LLNL Update

Tom Piggott, Ryan Abbott, Charles Brown,
Jeff Gronberg, Lisle Hagler, Jay Javedani

S&T Principal Directorate

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Increasing Positron Yield

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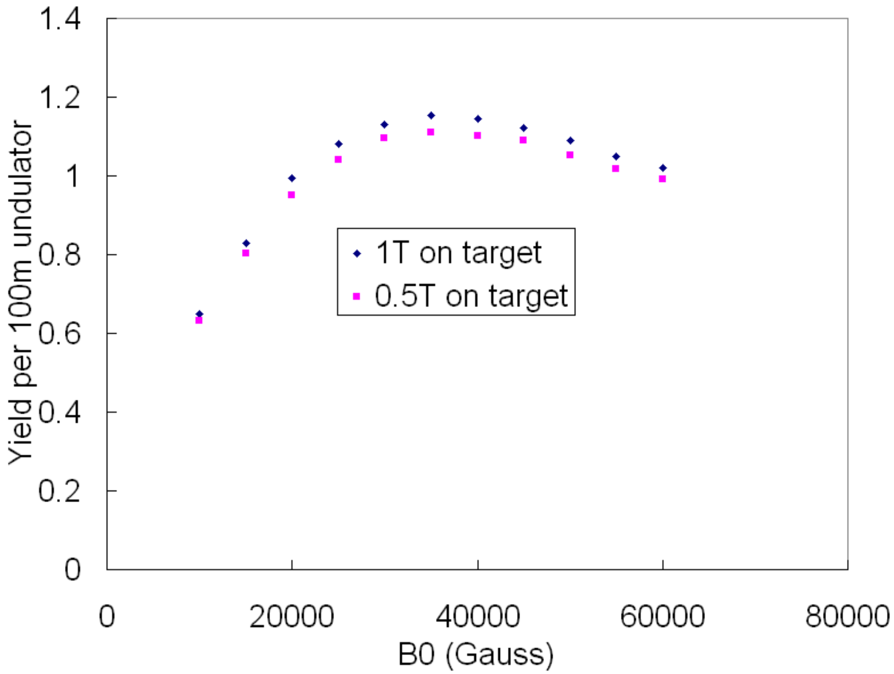
- Flux concentrator design provides an external magnetic field after the target to increase positron yield



Graphic from W. Liu and W. Gai, Argonne National Laboratory

Approach

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- Form an idea of what is really achievable
- Match this to the performance envelope, provide basis for an informed decision
- Look at produced magnetic field- power supply required
- Evaluate heating and mechanical loads on device
- Evaluate special loads due to operation area
- Evaluate effects of magnetic field on target

Specifications

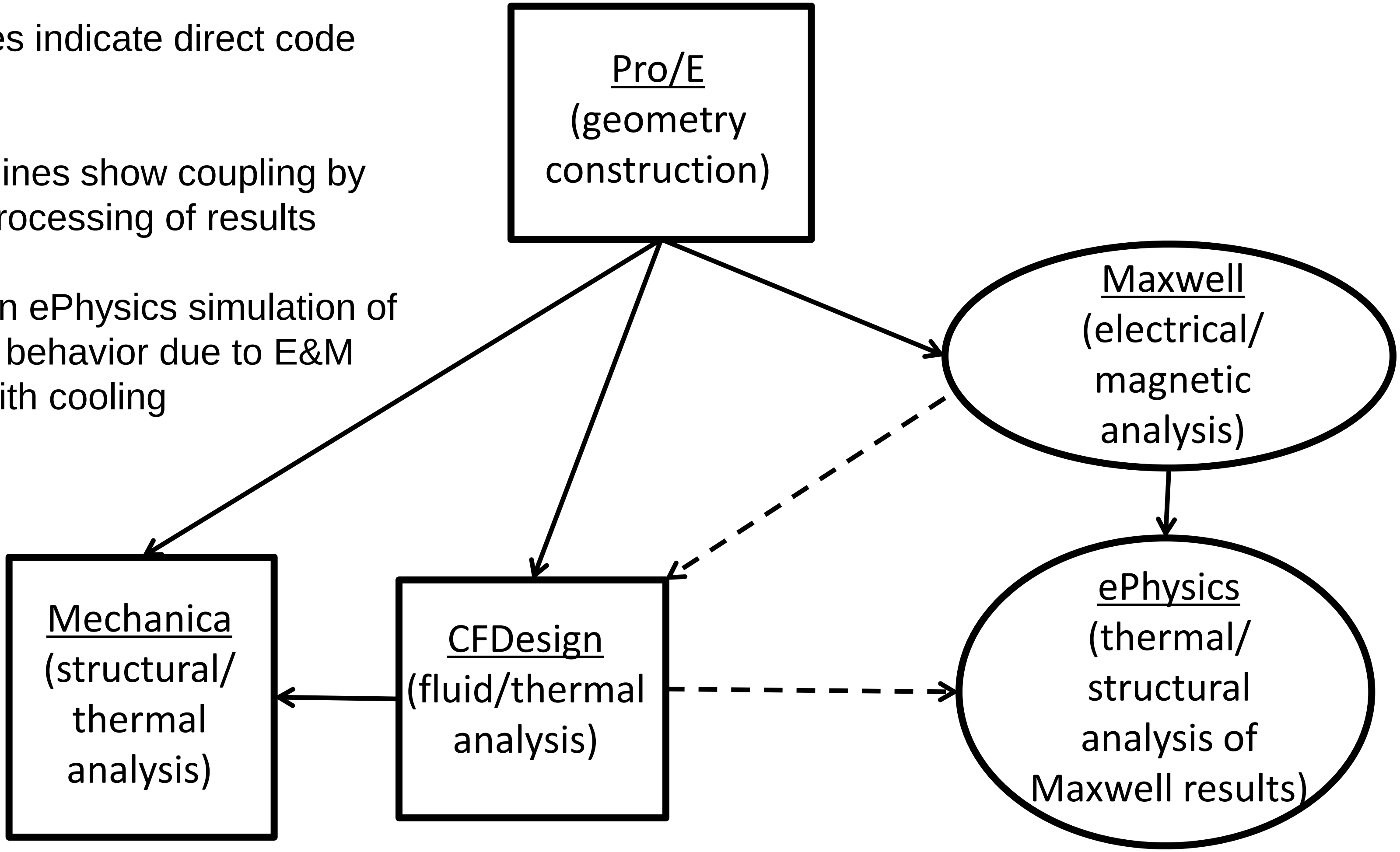
- ~4 T max field, with 1 ms pulse length, operated at 5 Hz for 9 months at a time
- Placed behind target to provide focusing effect
- Consulting outside sources and working on analysis
- Future analysis will need to look into effects of beam particles impacting the device as well

Code Structure for Analysis

•Solid lines indicate direct code coupling

•Dashed lines show coupling by manual processing of results

•Results in ePhysics simulation of structural behavior due to E&M loading with cooling



Modeled Geometry: Overall

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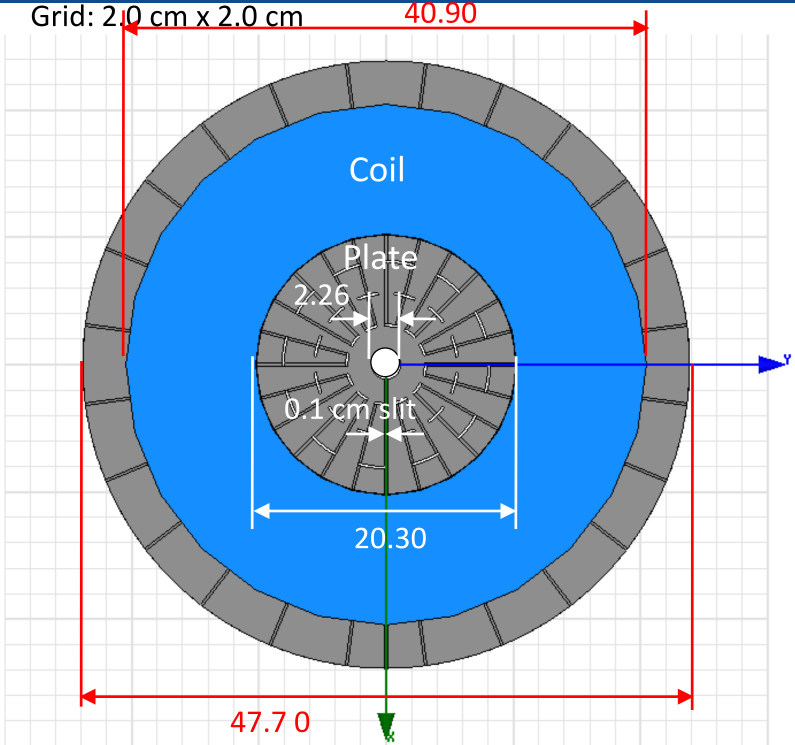


Note1: This geometry is our depiction of Wang's Flux Concentrator model where 4 Coils and 4 disks with a straight bore are modeled.

H. Wang, et. al., "Modeling of Flux Concentrator, Argon National Lab, WF-NOTE-234, August 2006. ANL.

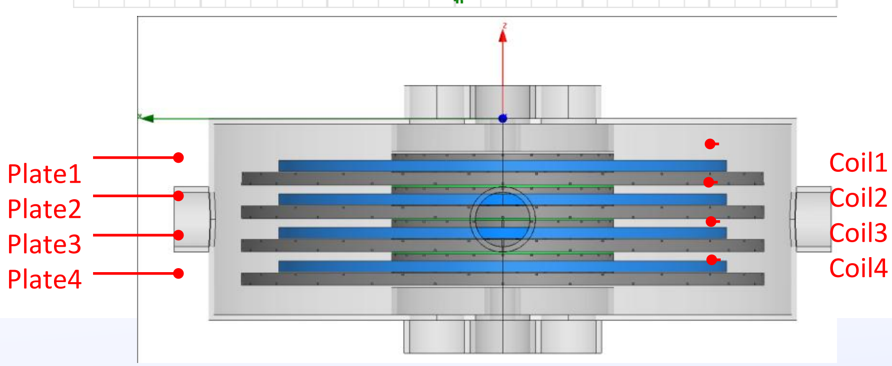
Note 2: Disks and Coils material is Cu-OFHC; electrical conductivity of 3.5714E+08 S/m. The cooling container is of stainless steal with electrical conductivity of 1.E+06 S/m.

