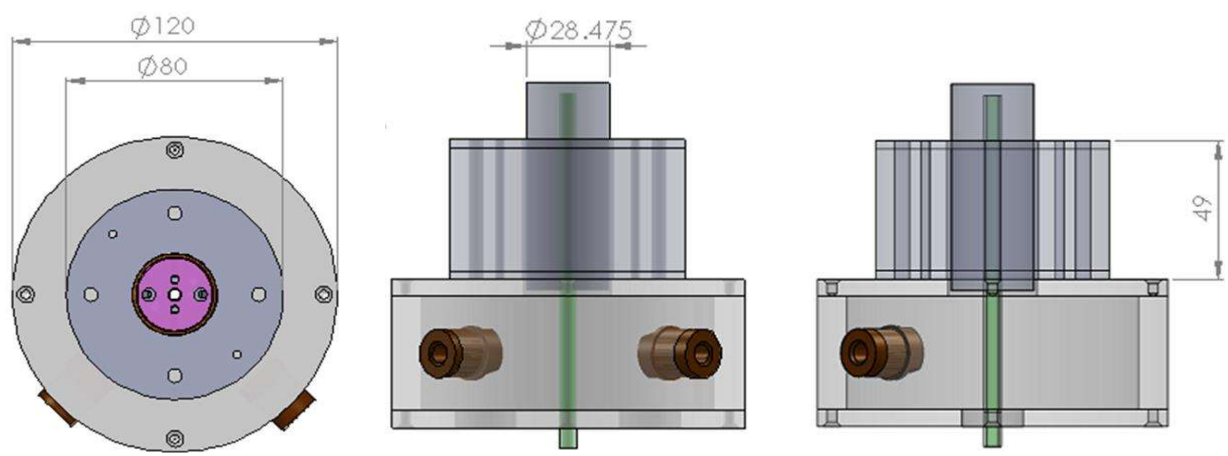


Winding diagram
Core top view



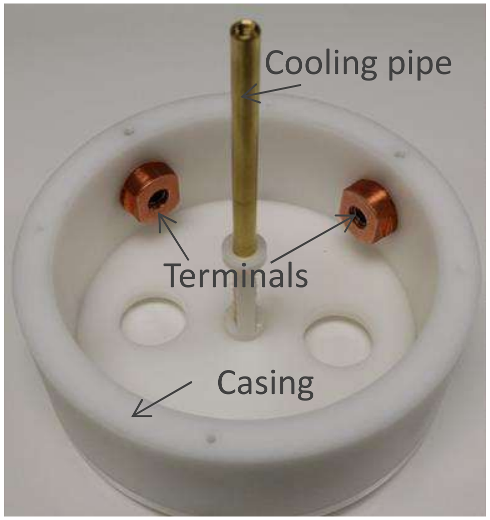
Core bottom view
(Turning right side)



