Bonded Neo Magnetization Guide

Presentation Outline

1. **Magnetizing Systems**
2. Fixture Design
3. Construction
4. Testing
5. Design Study

Magnetizing Systems

- A typical magnetizing system consists of a magnetizer and a fixture. One magnetizer is suitable for many different applications, while a fixture is usually custom made for each application
- Magnetizing may be performed at many points in the manufacturing process (magnet, magnetic sub-assembly, or fully assembled product)
- Fixture designs range from simple solenoids to very complex multi-pole arrangements
- For best results magnetization should be considered when designing an application

Magnetizer

Magnetizing Fixture

Applications requiring magnetization

Magnetizing Systems
Magnetizer

The Magnetizer is the power supply of a magnetizing circuit. A single magnetizer may be suitable for many different applications.

- Types of magnetizers include:
  - Capacitive discharge
  - Half cycle
  - Permanent magnet (No Power Required)

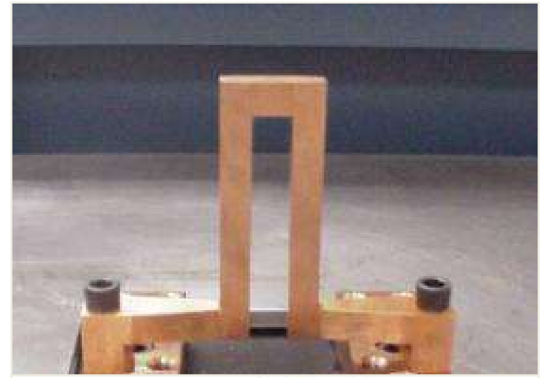
- Capacitive discharge magnetizers are the most common and are specified by:
  - Maximum operating voltage
  - Maximum capacitance
  - Special options

Important

Magnetizers which magnetize ferrite sometimes do not have enough energy to fully magnetize bonded Neo.

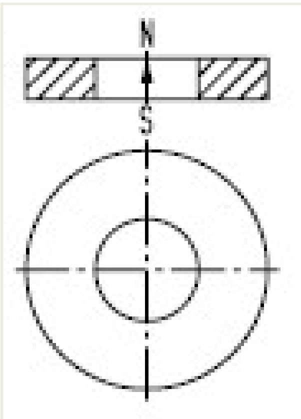
Magnetizing Systems
Fixture

- Fixtures are generally application specific and are specified by:
  - Magnet material
  - Magnet material orientation
  - Magnetization orientation
  - Number of poles
  - Magnet geometry
  - Cycle rate (water cooling for faster rates)
  - Magnet calibration (if desired)

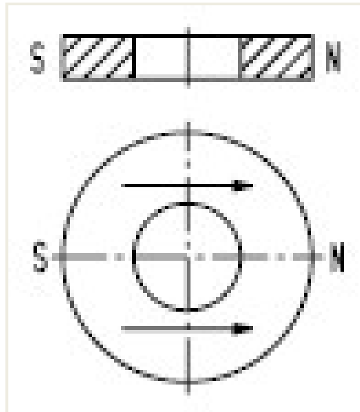


Magnetizing Systems
Fixture

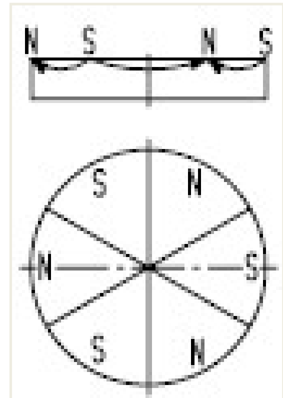
Fixtures can be designed for many types of pole configurations



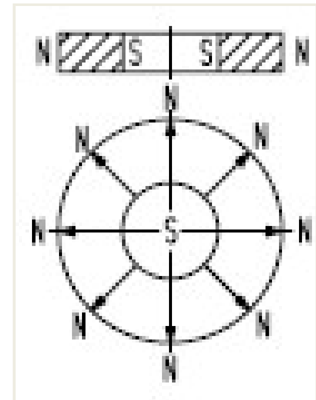
Axial



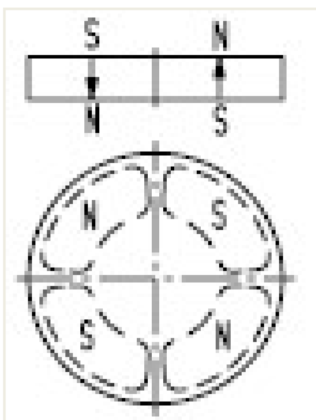
Diametrical



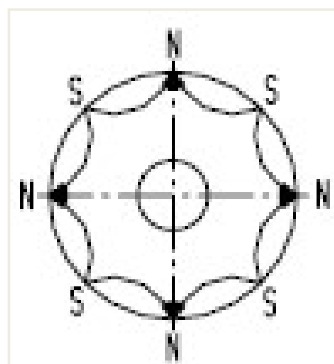
Surface magnetization



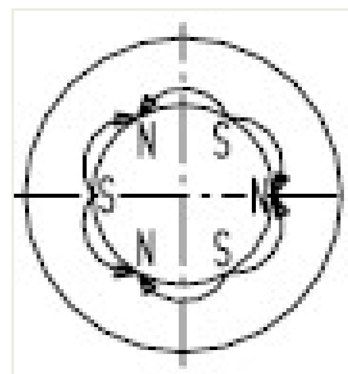
Uni-polar radial



Multi-pole axial



Outer-diameter Halbach



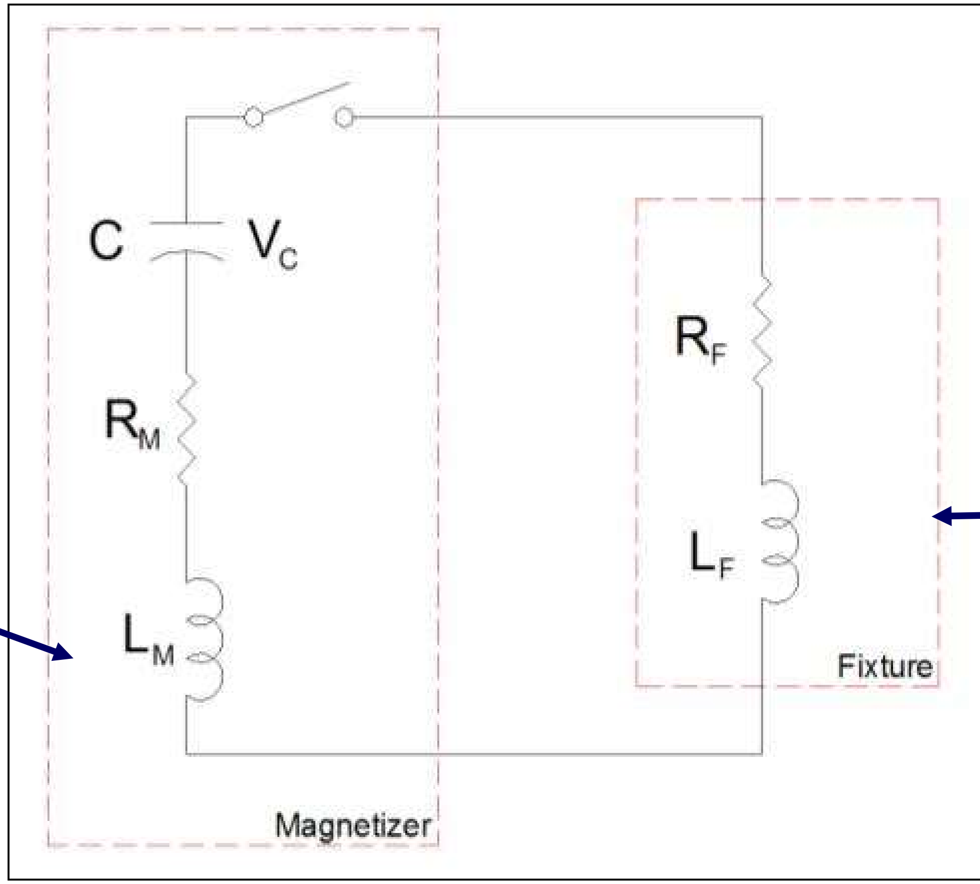
Inner-diameter Halbach

Magnetizing Systems
Fixture

- Fixtures can be integrated into automated part handling systems.

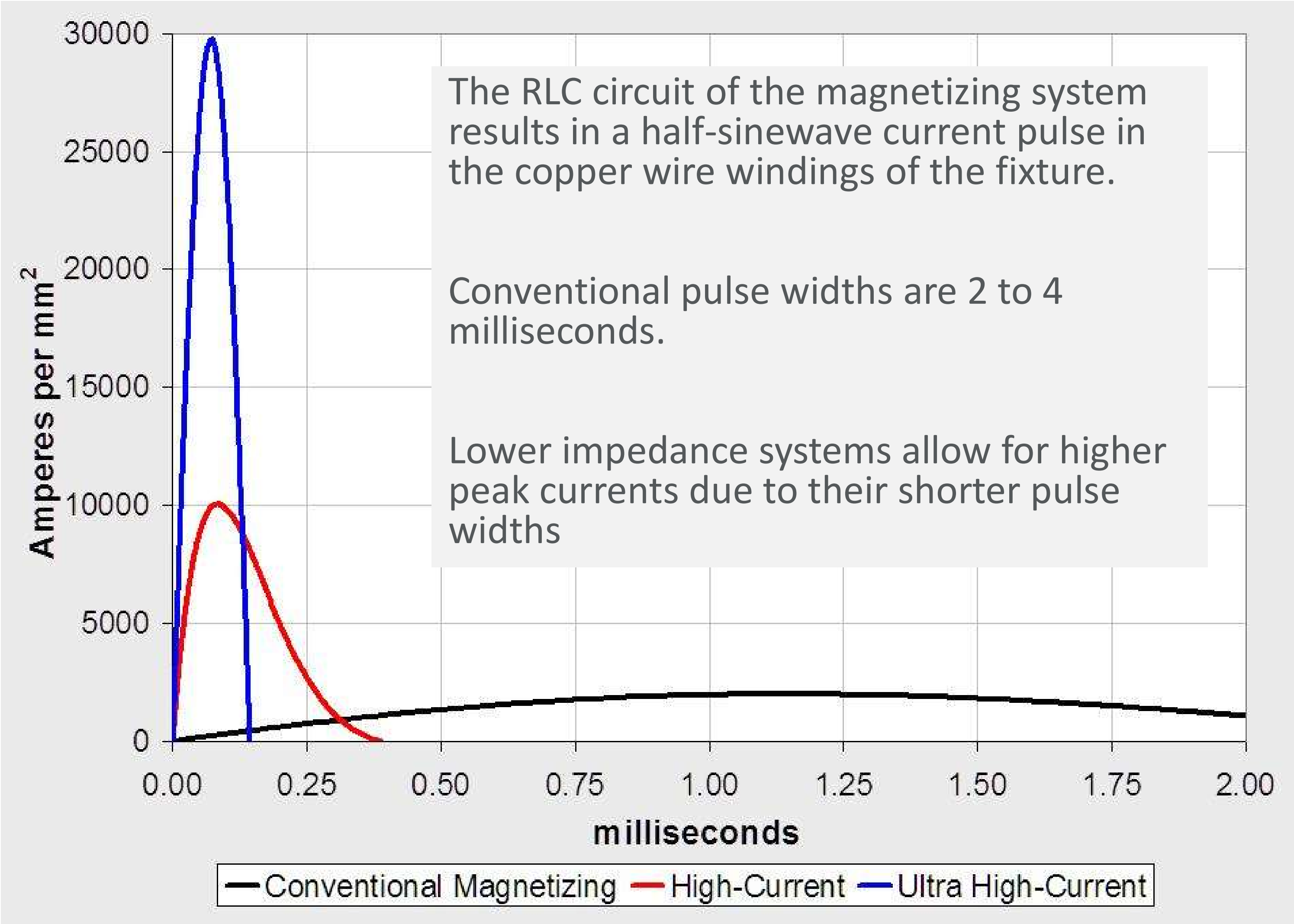
- Possibilities include:
  - Fully automated magnetization
  - In-line testing (quality check)
  - Calibration
  - Safety Features

Magnetizing Systems
RLC Circuit



When a magnetizing fixture is coupled to a capacitive discharge magnetizer the system forms an RLC circuit.

Magnetizing Systems
RLC Circuit



The RLC circuit of the magnetizing system results in a half-sinewave current pulse in the copper wire windings of the fixture.

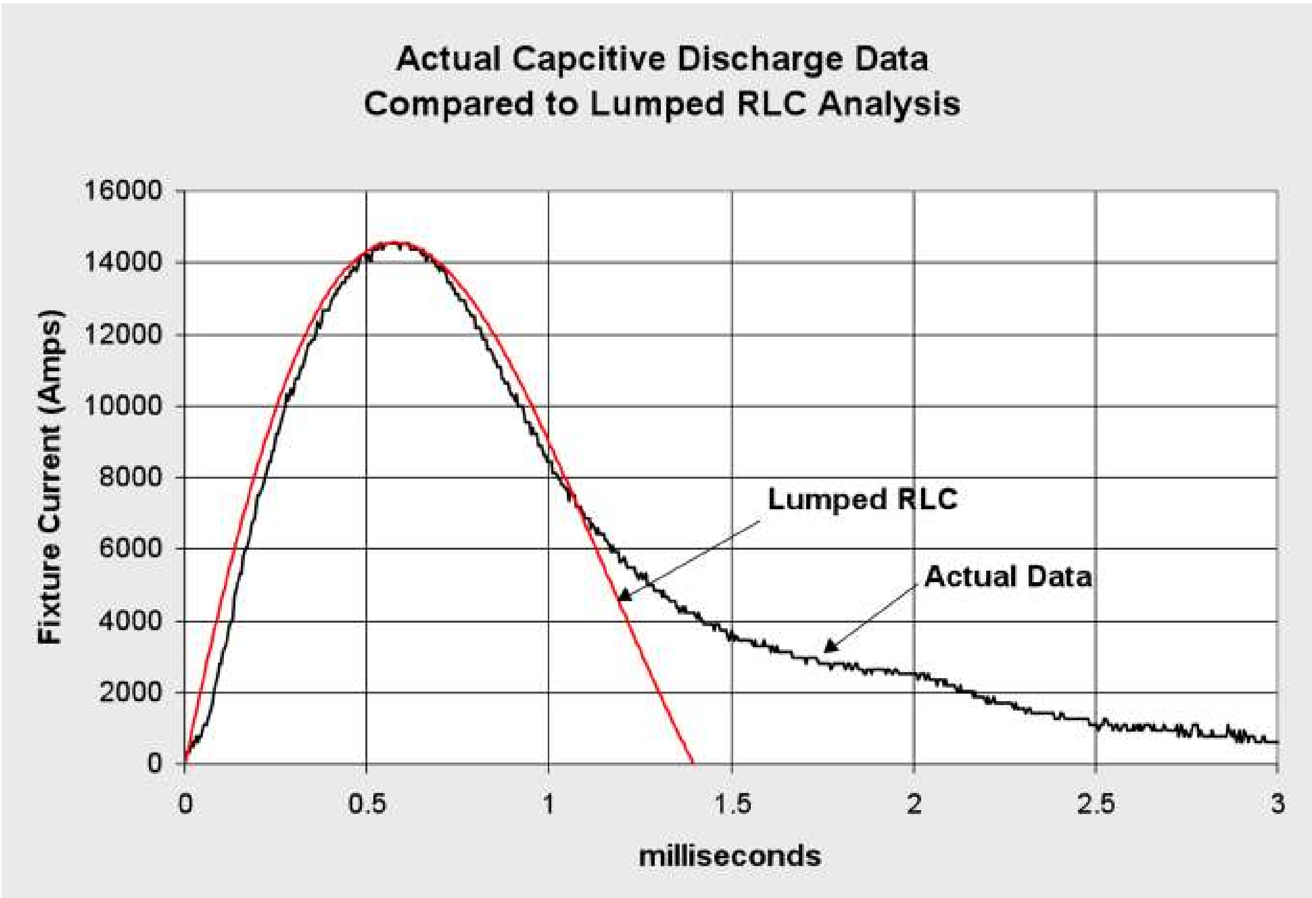
Conventional pulse widths are 2 to 4 milliseconds.