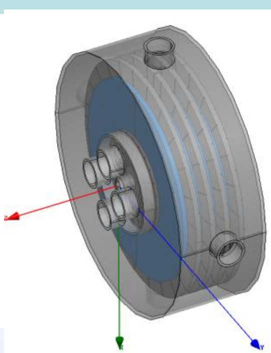
H. Brechna, et. al, "150 kOe Liquid Nitrogen Cooled Pulsed Flux-Concentrator Magnet," Review of Scientific Instruments, V.36, No. 11, Nov 1965, pp. 1529-1535.

Note 3: Each plate has a 0.2 cm wide slit and each slit is rotated by 90° in each successive plate.

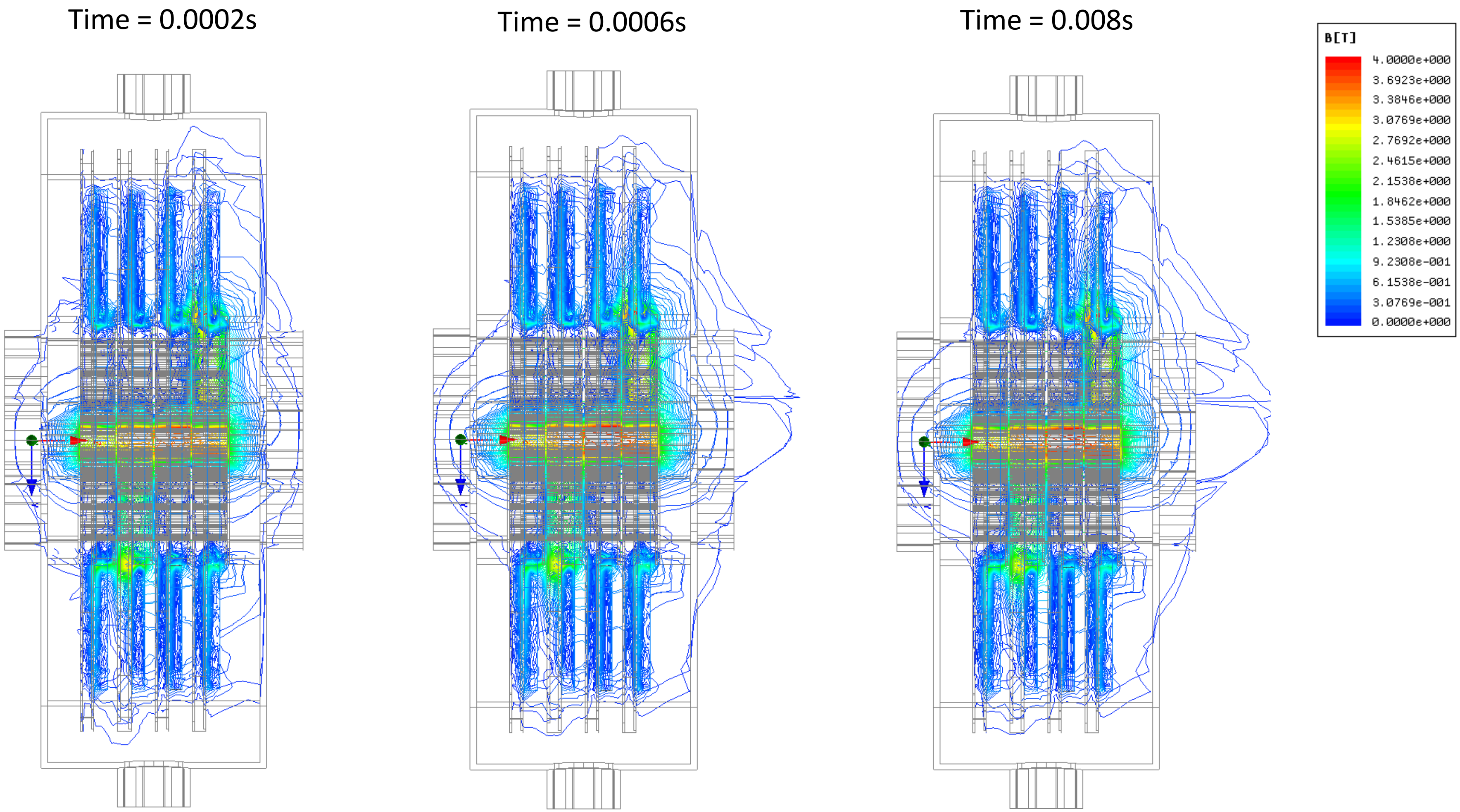
Note 4: Cooling Channels were added based on Bitter Magnet Design.

http://www.magnet.fsu.edu/education/tutorials/magnetacademy/makingmagnets/page2.html

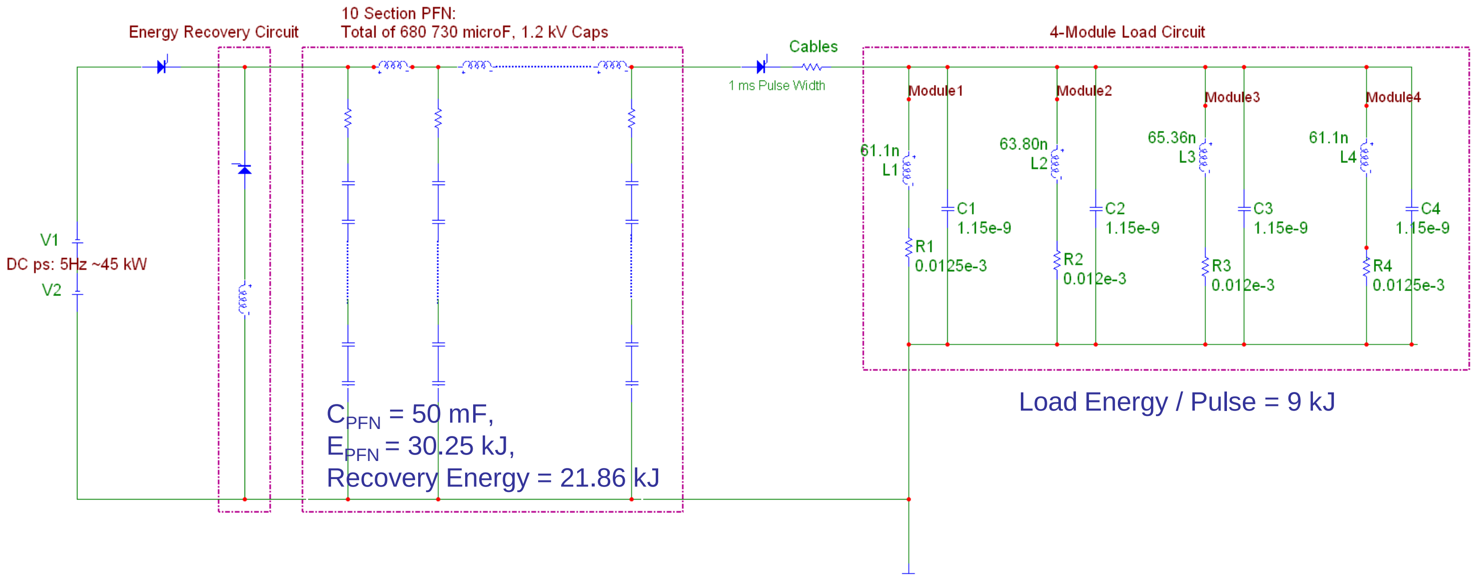


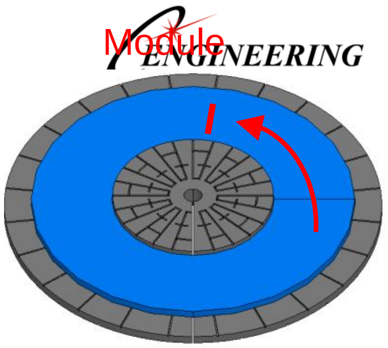


Maxwell 3D used to predict magnetic field



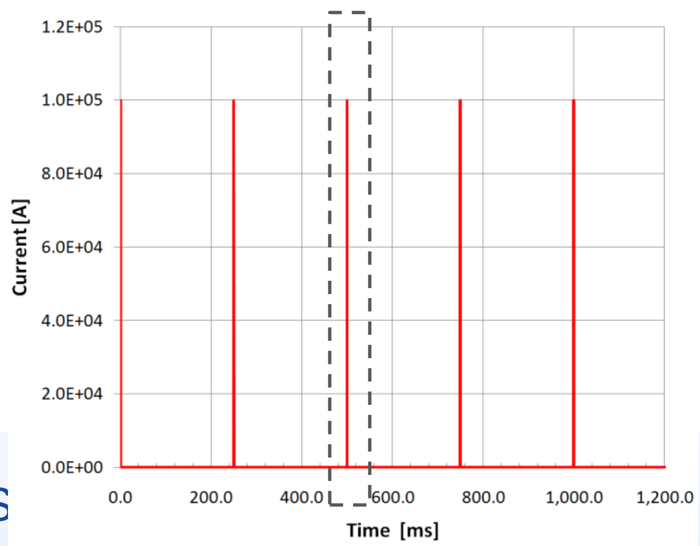
Schematic of the 100 kA Power Supply (PFN Scheme) and the Load