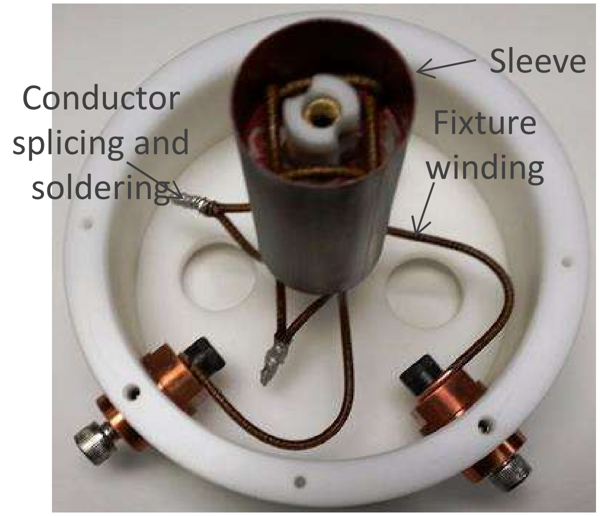


Fixture and back iron structural dimensions

Fixture Fabrication

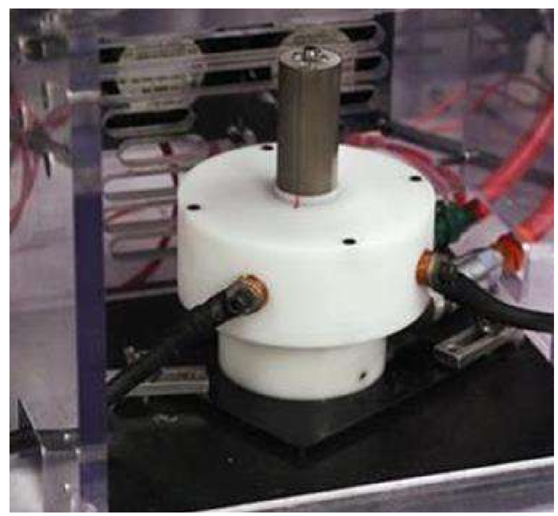


Fixture casing with cooling pipe installed



Wound core mounted on the cooling pipe and connected to the terminals

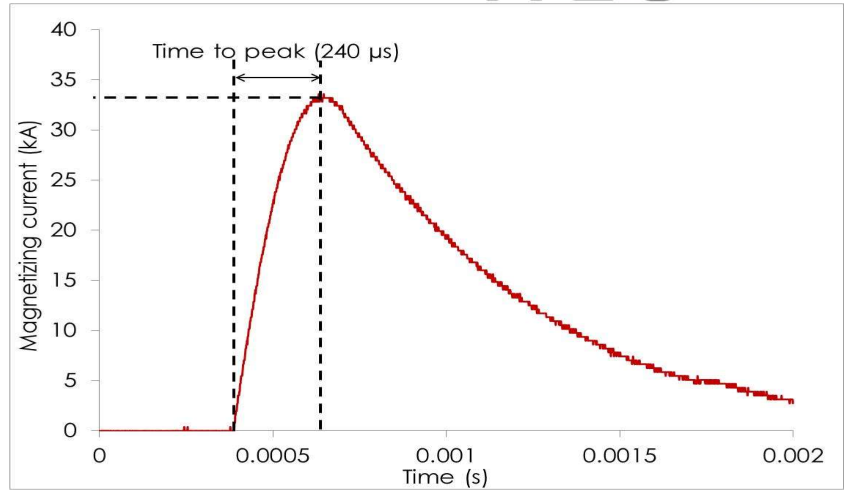
Completed fixture



Fixture set-up for magnetization

Magnetization parameters and Flux scan

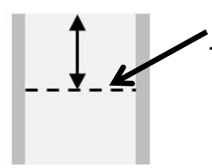
- Magnetizing parameters used by MQT
  - •Voltage =1950 V
  - •Capacitance = 4000 μF
  - •Cycle time = 15 min
  - •Cooling type = Forced water cooling inside the fixture core, Forced air on outer body of the fixture
- Peak Current = 33.6 kA
- Time to peak = 240 μs