Lower impedance systems allow for higher peak currents due to their shorter pulse widths

Magnetizing Systems
RLC Circuit

<u>Typical Current Pulse</u>

Fixture for OD magnetization of 6-pole 40mm diameter ring



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2. **Fixture Design**
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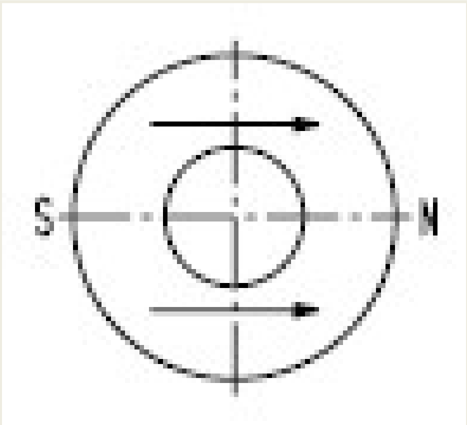
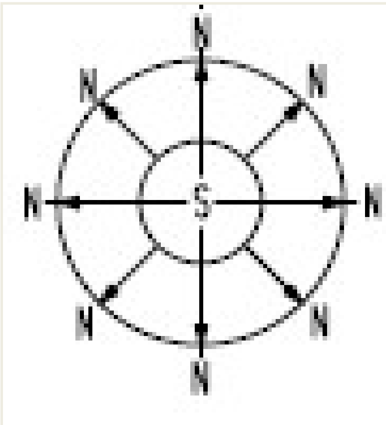
Magnetizing Fixture Design
Magnet Orientation

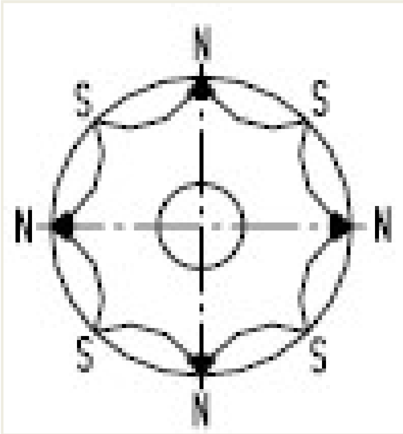
- Radial-flux motor magnets are commonly magnetized with one of three basic orientations
  1. Straight – Flux lines are parallel and unconstrained by magnet geometry
  2. Radial – Flux enters and exits the ring along a radial vector
  3. Halbach – Flux orientation is continuously rotating with respect to the magnet



Straight

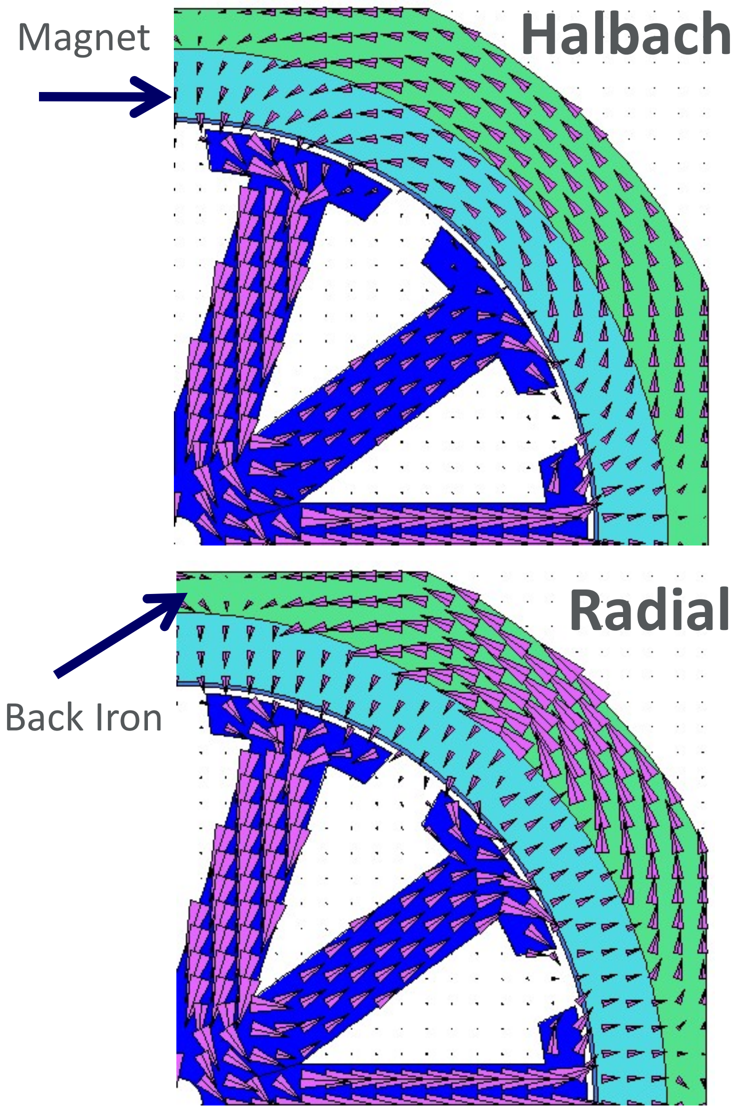


Radial

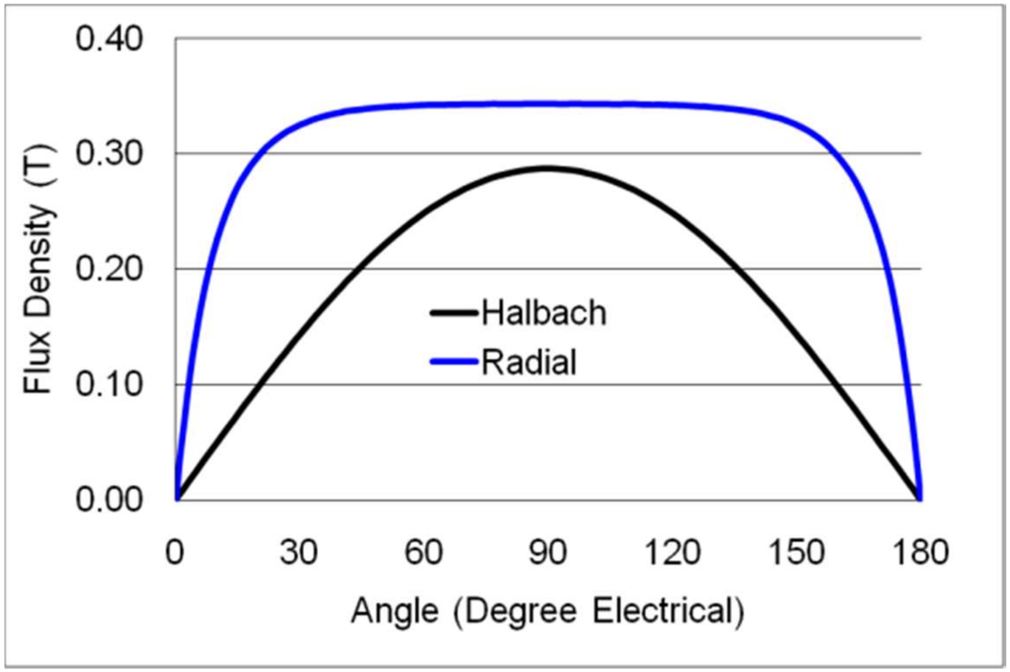


Halbach

Magnetizing Fixture Design
Magnet Orientation

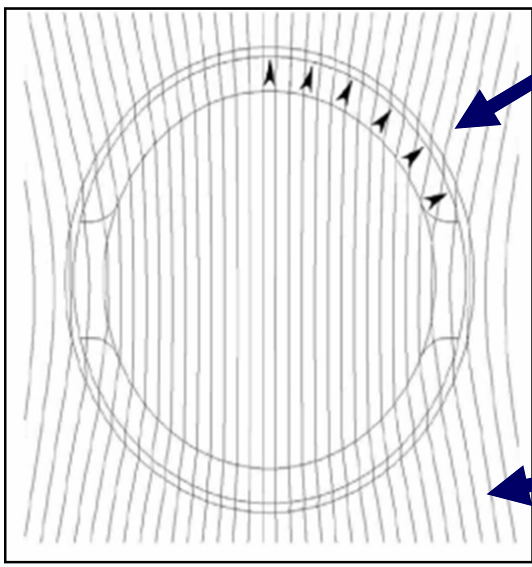


Halbach and radial magnet orientations are shown on the left. The resulting flux profiles in the air gap are shown in the chart below.



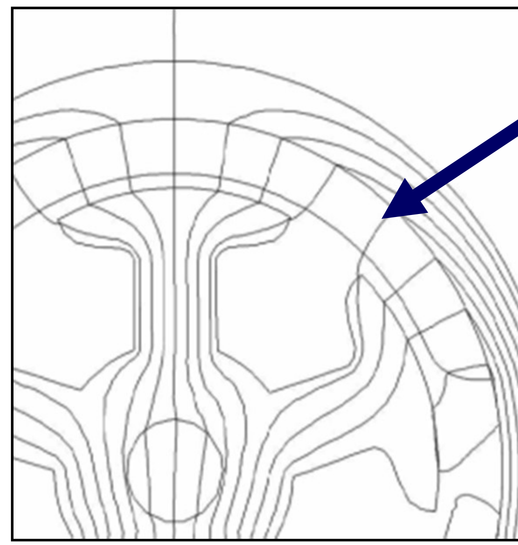
Magnetizing Fixture Design
Anisotropic, or oriented material

Bonded magnets made from HDDR and MQA powders are anisotropic. Sintered ferrite and sintered Neo are also typically anisotropic. Anisotropic magnets have enhanced properties in a specific direction and must be oriented during magnet manufacturing. It is typically not necessary to consider orientation when designing a magnetizing fixture for an anisotropic magnet, because the orientation has already been fixed.



Radial material orientation denoted by black arrows

Magnetizing field is relatively straight



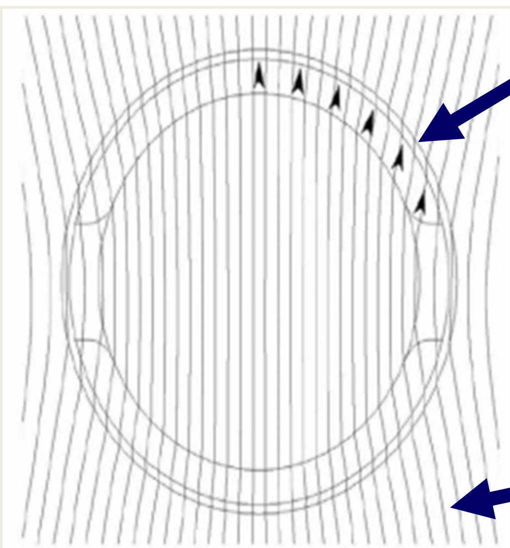
Orientation is radial in the motor

Even though the magnetizing field is straight the magnet keeps the radial orientation that it received during the magnet manufacturing process.

Magnetizing Fixture Design
Isotropic, or non-oriented material

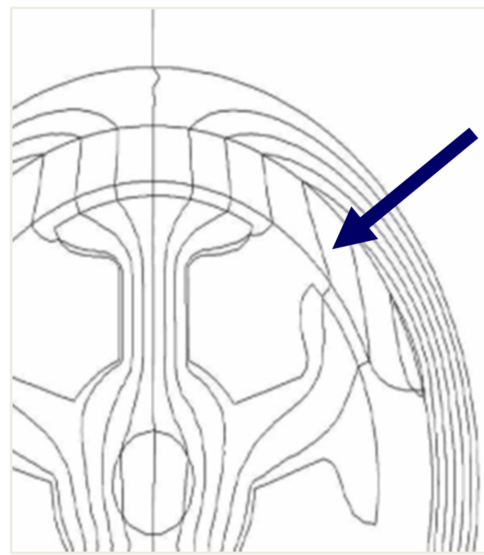
Magnets made from MQP are Isotropic. Isotropic magnets have uniform properties in all directions, so there is no need to orient them during magnet manufacturing. It is ***highly important*** to consider orientation when designing a magnetizing fixture for an isotropic magnet, because the orientation will be determined during the magnetization process. ***Fixtures designed for anisotropic magnets typically will not properly magnetize isotropic magnets.***

Important



The orientation denoted by the black arrows is identical to the orientation of the magnetizing field

Magnetizing field is relatively straight



Orientation in the motor is straight, as it was determined by the magnetizing field.

In the isotropic magnet a straight magnetizing field results in a straight magnet orientation.

Magnetizing Fixture Design
Skewed Magnetization

A magnetizing fixture can be designed to skew the transition zone. This is typically done to reduce cogging or noise in a motor.

Straight pole transition zone

Magnetized magnet without skew magnetized

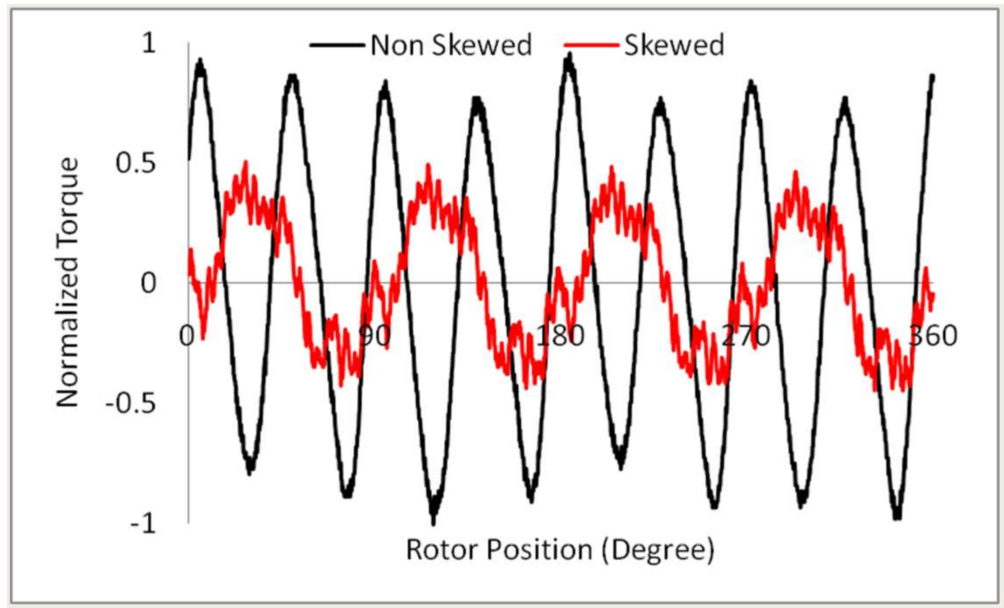
Shifted pole transition zone

Magnetized magnet with skew magnetized

Magnetizing Fixture Design
Skewed Magnetization

Skewed magnetization on the magnet helps in reducing the cogging torque. Skewing the magnet is simpler than skewing the armature.

