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ISSUES FOR THE ROTATING W/Ti TARGET

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First reported at UK positron Source meeting this September

Conversion Target

LLNL, SLAC, Liverpool collaboration carry out design studies of the conversion target for the polarised positron source. BINP, Daresbury and Rutherford have recently joined.

- Developing water-cooled rotating wheel design.
- 0.4 radiation length titanium alloy rim.
- Radius approximately 1 m.
- Target rotates at 1000 rpm.

Two options under consideration for the AMD

DC AMD

- Option 1: DC Superconductor
 - Coil upstream of the target
 - Target sees a full 5T field
 - Spinning metal in magnetic field, we have reinvented the magnetic brake

Pulsed AMD

- Option 2: Pulsed Flux Concentrator
 - Magnet downstream of target
 - Lower field at target
 - Target being hit with a kick at 5Hz
 - Can a pulsed magnet be designed and built?

Target Wheel Design

Eddy Current Simulations

- Simulations by LLNL indicate:
- 1m radius solid Ti disc in 6T field of AMD works really well as a magnetic brake (~2MW power loss)
- Change to rim design then 14kW power loss – 'comfortable'
- Simulations to be calibrated to SLAC rotating disc experiment.
- Pulsed AMD design conservatively assumed at present (lower field on target but less positrons captured)

More details of target design in:
I. Bailey et al, Development Of A Positron Production Target For The ILC Positron Source, EPAC 06

One can expect that power is proportional to the width of rim

As an aid in the project we also made field calculations and explored the consequences for power loss and transverse deflection fields and pulsed torques in pulsed solenoid case

We erected Model, using FlexPDE Solutions©

First, one can make simple quantitative estimation of losses as the following.

In moving metal the electric field is $\vec{E} \cong \vec{v} \times \vec{B}$; v stands for velocity, so the Poynting vector flooding into metal comes to $\vec{S} \cong (\vec{v} \times \vec{B}) \times \vec{H}$

$$j \sim \sigma E \sim 5 \times 10^9 \text{ A/m}^2$$

Taking into account, that the area swept by coil per second comes to $\Sigma \cong \Omega R d$, amount of energy flooded into metal per second comes to

$$P \cong S \Sigma \cong \Omega^2 R^2 d \mu \mu_0 H^2$$

where R stands for the radial displacement of coil (\sim radius of rim), d -is coil diameter, Ω stands for angular speed, μ_0 –magnetic permeability of vacuum

One can see, that power proportional to magnetic pressure.

When angular speed increased, the Poynting vector deflects from inside direction. The estimations can be given by considerations of magnetic pressure. Really, the pressure of magnetic field is simply field density, so

$$\text{Pressure} \cong B \cdot H$$

coming to the force $F \cong B \cdot H \cdot \delta \cdot d$

where δ stands for the skin-depth $\delta \cong 1 / \sigma \mu \mu_0 \Omega$ and power arrives to

$$P \cong F \cdot v \cong B \cdot H \cdot \delta \cdot d \cdot \Omega \cdot R \cong B \cdot H \cdot d \cdot R \sqrt{\Omega / \sigma \mu \mu_0}$$

At intermediate speeds between quadratic and square root, \sim linear

MODEL

Maxwell's equations

$$\vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}; \quad \vec{\nabla} \times \vec{H} = \vec{j} + \frac{\partial \vec{D}}{\partial t}; \quad \vec{\nabla} \cdot \vec{B} = 0; \quad \vec{\nabla} \cdot \vec{D} = \rho; \quad \vec{B} = \mu\mu_0 \vec{H}; \quad \vec{D} = \epsilon\epsilon_0 \vec{E}$$

4-potential as usual

$$\vec{B} = \vec{\nabla} \times \vec{A}; \quad \vec{E} = -\frac{\partial \vec{A}}{\partial t} - \vec{\nabla} \varphi \quad \vec{\nabla} \cdot \vec{A} = 0; \quad \varphi = 0$$

Equation modeled

$$\Delta \left(\frac{1}{\mu\mu_0} \vec{A} \right) = -\vec{j}_0 - \sigma \frac{\partial \vec{A}}{\partial t} + \epsilon\epsilon_0 \frac{\partial^2 \vec{A}}{\partial t^2} \quad \text{Last term omitted}$$

$$-\sigma \frac{\partial \vec{A}}{\partial t} \rightarrow -\sigma (\vec{v} \cdot \vec{\nabla}) \vec{A}$$

$$\vec{v} = (-\Omega y, \Omega x, 0)$$

Forces

$$\vec{F} = \int_V (\vec{j} \times \vec{B}) dV$$

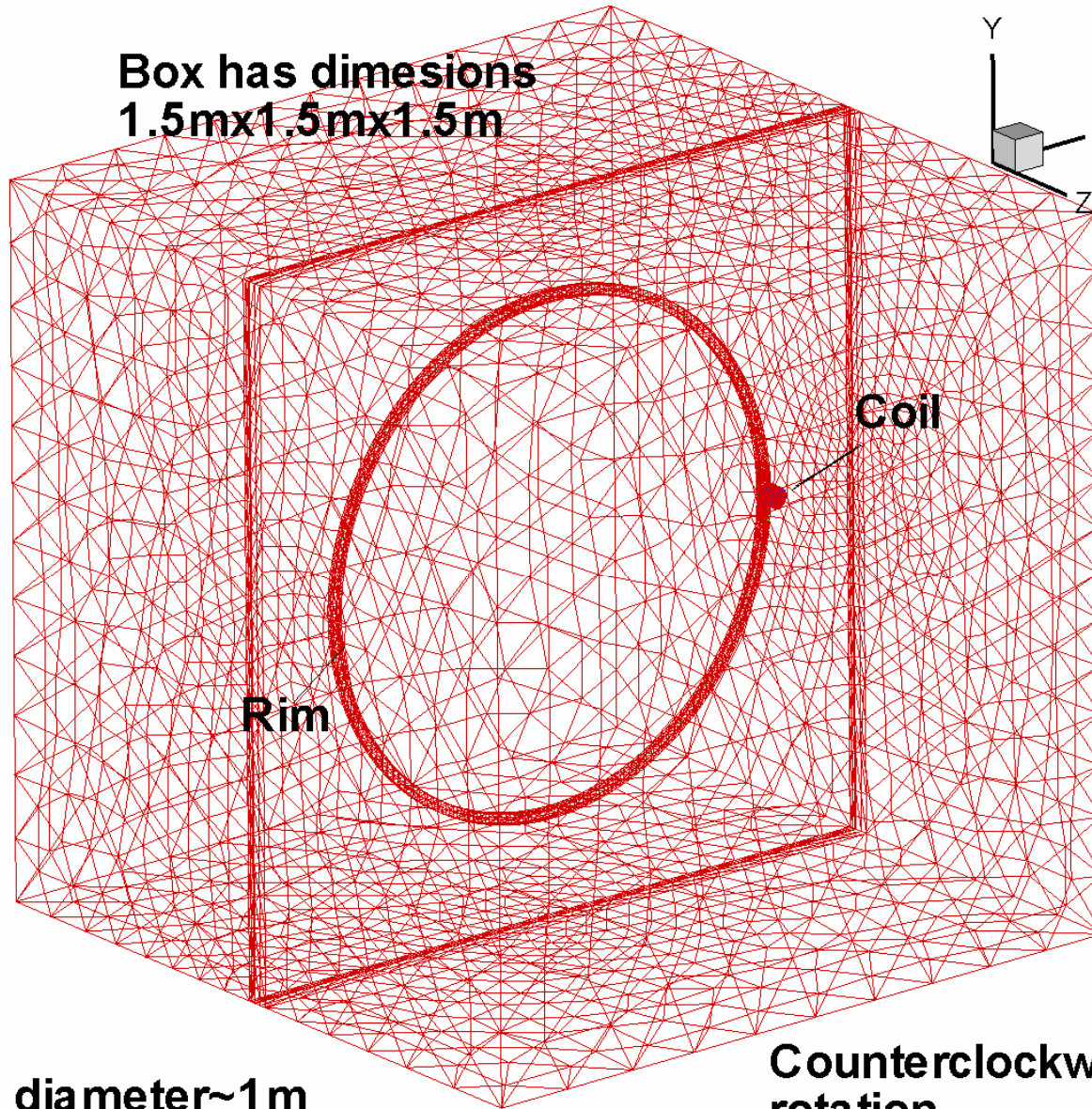
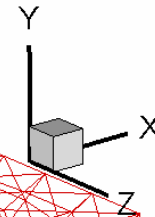
Power