Magnetizing current

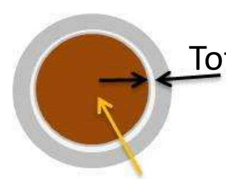
Flux scan setup

Magnet side view



The flux scan measurement is at the magnet axial center

Closed circuit flux scan

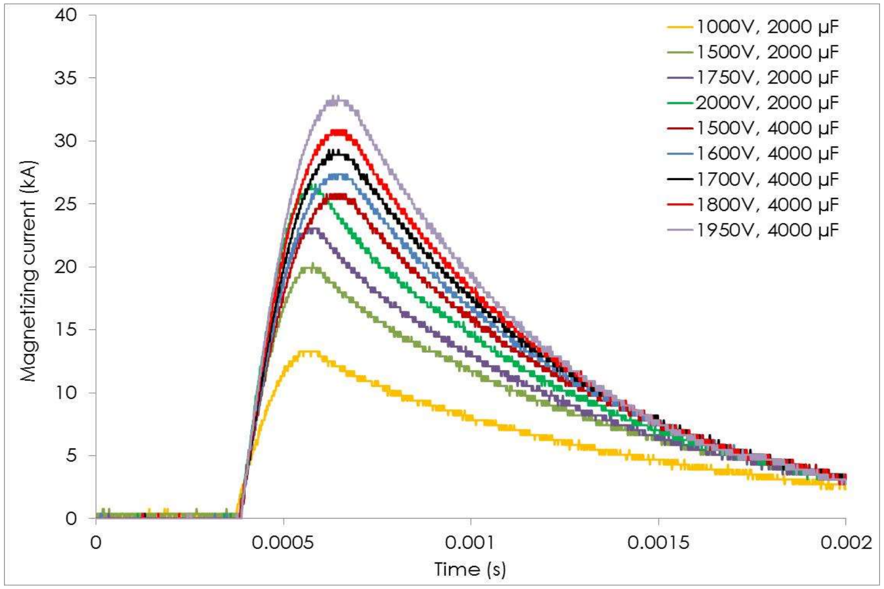


Total air-gap length is 1.43 mm

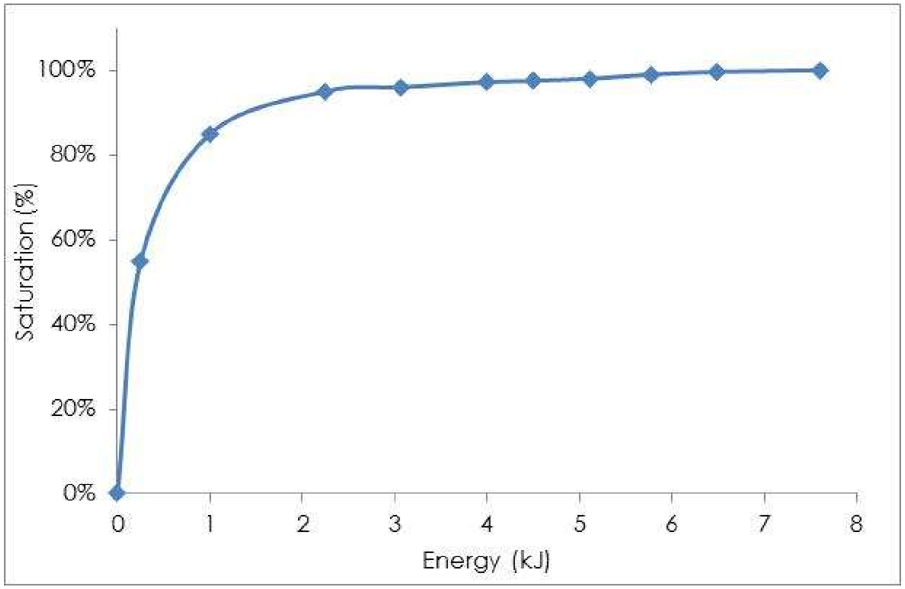
Solid iron centre core

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



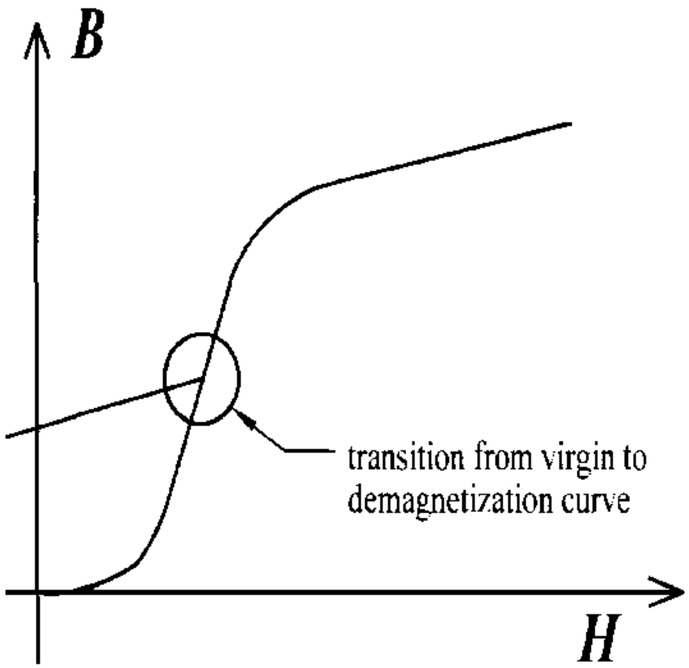
Magnetizing current for various magnetization energy conditions