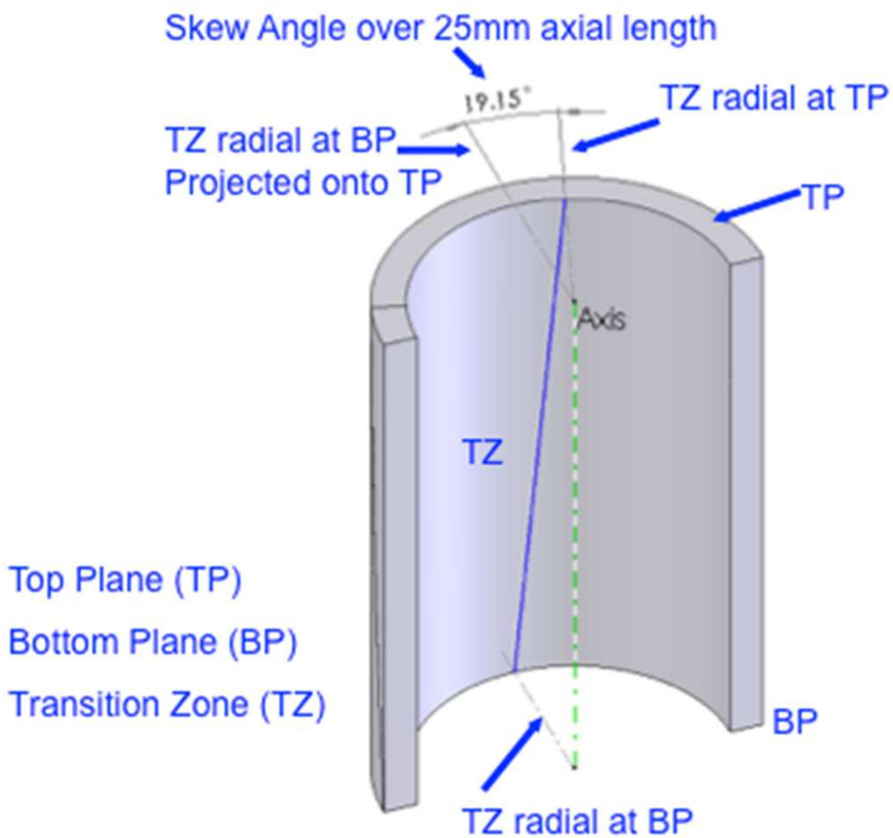
Magnetized magnet with and without skewing



Normalized Cogging Torque for skewed and non-skewed magnetization

Magnetizing Fixture Design
Skewed Magnetization

The proper skew angle is determined by the number of slots on the armature. Typically a skew angle is [360° / # of slots] or [180° / # of slots]. The second formula results in a smaller angle and is more commonly used, since larger skew angles result in greater reduction in the output torque of a motor.



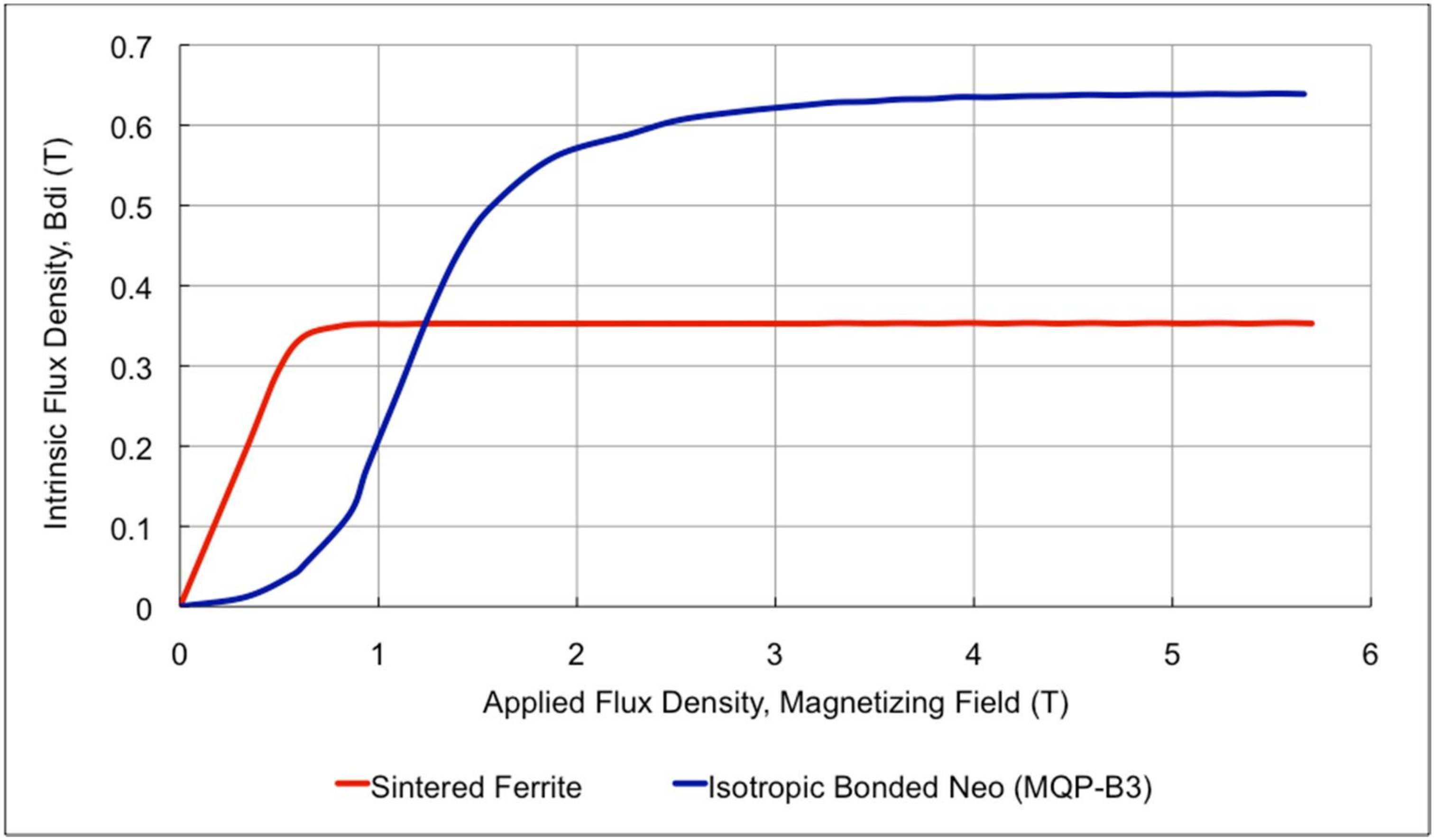
The proper measure of the skew angle is defined in the figure on the left.

Proper skew angle is important, and ***improper skew angle will result in poor motor performance***.

Important

Magnetizing Fixture Design
Applied Field Required for Full Magnetization

Intrinsic flux density vs Magnetizing Field (cylindrical magnet 9.7mm diameter x 6.3mm length)



Important

Note that a magnetizing system designed to magnetize ferrite will likely not be capable of full magnetization of bonded Neo.

Magnetizing Fixture Design

Steel is saturated in bonded Neo fixtures

3 to 4 Tesla is required for full magnetization of bonded Neo. Therefore steel in a bonded Neo fixture becomes partially or fully saturated during the current pulse and will not focus flux the way that it tends to do in ferrite magnetizing fixtures – saturated steel has the same permeability as air. ***Fixtures designed for ferrite often will not give proper orientation to bonded Neo magnets.*** For this reason the shape of a steel pole in a bonded Neo fixture is relatively unimportant.

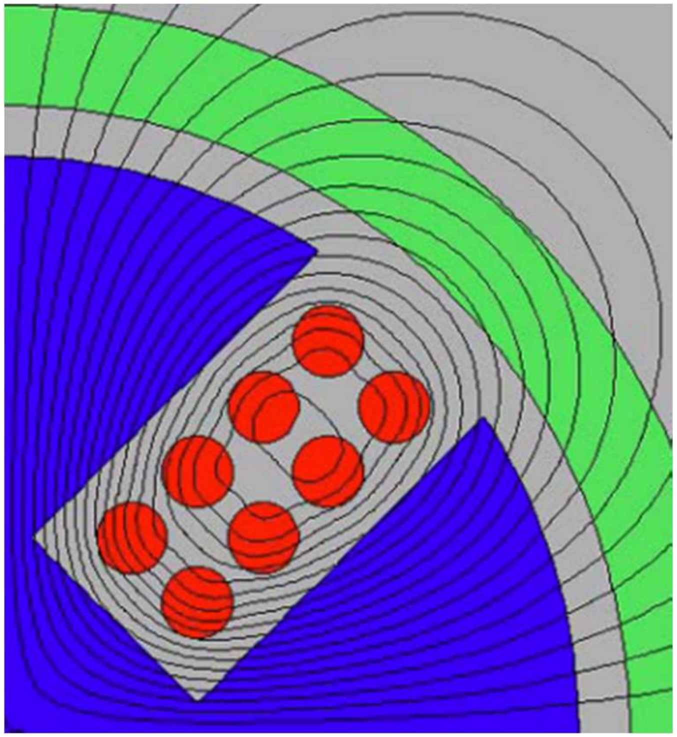
Important

Important

The most important considerations when designing a bonded neo fixture are:

- Location of conductor
- Shape of conductor
- Current density of conductor

These items should be considered first in the design process.



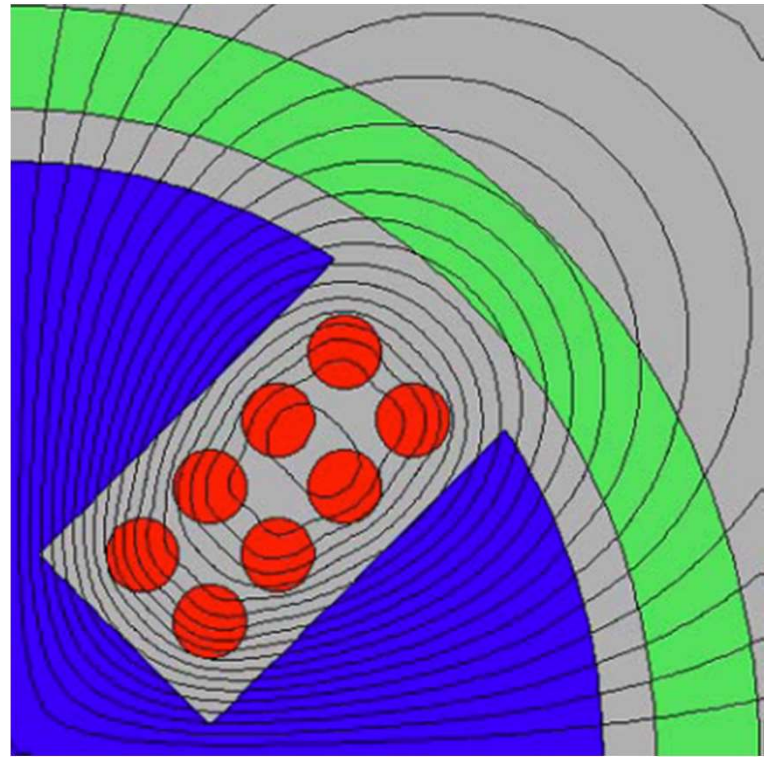
In the regions near the red conductors flux lines can be seen to exit the blue steel regions at non-orthogonal angles. This is due to the steel's being saturated and having the same permeability as air.

Magnetizing Fixture Design

Steel is useful even though it is saturated

- Due to B-fields well above 3 Tesla the steel in a bonded neo fixture is saturated and has only three purposes:
  1. Decrease the amount of current required to produce a given B-field.
  2. Improve the mechanical strength of the fixture.
  3. Improve the cooling efficiency of the fixture.

Steel is often very useful for all of the above purposes. Therefore, steel is often used in bonded neo fixtures.



Even though the steel above is saturated it reduces the conductor current necessary for magnetization, enhances the fixture's mechanical strength, and improves cooling efficiency.

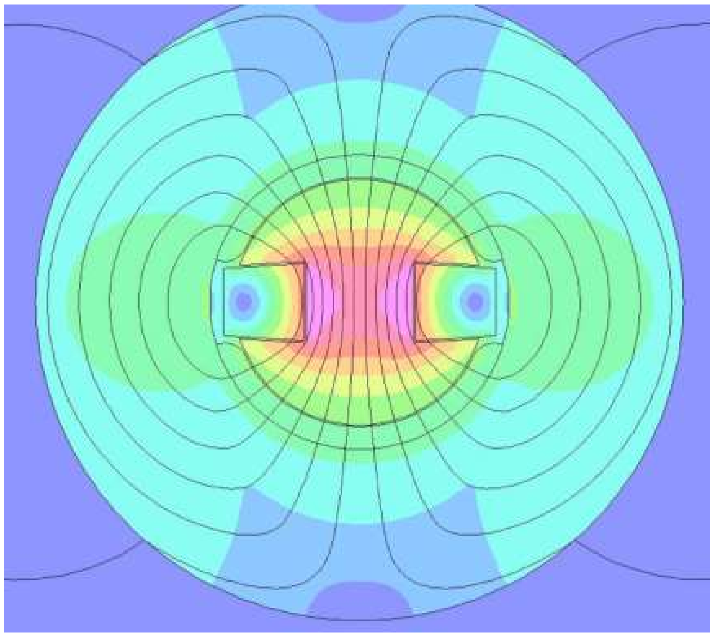
Magnetizing Fixture Design

Steel should be laminated

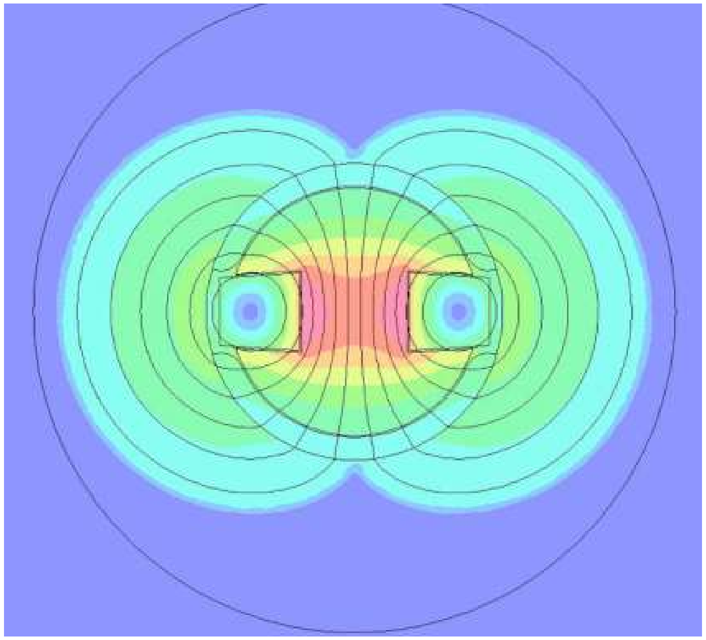
If steel is used it should be laminated and not solid. With solid steel there may be significant eddy current losses.