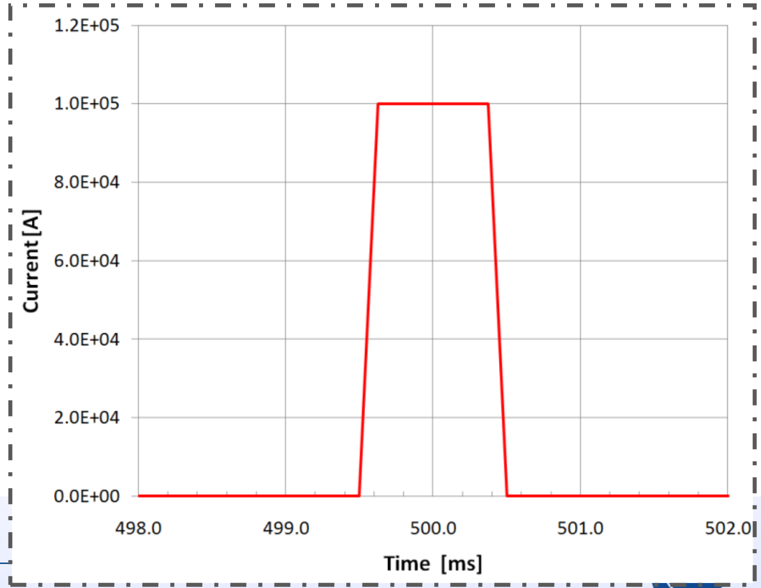


100 kA of 1.0 ms pulses at 5 Hz for ~2.3E+07s (9 months) for each coil

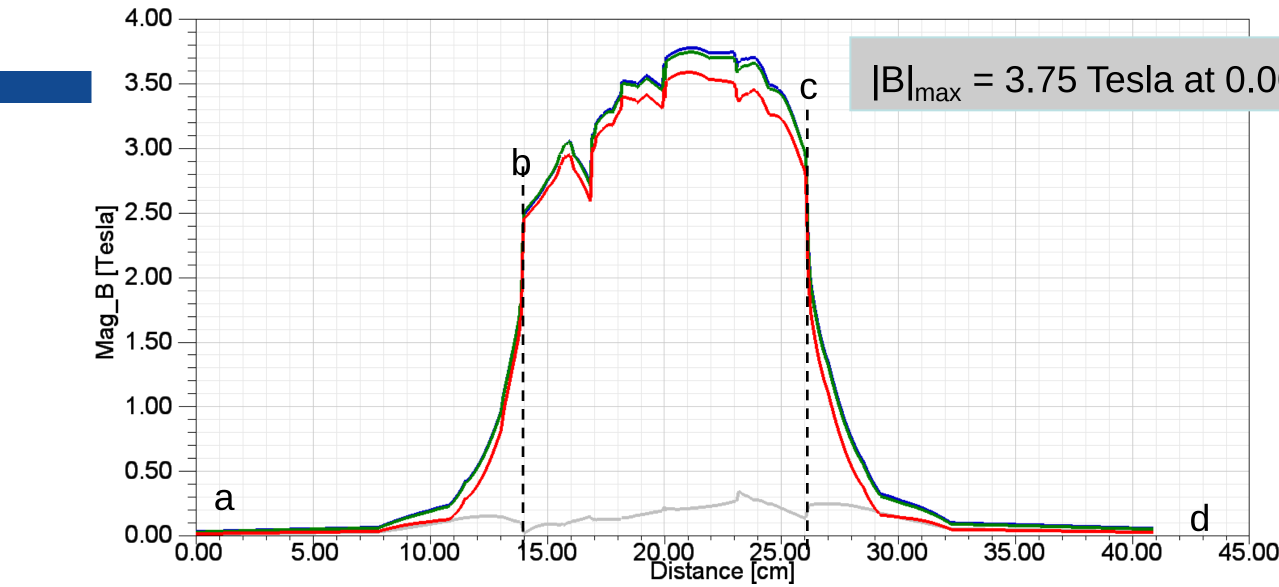
See Detail A



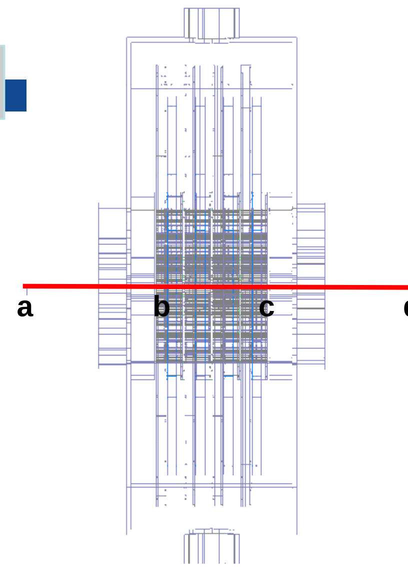
Detail A

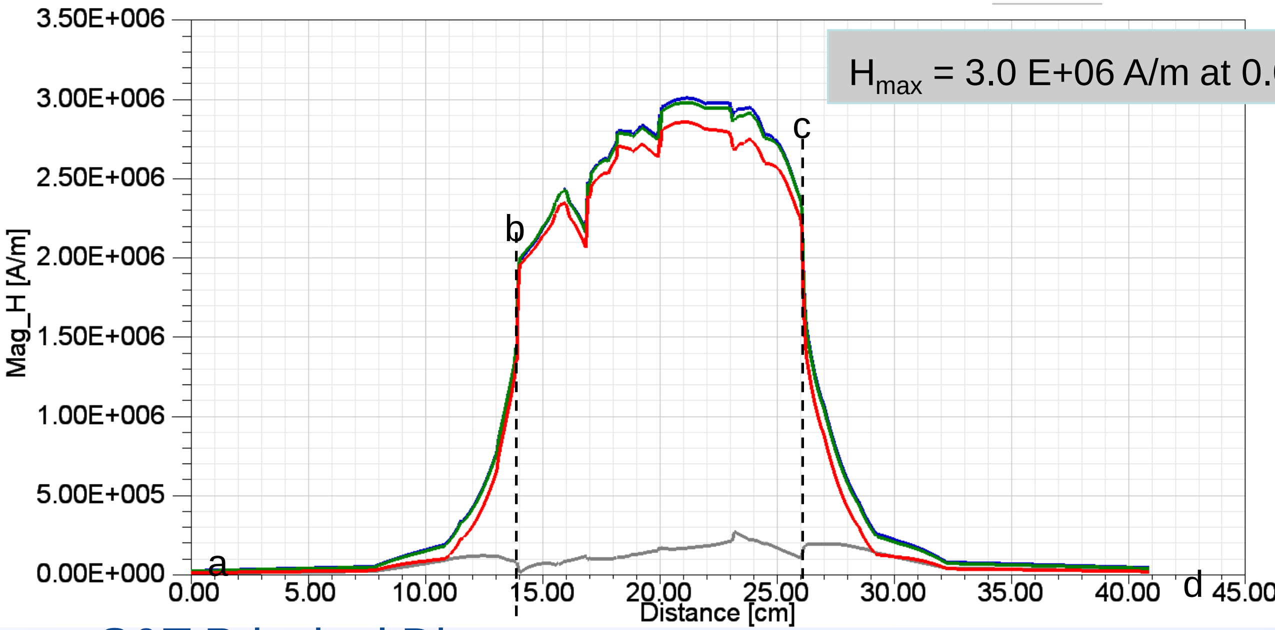


|B| and H along center-line



$|B|_{max}$ = 3.75 Tesla at 0.0006 s





H_{max} = 3.0 E+06 A/m at 0.0006 s = 37.5 kOe

J and |J| at the xy cut-plane of plate3 and coil3 at 0.0006 s

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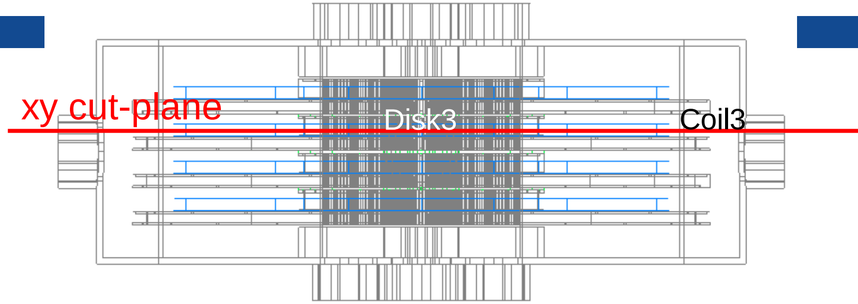