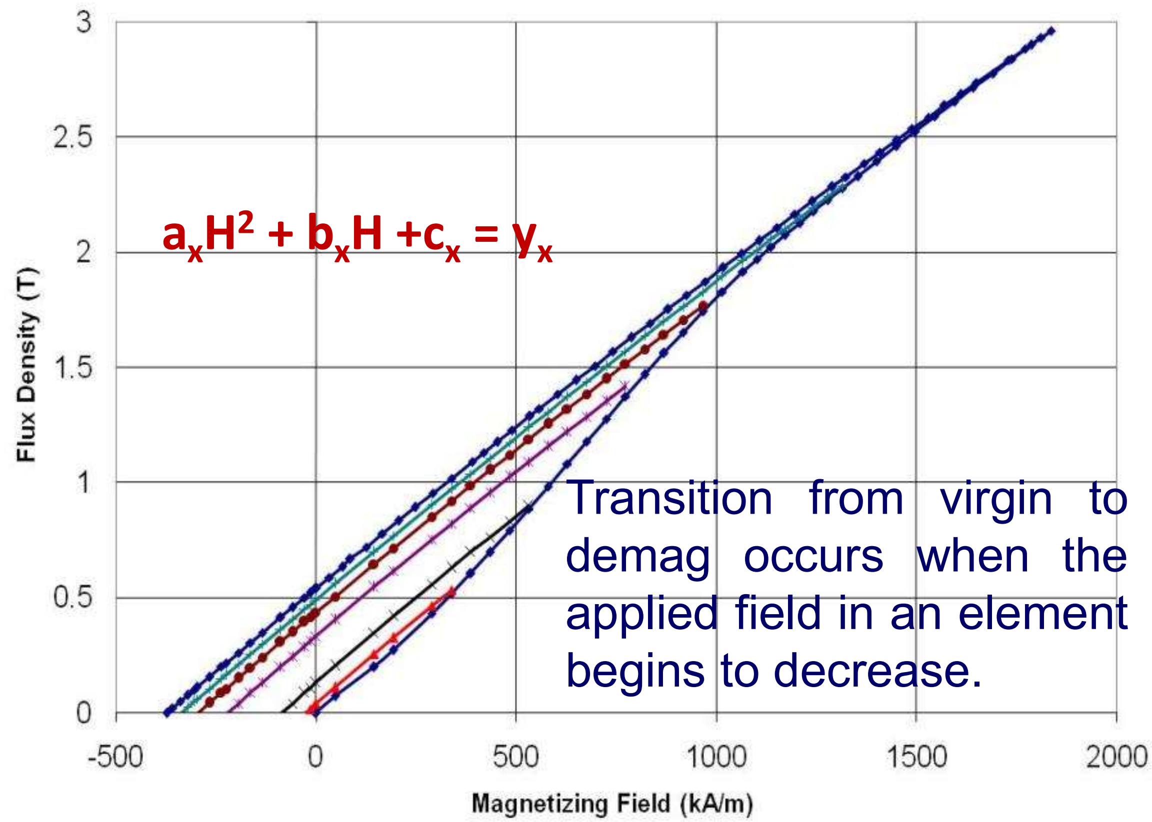


Saturation curve

- 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