Important

Higher flux density in laminated steel fixture



Lower flux density in solid steel fixture



The effect of eddy currents is seen in the comparison of these two pictures. The same fixture design is shown at the time of peak field in the magnet using an identical color scale. The fixture on the right has a solid steel outer pole piece, while the fixture on the left has a laminated steel outer pole piece. Eddy currents form in the solid steel on the right and reduce the peak field that is reached in the magnet. The fixture with laminated steel on the left is clearly superior.

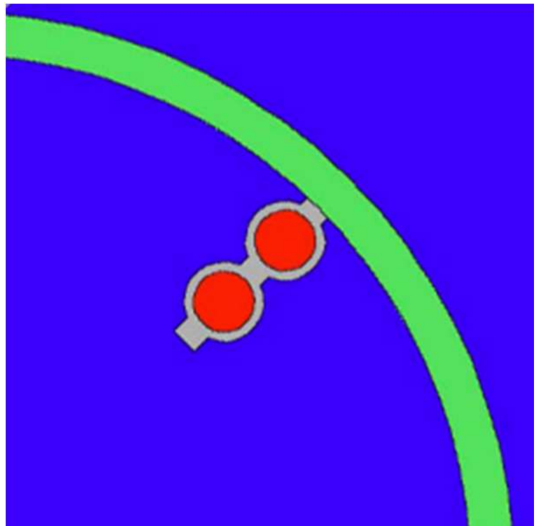
Magnetizing Fixture Design

Magnetizing Isotropic Material with Radial or Halbach Orientation

Inside diameter magnetization of an isotropic ring

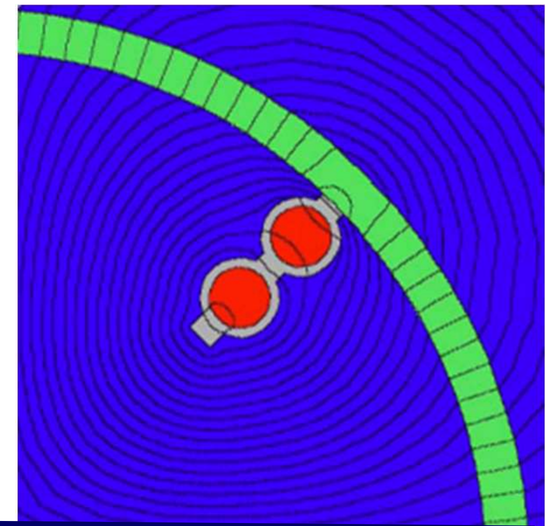
Radial Magnetization

- Conductor nearer to magnet
- Narrower slot
- Back iron behind the magnet



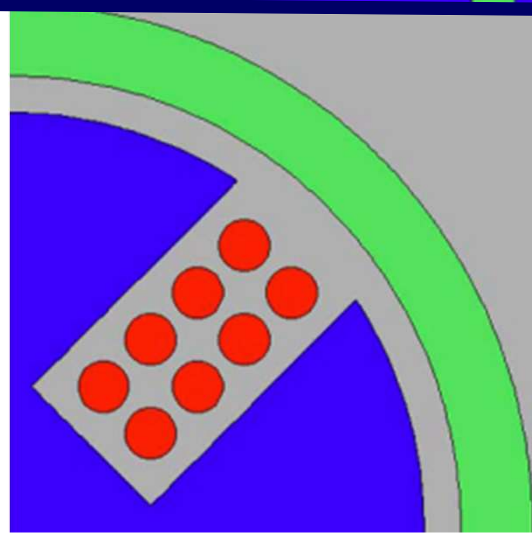
Flux lines are radial in the magnet

Green is magnet
Blue is steel
Gray is air
Red is copper



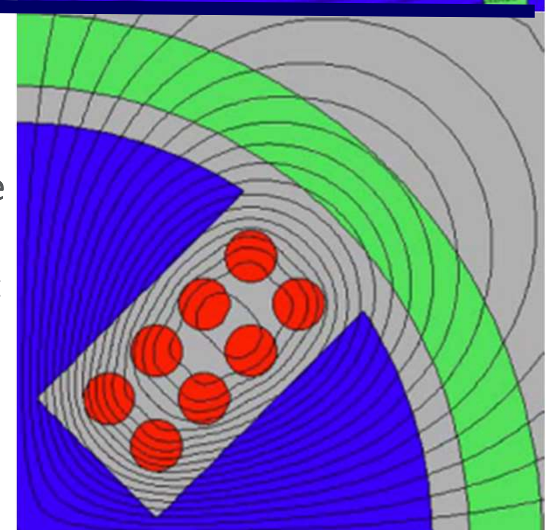
Halbach Magnetization

- Conductors further from the magnet
- Wider slot (2 rows of conductors)
- No back iron behind the magnet



Flux lines are Halbach oriented in the magnet

Green is magnet
Blue is steel
Gray is air
Red is copper

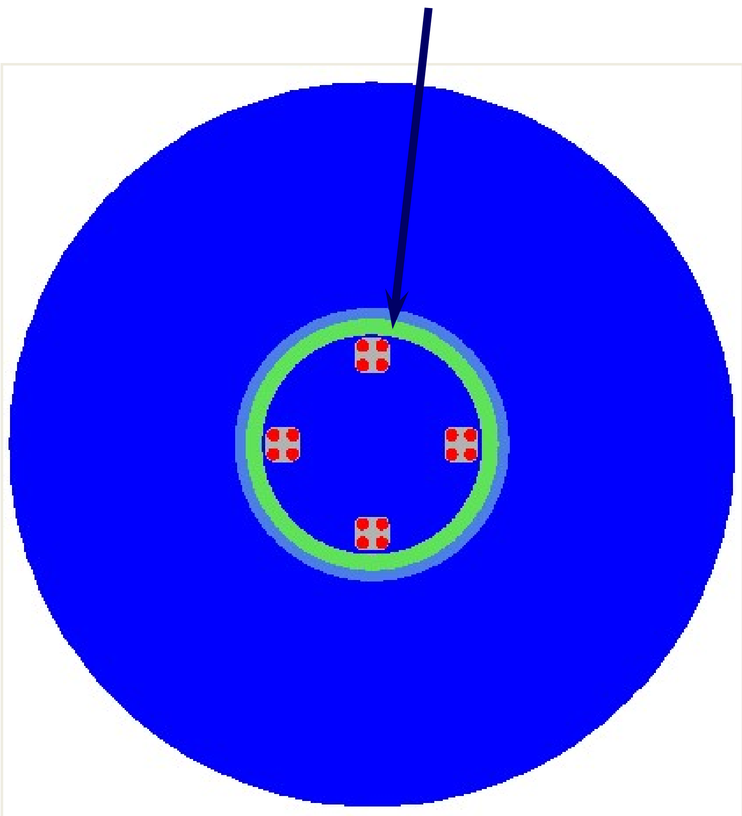


Magnetizing Fixture Design

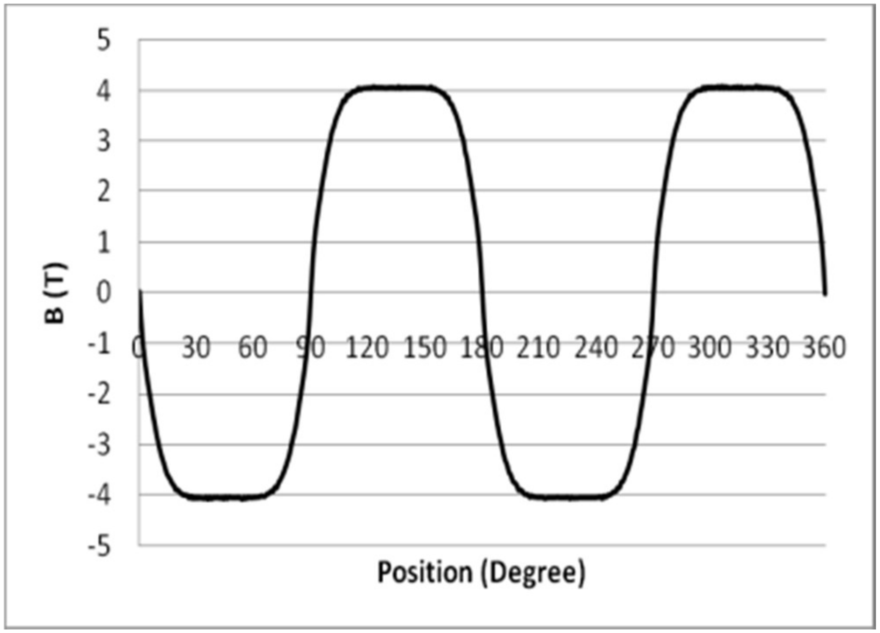
Predicting the current required to achieve full magnetization

Static finite element analysis (FEA) can be used to predict the current required to generate 3 - 4 Tesla flux density at the back of the magnet.

Back surface of Magnet



FEA output: Predicted flux density at the back surface of the magnet at a given conductor current

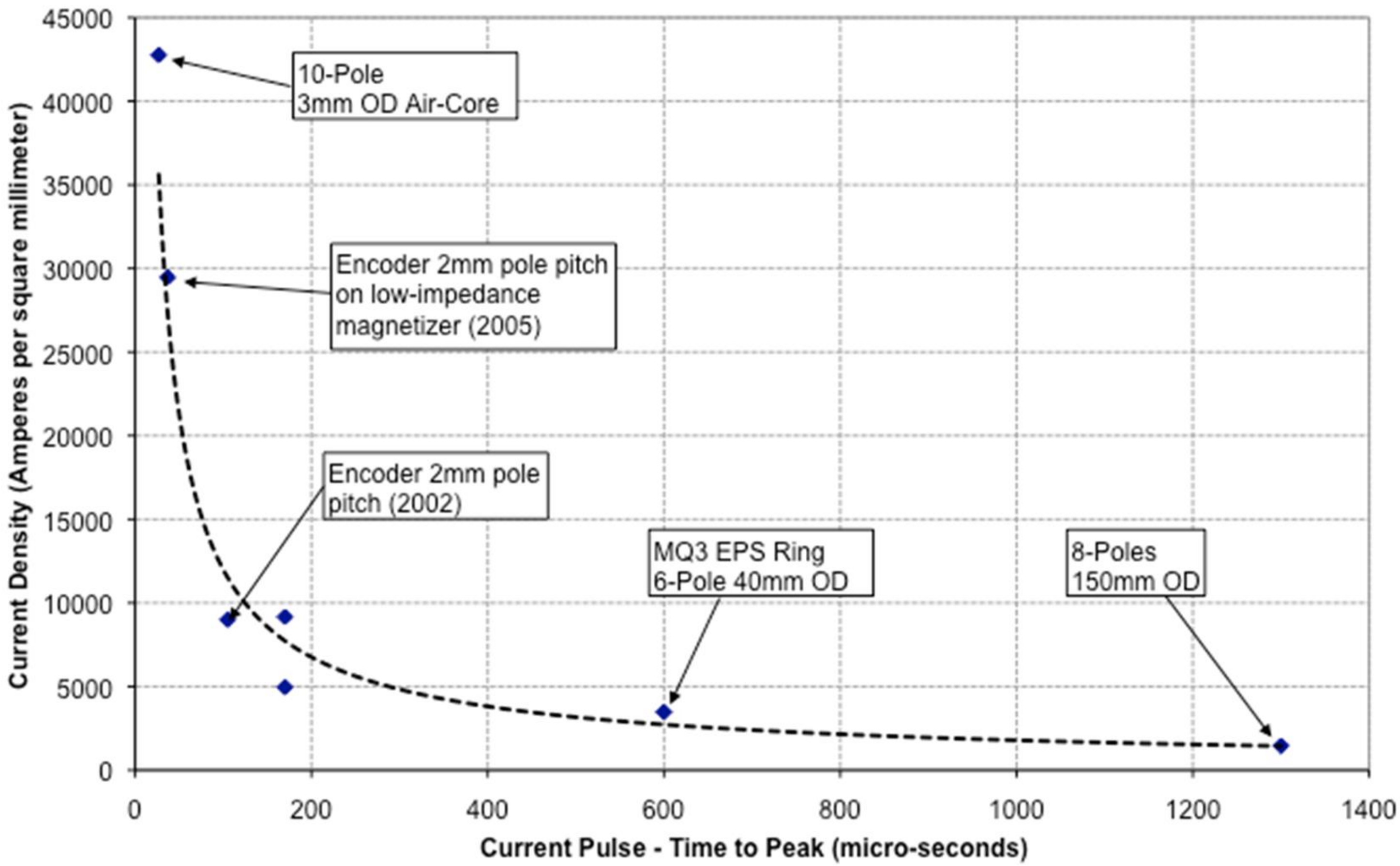


Magnetizing Fixture Design

The safe limit of current density in a magnetizing fixture conductor

neo Magnequench

The safe limit for current density in a conductor depends on pulse time-to-peak. Fixtures operating below the dashed line are at lower risk of failure.



Magnetizing Fixture Design
Design Logic

1. In static electromagnetic FEA model the magnet and any steel in the application that will be present during the magnetization step.
2. Next choose conductor size, location, and number of turns.
   - It is generally desirable to keep the conductors as close to the magnet as possible.
   - The size of conductor and number of turns will need to result in enough conductive area to achieve the required ampere-turns per slot. Typical wire size will range from #19 AWG to #11AWG.
   - The current in each conductor will be limited by a maximum allowable current density (Amperes per square millimeter). Very safe magnetizing is limited to less than 5000 A/mm^2. Small bonded Neo fixtures often require current density closer to 20,000 A/mm^2. At 20,000 it is extremely important to observe the safety limits at a given half-pulse width (see slide 25).
   - For the first design iteration choose a current density of 5000 or 10,000 A/mm^2.
3. Add steel around the copper to improve strength, electromagnetic efficiency and thermal efficiency
4. Run the FEA solver and check for 3 to 4 Tesla in the magnet regions
5. Iterate – Increase the current density or modify the conductor design if 3T is not achieved in the entire magnet volume

Magnetizing Fixture Design
Design Tips

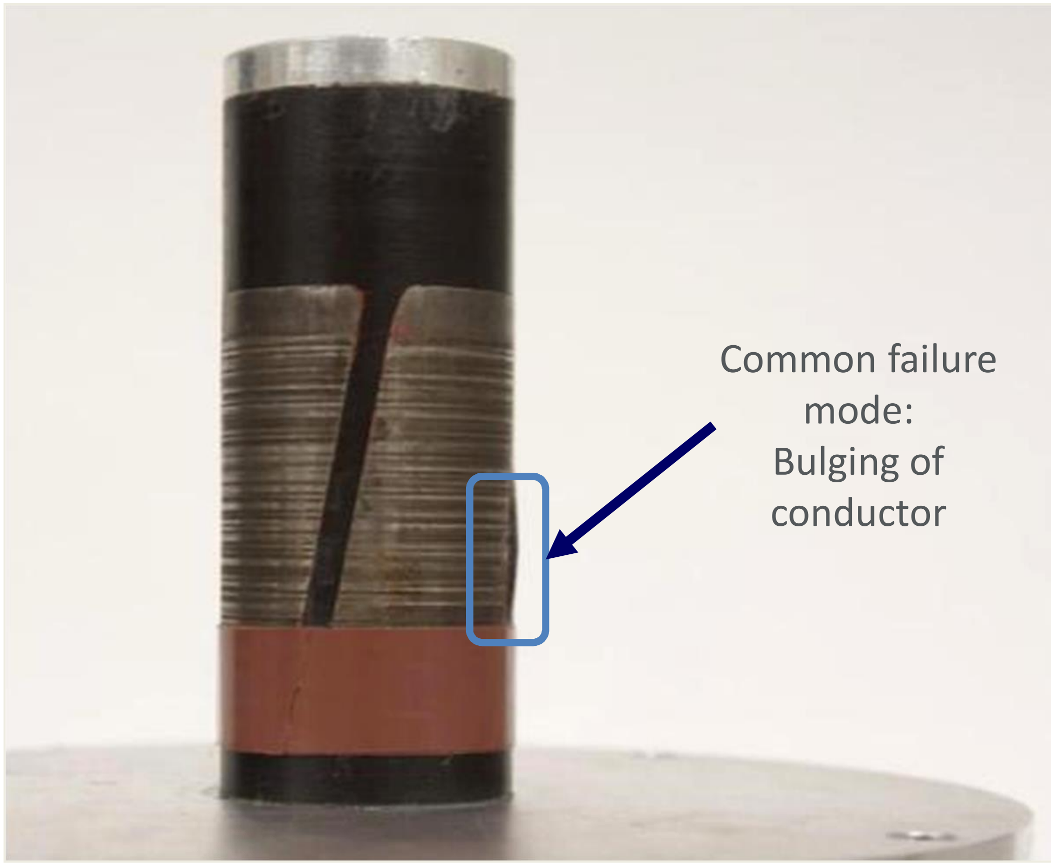
1. To minimize the effect of fixture end-turns on the magnet the axial length of the fixture should be 1-1/2 to 2 times the magnet axial length.