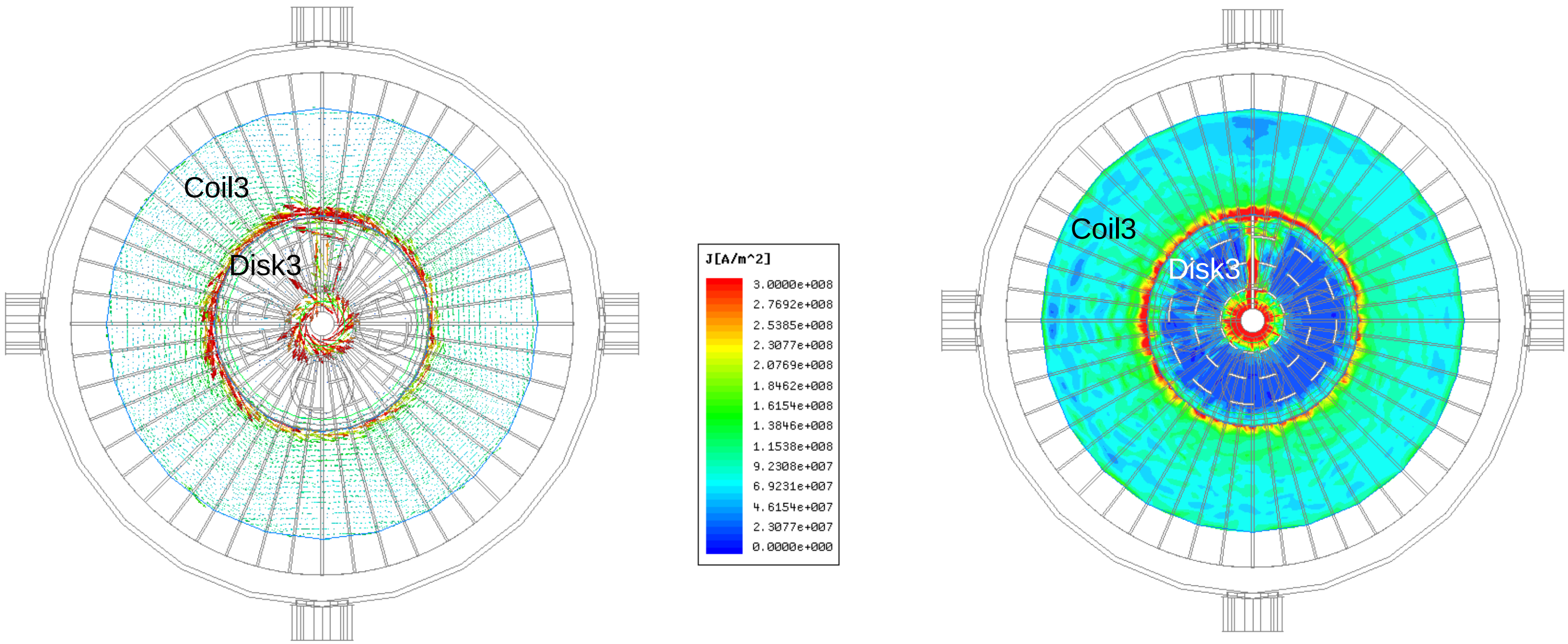

Cfdesign predicts the heat transfer conditions from the cooling flow

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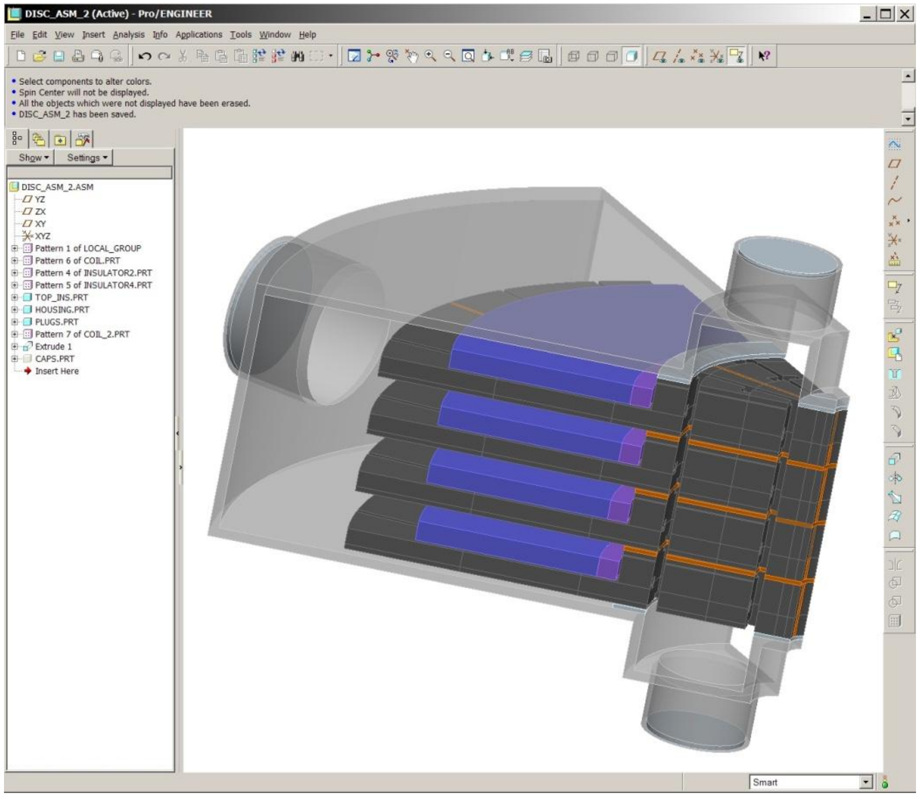

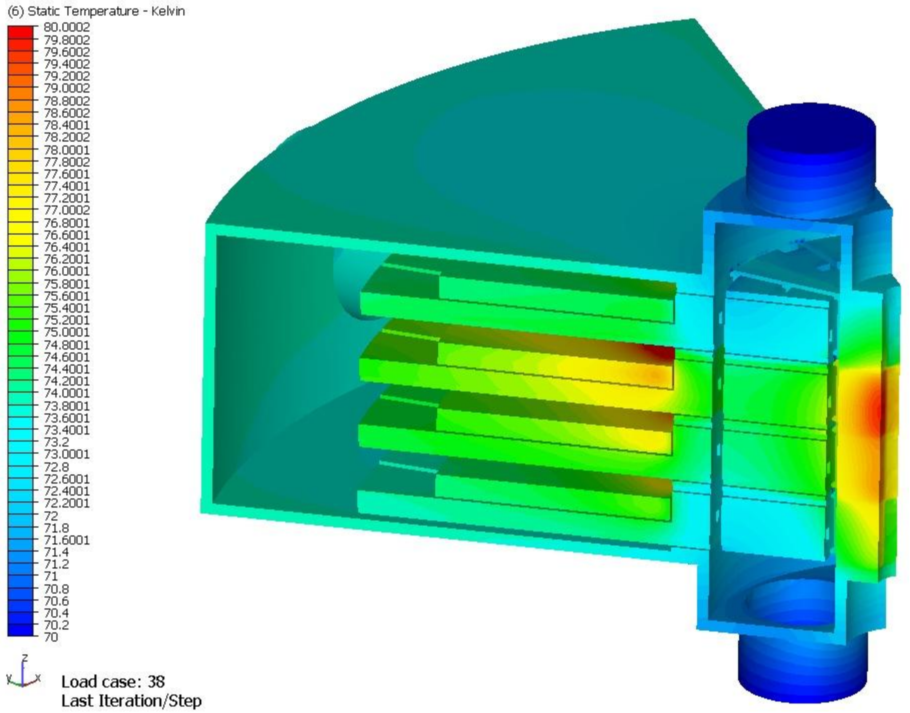

Geometry, EM loads, and cooling conditions are being analyzed in ePhysics

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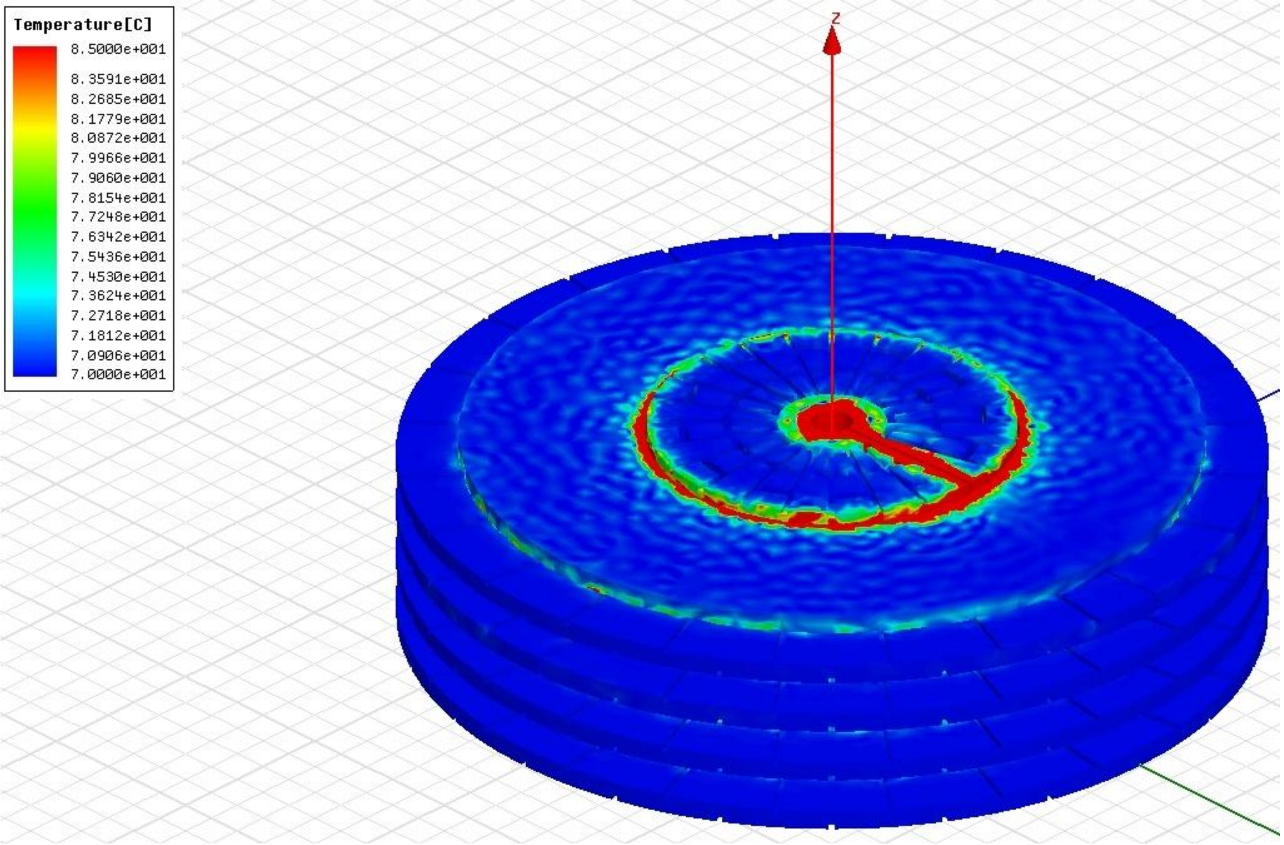

Force Density (N/m^3)

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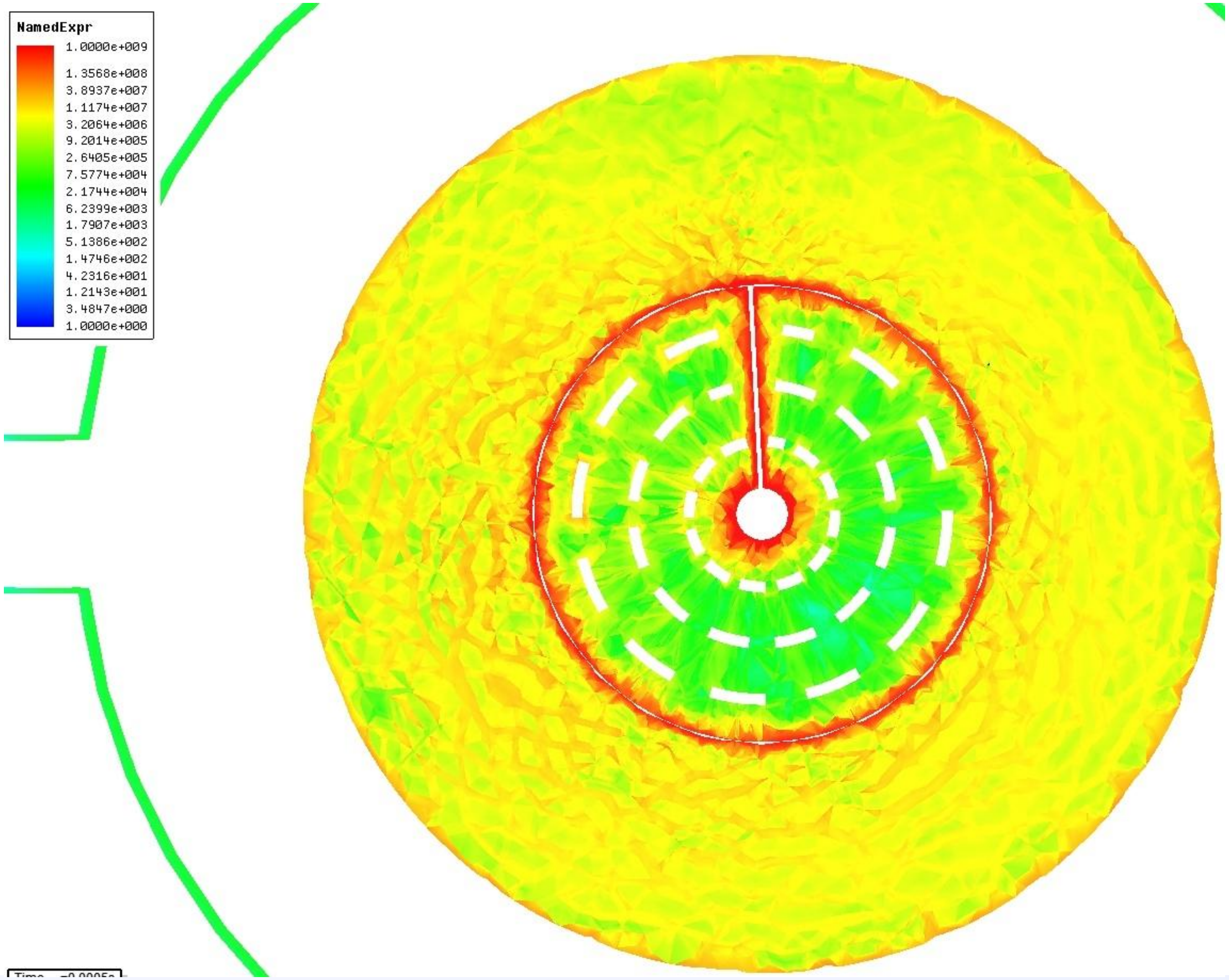