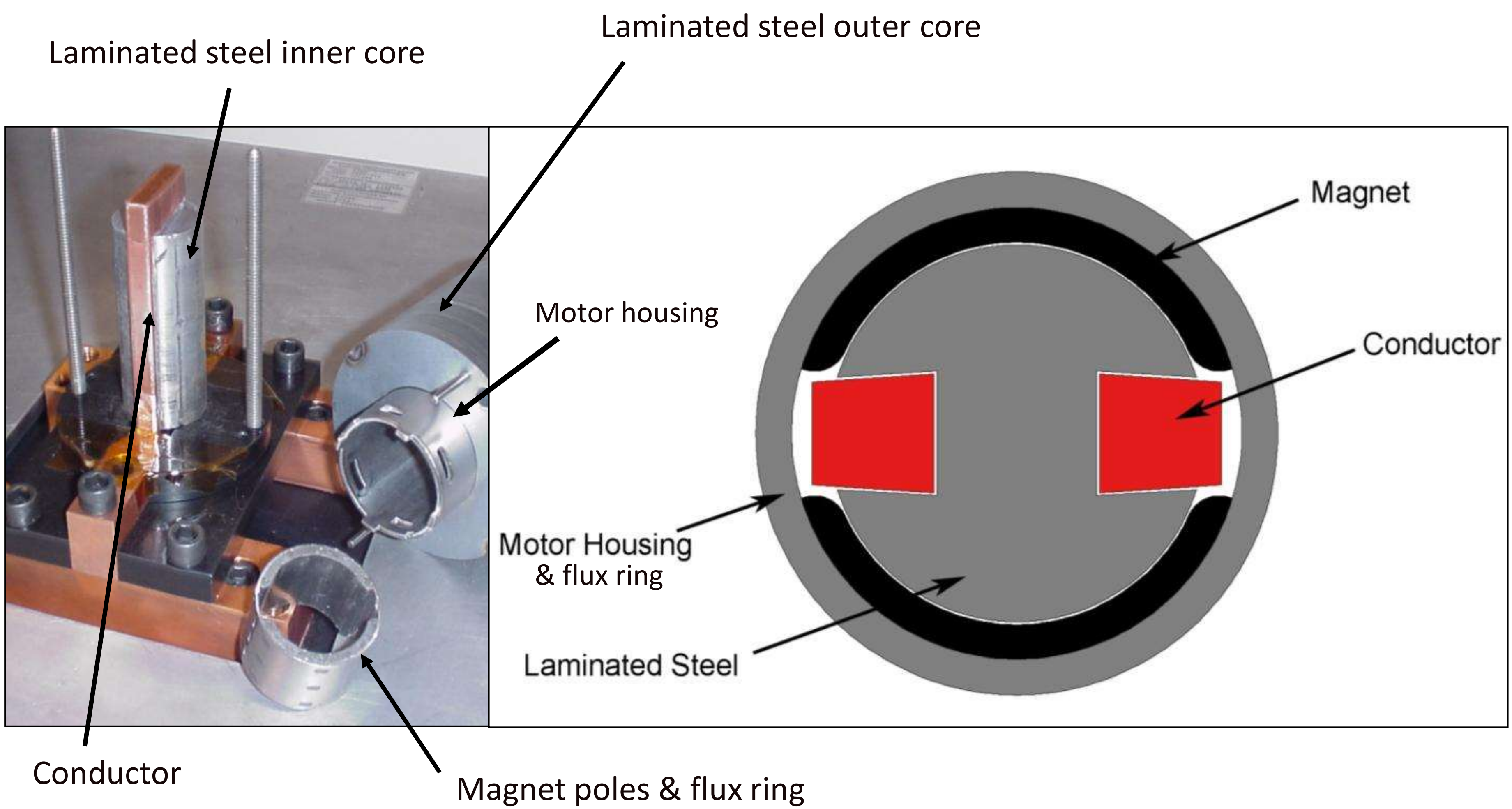




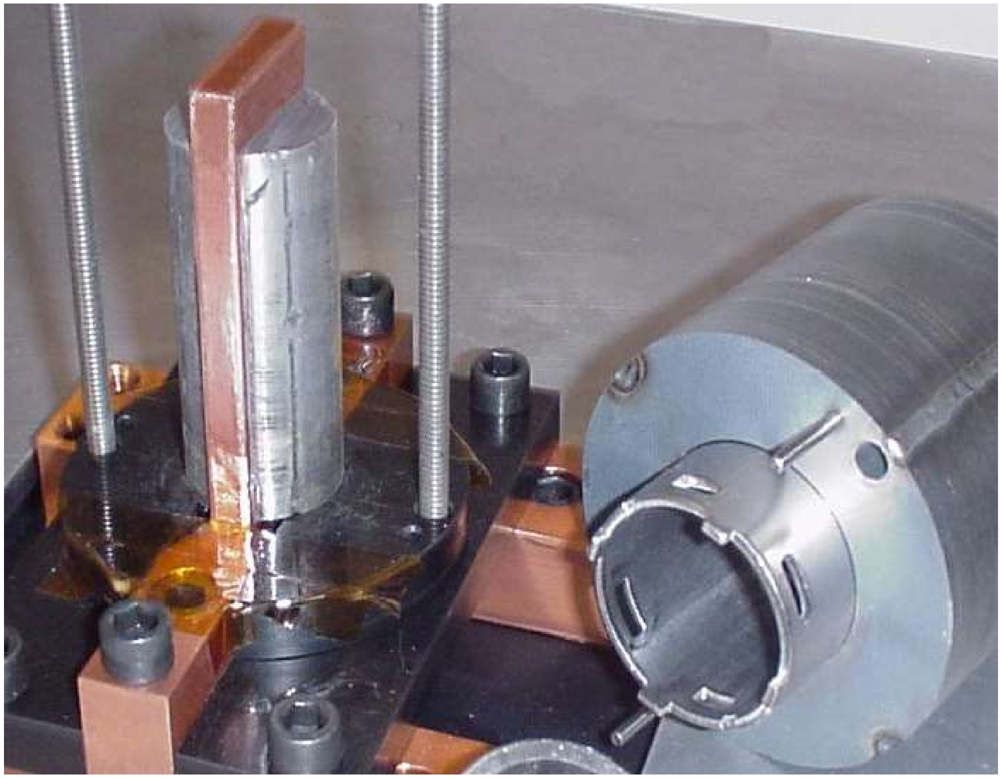
$a_x H^2 + b_x H + c_x = y_x$

