MDP Modeling Working Group Meeting

Modeling Transient Forces in Hybrid Tests

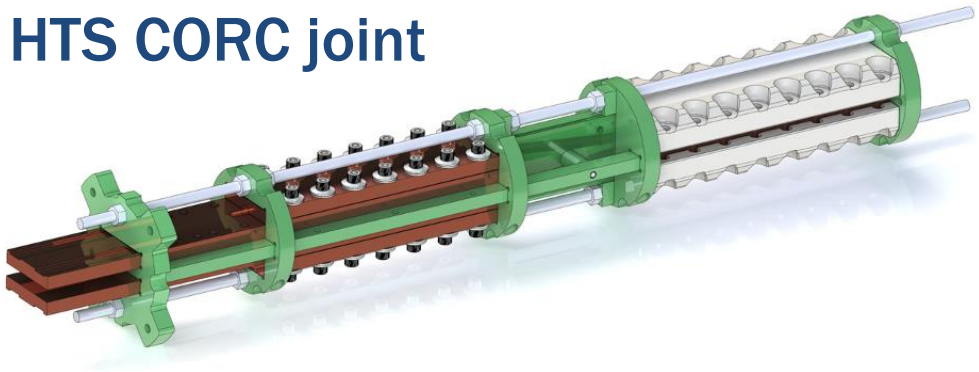
March 5th, 2024

Lucas Brouwer, Reed Teyber, Diego Arbelaez, Laura Garcia Fajardo, and Tengming Shen

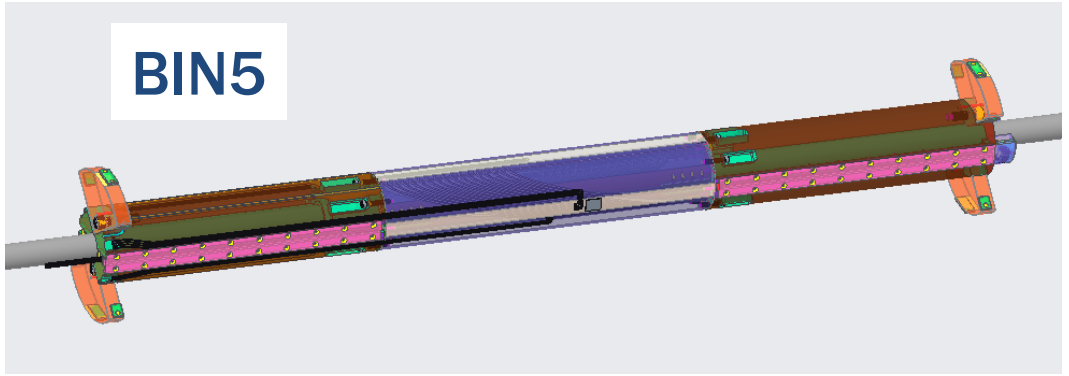
Motivation

Two upcoming hybrid tests in the 90 mm, ~8 T dipole magnet CCT5 place metallic material in regions of spatially changing field which see high dBdt during extraction (leading to net transient force)

HTS CORC joint



BIN5



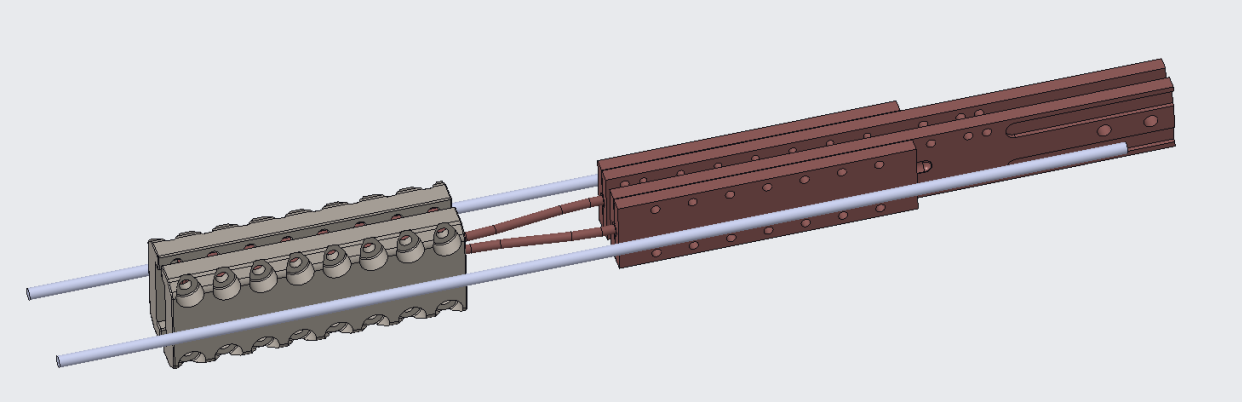
What is the impact of transient forces due to eddy currents in this conducting material?

Testing of demountable CORC joints in CCT5 for fusion applications

PAPER

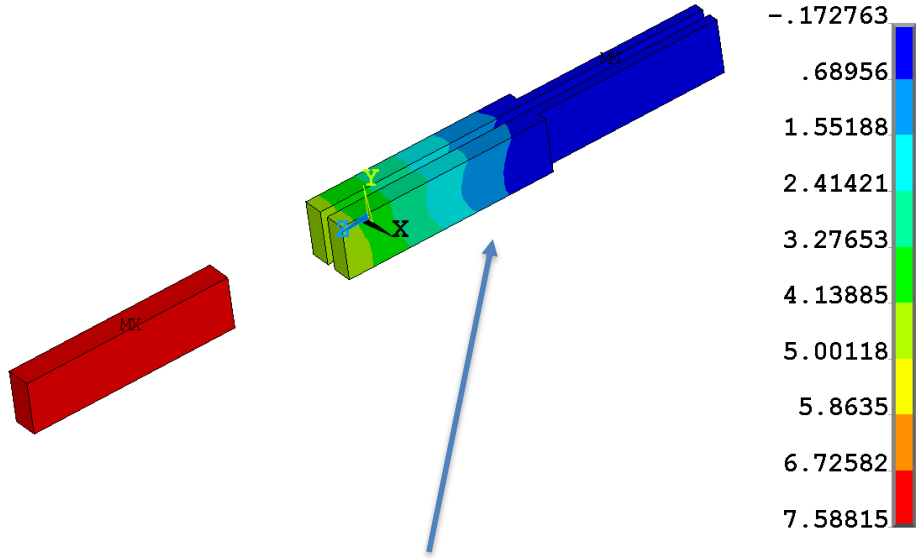
Performance of low-loss demountable joints between CORC® cable-in-conduit-conductors at magnetic fields up to 8 T developed for fusion magnets

To cite this article: Jeremy D Weiss *et al* 2023 *Supercond. Sci. Technol.* **36** 085002