2. Dielectric insulation is required between the steel poles and the slot conductors to prevent short circuiting. Epoxy powder coating is the best means of insulation. Non-rigid insulation such as Polyimide film, rubber tubing, and motor winding paper should be avoided. Non-rigid items such as films and papers will vibrate and ultimately cause fixture failure.

3. Fill the voids with Epoxy for enhanced dielectric insulation and maximum mechanical strength. Use a vacuum process to ensure complete fill with epoxy.
4. Use a back-iron behind the magnet for more radial orientation. Use no back-iron behind the magnet for more Halbach orientation. Magnetization of radial orientation is achieved at lower currents due to the presence of the back-iron.
5. All steel should be laminated to reduce eddy current losses.

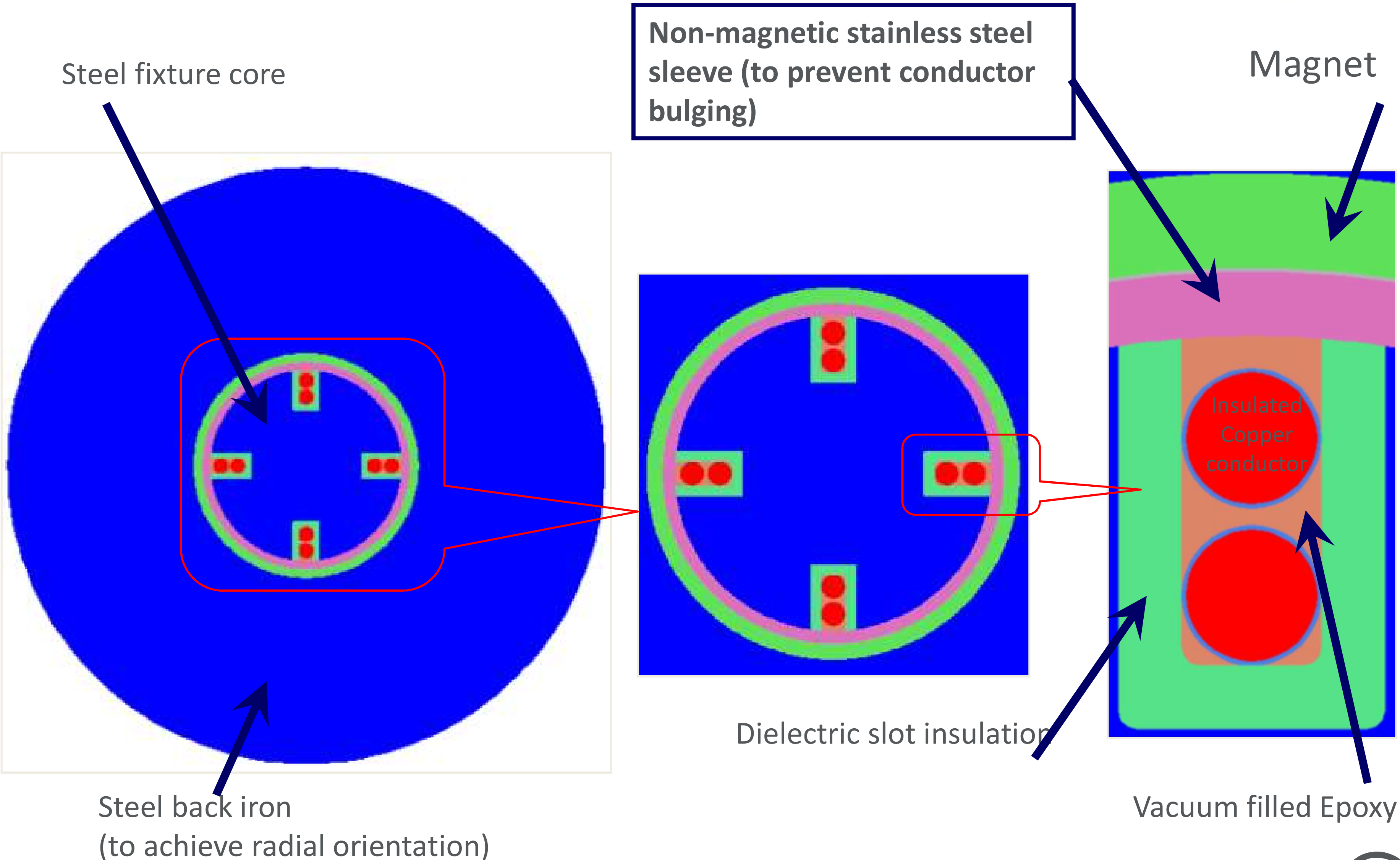
Magnetizing Fixture Design
Keeping Conductors in the Slot

Fixture conductors are subjected to extremely high forces during the magnetization pulse. Precautions should be undertaken to hold the wires in the slot.

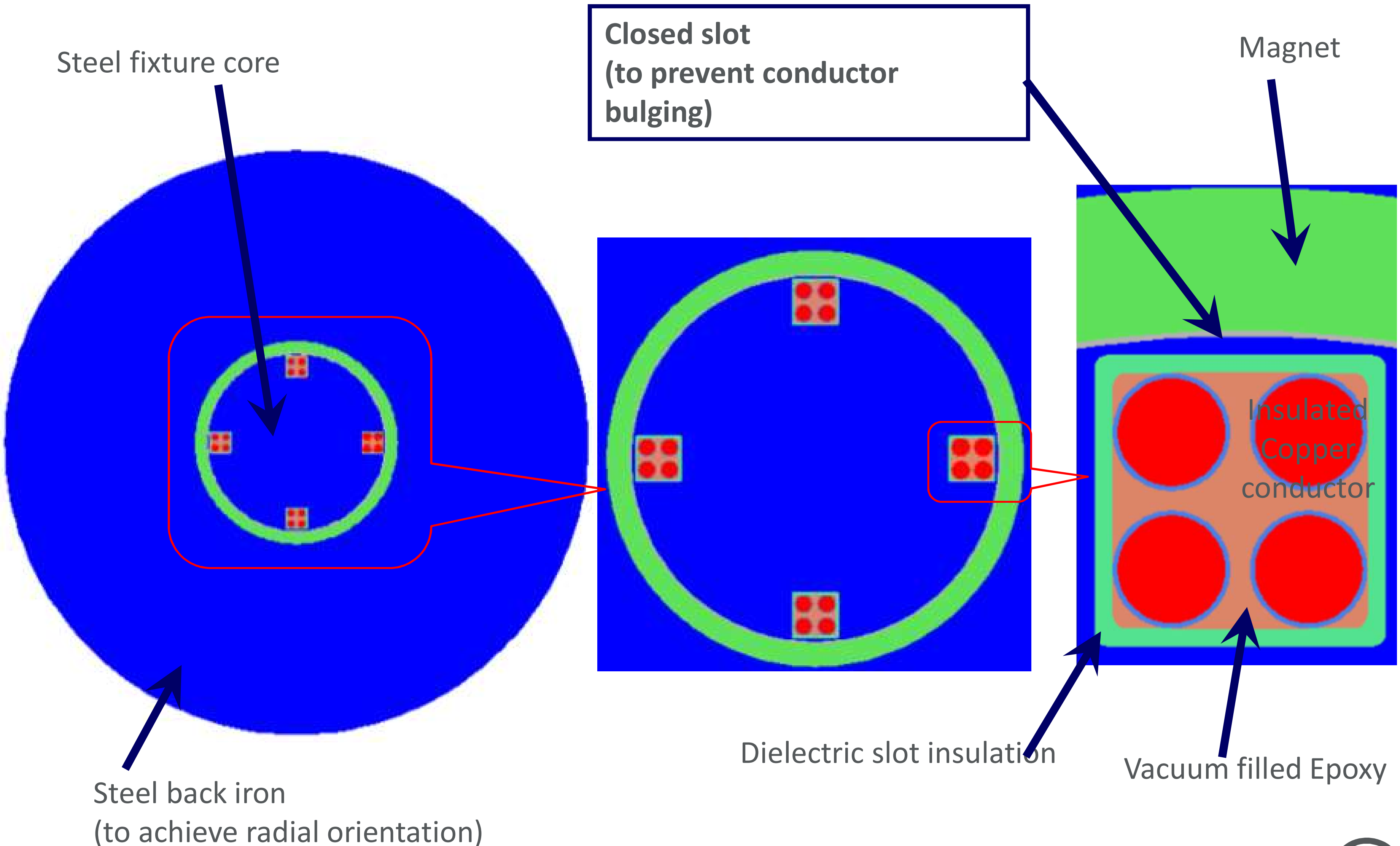


Common failure mode:
Bulging of conductor

Magnetizing Fixture Design
Keeping Conductors in the Slot: Sleeve



Magnetizing Fixture Design
Keeping Conductors in the Slot: Closed Slot



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Construction – Case #1
Magnetizing a Ring Magnet for an EPS Motor

Magnet Ring

40mm OD x 35mm ID x 60mm length

Extruded MQ3

Anisotropic – radial orientation determined during magnet manufacturing

Magnetization Requirement

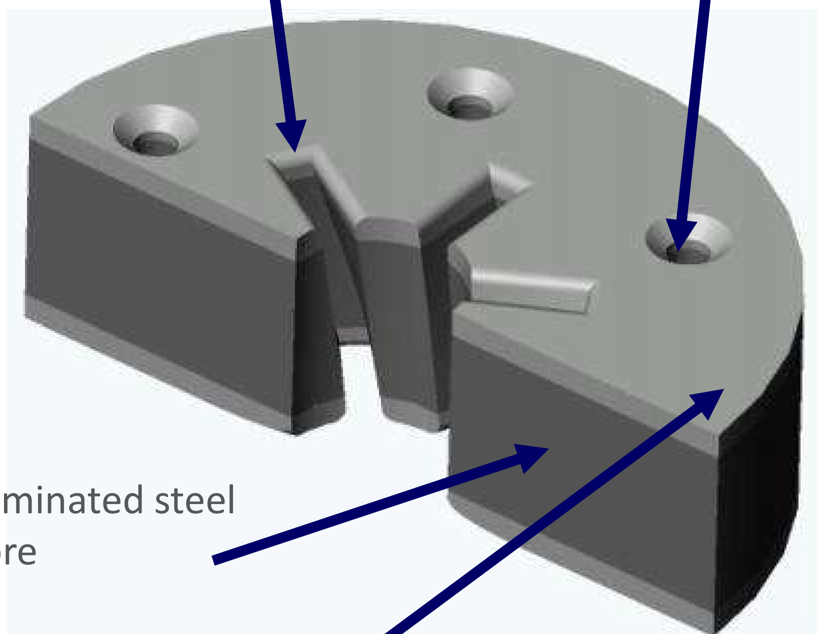
No. of Poles = 6

skew angle = 20°

Construction – Case #1
Magnetizing a Ring Magnet for an EPS Motor

Helical slots
(for skewed magnetization)