Magnetic Forces on Components

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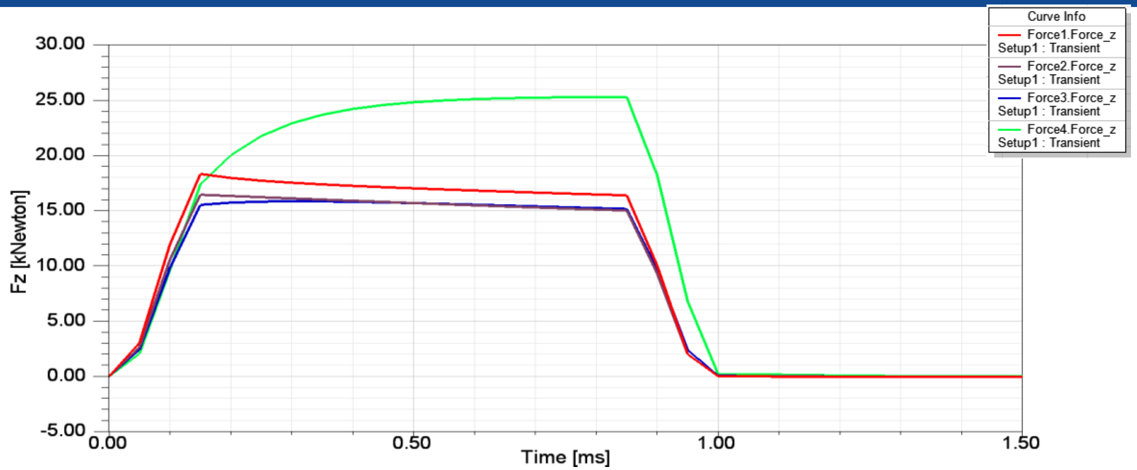

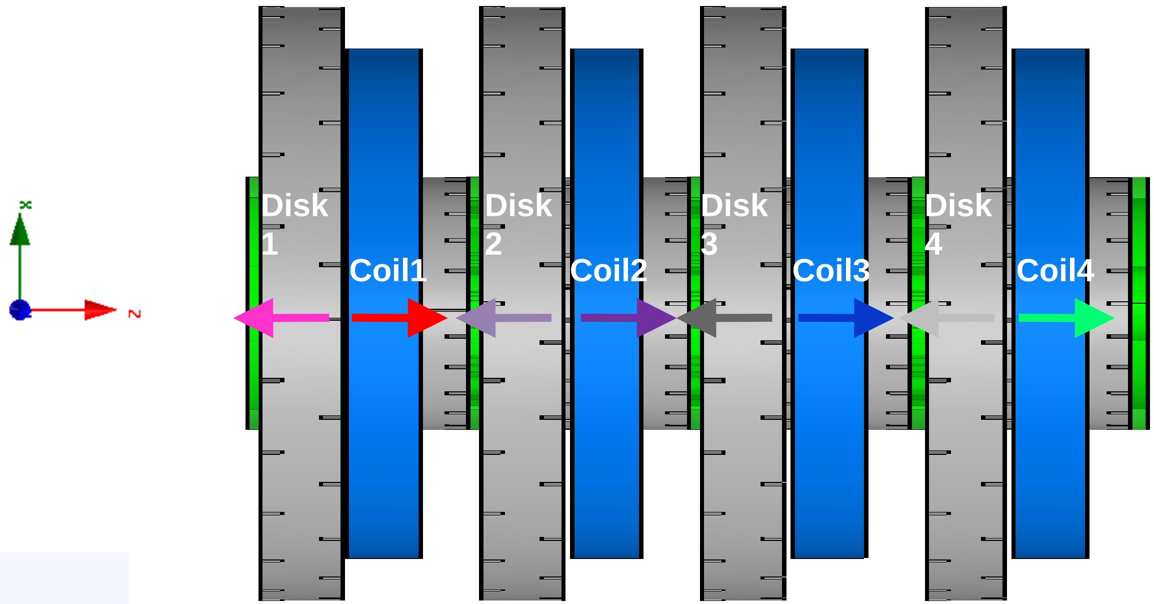

<u>$(J \times B)_{z\_max}$ Forces (t = 0.50 ms)</u>

Coil1: +17.0 kN Disk1: -21.0 kN

Coil2: +15.6 kN Disk2: -15.7 kN

Coil3: +15.6 kN Disk3: -16.8 kN

Coil4: +25.0 kN Disk4: -21.0 kN

As much as 50 kN of force for a coil-disk pair needs to be constrained.

Cryocooler Cost Estimate

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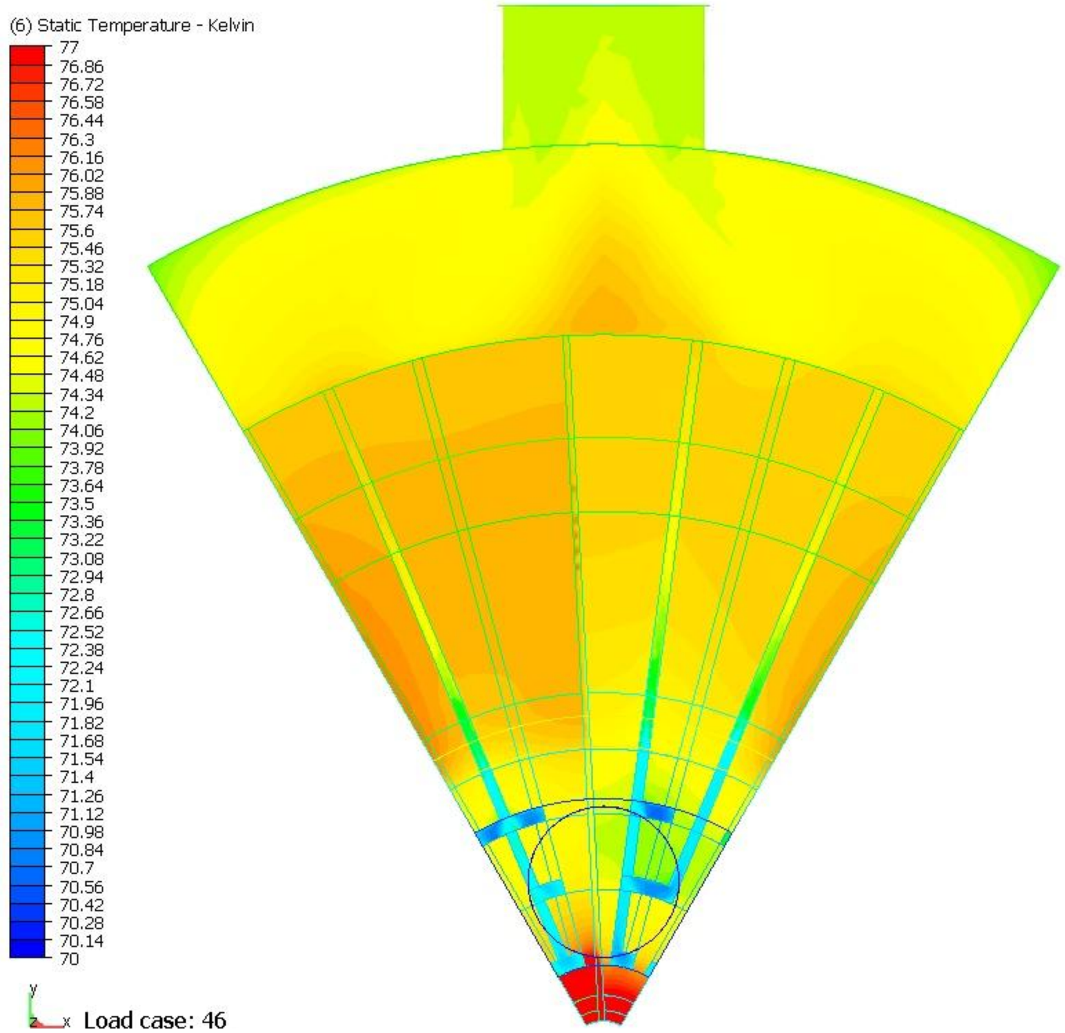
- Real FC will dissipate ≈ 10 kW in ohmic losses
- Largest commercial cryocoolers able to remove 0.5 – 1 kW at ≈70 K with 4% efficiency and cost ≈ 100 $/W
- FC cryocoolers will cost ≈ 1 M$ for equipment and 330,000 $/yr in electricity assuming rates of 15 ¢/kW-hr

LN Flow Will Remain Liquid

- LN pumped into the test FC assembly at 70 K and a rate of 60 l/min for average $\Delta T < 4$ K
- Peak LN temperatures well below 77 K
- Peak LN flow speeds are approximately 40 cm/s
- Copper components stay below 80 K