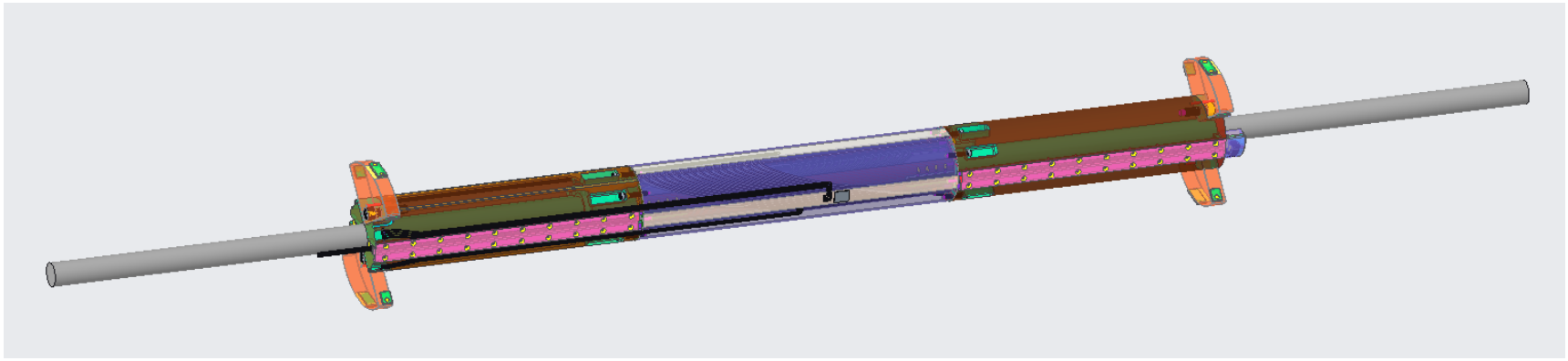
Reed Teyber

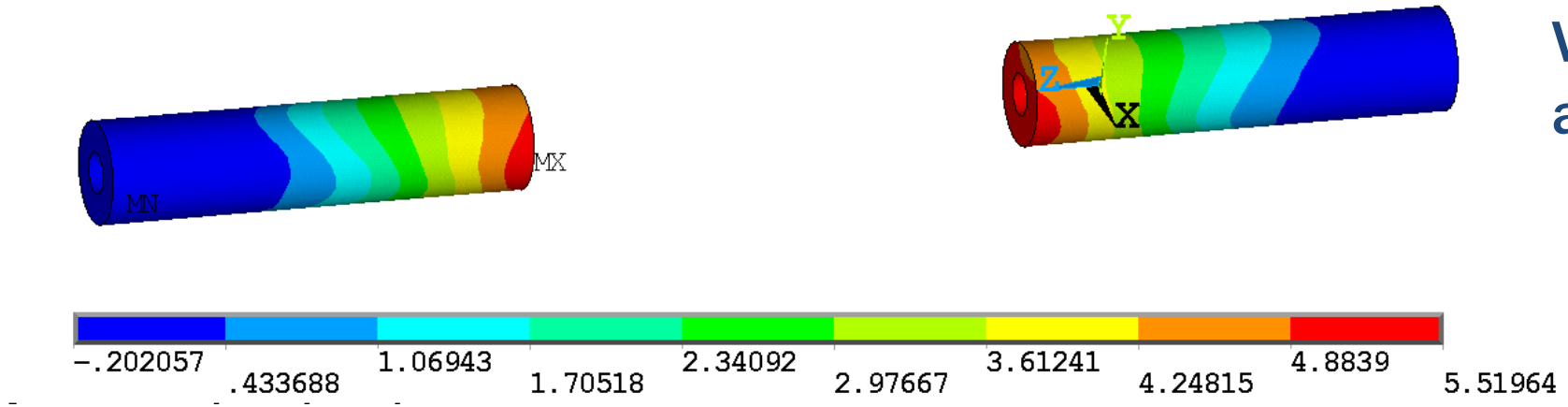
Vertical field on the joint in CCT5



Field gradient on high RRR copper

Testing of BIN5 in CCT5





Vertical field on the aluminum extensions

Laura Garcia Fajardo / Tengming Shen

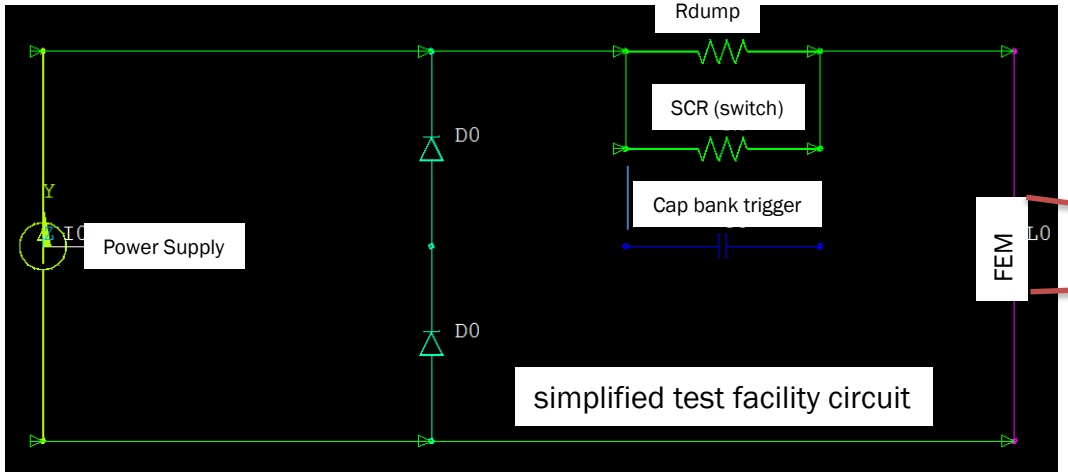
Overview

- **transient electromagnetic modeling approach in ANSYS to determine dynamic forces from eddy currents**
- model/results for the planned GA CORC joint test in CCT5
- model/results for the planned BIN5 test in CCT5

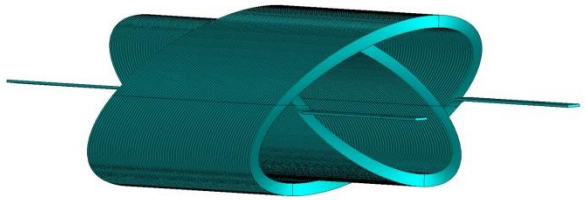
Existing 3D magnetic model in ANSYS for CCT5

ANSYS solves the coupled electric-magnetic problem to predict the current decay of the magnet in the test facility circuit

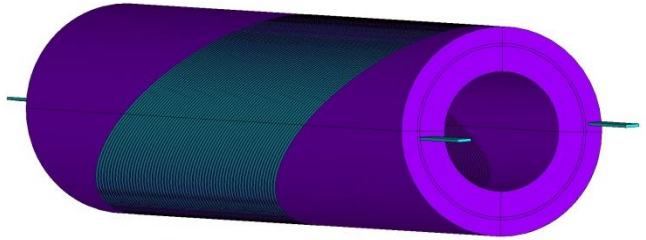
- no assumptions about the magnet inductance or decay curve (part of simulation)
- no quench resistance growth or conductor losses (only structure eddy currents for now)
- Soild97 (A,curr,emf), Circu124 (V,curr,emf), Solid237 (Az,V,emf)

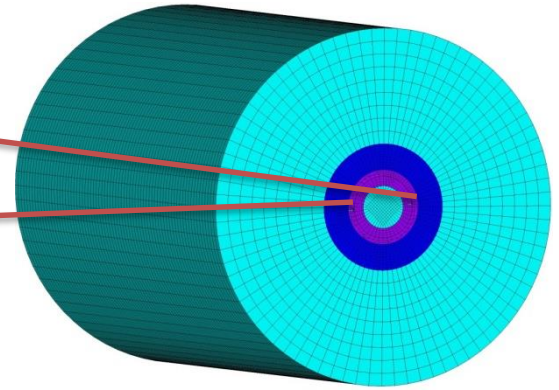


conductor layers



conductor and Al-bronze mandrels

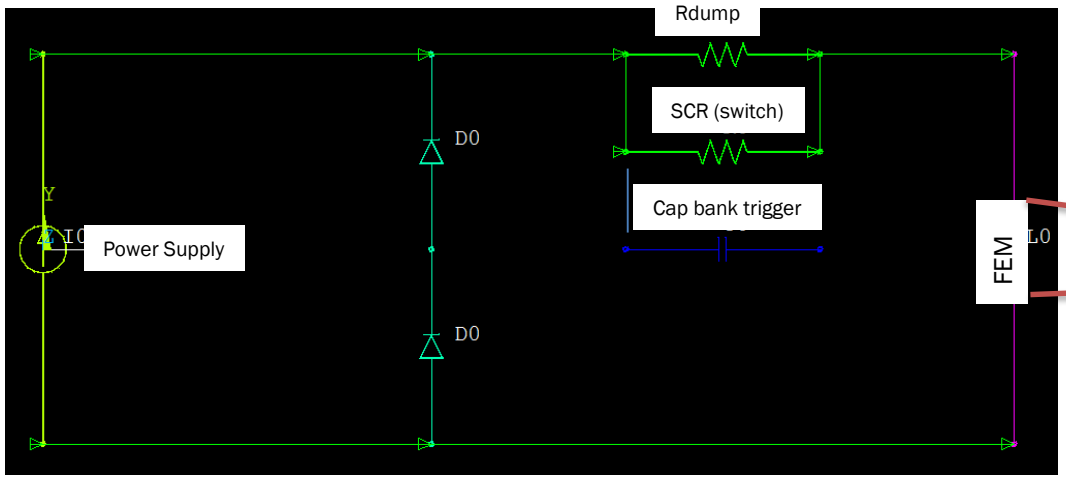




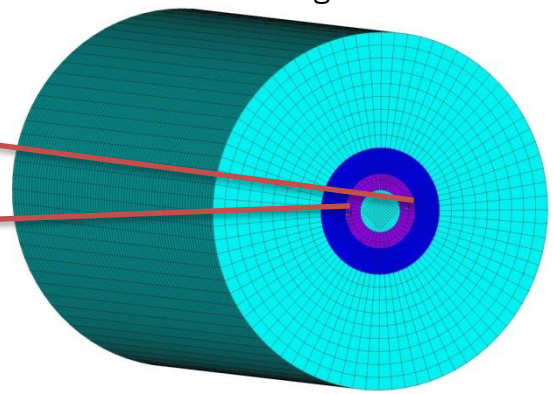
FEM: Layers, shell, bounding box for magnetic B.C.

Circuit-Coupled Eddy Current Models

The finite element mesh (full or periodic) is coupled to a simplified test facility circuit



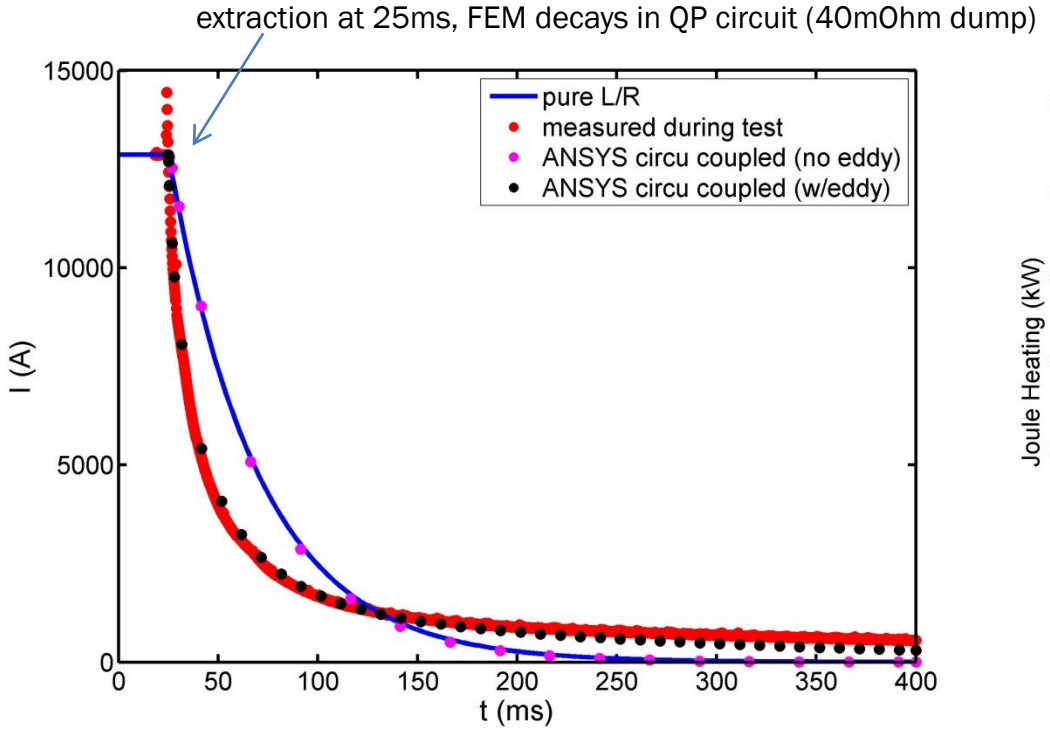
FEM: Layers, shell, bounding box for magnetic B.C.