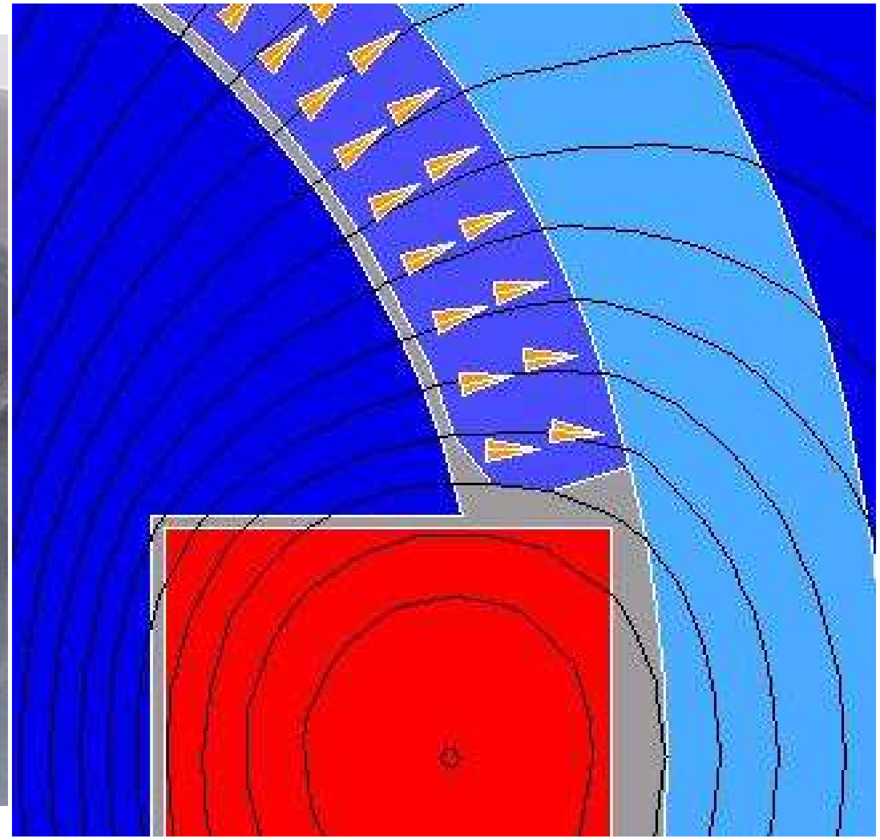
Transition from virgin to demag occurs when the applied field in an element begins to decrease.