$$P = \int_V ((\vec{j} \times \vec{B}) \cdot \vec{v}) dV \quad P \cong \vec{F} \cdot \vec{v}$$

$$\sigma = 2.38 \cdot 10^6 \quad \text{1/ohm/m}$$

Radius ~0.5m, thickness ~1.4cm

**Box has dimensions
1.5m x 1.5m x 1.5m**



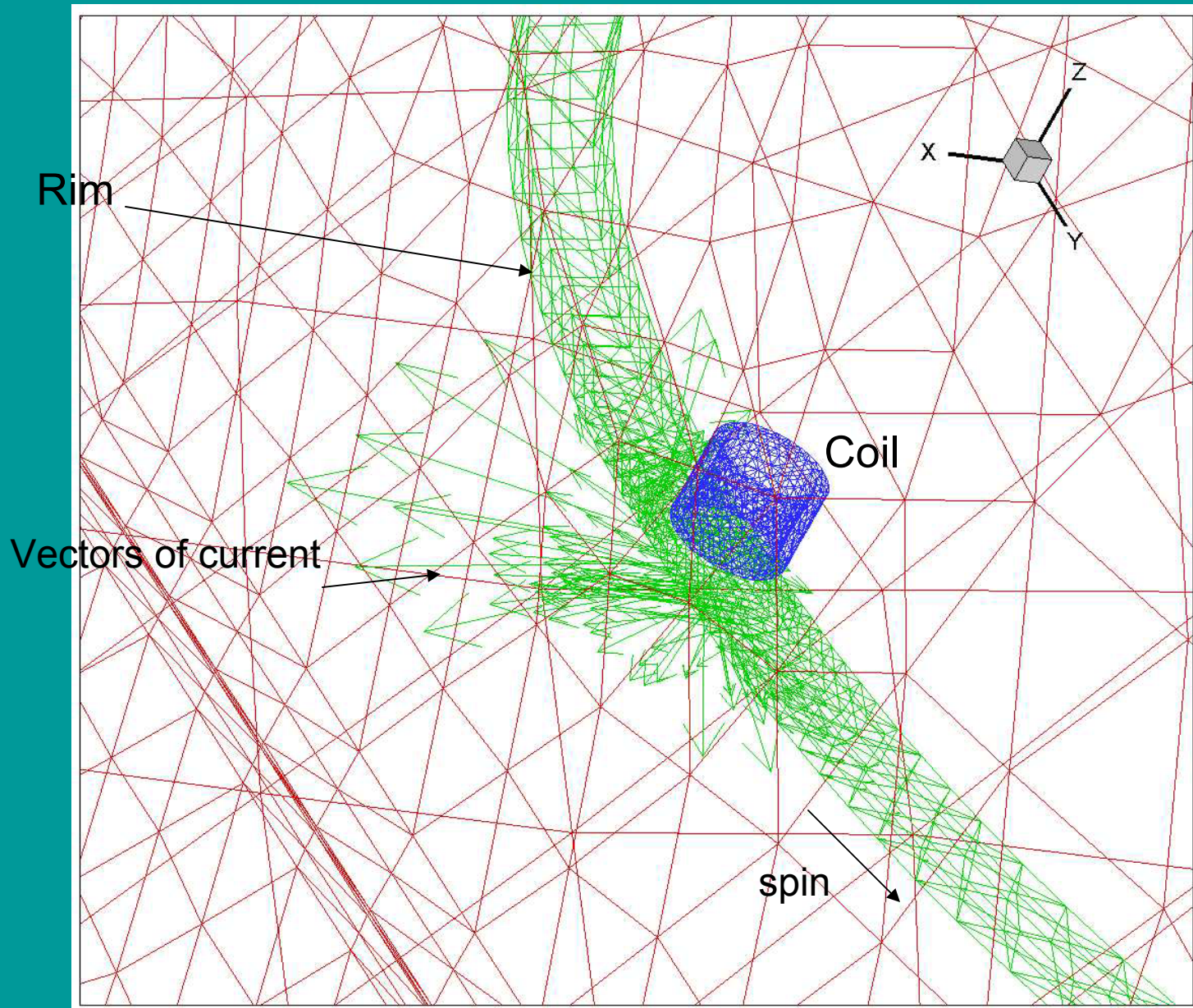
Rim

Coil

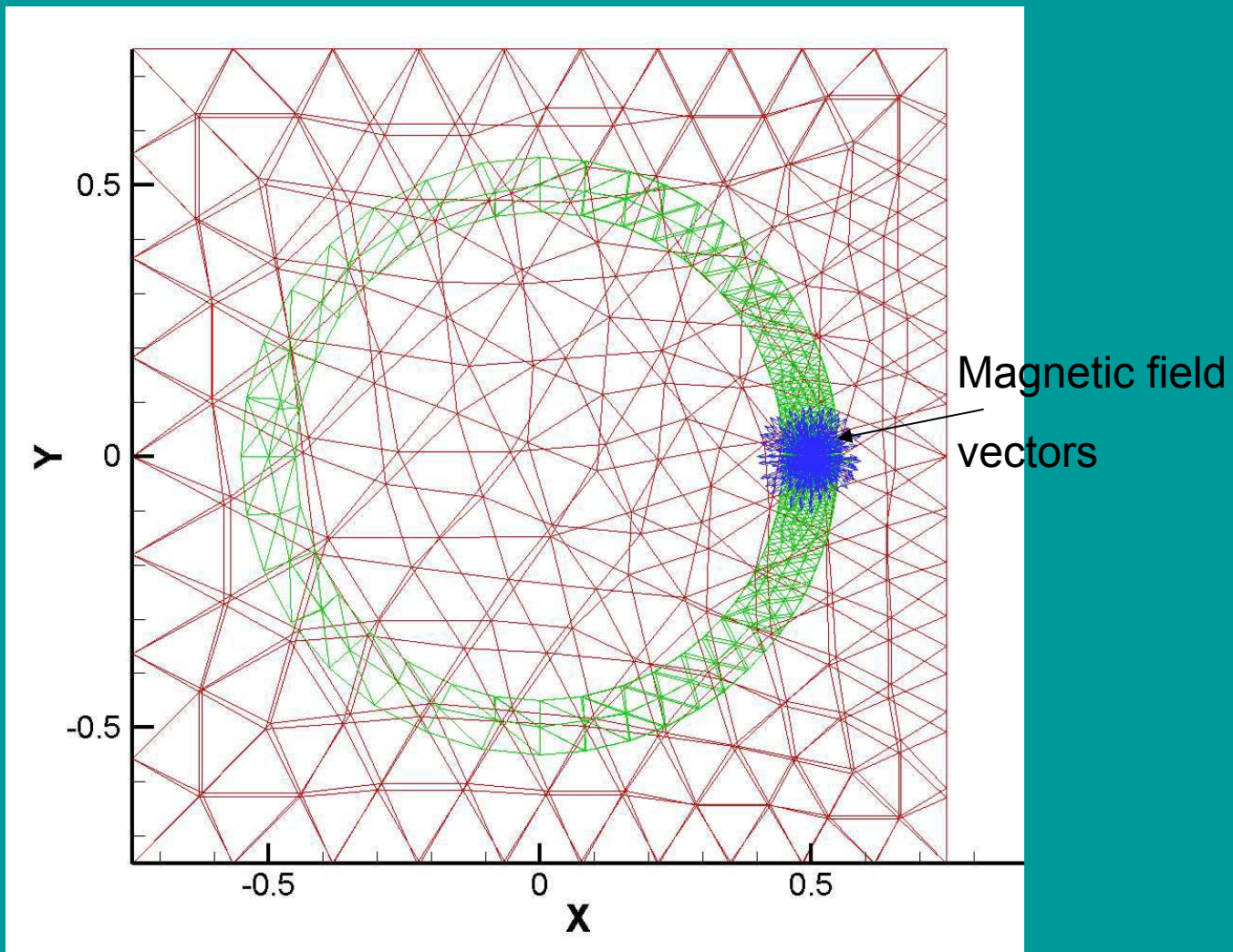
Rim diameter ~ 1 m

**Counterclockwise
rotation**

Mesh box.