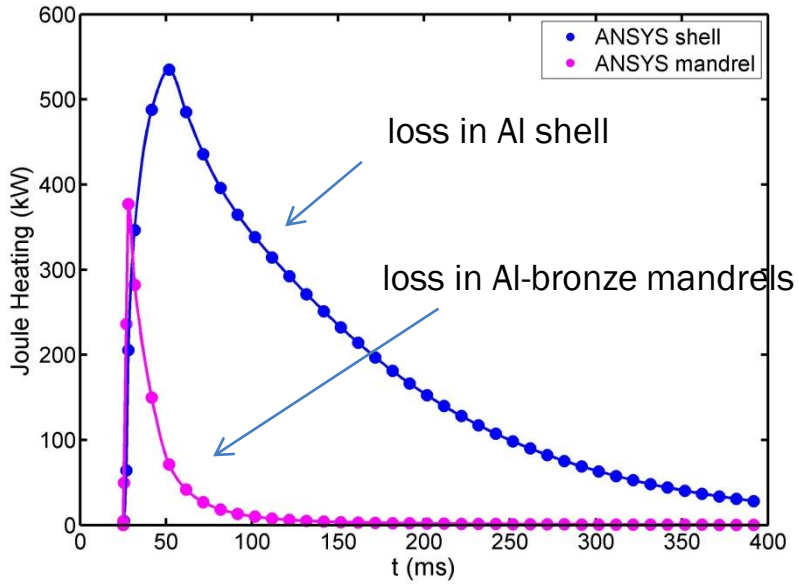


ANSYS solves the coupled electric-magnetic problem to predict the current decay of the magnet in the test facility circuit

- no assumptions about the magnet inductance or decay curve (part of simulation)
- no quench resistance growth or conductor losses (only structure eddy currents for now)

This 3D model agrees with standalone test of CCT5 and answered the critical question of how coupling to the aluminum shell impacts extraction



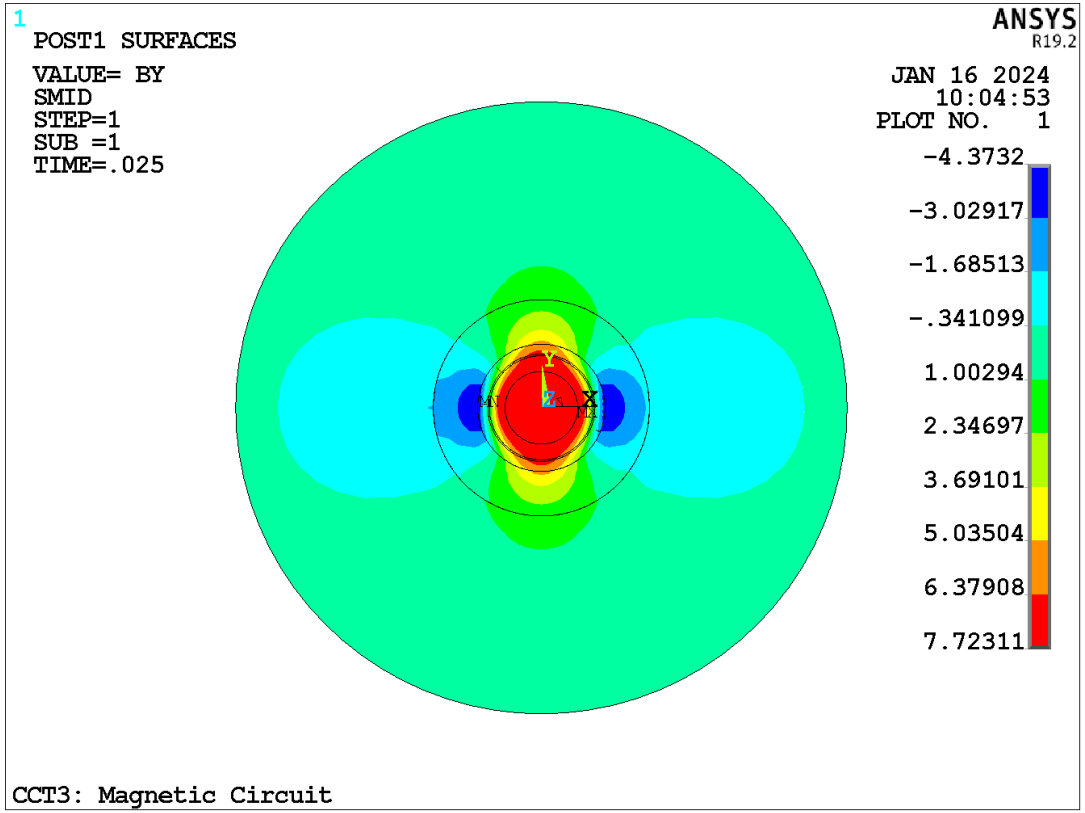


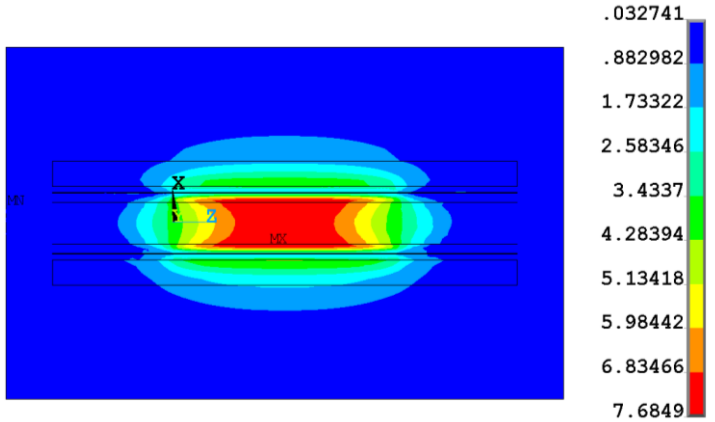
	MIITS	Edump (kJ,%)	Eshell (kJ,%)	Eman (kJ,%)
ANSYS (no eddy)	3.76	150 (100%)	0	0
ANSYS (eddy)	1.80	72 (47%)	70 (46%)	7 (5%)
Test Data	1.76	71 (47%)	unknown	unknown

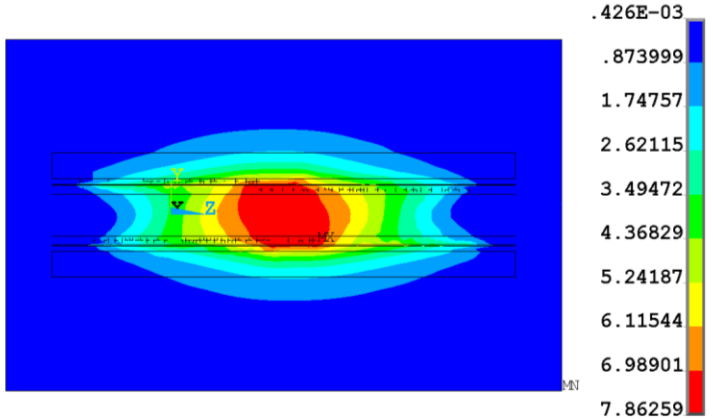
- MIITS is halved due to eddy losses
- 52% of the stored energy is dissipated by eddy currents, the majority of which is in the shell

Assumptions for CCT5 during the insert testing

- 15.5 kA starting current (7.7 T in model – with no iron)
- Extraction with 40 mOhm dump