Case Study – Magnetizing of an Isotropic Bonded Neo Arc Magnets – Magnetizing Fixtures

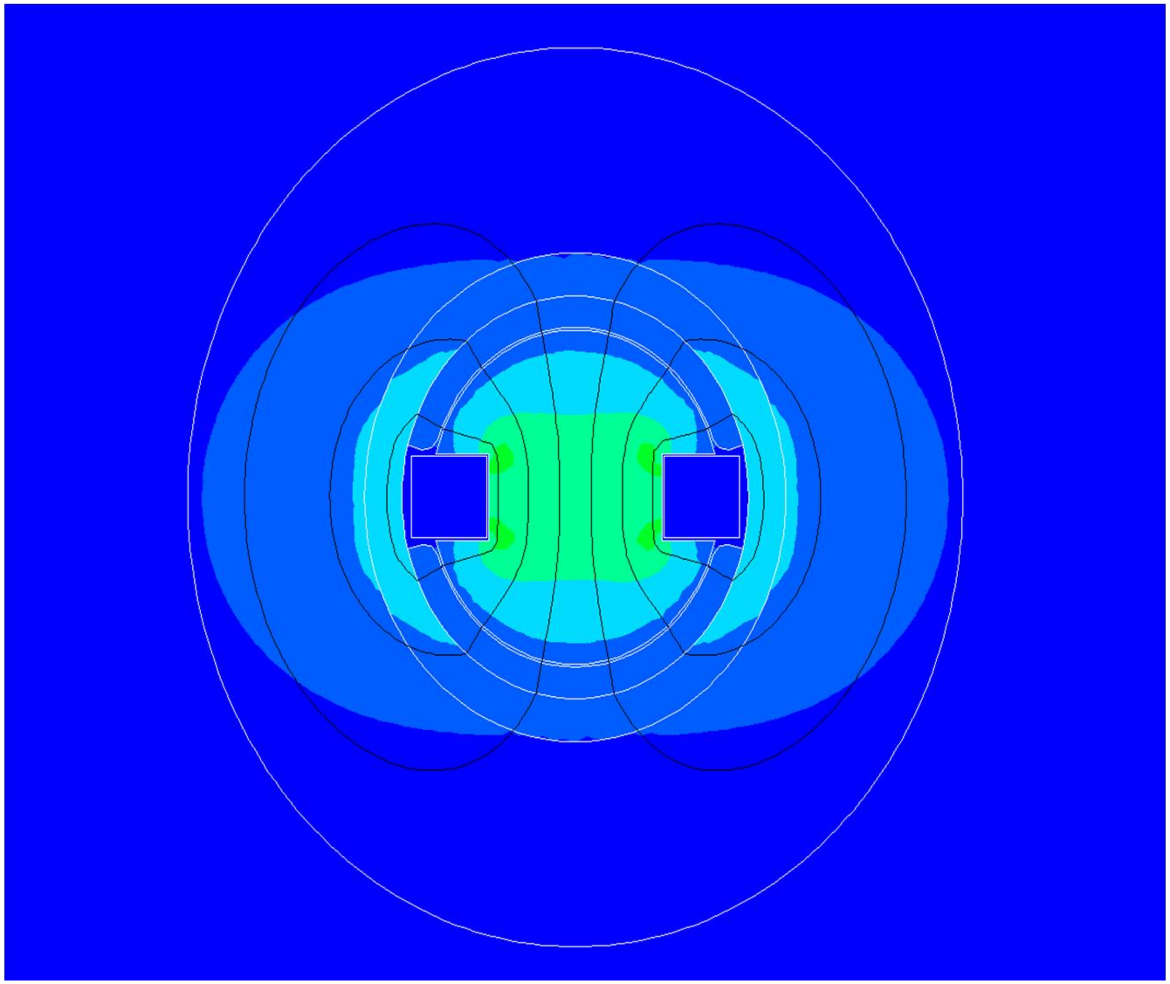


Case Study – Magnetizing of an Isotropic Bonded Neo Arc Magnets – Magnetizing Fixture and Orientation of Flux