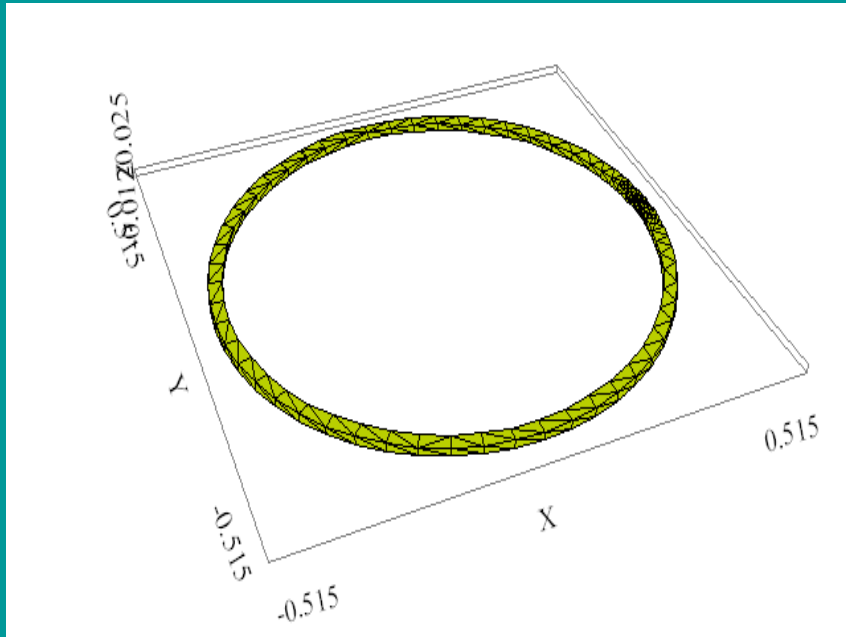
A bit more detailed picture. Mesh is denser in vicinity of coil



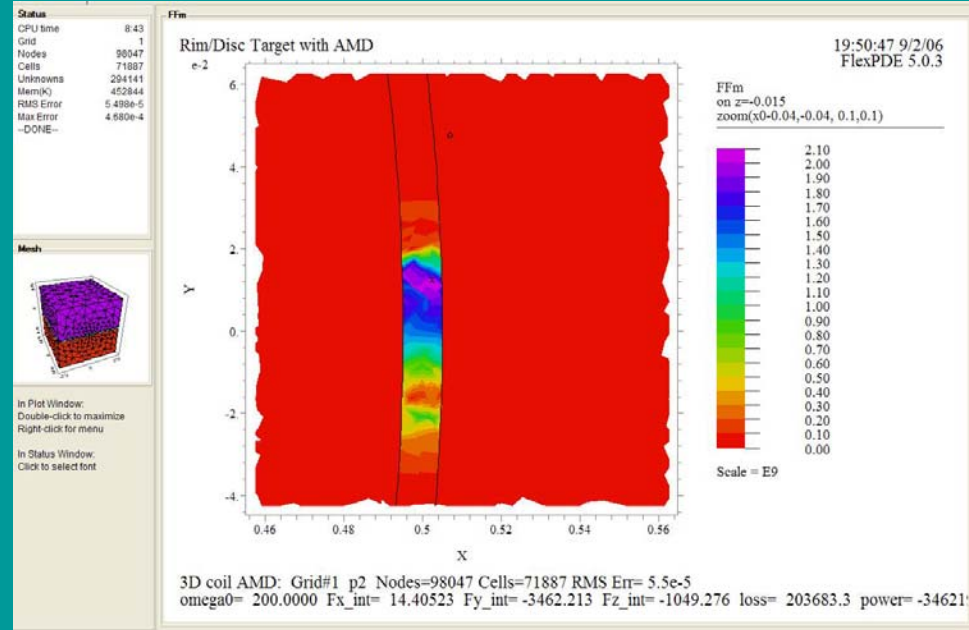
Top view. Rim with intermediate width. Dimensions are in meters.

Rim is spinning in XY plane around $X=0$; $Y=0$; counterclockwise

Geometry of rim

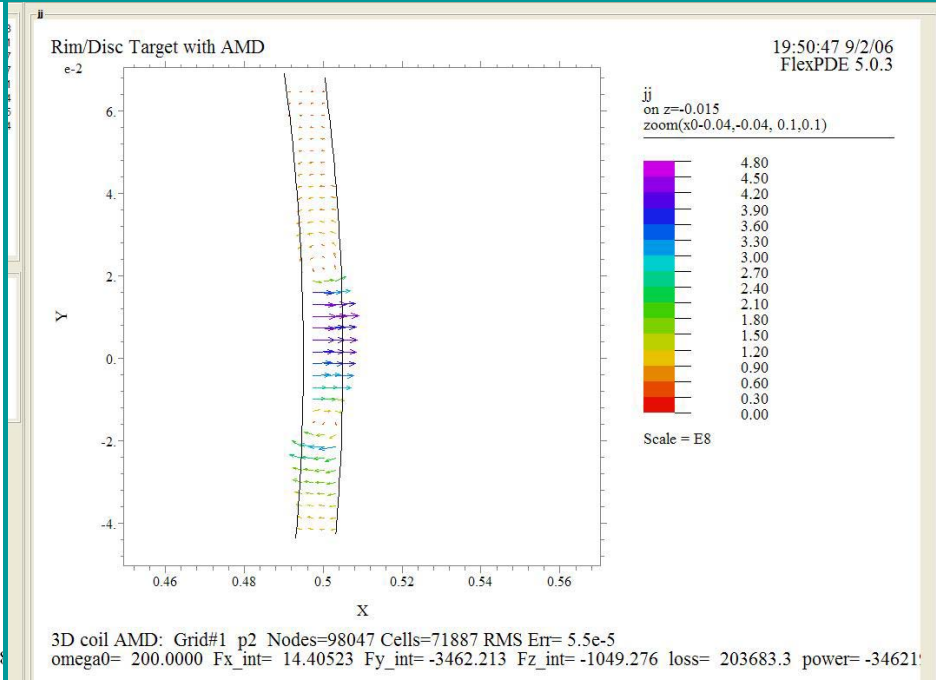
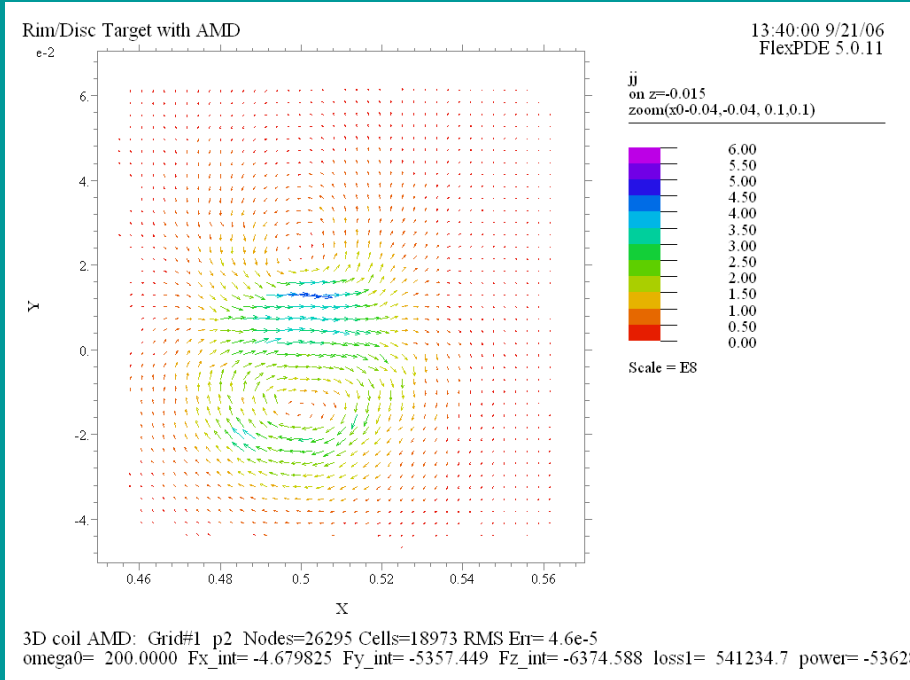


Thickness of rim ~ 0.4 rad length
Full width varied from 0.25 cm to full disc



Contour plot of forces induced by eddy currents in rim. Drag is seeing clearly

Two examples with wide and narrow rim in comparison



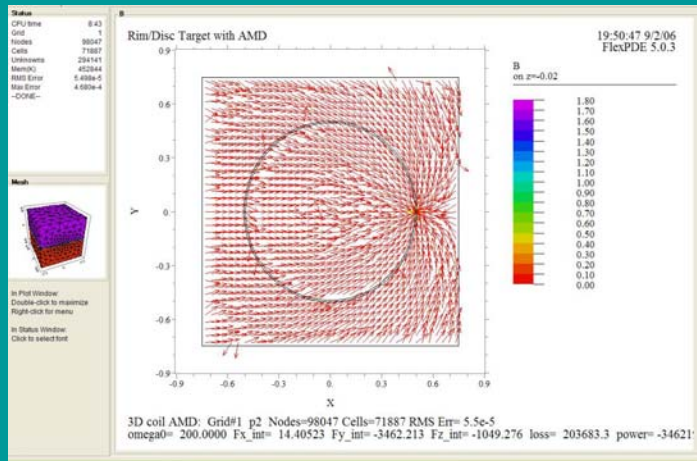
Current distribution inside wide rim

Center of coil located at $x=0.5; y=0$. One can see, that the field is dragged by spinning metal. As there is an attenuation, this transverse field varying into depth.