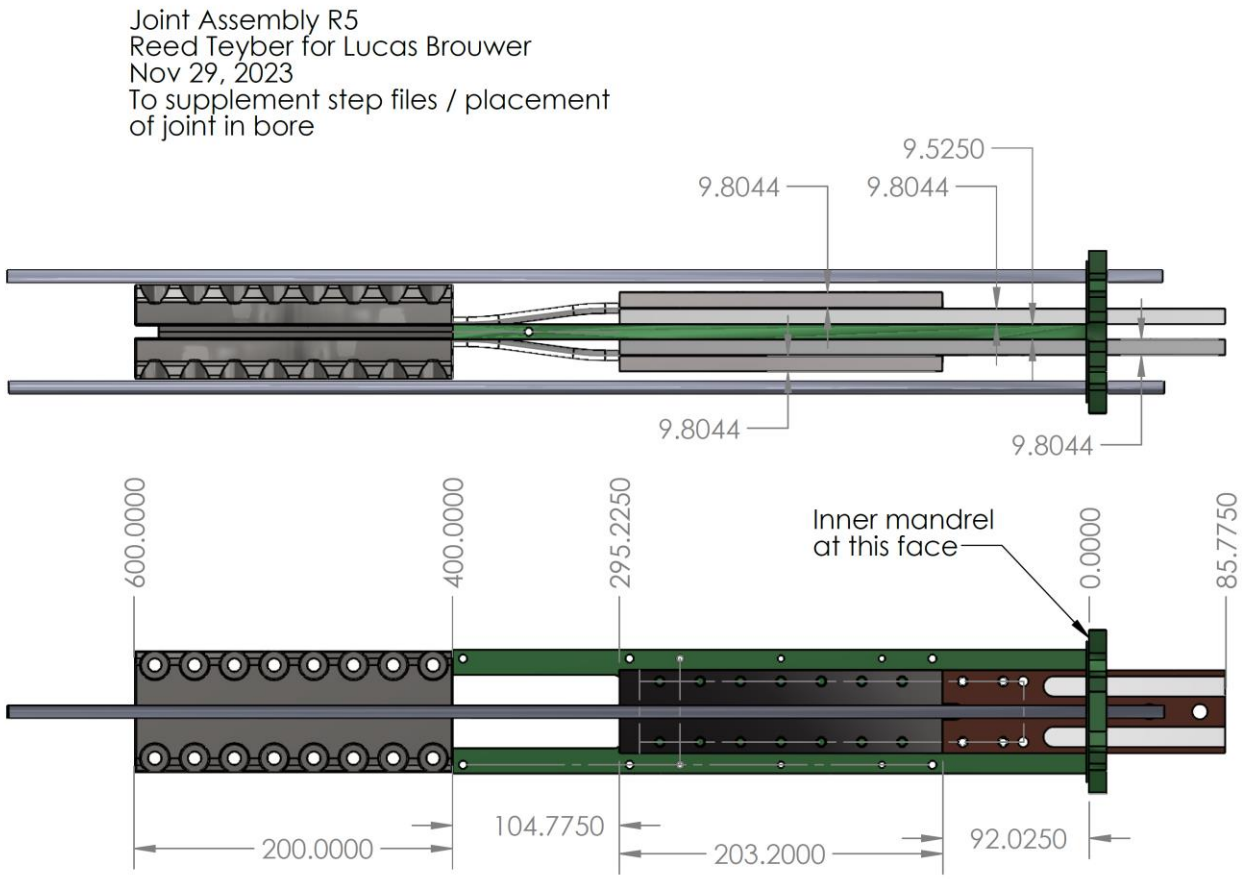


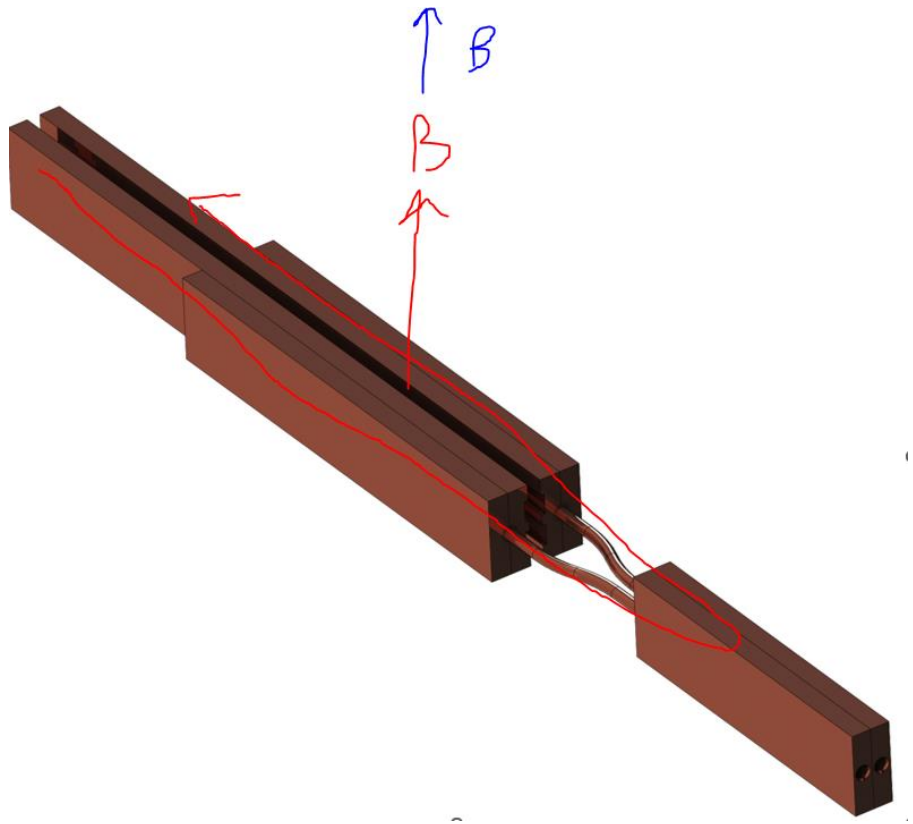


Overview

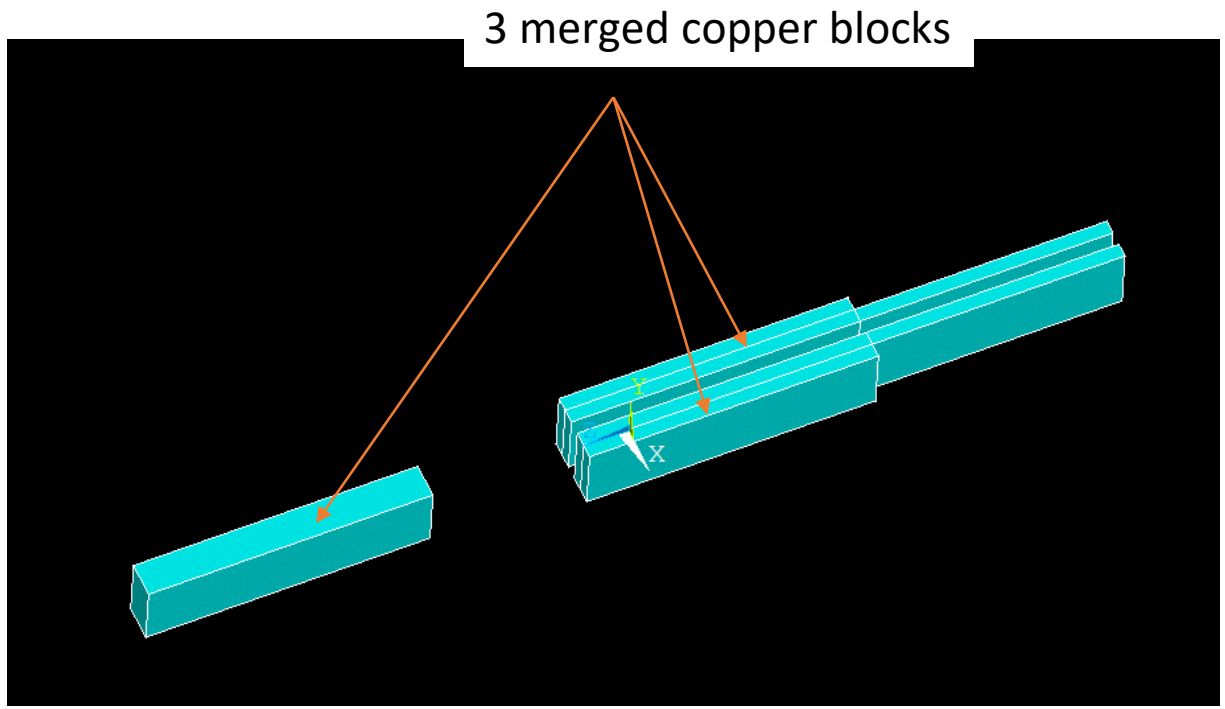
- transient electromagnetic modeling approach in ANSYS to determine dynamic forces from eddy currents
- **model/results for the planned GA CORC joint test in CCT5**
- model/results for the planned BIN5 test in CCT5