Bolt holes



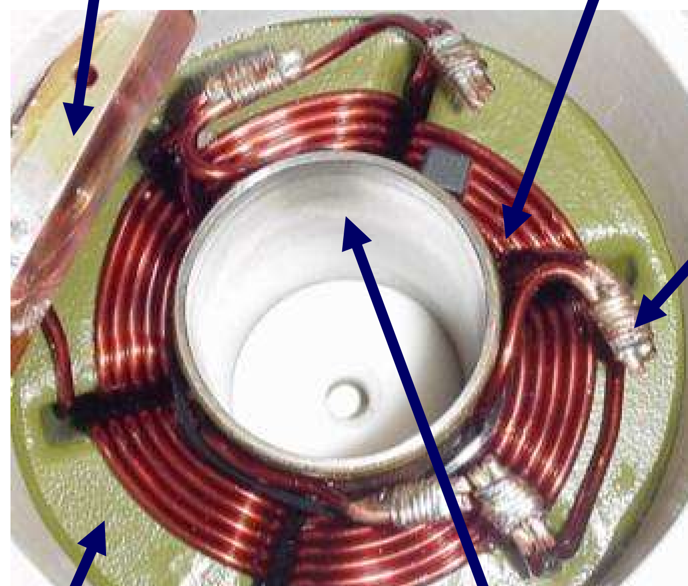
Laminated steel
core

Solid steel “clamping” plates

Solid copper bus

7 turns per pole
heavy-build magnet wire
#11 AWG

Splice



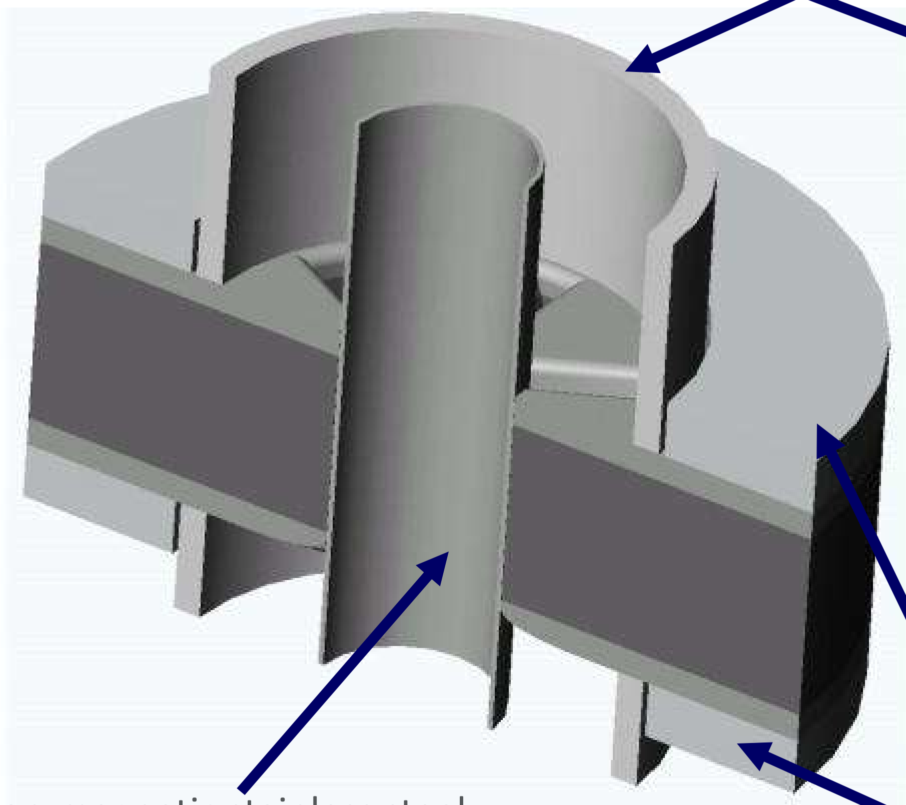
Dielectric epoxy
powder coating

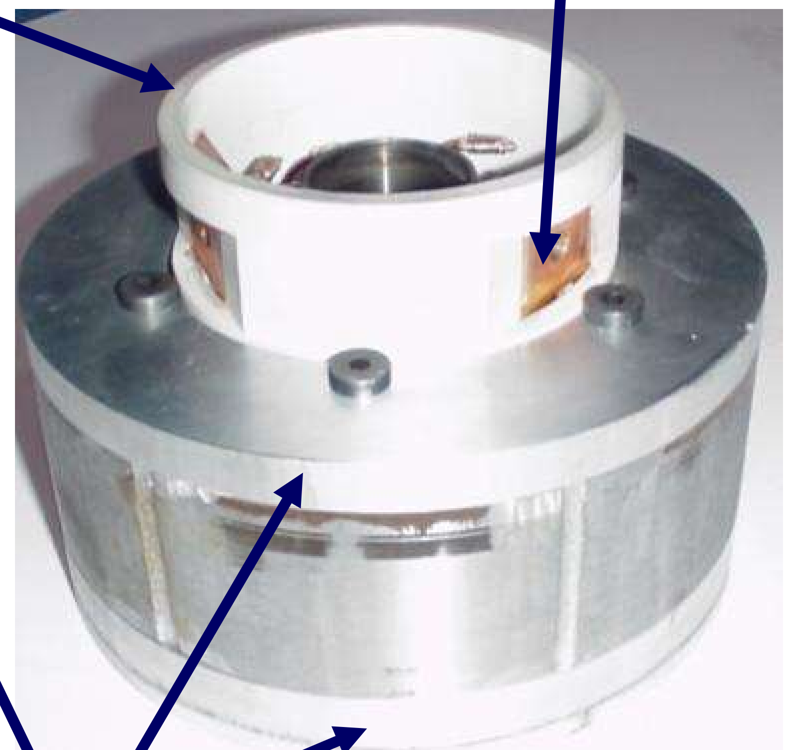
Non-magnetic stainless steel
sleeve (to prevent conductor
bulging)

Construction – Case #1
Magnetizing a Ring Magnet for an EPS Motor

potting dam

solid copper bus



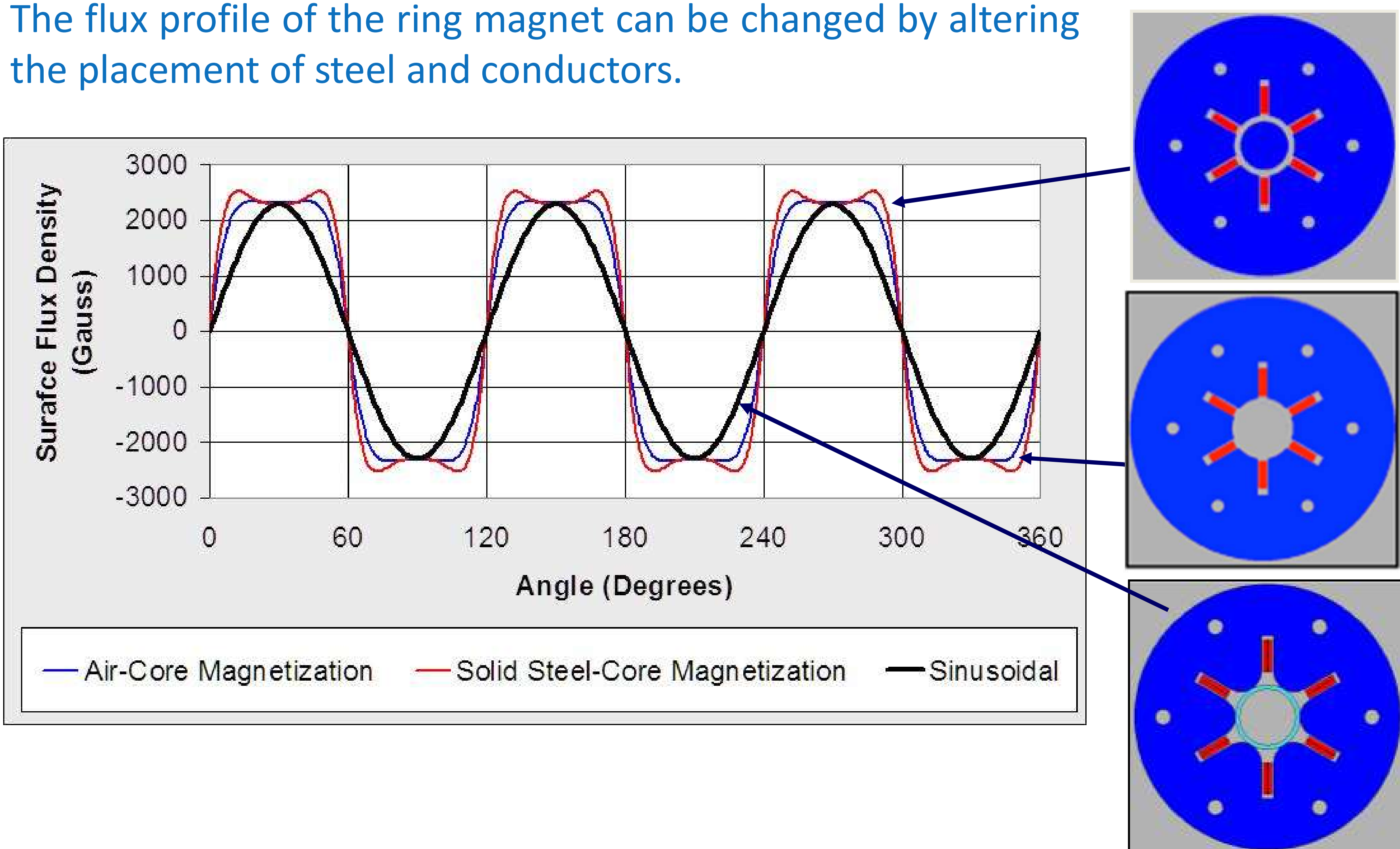


Non-magnetic stainless steel sleeve (to prevent conductor bulging)

aluminum cooling plates
(water channels may be added)

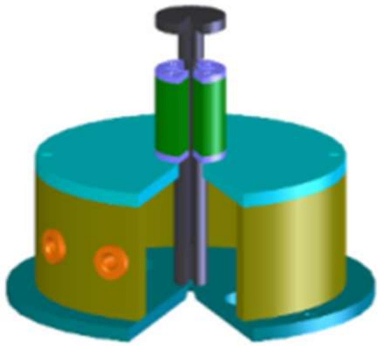
Construction – Case #1
Magnetizing a Ring Magnet for an EPS Motor

The flux profile of the ring magnet can be changed by altering the placement of steel and conductors.



Construction – Case #2
Isotropic Bonded Neo Ring - Automotive Seat Motor

Solid Model of Assembly



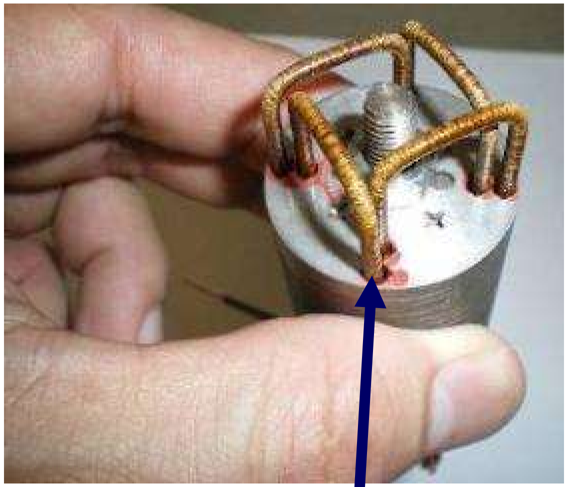
4 Pole magnetization on inside diameter of 30mm diameter ring

Time to peak current ≈ 100μs

Peak current density = 20,000 A/mm^2

M15 #29AWG silicon steel laminations

Insulated Copper wire
Wire Size = AWG13



2 Turns per slot
Closed slot design

Solid Copper Bus
(cable-free design)

Construction – Case #2
Isotropic Bonded Neo Ring - Automotive Seat Motor

Containment Sleeve for epoxy

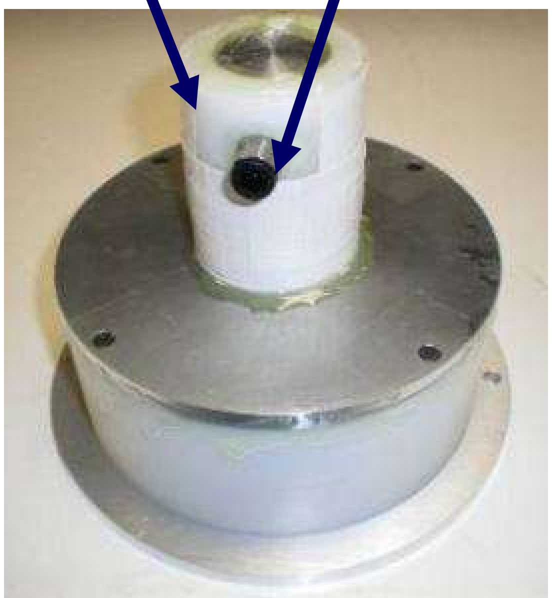
Epoxy inlet port

Vents

Vacuum-chamber

Aluminum container for epoxy reservoir

Cured Epoxy



Fixture is sealed and ready for vacuum potting of epoxy

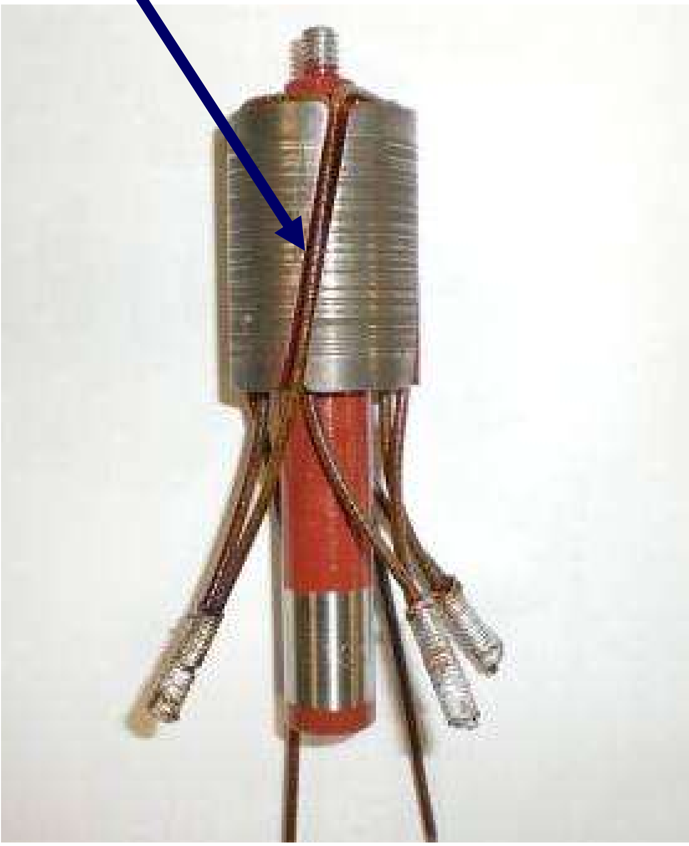
Fixture in vacuum chamber

Completed Fixture

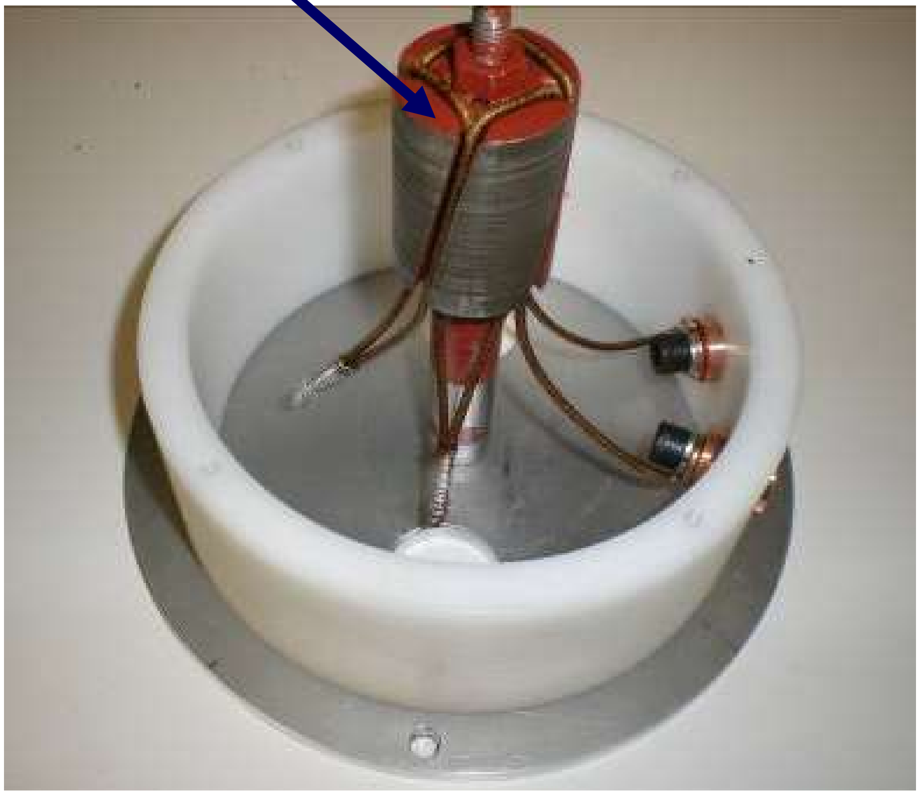
Construction – Case #3
Skewed Isotropic Bonded Neo Ring

Open Slot design with Conformal Coating Dielectric

18° Skew slot fixture



Conformal coating in orange



Fixture still requires vacuum potting in epoxy

Presentation Outline

1. Magnetizing Systems
2. Fixture Design
3. Construction
4. **Testing**
5. Design Study

Testing

Determining whether the fixture achieves full magnetization

Important

Proper testing of a fixture's performance is extremely important.
Testing must be undertaken to determine if full magnetization is achieved.