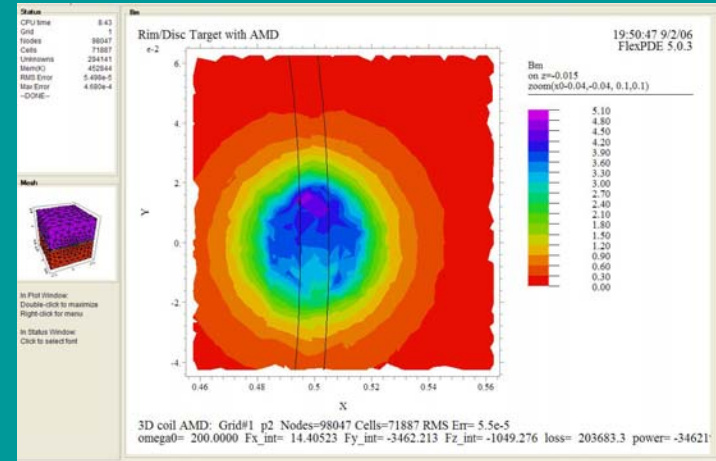
Zone with intense currents ~area under the coil, so it does not matter what is beyond this region.

Curly current flow dragged by moving metal.

Current distribution inside narrow rim

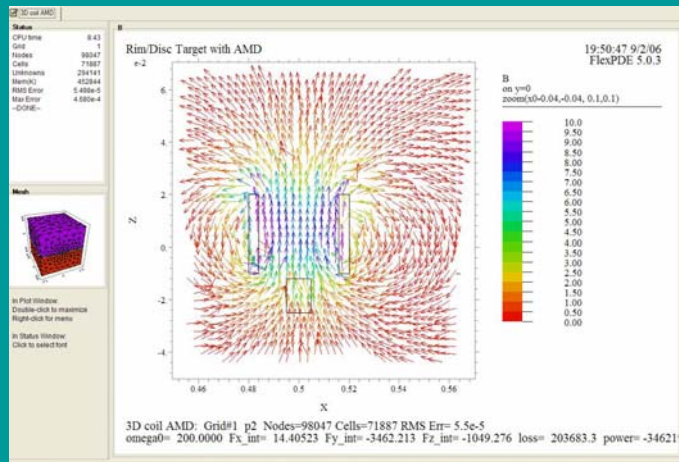


Top view to the vector field

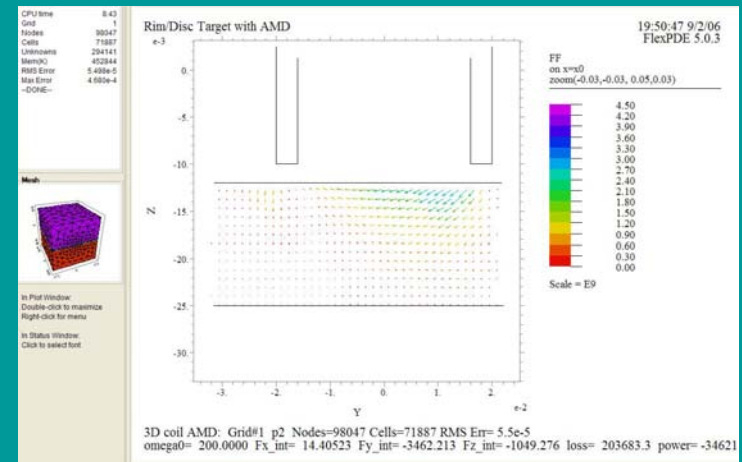


Contour plot of field amplitude.

Drag is seen here



Fields in cross section through the center of coil

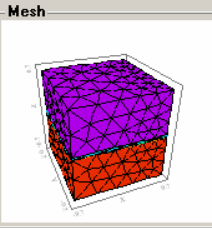


Forces in cross section YZ plane through the center of coil

Palette output for wide rim

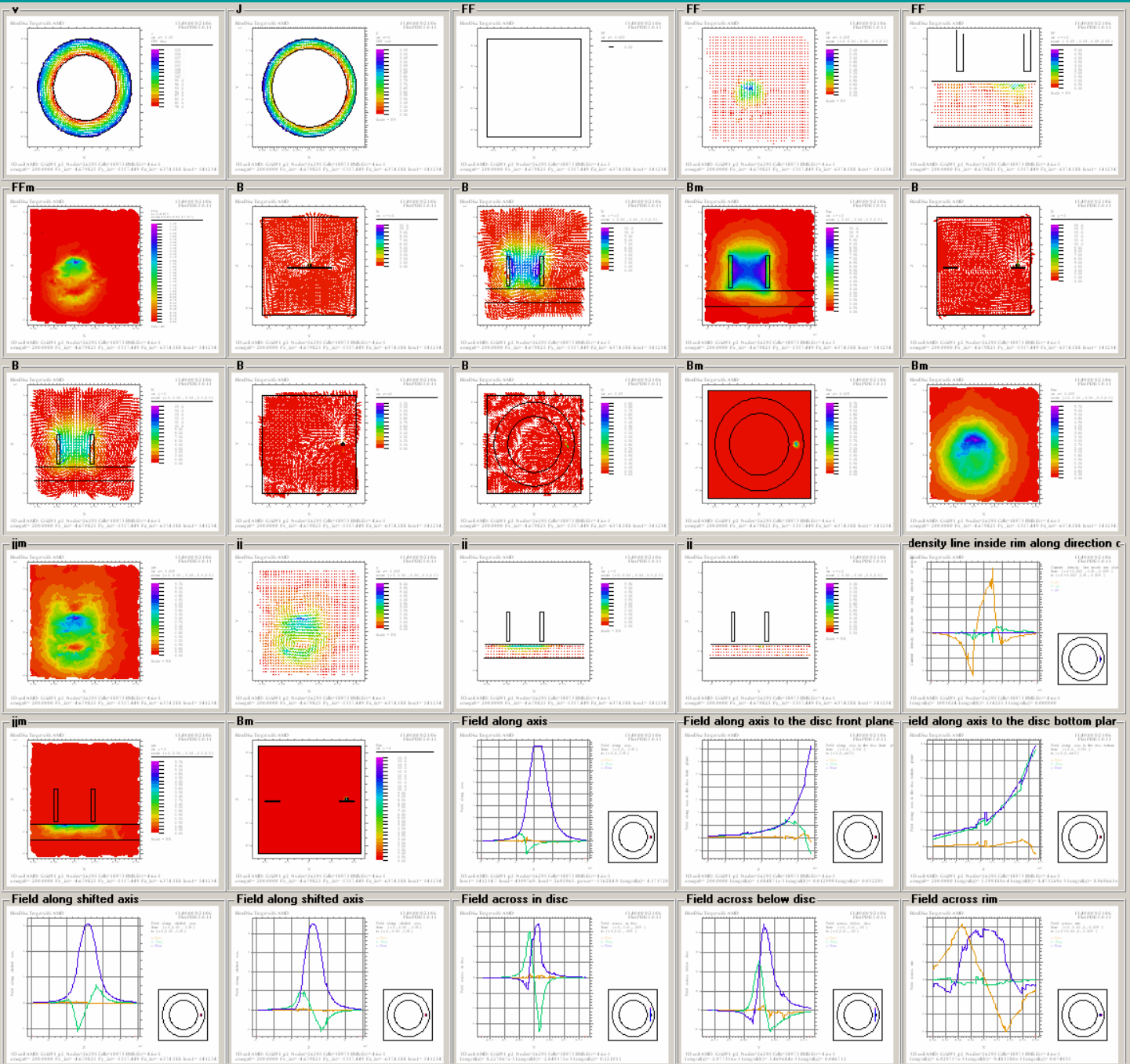
Status

CPU time 1:58
 Grid 1
 Nodes 26295
 Cells 18973
 Unknowns 78885
 Mem(K) 135326
 RMS Error 4.564e-5
 Max Error 2.963e-4
 --DONE--