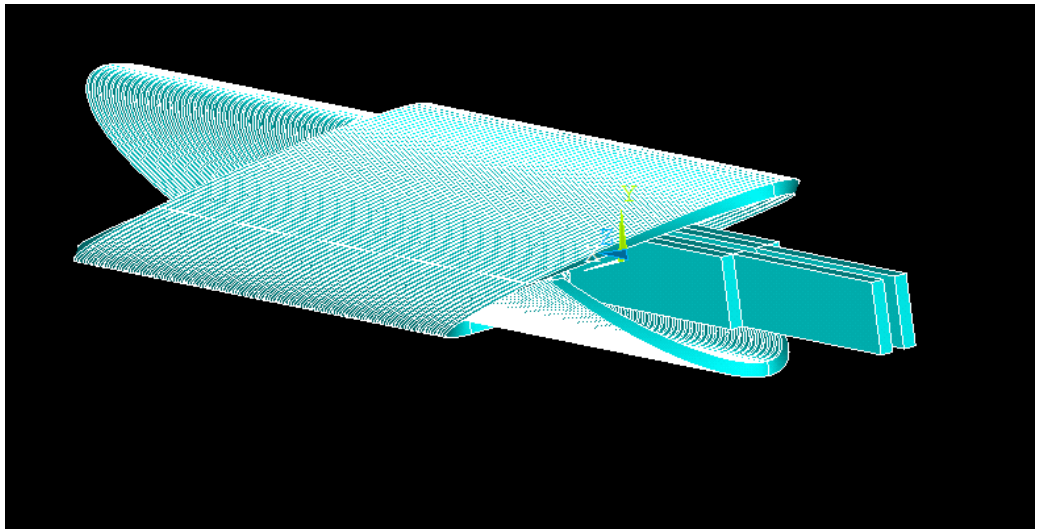
Assumptions for the GA Joint Simulation





Assumptions for the GA Joint Simulation

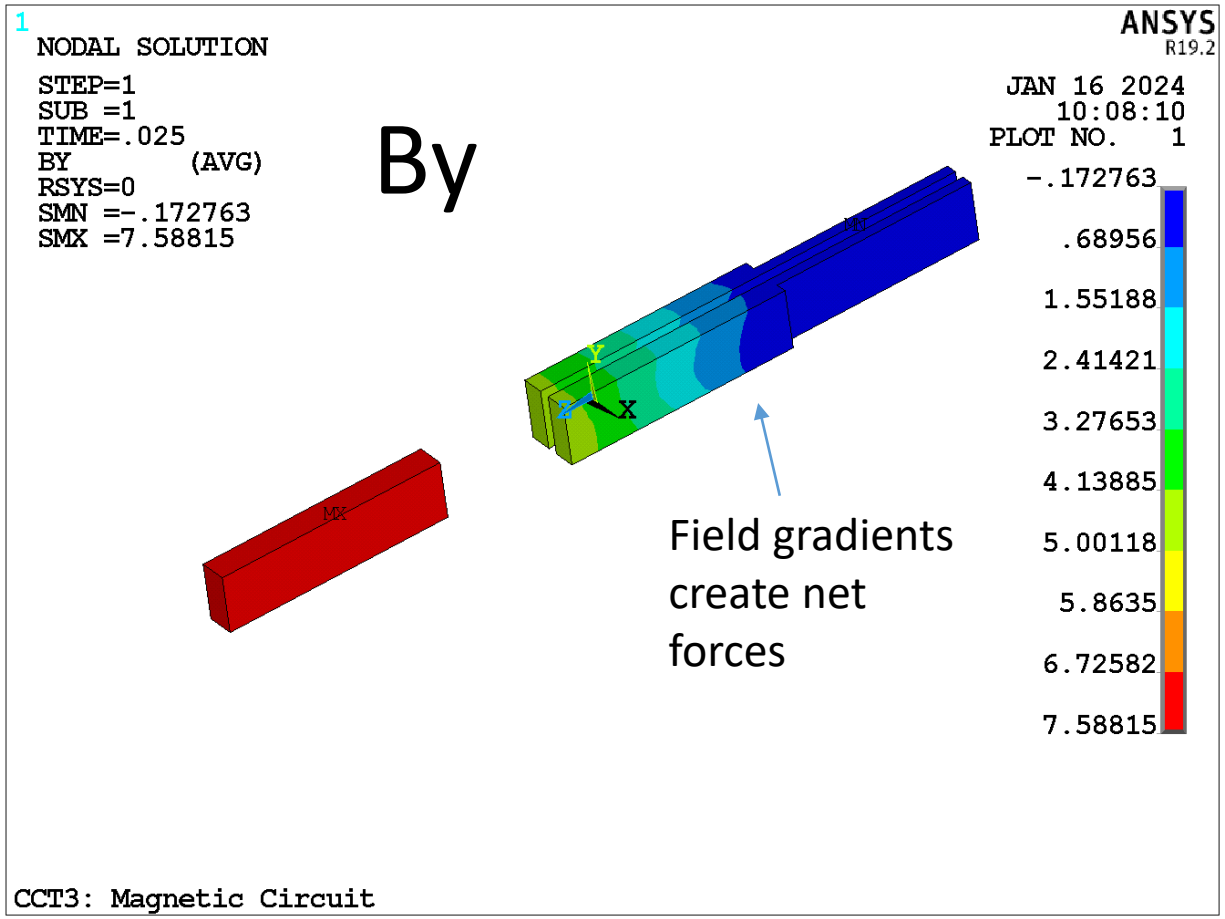




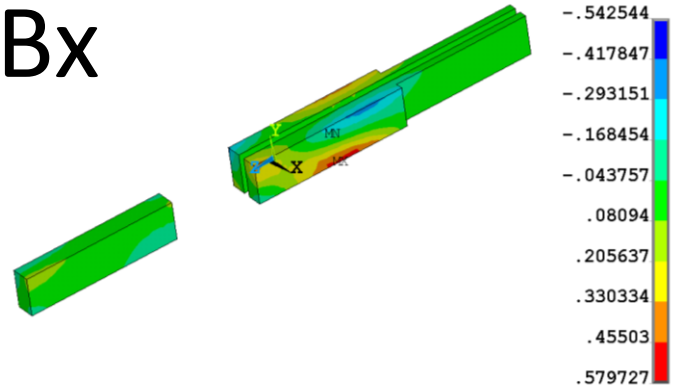
Fixed resistivity

- no temperature effect
- no magneto-resistance
- solve for RRR=100 and RRR=5 to see sensitivity

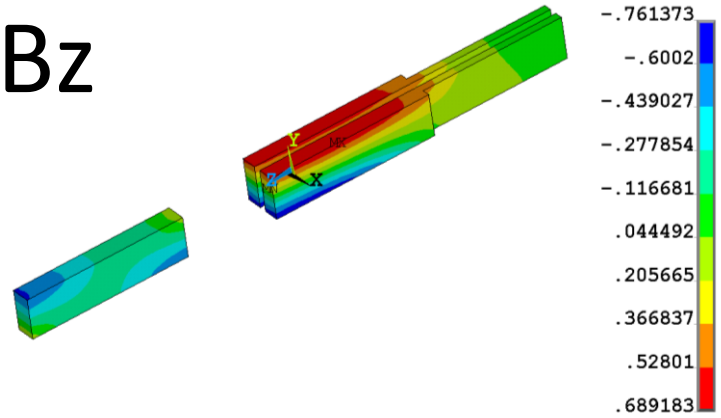
Fields on the eddy current regions (Cu) of joint