Testing

The saturation Curve

Important

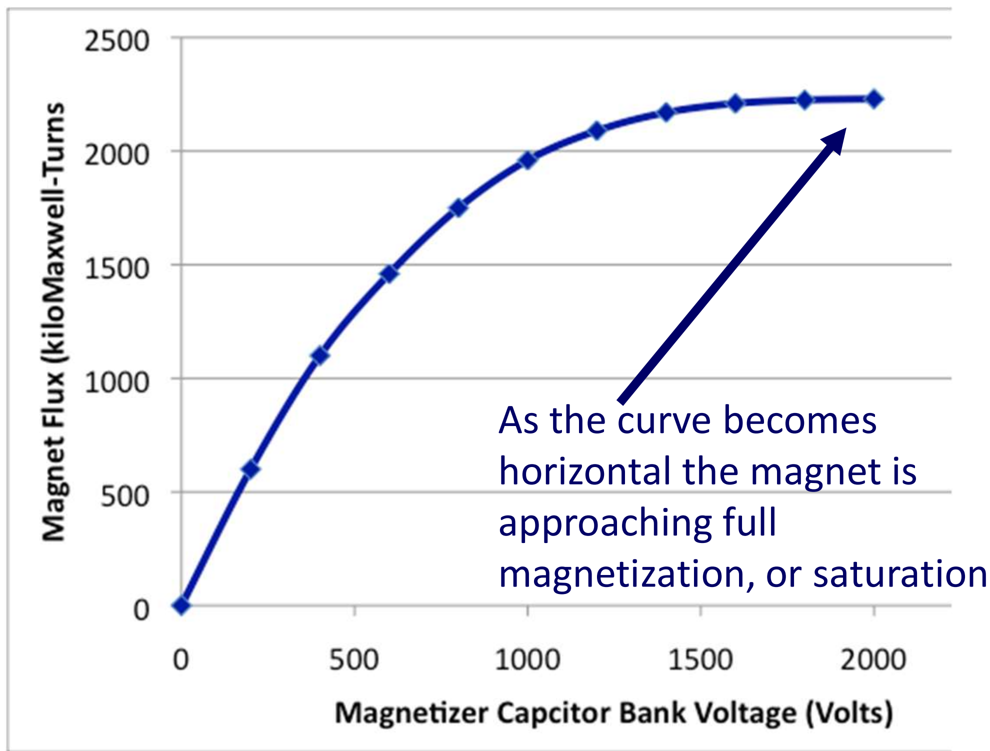
A saturation curve should always be measured for any new fixture design or anytime a new magnet or new magnet material is used on an existing fixture.

To generate a saturation curve any measure of magnet performance is charted incrementally as magnetizer charge voltage is increased.

If the curve does not approach horizontal, then the fixture does not produce enough applied field to fully magnetize the magnet.

Suitable measures of magnet performance include:

1. Magnet flux
2. Magnet flux density
3. Motor back-emf at a fixed speed

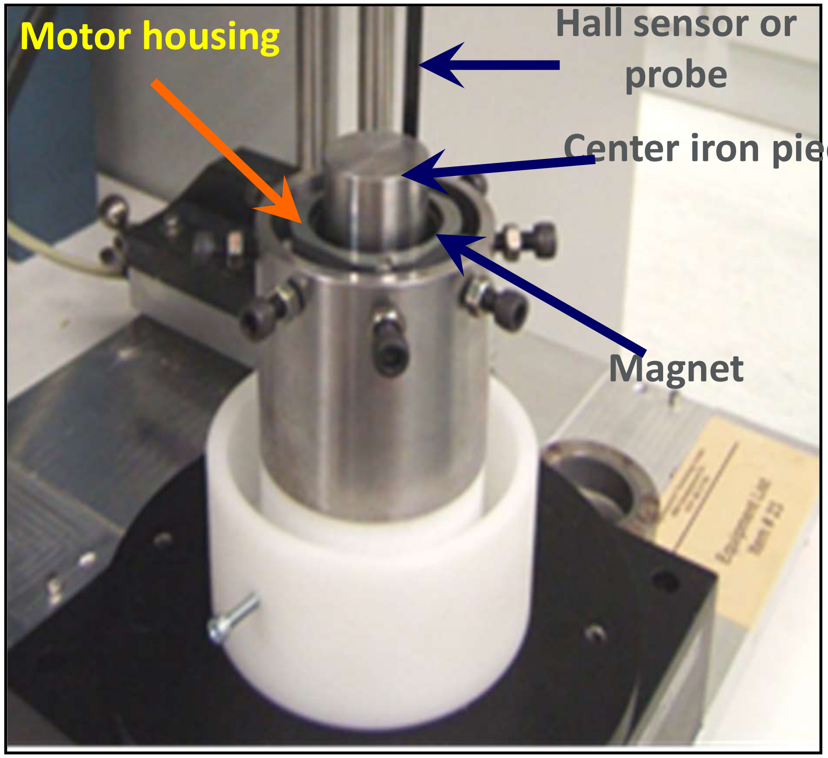


Testing – Example #1

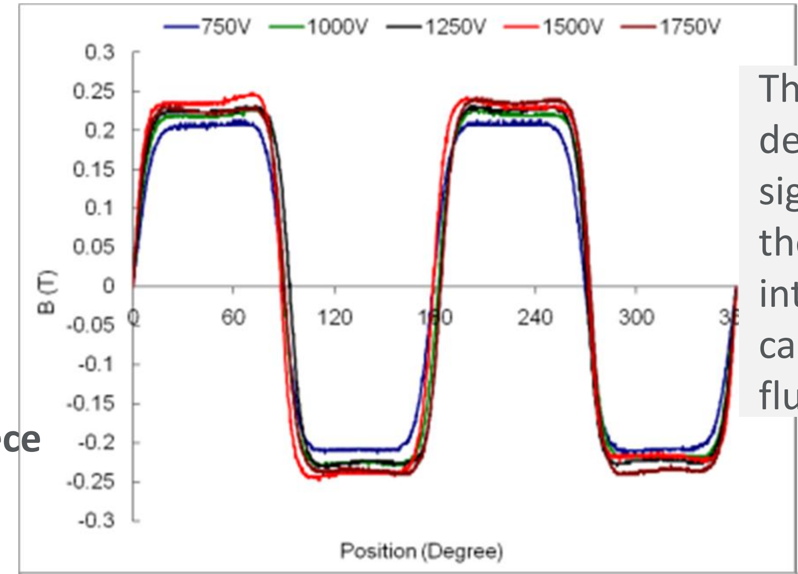
Determining whether the fixture achieves full magnetization

Using Air gap Flux Density Scan to Check Saturation

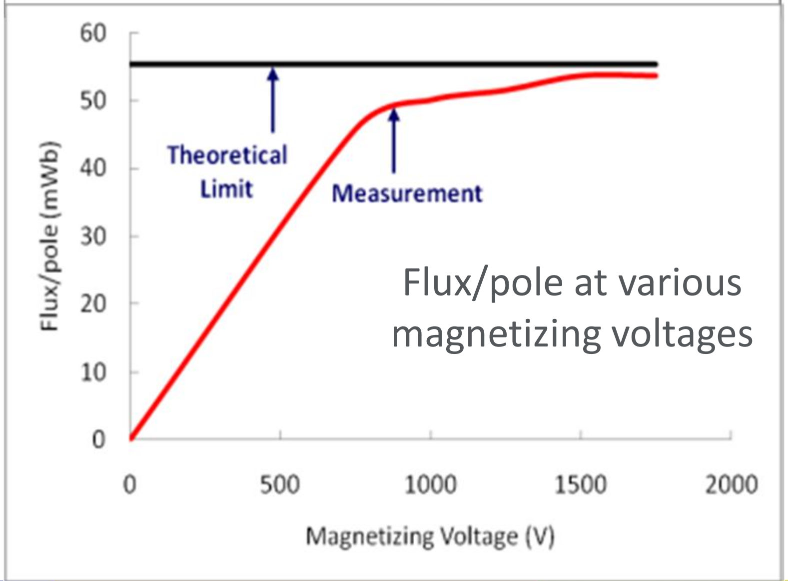
The scan is made after charging at each voltage increment



Slotless-Core Air-Gap Flux Scan



The flux density signal from the scan is integrated to calculate flux/pole



Testing – Example #2

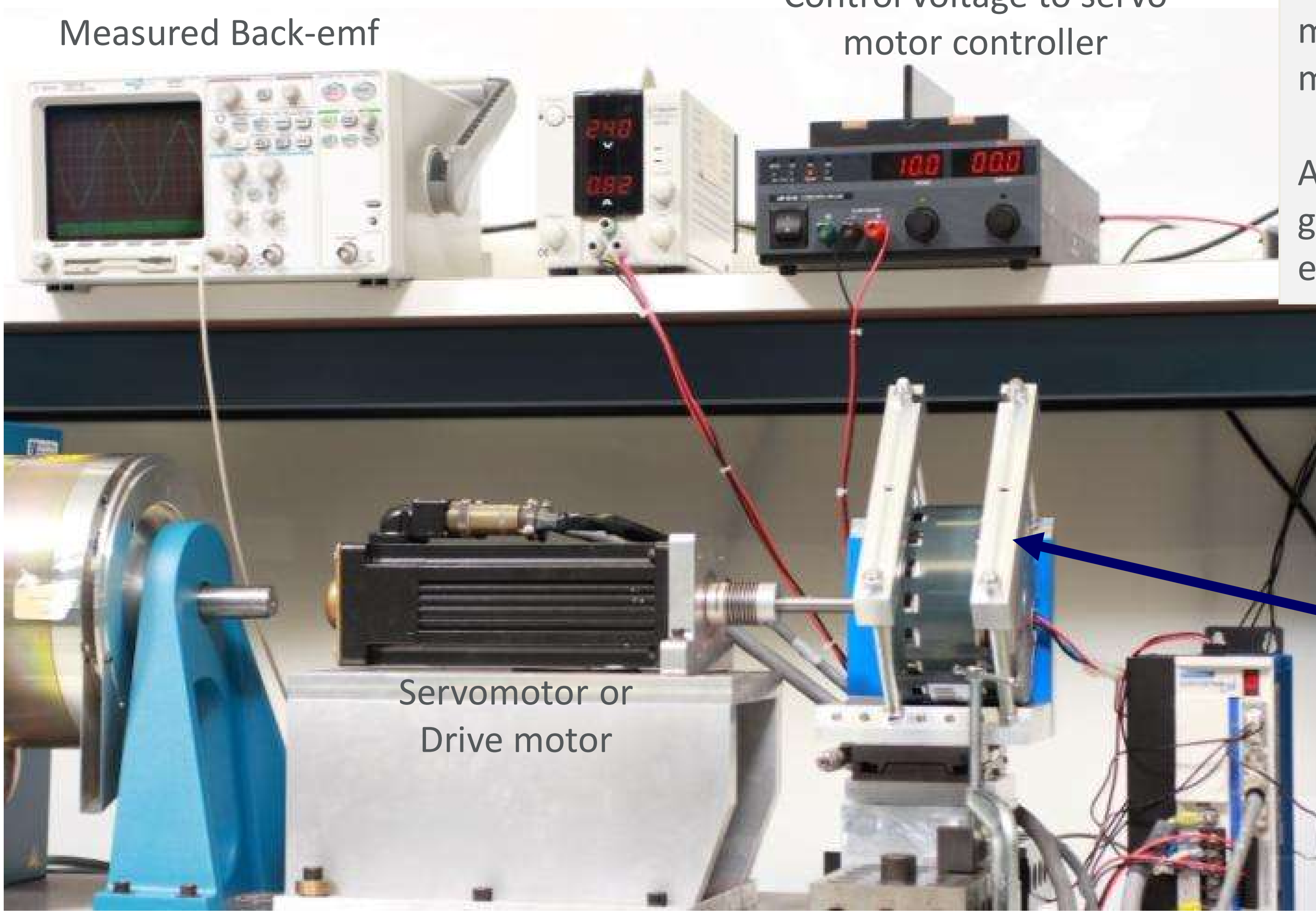
Determining whether the fixture achieves full magnetization

Back emf can be used to measure whether a magnet is fully magnetized.

A saturation curve can be generated using back-emf data.

Measured Back-emf

Control voltage to servo motor controller



Motor on Test

Servomotor or Drive motor

Servo motor controller

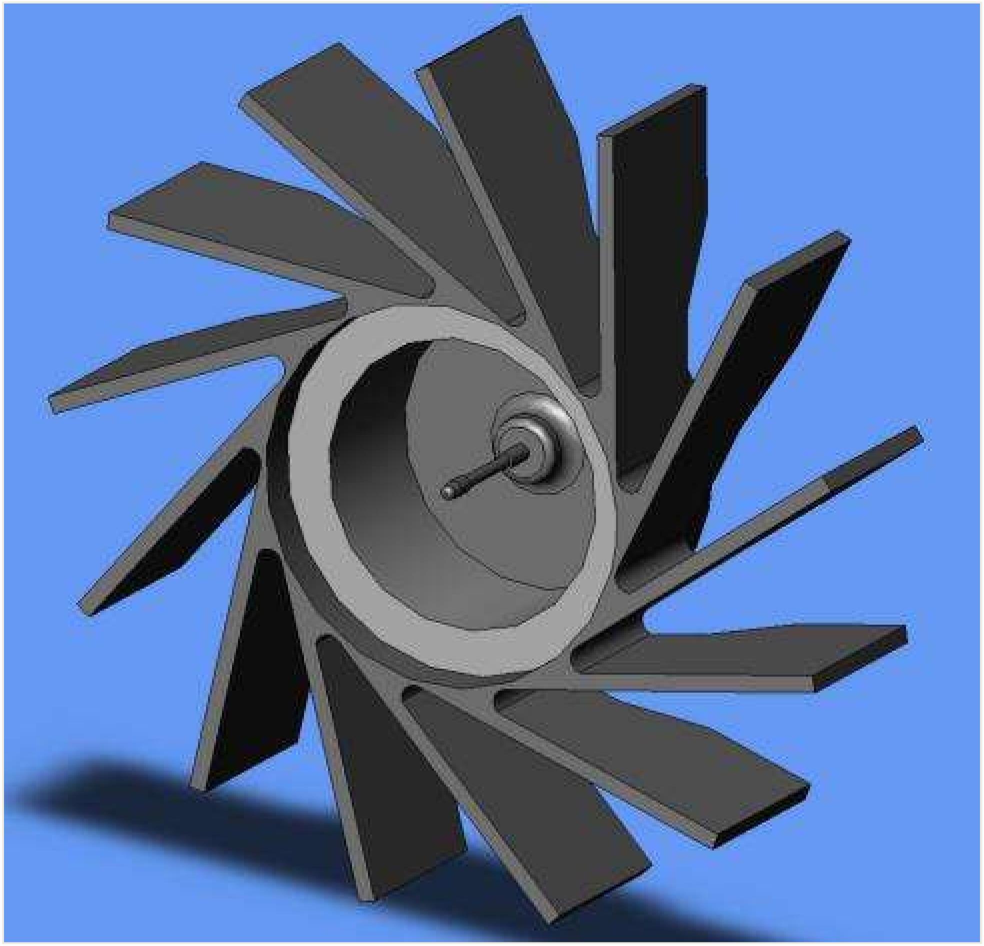
Presentation Outline

1. Magnetizing Systems
2. Fixture Design
3. Construction
4. Testing
5. **Design Study**

Design Study
In-situ Magnetization of Fan Assembly

4-pole radial magnetization of a bonded Neo ring magnet.