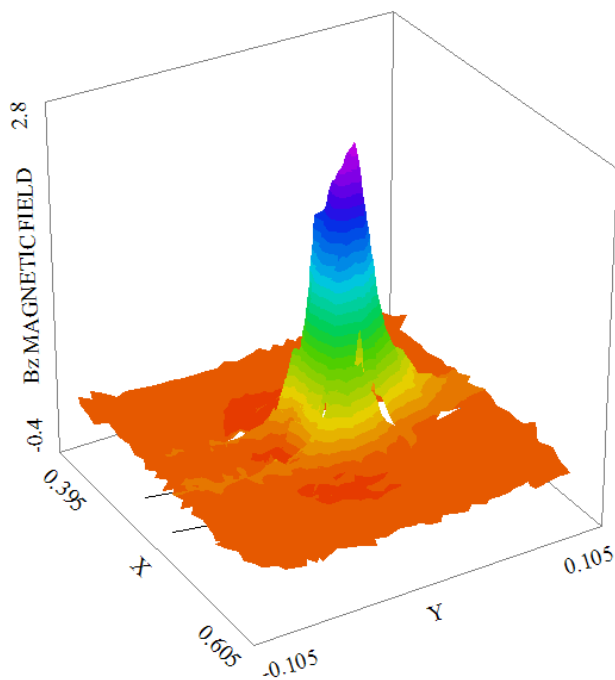
In Plot Window:
 Double-click to maximize
 Right-click for menu

In Status Window:
 Click to select font

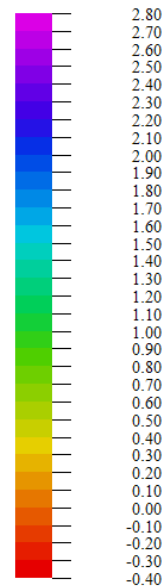


Rim/Disc Target with AMD

22:21:46 10/20/06
FlexPDE 5.0.12



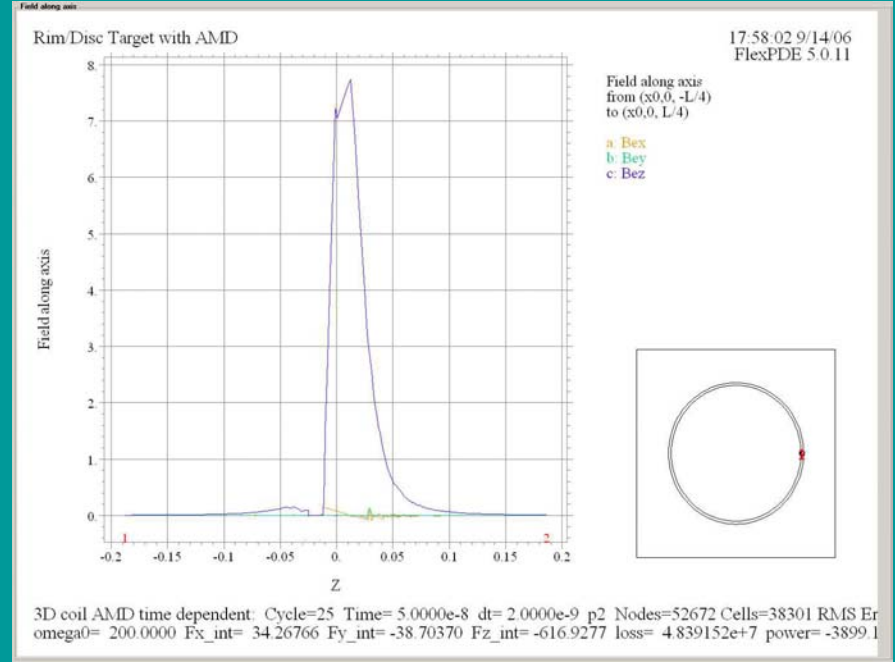
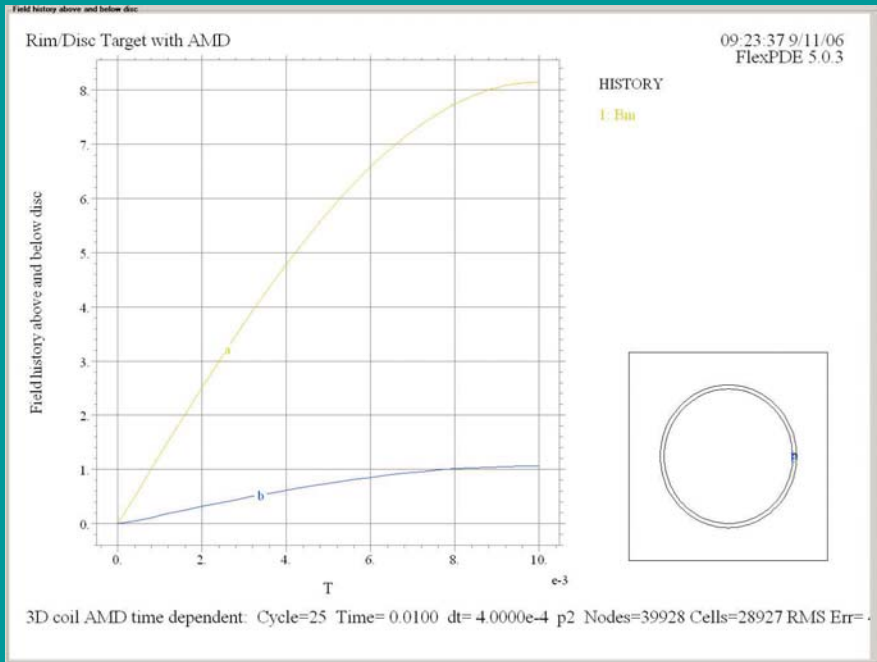
Bz MAGNETIC FIELD
viewpoint (-1,-1,30)
on z=zd1+z_thick/2
zoom(x0-0.1,-0.1,2.,2)
(3.05,-1.53,30.)



3D coil AMD: Grid#1 p2 Nodes=28721 Cells=20484 RMS Err= 7.1e-5
Integral= 1.952168e-3

We investigated pulsed feeding also.

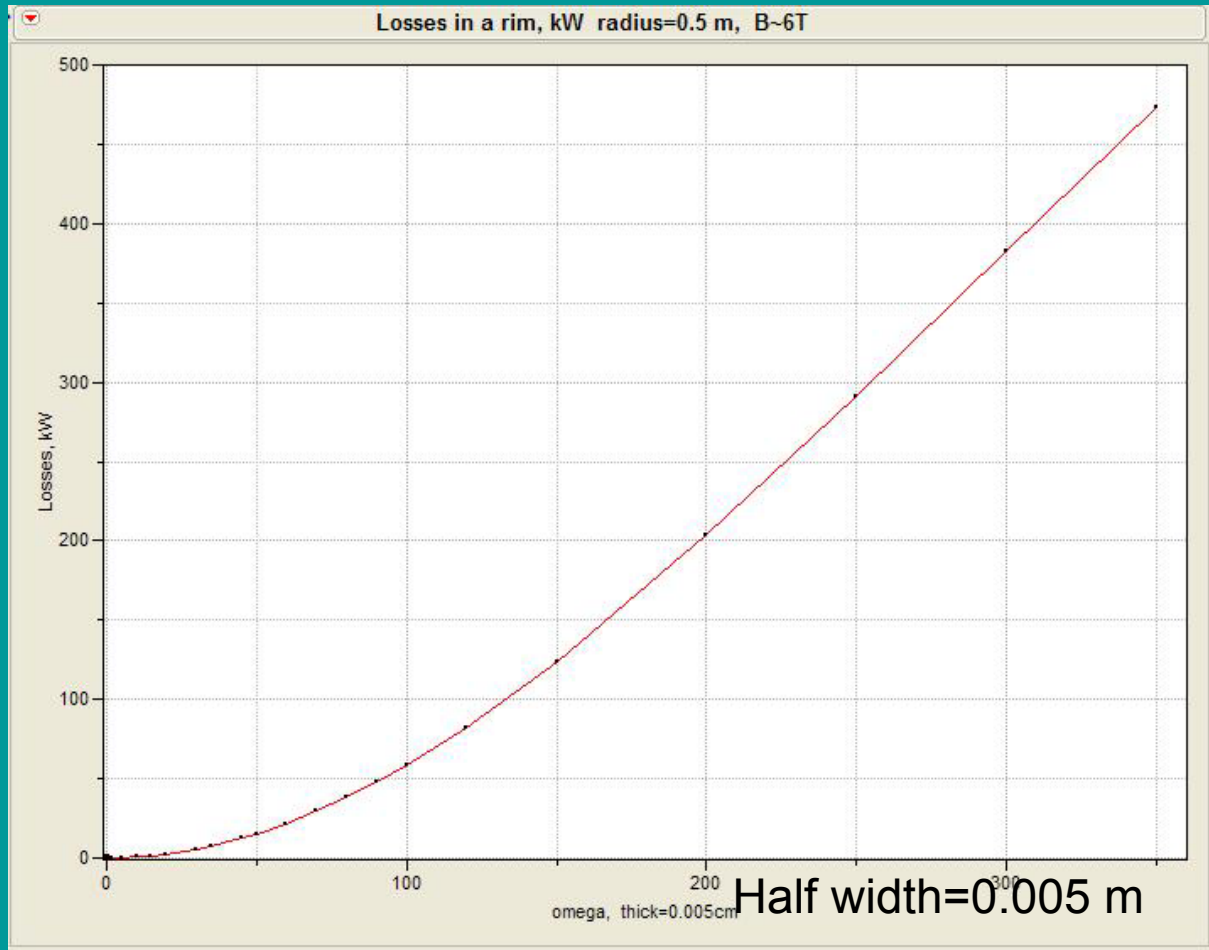
Range zero-top rise time within 50 nsec-20 msec.