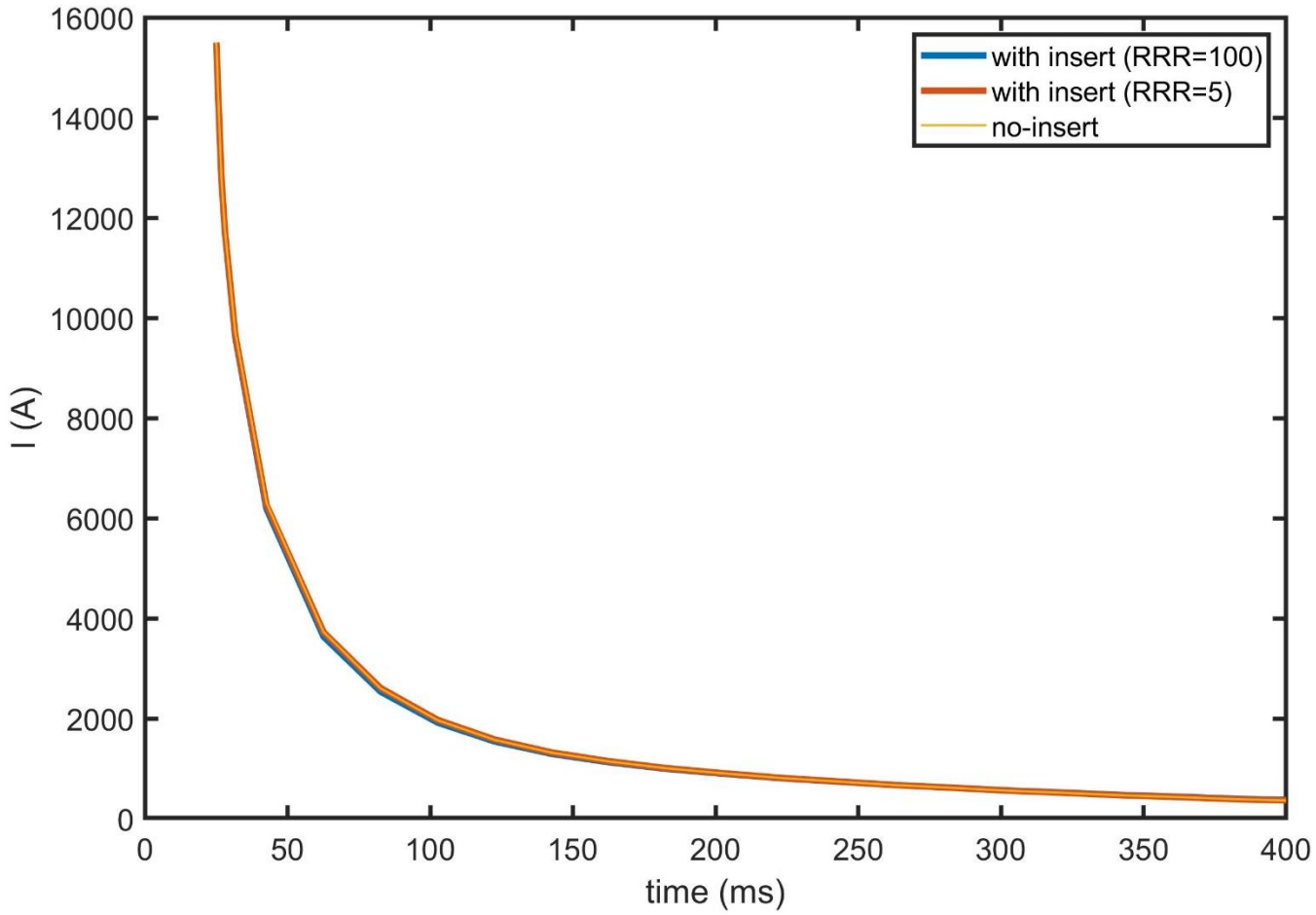
Bx



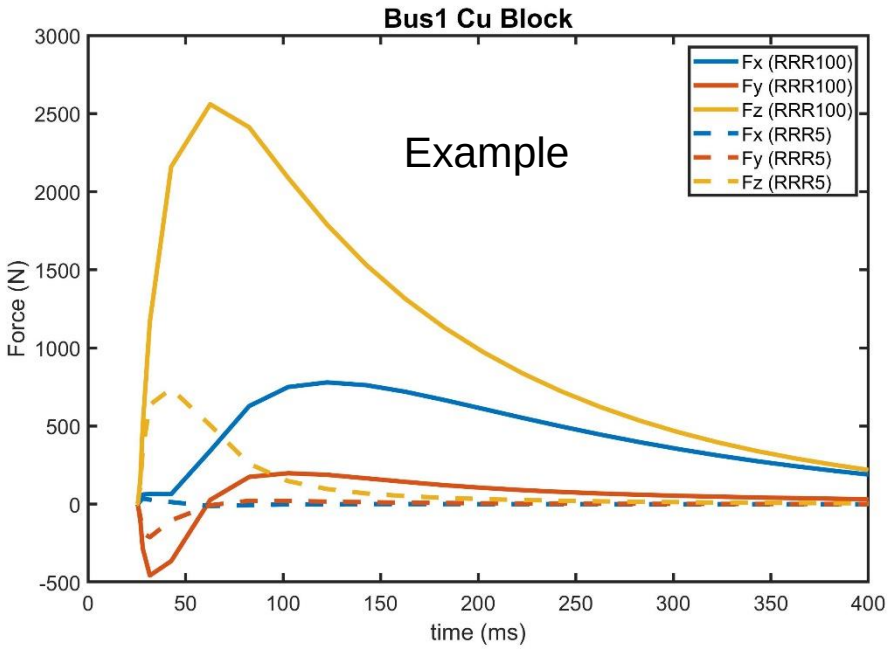
Bz



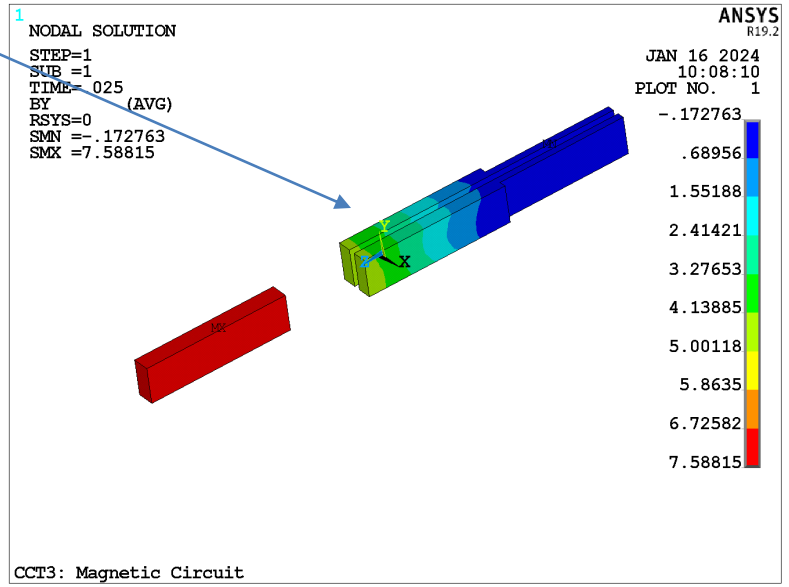
The current decay of CCT5 is not impacted by the additional eddy currents in the joint Cu (it is dominated by the aluminum shell of CCT5)



Post-process the model to find the net force vs. time in each copper block



Find the net force on each element and then sum all elements within the block



5.3.4.1. Lorentz forces

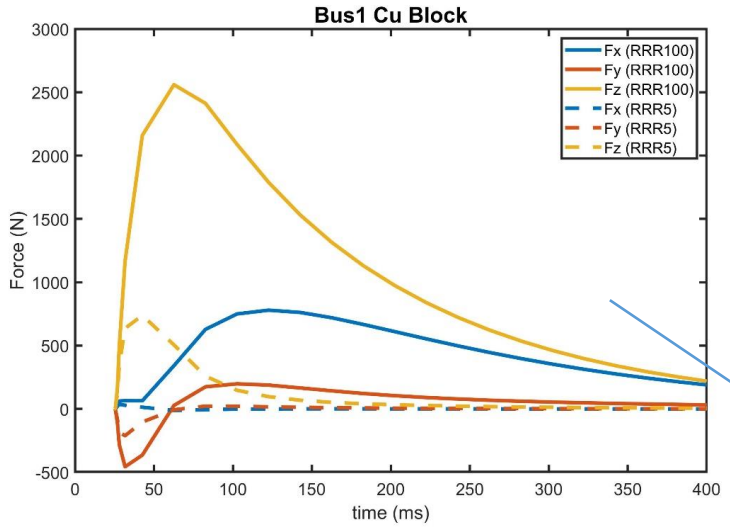
Magnetic forces in current carrying conductors (element output quantity FJB) are numerically integrated using:

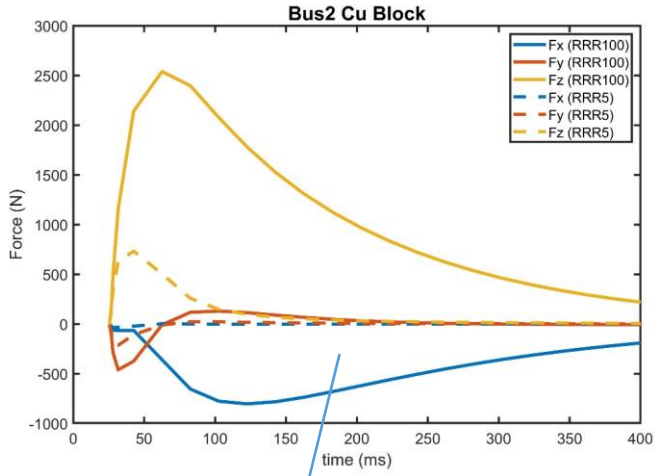
$$\{F^{jb}\} = \int_{vol} \{N\}^T (\{J\} \times \{B\}) d(vol) \qquad (5.132)$$

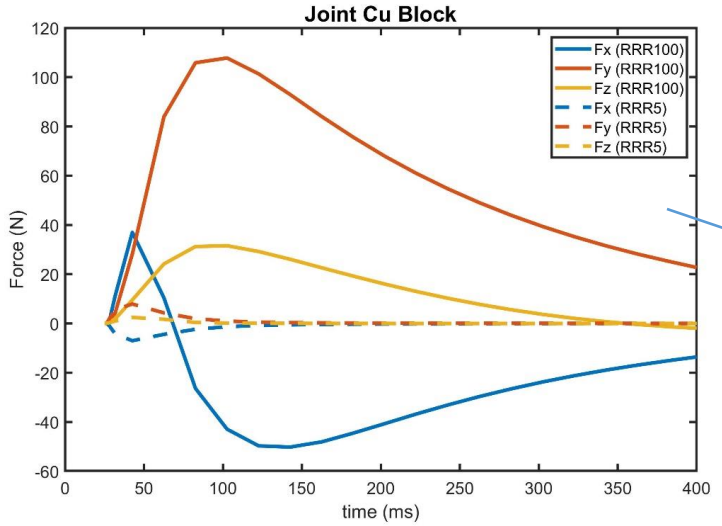
where:

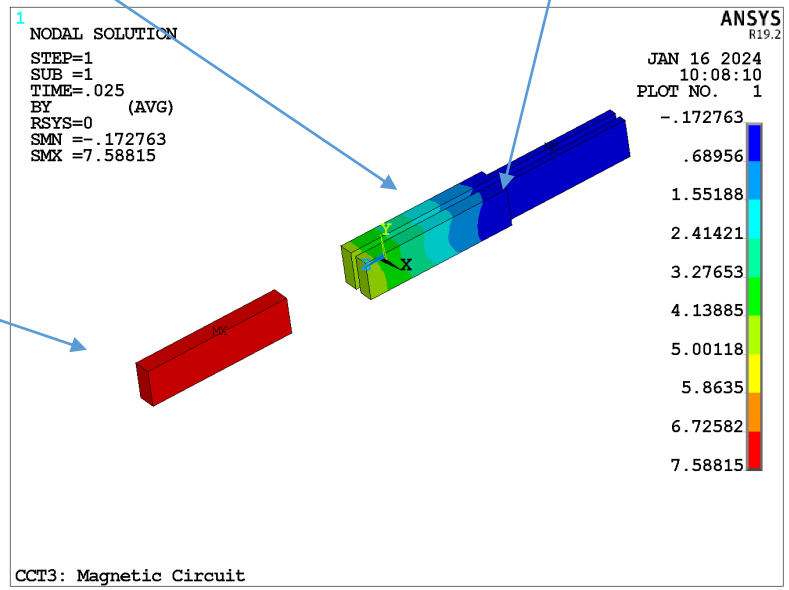
{N} = vector of shape functions

Results for all blocks









- ~600 lbs force peak (towards axial center) for each bus with RRR=100
- bus bar blocks are worse then the joint because they are in the ends where there is a strong field gradient

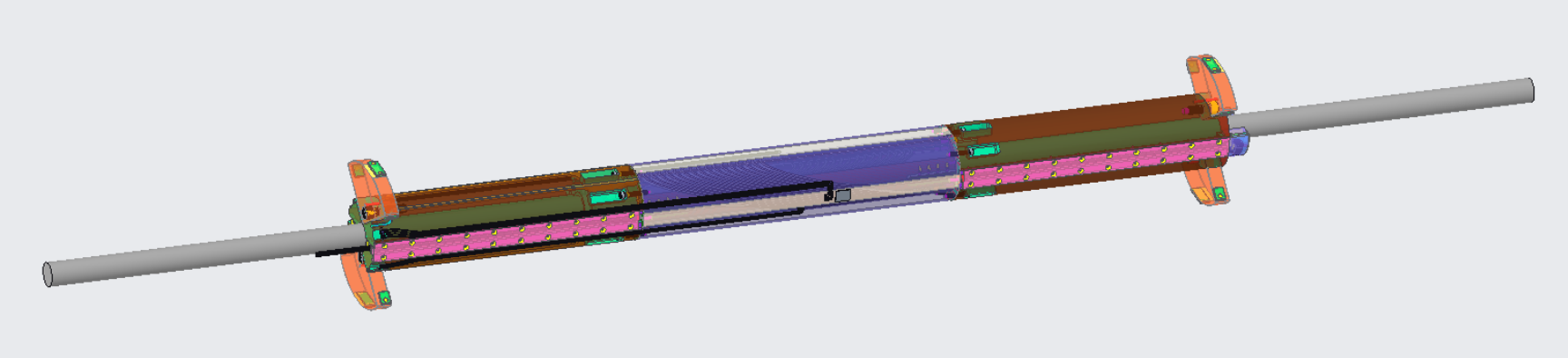
Summary for GA joint test

- Asymmetry of the system leads to unbalanced net force during extraction - just due to the interaction between induced eddy and fields (nothing to due to with insert powering)
- Transient forces from eddy currents should not be neglected in the mechanical design (~1200 lbs net force on bus bar)