Magnetization must take place while the magnet ring is in the rotor assembly.



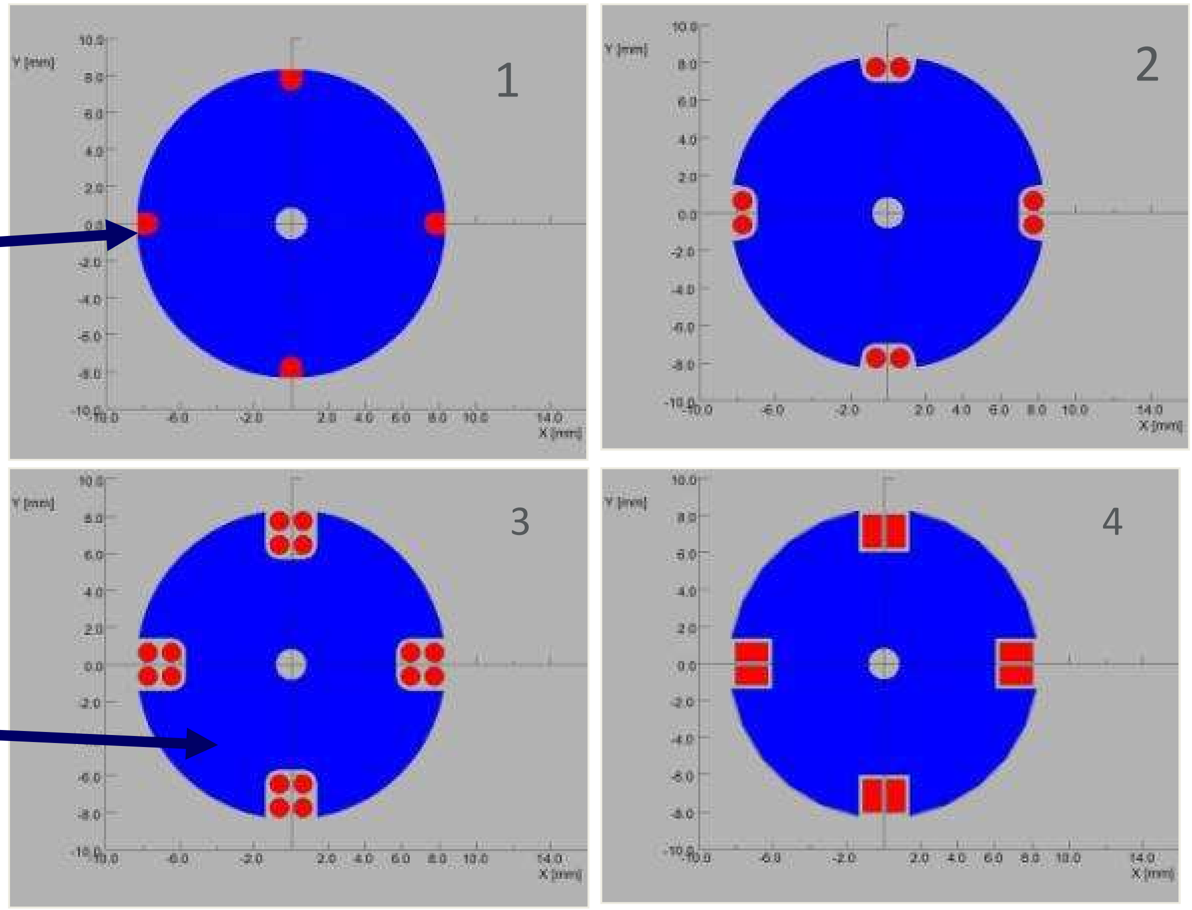
Design Study
iterations to optimize the conductor design

neo Magnequench

Six (6) design iterations were modeled in 2D. The first four (4) are pictured.

Conductors @ 20kA/mm^2

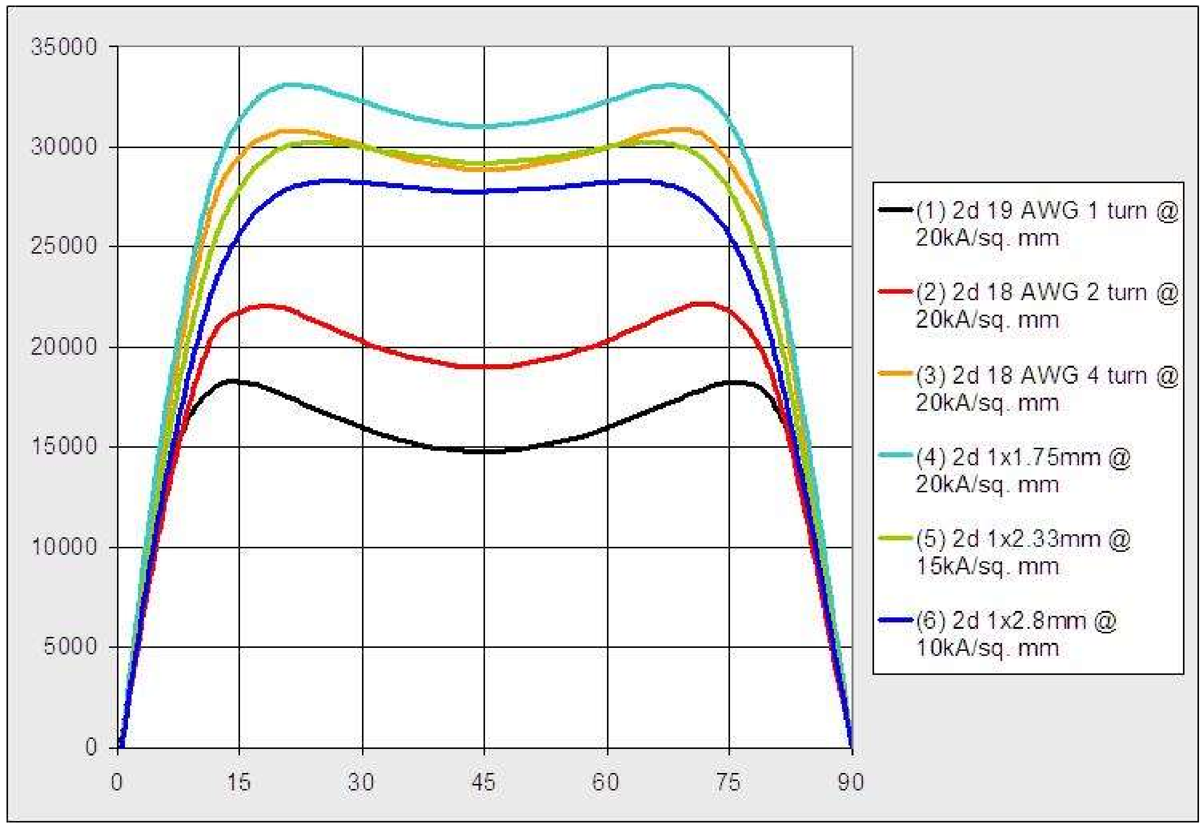
Magnetizing fixture laminations



Design Study
Checking the flux density at the back of the magnet

FEA data for 6 design concepts.

Design concept 5 produces 30,000 Oersteds at the back of the magnet at a current density of 15,000 A/mm^2. This is judged to be sufficient.



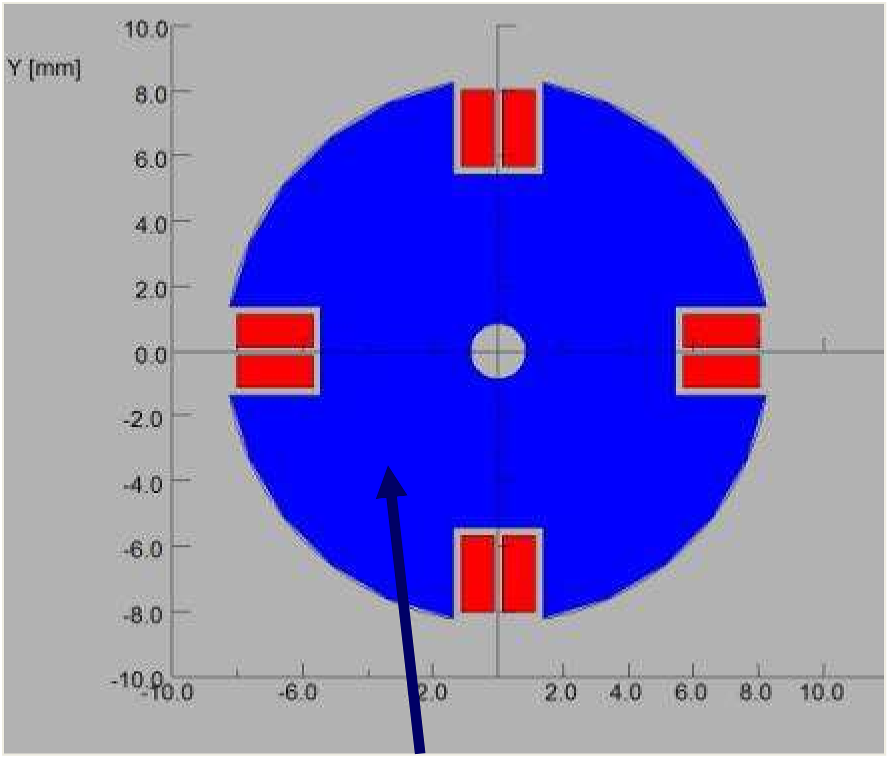
Design Study
Details of Chosen Design

2 conductors per slot

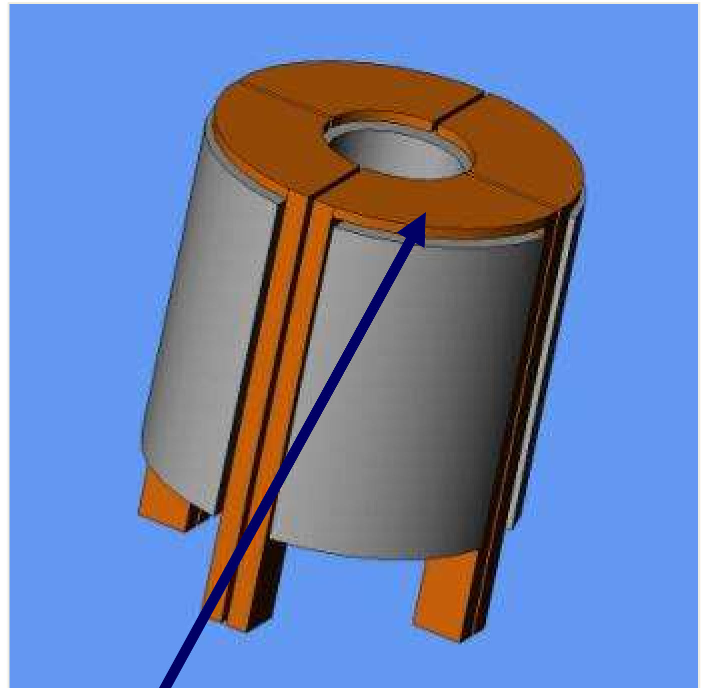
Rectangular conductor – 1mm x 2.33mm

Operate at 15,000A/mm^2 (Current Density in flat end-turns will be 20,000)

Total current per slot = 69.9kA

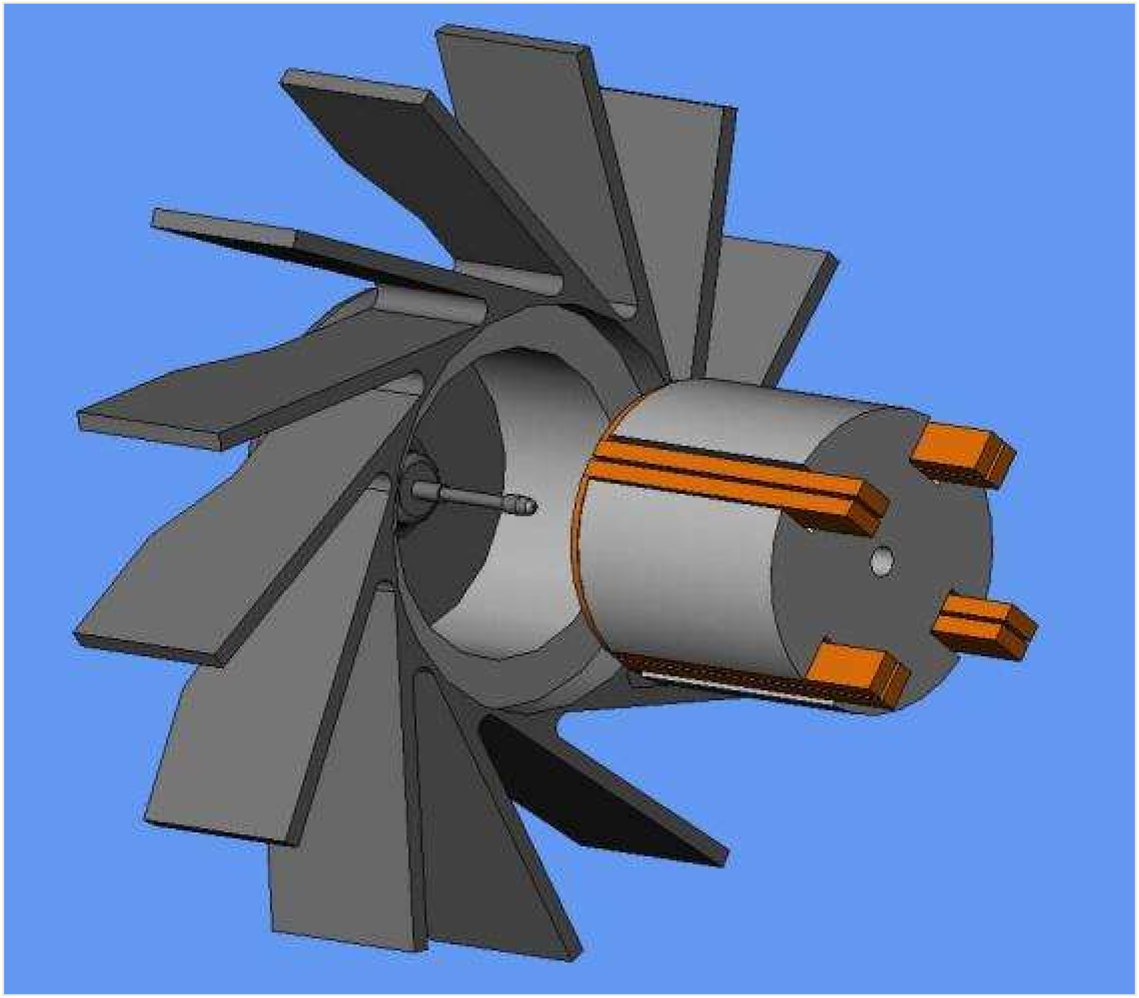


Laminated steel



Flat end-turns due to in-situ magnetization

Design Study
Simple 3D Model and Fan Assembly



Please contact Magnequench for assistance with any magnetization or applications issues

Thank You!