Field history below and above rim for 10 msec pulse duty (from zero to the top)

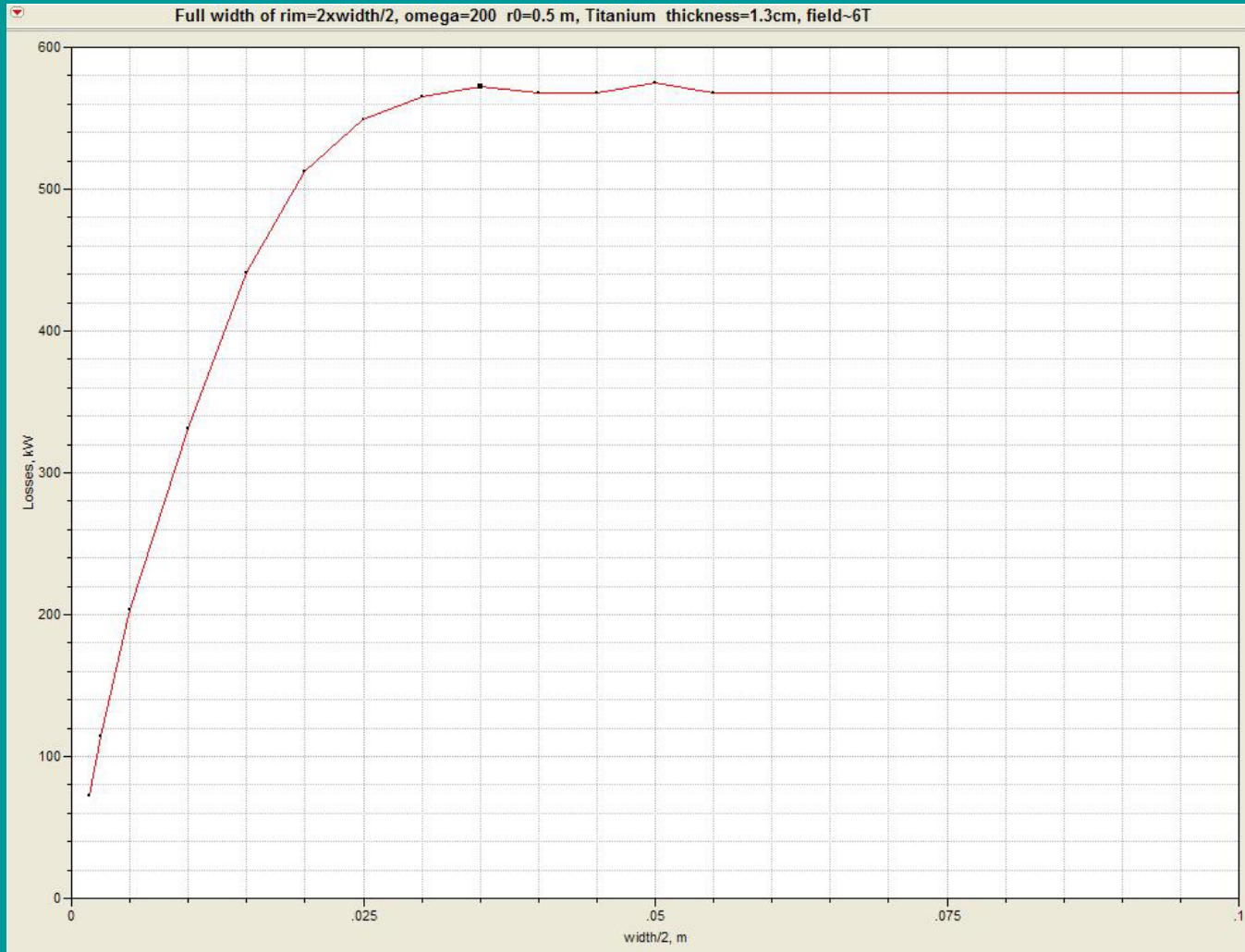
Field elevation along axis at 50 nsec pulse duty. AMD philosophy is not working for short feeding pulse

Ti target

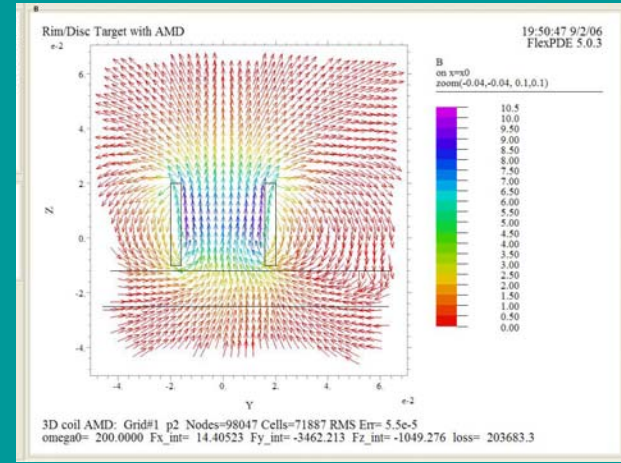
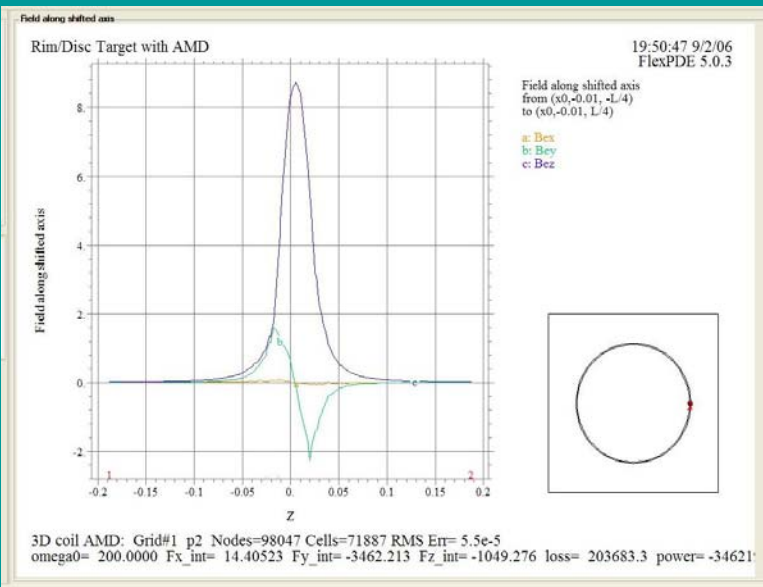