Overview

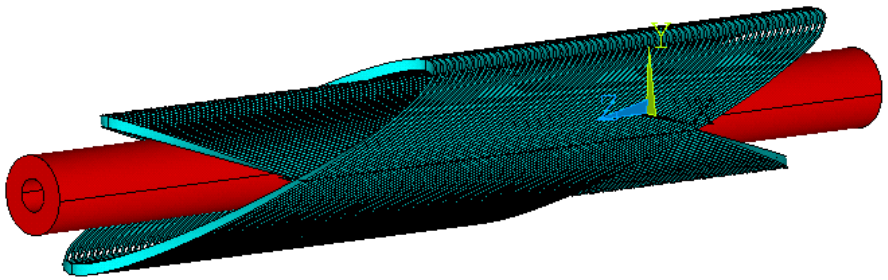
- transient electromagnetic modeling approach in ANSYS to determine dynamic forces from eddy currents
- model/results for the planned GA CORC joint test in CCT5
- **model/results for the planned BIN5 test in CCT5**

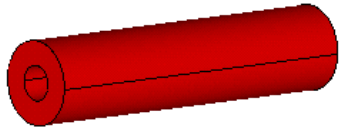
Assumptions for the BIN5 test

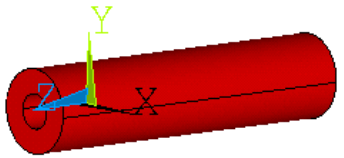


Assume symmetric Aluminum cylinders with no features (cuts etc.)

- Fixed 4 K resistivity of 1.4e-8 Ohm-m

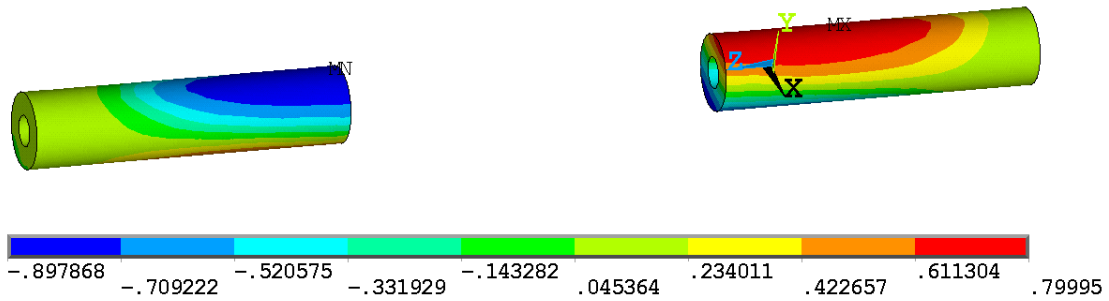




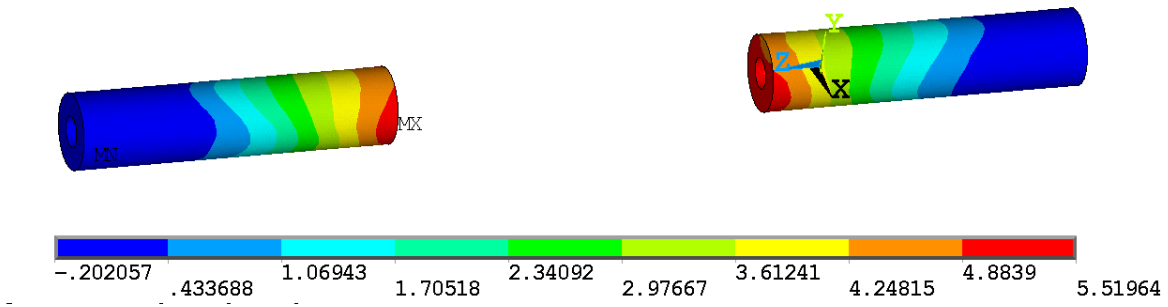


Field on the Bin5 extensions

Bx

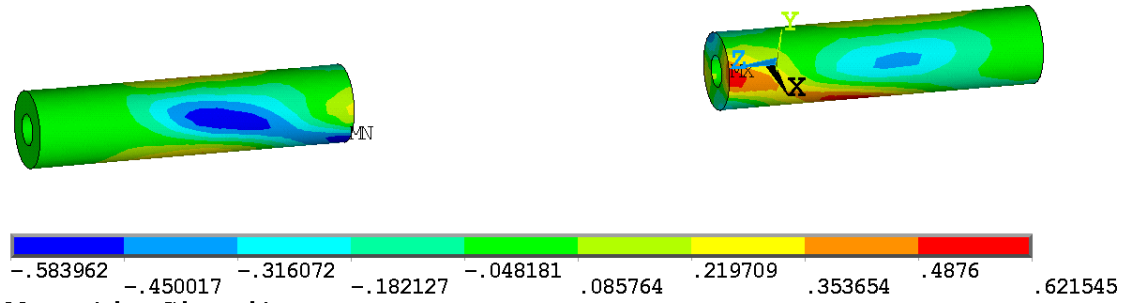


By



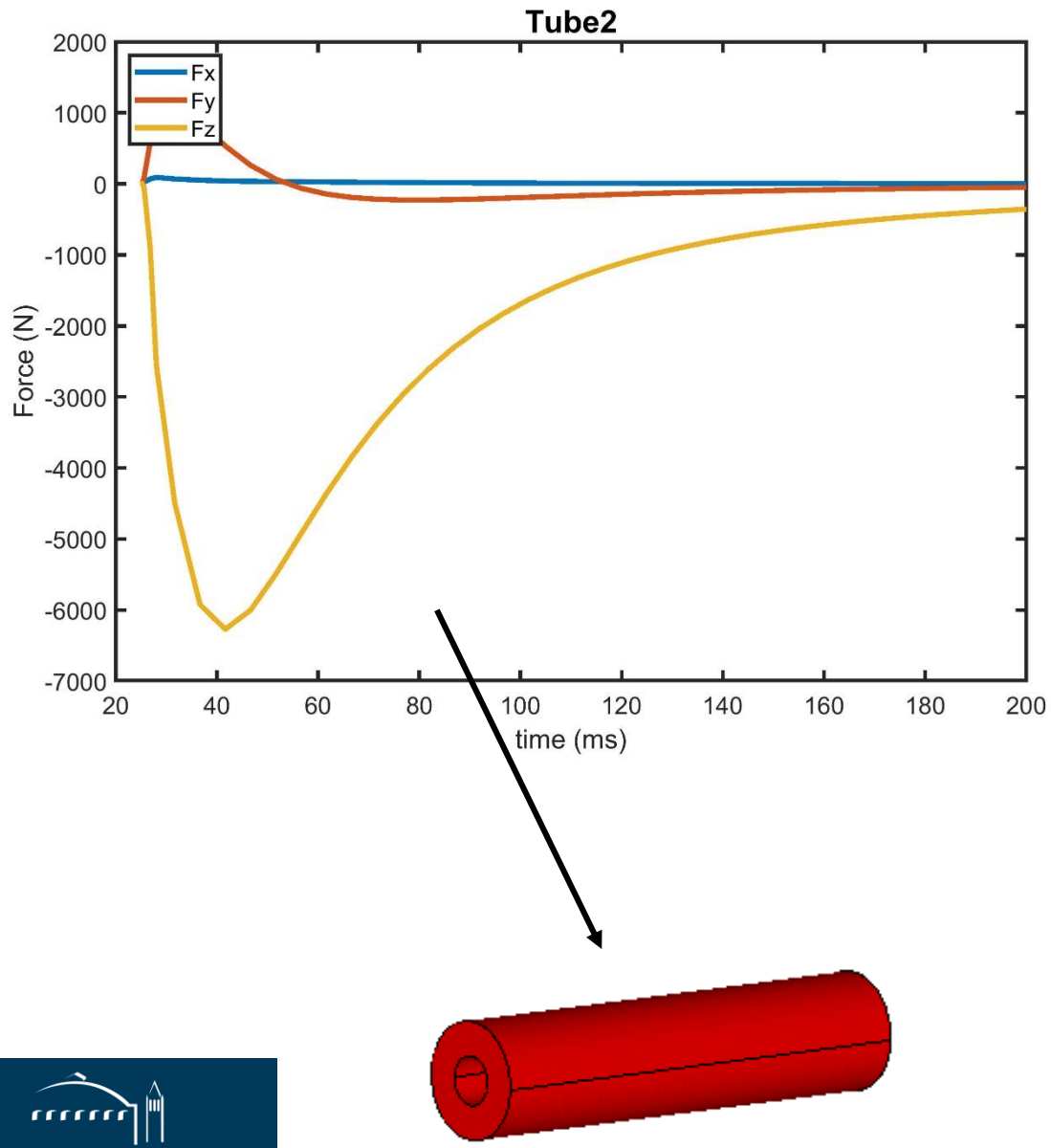
We expect dBy/dt with a field gradient to create axial force towards the high field (center of CCT5)