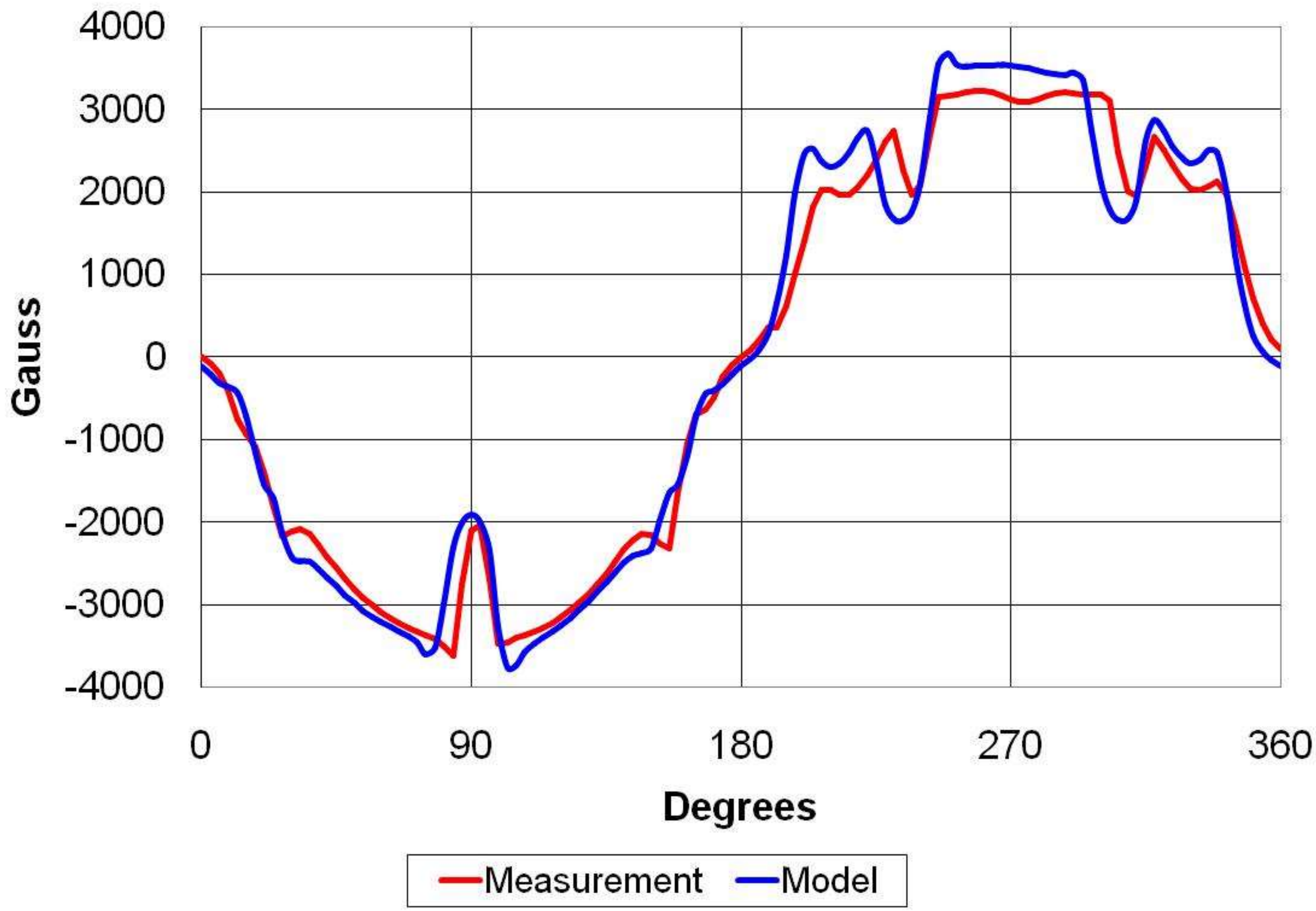




Case Study – Magnetizing of an Isotropic Bonded Neo Arc Magnets- Magnetization Process



Case Study - Magnetizing of an Isotropic Bonded Neo Arc Magnets – Mid Airgap Flux Density



Mid airgap Flux Density

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.