Losses as function of rotation speed Ω

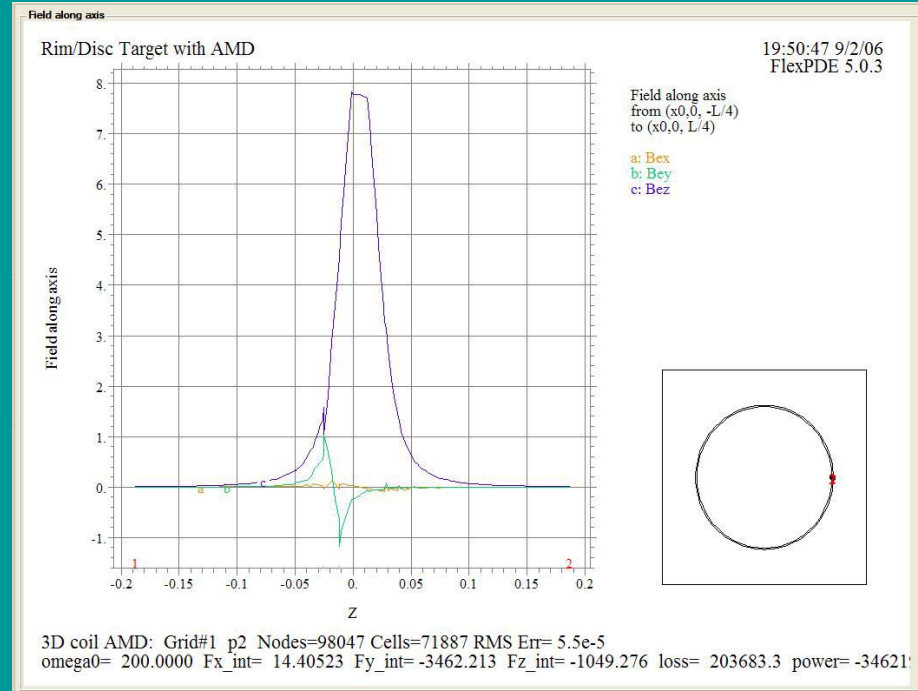
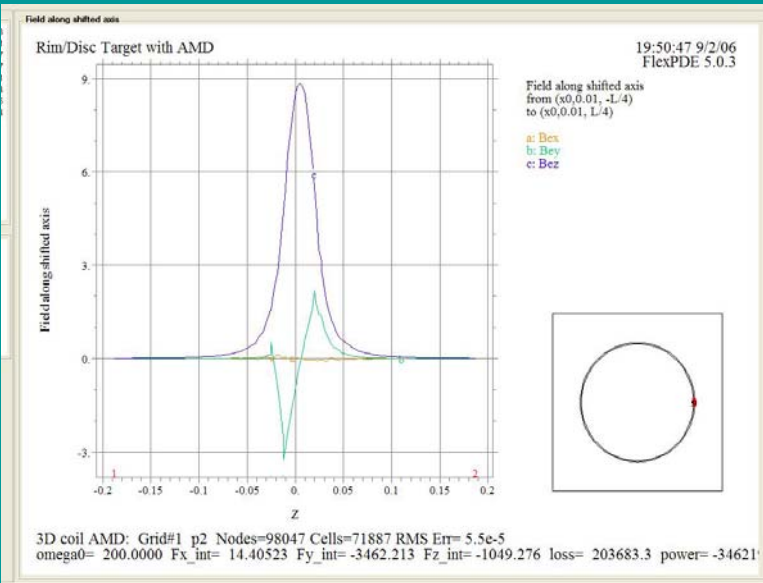
Ti target



Losses as function of width of rim. After reaching the width of coil, power does not change, naturally. For narrow rim the power is dropping proportionally to the width.



Metal is moving to the right

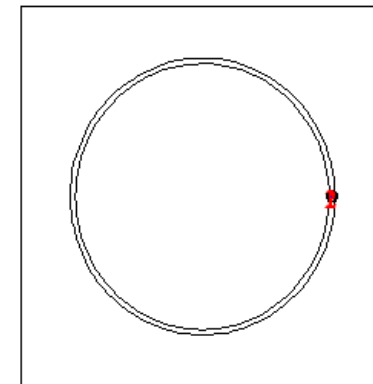
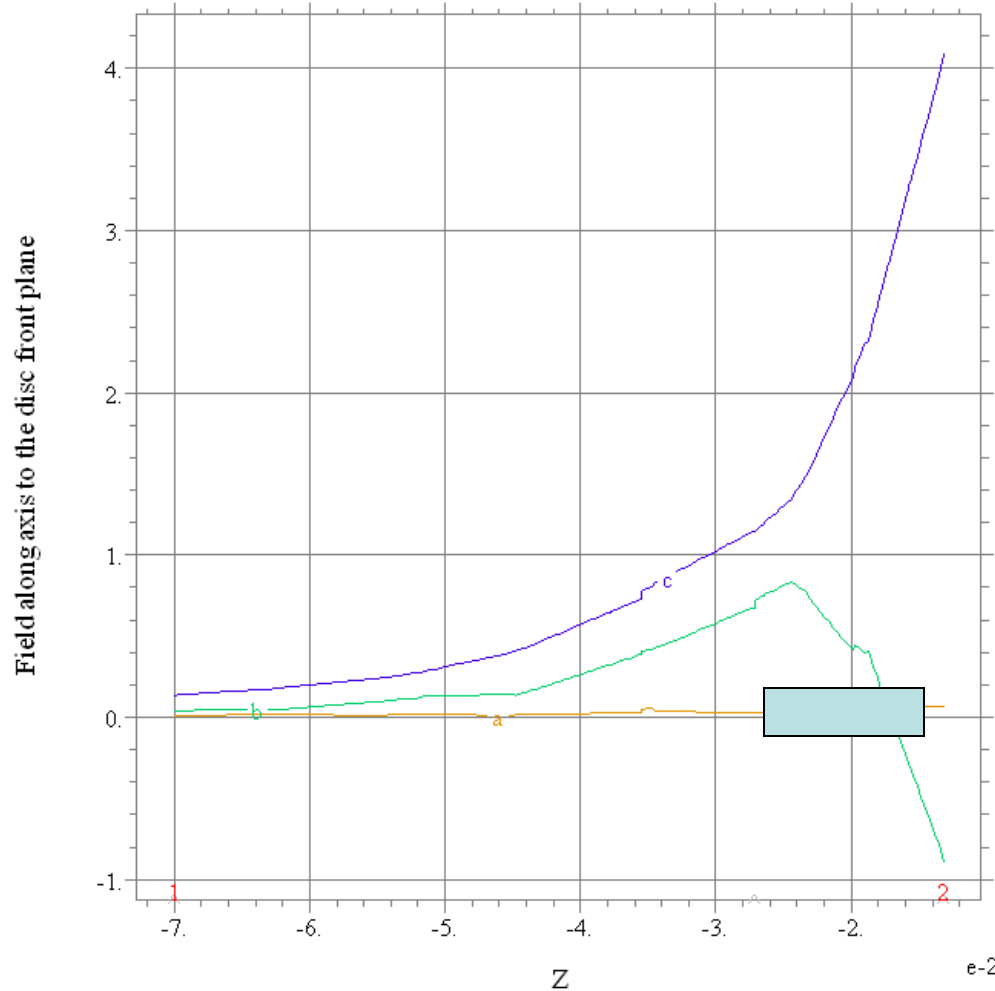


Inside metal, strong currents are running

Magnetic fields induced in target sweep the beam

Rim/Disc Target with AMD

17:54:27 9/22/06
FlexPDE 5.0.11



3D coil AMD: Grid#1 p2 Nodes=49252 Cells=35658 RMS Err= 5.e-5
 $\omega_0 = 200.0000$ Integral(a)= 1.652194e-3 Integral(b)= 0.013170 Integral(c)= 0.050985

Field elevation from bottom of box to the plane of rim at the coil side.