LN and Copper Temperature



LN Flow Speed

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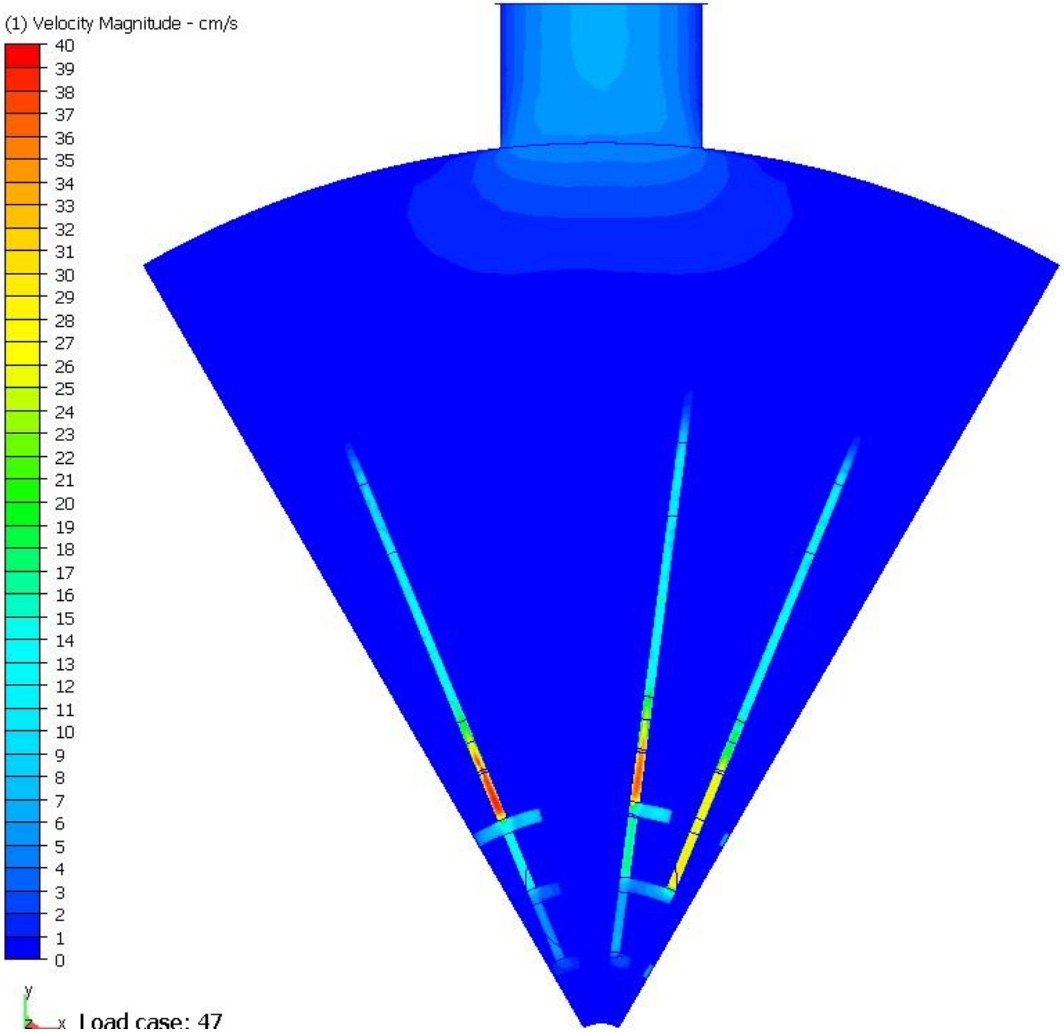
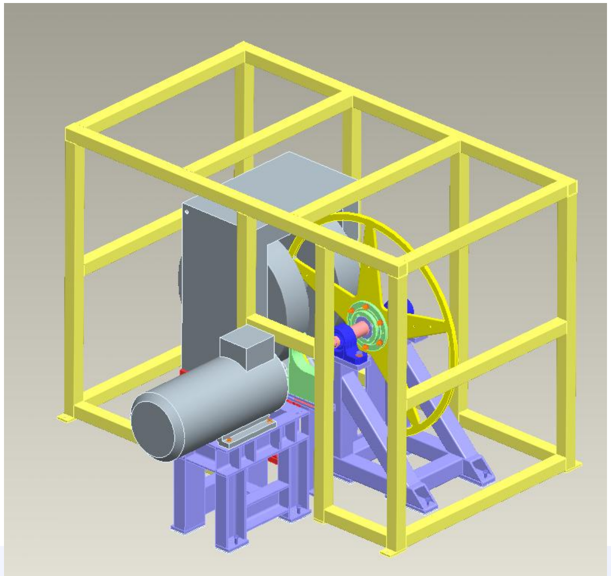


Further Steps

- Determine what can realistically be built
- Linear effects only modeled- check to ensure this is the operating range- device lifetime indicates probable failure outside this regime
- Investigate effects of temperature on material properties (do thermal, mechanical, or electrical properties vary enough to be important)

Rotordynamics

- Working with experimental team at Daresbury Laboratory
- Produced an FEA model of rotordynamic system
  - Aids in interpretation of experimental data from rotor system
  - Useful in predicting important behavioral features in dynamic behavior of wheel experiment

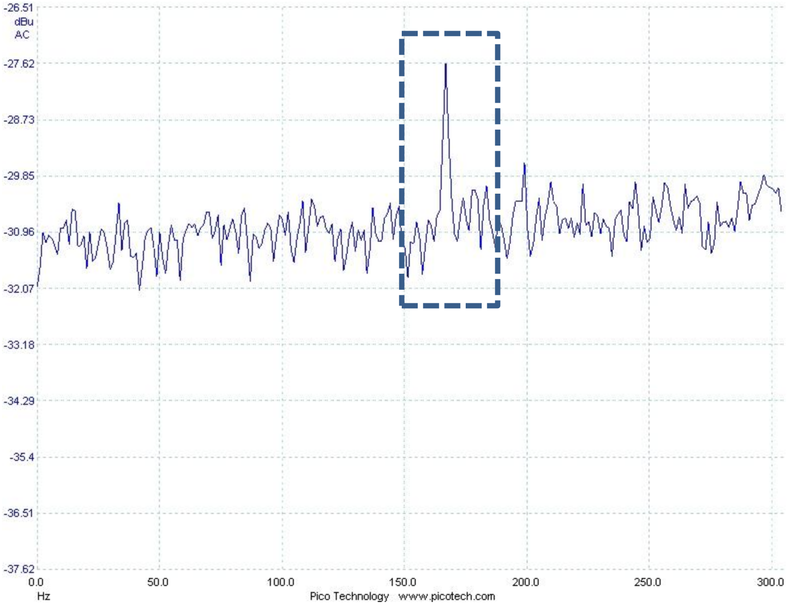


Rotordynamics

FEA Predicted Modal Frequency = 184 Hz

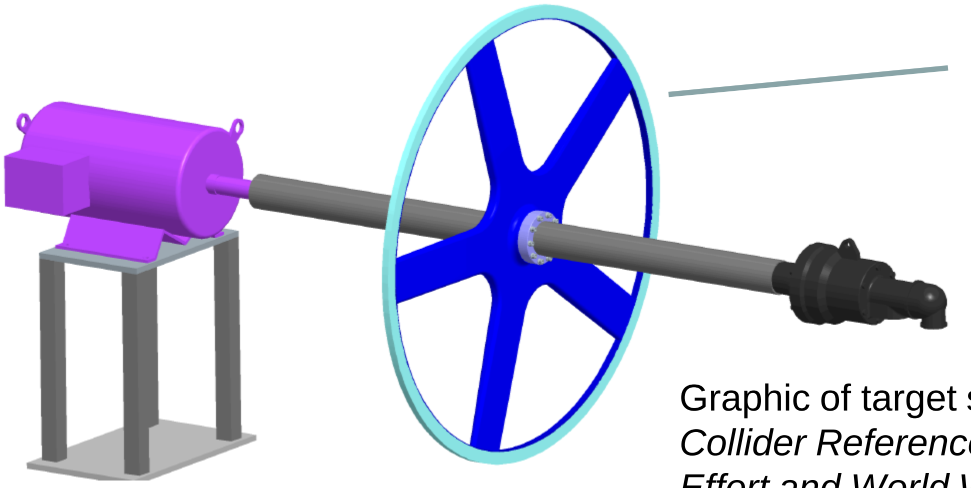
1st Transverse Bending Mode

Experimentally Observed Modal Frequency ~ 170 Hz



Variety of loads on the target wheel

- Radiation damage from the beam
- Thermal stress from the beam
- Mechanical stress from the rotation of the wheel (~ 1000 r.p.m.)



Ti6Al4V target wheel
Nominally 1 m diameter, 1.4 cm thick

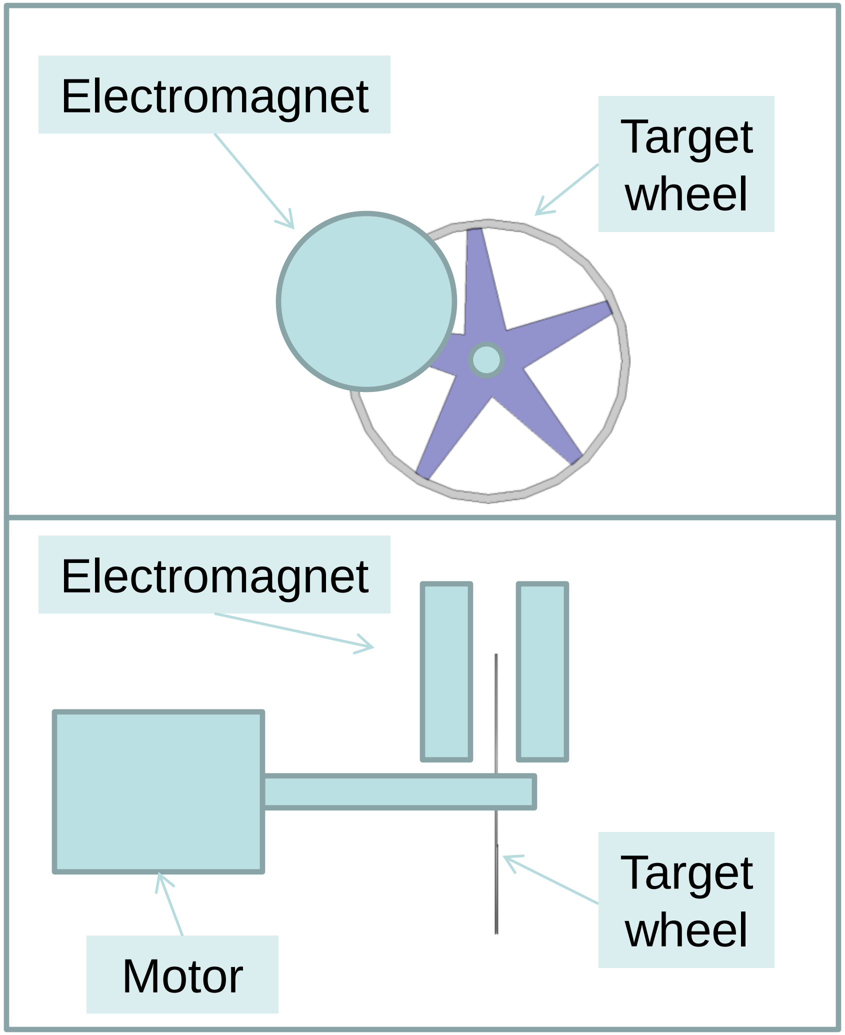
Graphic of target station layout from *International Linear Collider Reference Design Report: ILC Global Design Effort and World Wide Study*, August 2007