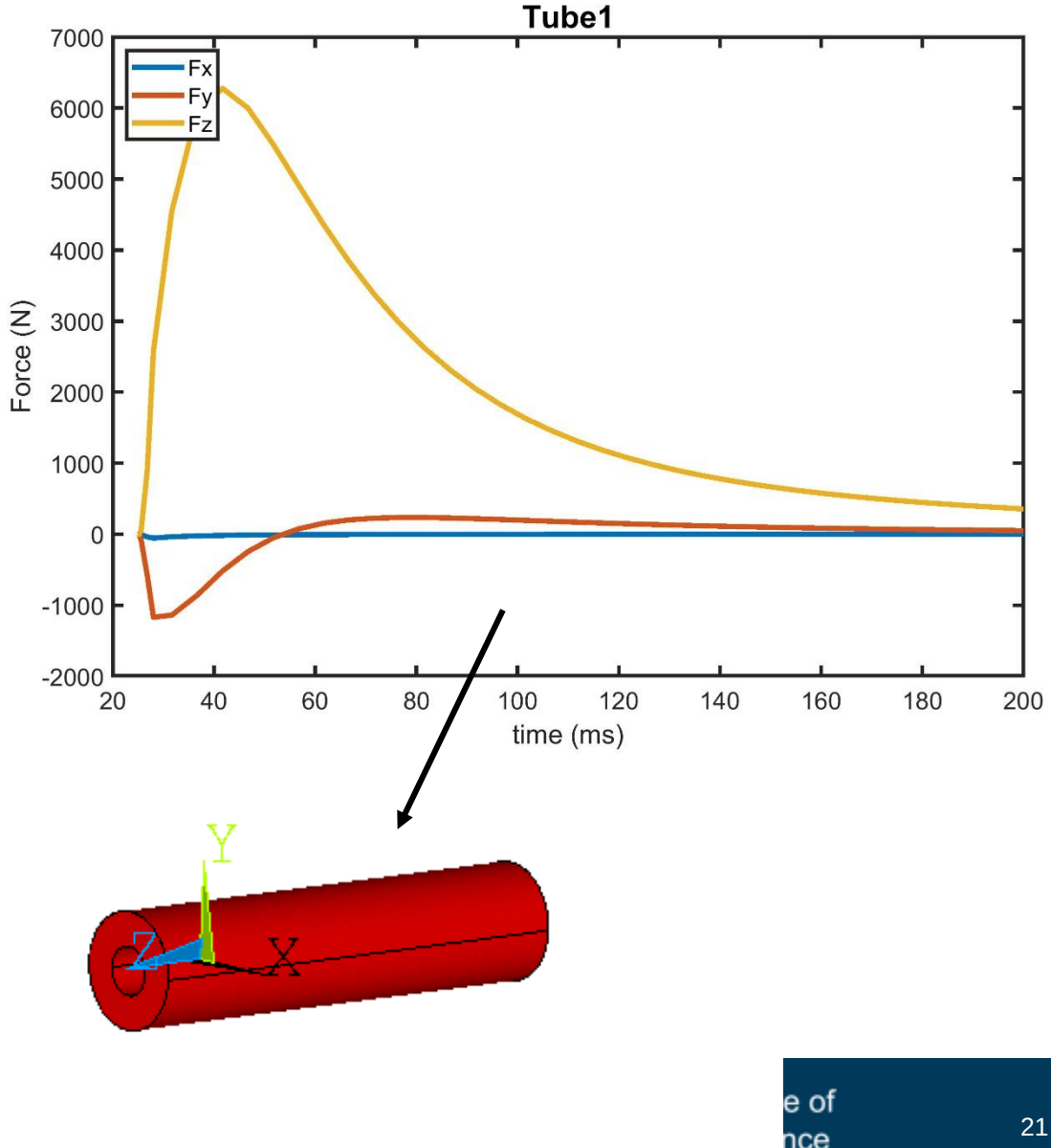
Bz



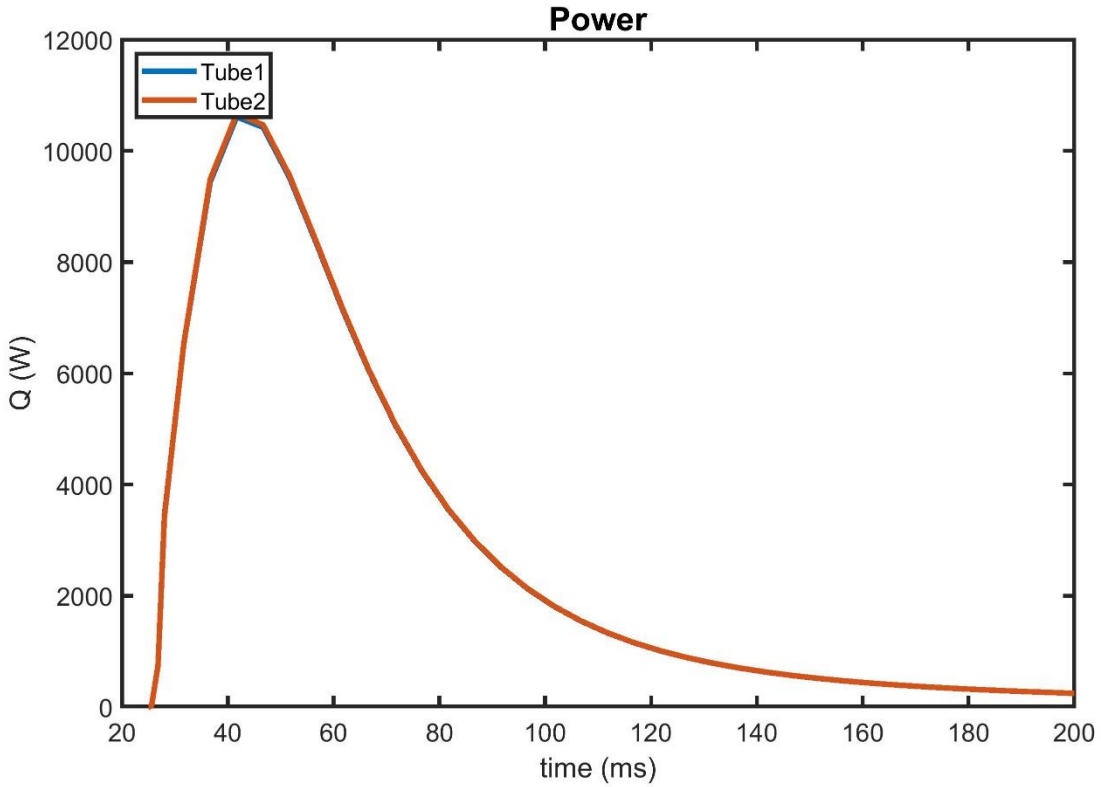
This is similar to GA joint, but now symmetric (so minimal total net force on the system)

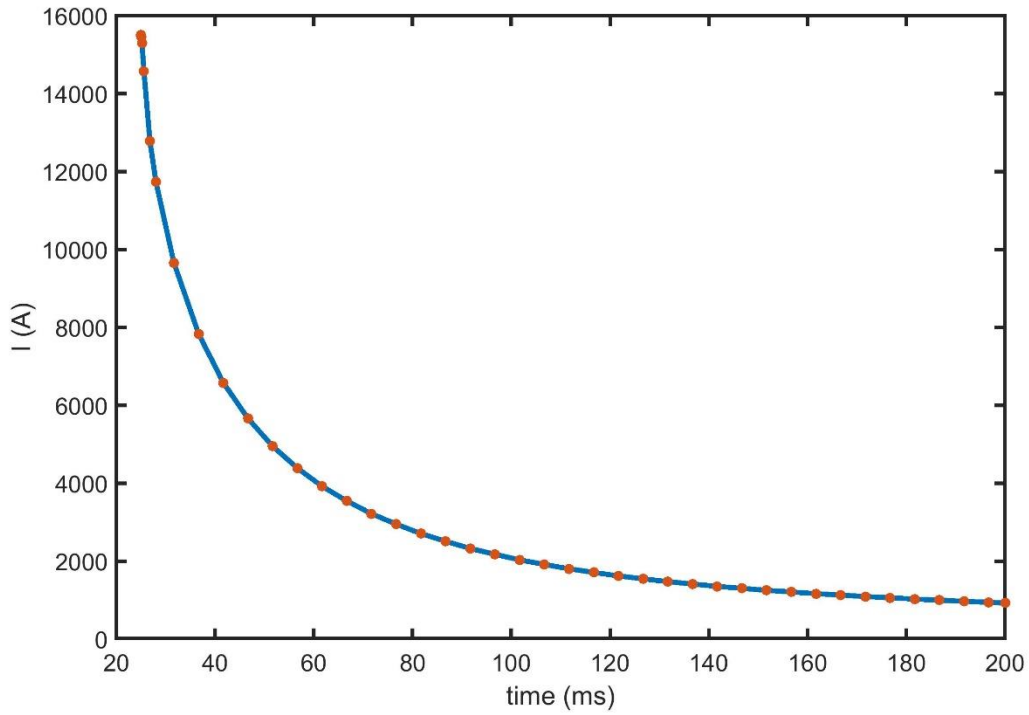
Net force on the individual extension tubes peaks at ~1300 lbs-force





Power deposited into the cryostat due to the eddy currents





Summary and Next Steps

Summary

- mechanical support of upcoming insert tests (GA joint, BIN5) are in regions of spatially changing magnetic field
- the eddy currents induced during extraction of CCT5 induce non-neglibile forces (independent of insert powering)

Next steps

- evaluate impact on mechanical support structures
- include more detail about part geometry (e.g. extension tube cuts) which may reduce eddy currents, but break further symmetries (so it's not clear if this is better or worse).

Next Steps

Extra