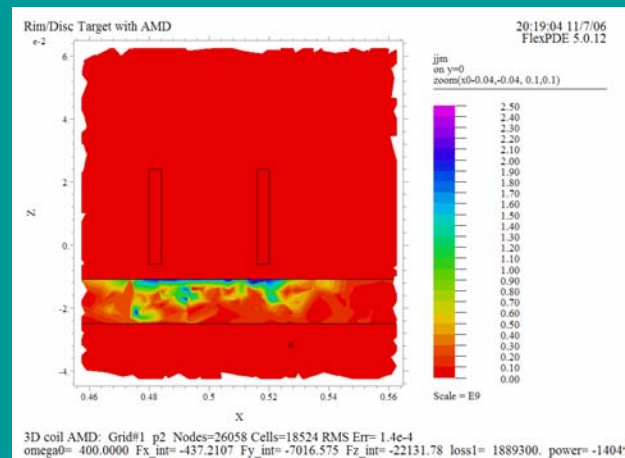
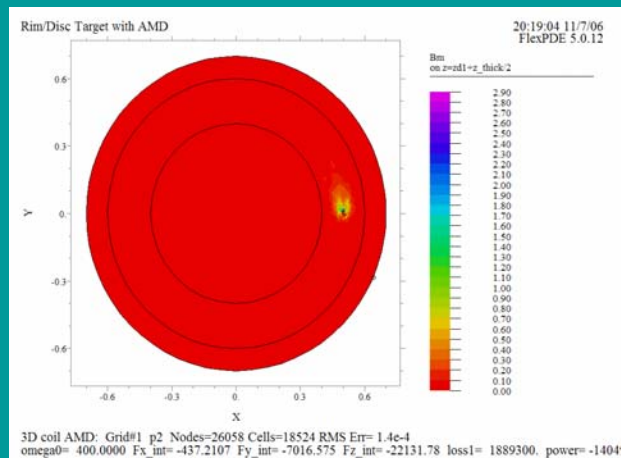
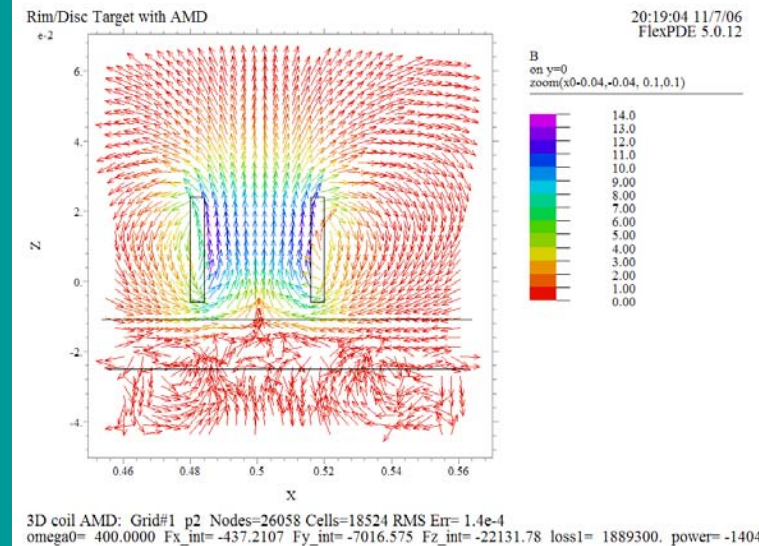
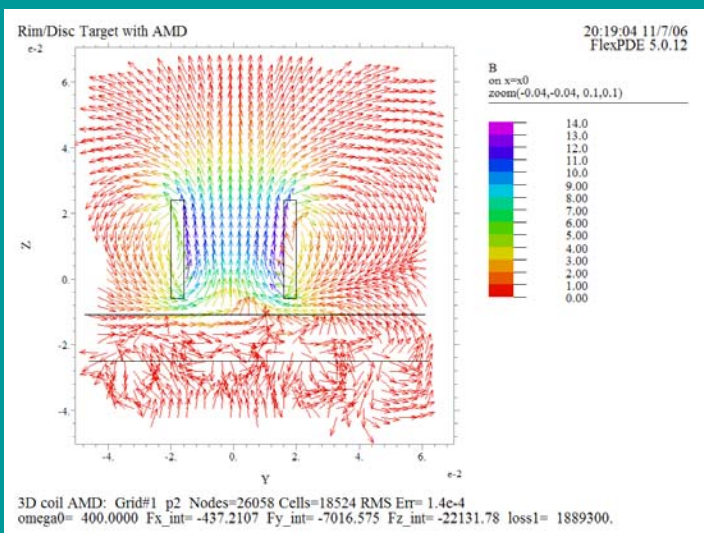
Gamma-beam supposed to move from the right to the left

Situation is somewhat better for equal fields from two opposing sides (tested), but there is no focusing fields here

Shift of center of gamma beam to the direction of rotation is also some helping procedure

Tungsten target 4X₀

Spinning with linear velocity 200 m/sec



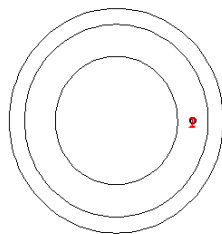
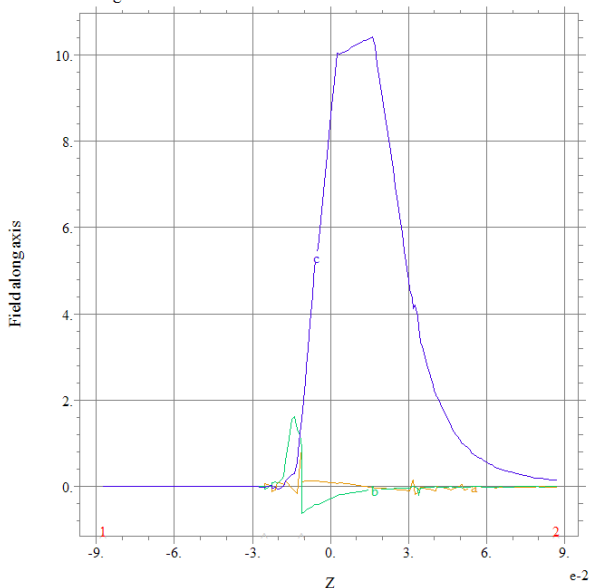
Field elevation along the beam trajectory

Rim/Disc Target with AMD

20:19:04 11/7/06
FlexPDE 5.0.12

Field along axis
from (x0,0, -L/8.)
to (x0,0, L/8.)

a: Bex
b: Bey
c: Bez



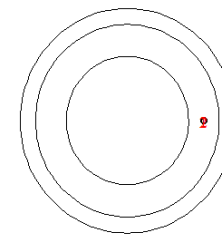
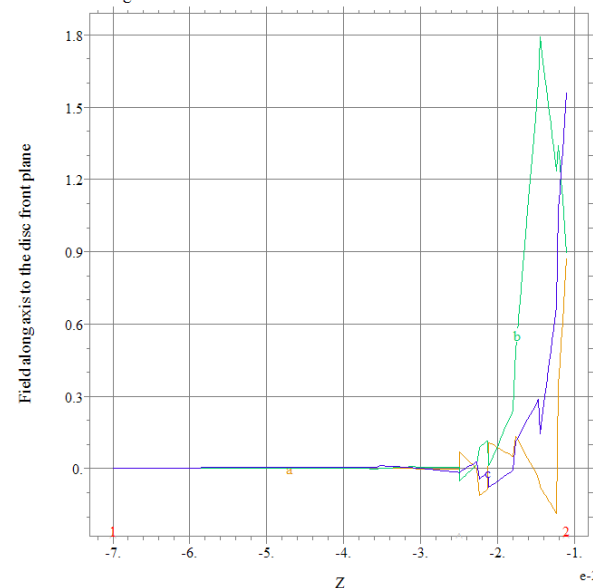
3D coil AMD: Grid#1 p2 Nodes=26058 Cells=18524 RMS Err= 1.4e-4
loss1= 1889300. loss2= 5.431009e+7 loss3= 4.961092e+7 power= -1404934. Integral(a)= 4.556828e-4 Integ

Rim/Disc Target with AMD

20:19:04 11/7/06
FlexPDE 5.0.12

Field along axis to the disc front plane
from (x0,0, -L/10.)
to (x0,0, zd2)

a: Bex
b: Bey
c: Bez



3D coil AMD: Grid#1 p2 Nodes=26058 Cells=18524 RMS Err= 1.4e-4
omega0= 400.0000 Integral(a)= 7.807719e-4 Integral(b)= 8.883915e-3 Integral(c)= 3.145310e-3

$$F_x = -437\text{N}; F_y = -7016\text{N}; F_z = -22131\text{N}$$

Power losses = -1.4MW

If disk/rim has interruptions, vertical kick acts as a pulsed one

CONCLUSIONS

Fields induced in rim have significant values. Typical integral $\sim 1\text{T}\cdot\text{cm}$ of transverse field
This value does not depend on width of rim practically, just changes the power deposition.

$(HR)=pc/300$ for 10 MeV particle $\sim 3\text{T}\cdot\text{cm} \rightarrow$ Angular spread $\sim 0.3-1$ rad for the beam

Power remains significant $\sim 100-200$ kW (~ 270 HP motor required to spin the rim)

Forces are $F \sim 0.3-0.4$ Tons opposing spin, $F \sim 0.2$ Tons expelling from coil (for narrow rim)

Pulsed feeding indicate worsen situation for long time pulsing. Investigated ~ 20 msec and 30 nsec pulses, For very short pulses motion does not influence much.

Situation for ordinary positron source target (spinning cross) complicated by pulsed hit by magnetic force ~ 0.2 T each time when metal passing the coil.

Not stationary field distribution kicking different bunches in a train to different angles

Pulsed torque required special attention (hydraulic muff)

AMD philosophy is not working here

We are planning to continue investigate this model, exact dimensions required for comparison however