Eddy currents produce further stresses

- Motion of wheel in magnetic field of beam-line elements (e.g. the OMD) generates eddy currents in the wheel
- The eddy currents produce additional thermal and mechanical stresses:
  - Thermal stress through Ohmic heating
  - Mechanical stress through Lorentz forces

Experiments and simulations are necessary to understand the effects of eddy currents on the target wheel

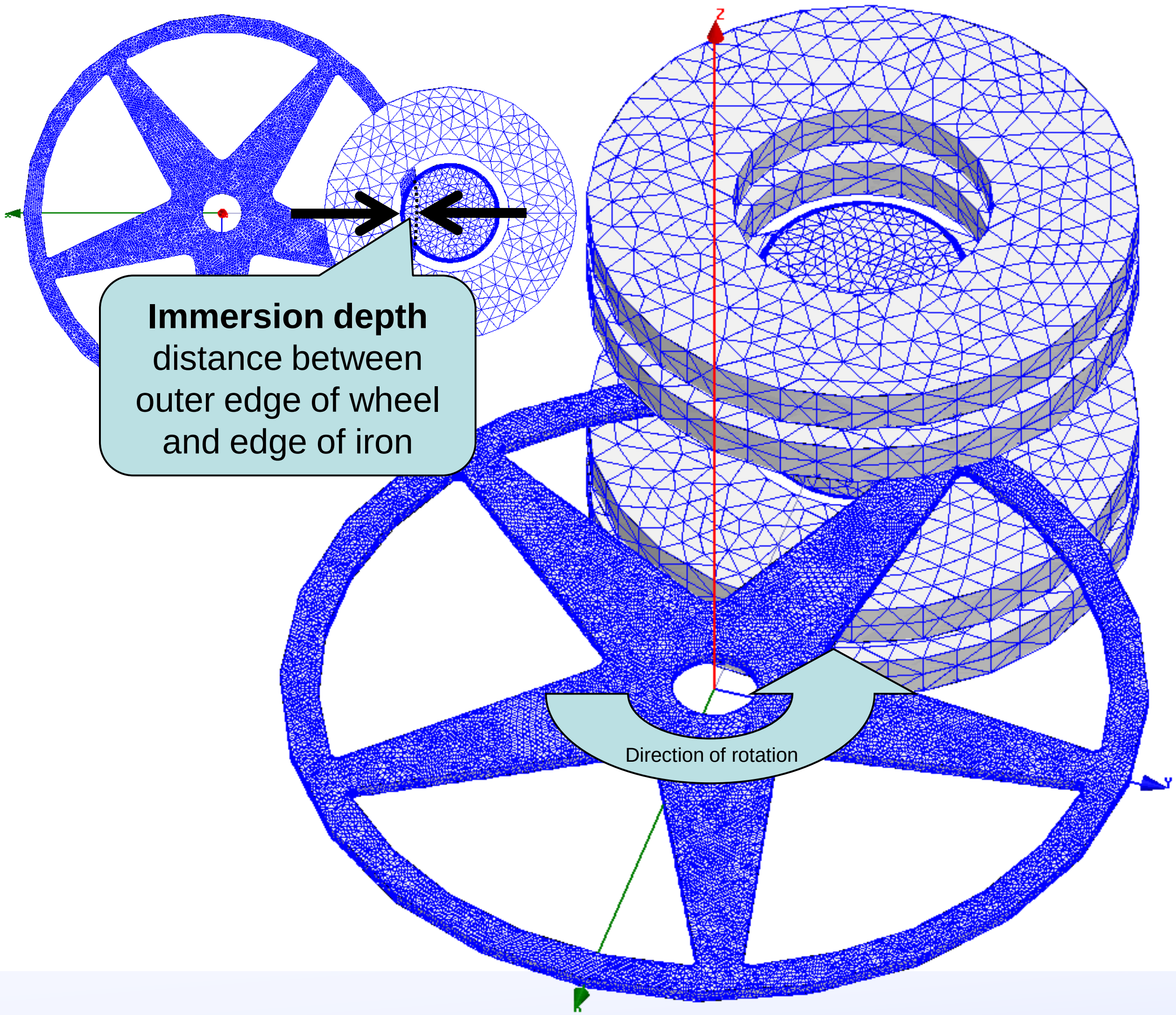
Experiment being conducted at Daresbury Laboratory



- DL experiments evaluating:
  - Magnetic field of the electromagnet
  - Torque
- Eddy current simulations underway at RAL

- Conducting EM simulations of the target wheel
- Coordinating simulations with RAL to ensure both use:
  - The same magnetic fields from the electromagnet
  - The same geometry
- Future collaborative design work to reduce eddy current effects

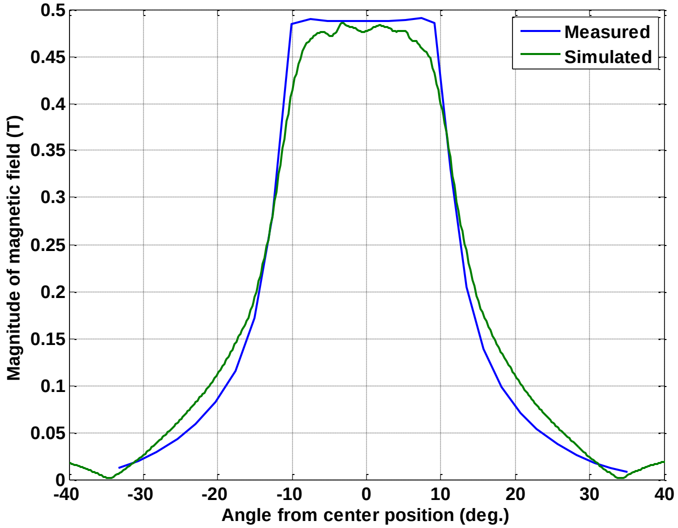
UK target wheel simulated in Ansoft Maxwell



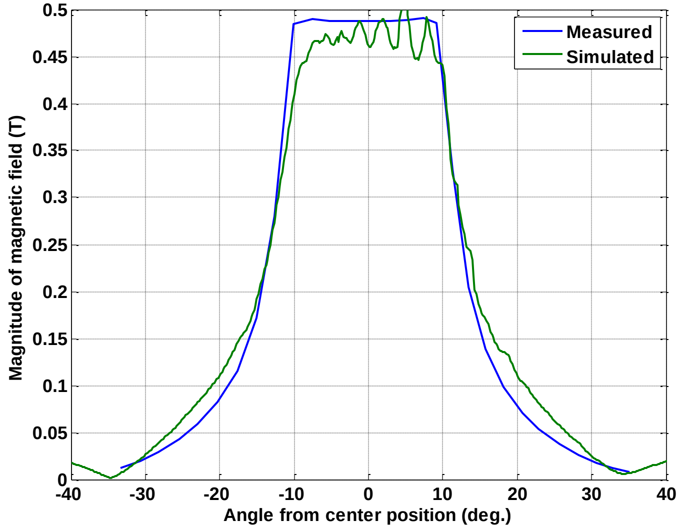
- Model from Jim Rochford
- Simulated with **immersion depths** of 50.25 and 55 mm (50.25 mm pictured)
- Mesh concentrated in wheel
- Mesh much less dense in copper, iron, and surrounding space
- Eddy currents simulated only in wheel
- Linear constitutive relation (B-H curve)

Reasonable agreement with measured magnetic field

Measurements compared with simulated field in slightly different locations



Simulated field from center of outside surface of rim, displaced 1 mm toward electromagnet



Simulated field from top of rim, displaced 1 mm away from electromagnet

10% agreement with Jim Rochford's results for 1000 rpm

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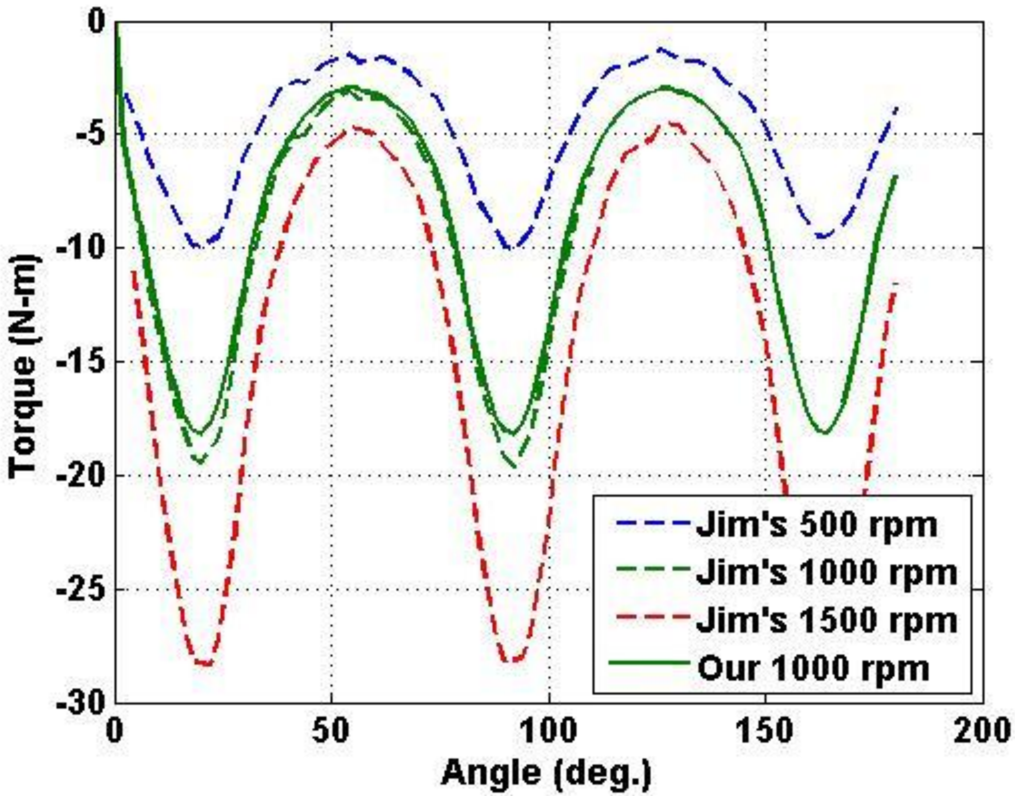

- **Immersion depth** is 55 mm
- Mesh is much less dense in the copper, iron, and surrounding space than in the 50.25 mm immersion depth case

Magnetic field effects seen in the measurements

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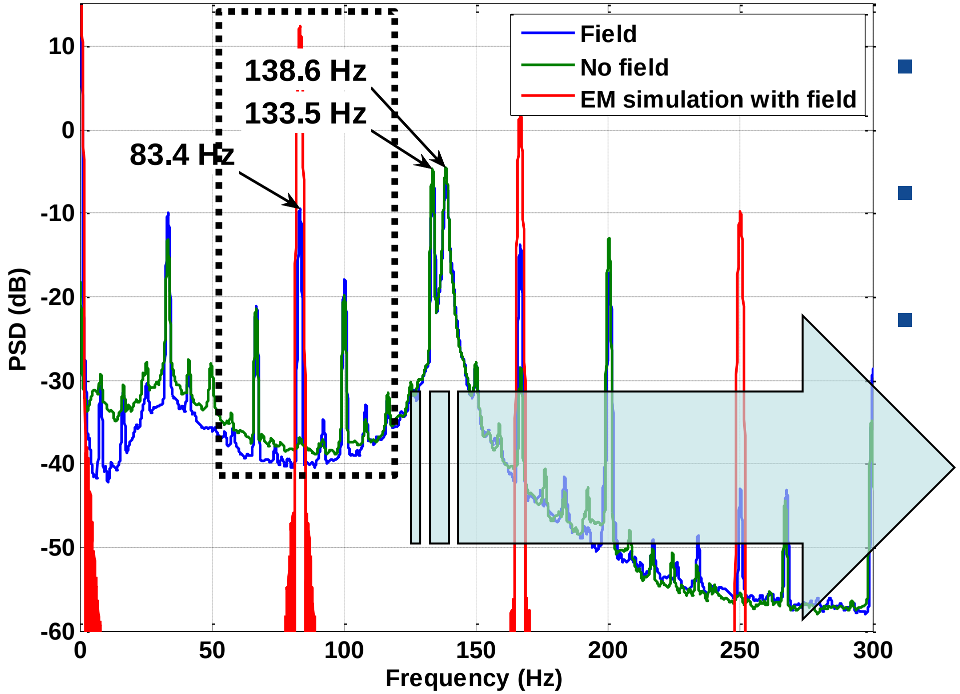
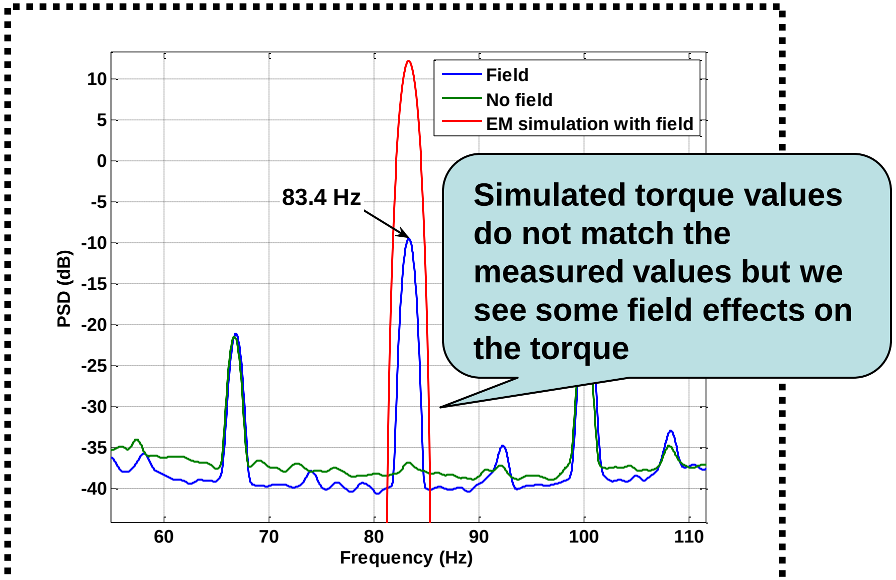


- PSD of measured and simulated data computed using Welch's method
- Simulated data replicated periodically to generate larger set
- Simulation for 1000 rpm and an **immersion depth** of 50.25 mm

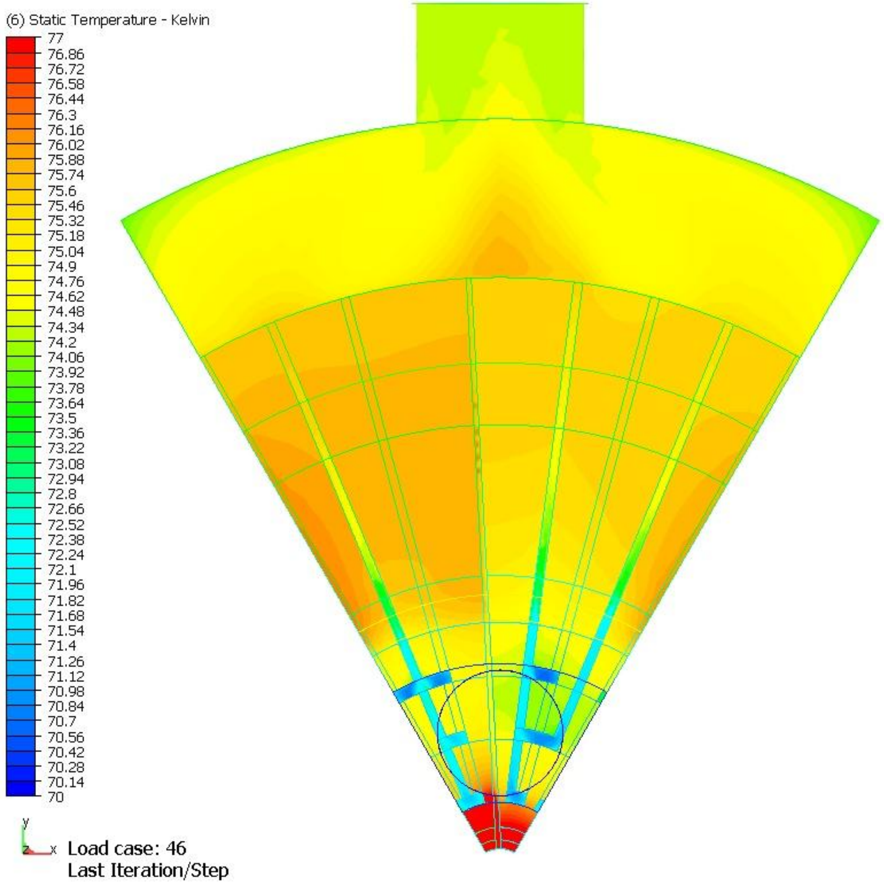


- The 83.4 Hz spike corresponds to the frequency at which the spokes pass through the electromagnet
- The severe attenuation of the 83.4 Hz peak with the electromagnet off ("No field") indicates that it is a field effect, not purely mechanical

LLNL Areas of Work

- Flux concentrator studies
- Magnetic simulations of Daresbury Laboratory spinning wheel experiment
- Rotordynamics analysis of Daresbury Experiment

Other plots…


(6) Static Temperature - Kelvin
77
76.86
76.72
76.58
76.44
76.3
76.16
76.02
75.88
75.74
75.6
75.46
75.32
75.18
75.04
74.9
74.76
74.62
74.48
74.34
74.2
74.06
73.92
73.78
73.64
73.5
73.36
73.22
73.08
72.94
72.8
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72.52
72.38
72.24
72.1
71.96
71.82
71.68
71.54
71.4
71.26
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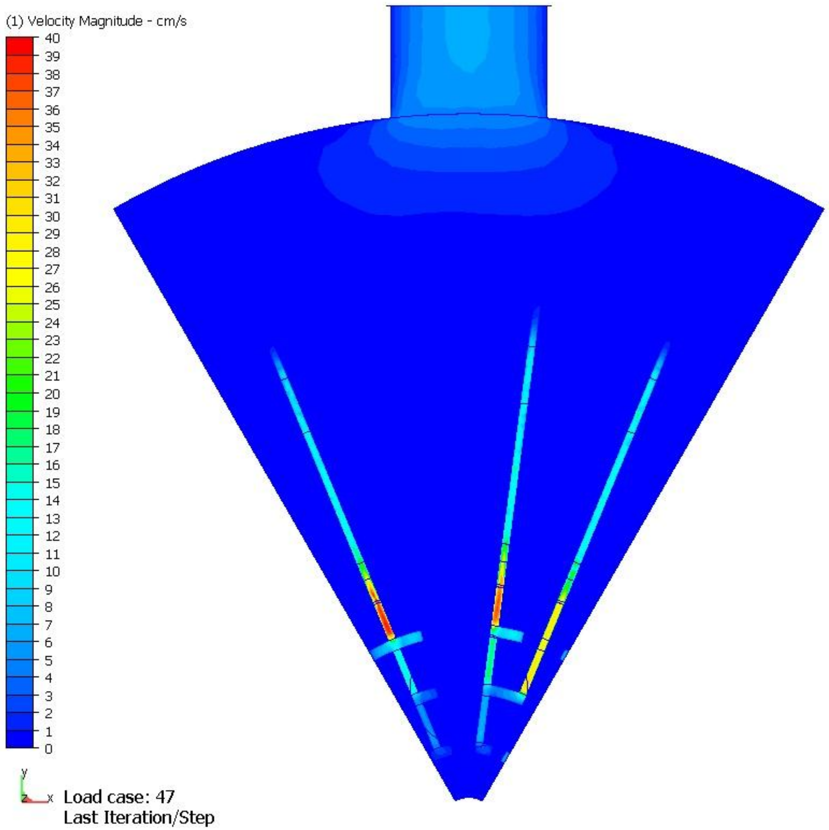
70.98
70.84
70.7
70.56
70.42
70.28
70.14
70
Load case: 46
Last Iteration/Step


(1) Velocity Magnitude - cm/s
40
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38
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25
24
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10
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8
7
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4
3
2
1
0
Load case: 47
Last Iteration/Step