CBN 07-2

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ISSUES FOR THE ROTATING TARGET

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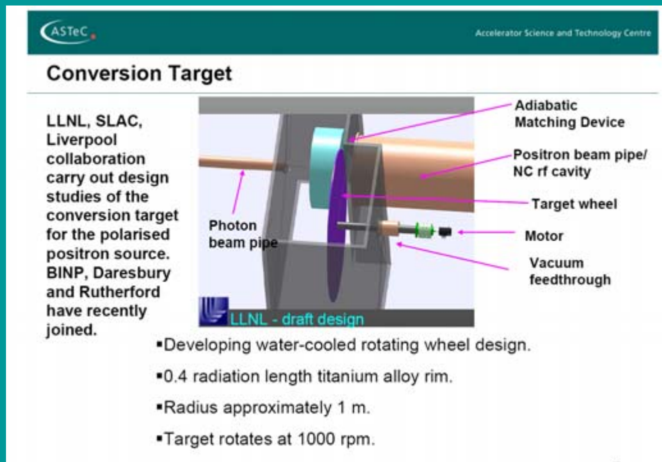
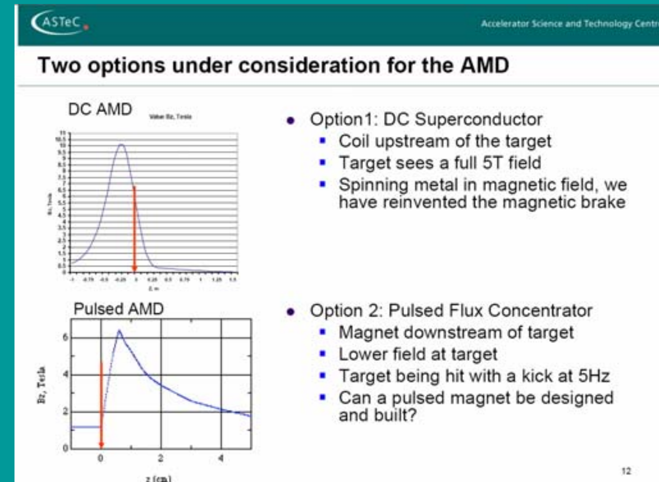
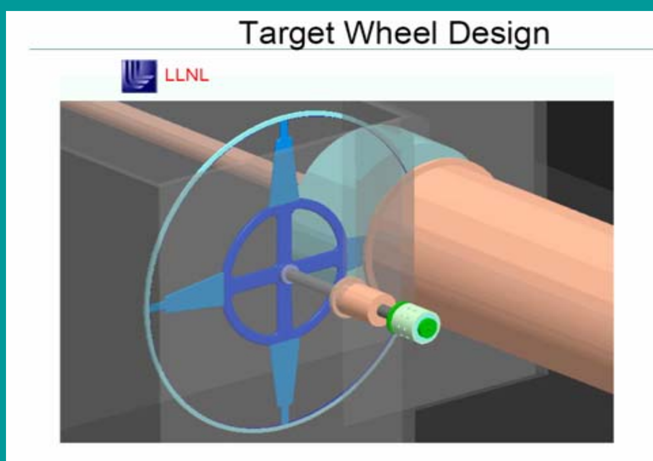
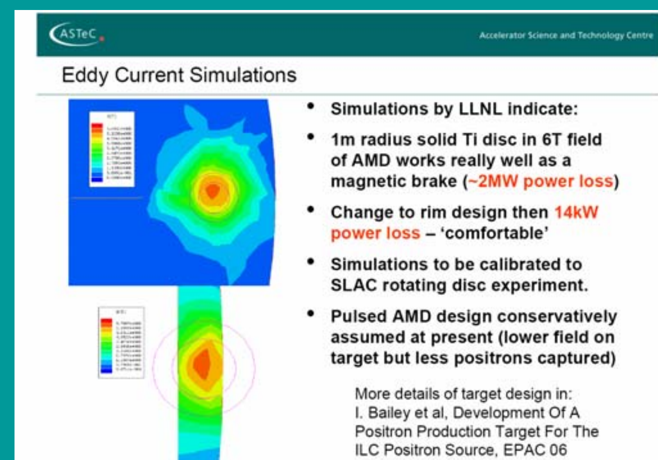
Electronic version is available at
http://www.lns.cornell.edu/public/CBN/2007/CBN07-2/cbn07-02.pdf

Some illustrations form J. Clarke talk at VLCW/GDE, UBC Vancouver, Canada, 19-22 July 2006









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 Pointing vector flooding into metal comes to $\vec{S} \cong (\vec{v} \times \vec{B}) \times \vec{H}$,

$j \sim \sigma E \sim 5 \times 10^9$ 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 (~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 Pointing 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

$$Pressure \cong B \cdot H$$

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, ~linear

MODEL

Maxwell's equations

$$\vec{\nabla}\times\vec{E} = -\frac{\partial\vec{B}}{\partial t}; \quad \vec{\nabla}\times\vec{H} = \vec{j} + \frac{\partial\vec{D}}{\partial t}; \quad \vec{\nabla}\cdot\vec{B} = 0; \quad \vec{\nabla}\cdot\vec{D} = \rho; \quad \vec{B} = \mu\mu_0\vec{H}; \quad \vec{D} = \varepsilon\varepsilon_0\vec{E}$$

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

Equation modeled $\Delta\left(\frac{1}{\mu\mu_0}\vec{A}\right) = -\vec{j}_0 - \sigma\frac{\partial\vec{A}}{\partial t} + \varepsilon\varepsilon_0\frac{\partial^2}{\partial t^2}\vec{A}$ Last term omitted

$$-\sigma\frac{\partial\vec{A}}{\partial t} \rightarrow -\sigma(\vec{v}\cdot\vec{\nabla})\vec{A} \qquad \vec{v} = (-\Omega y, \Omega x, 0)$$

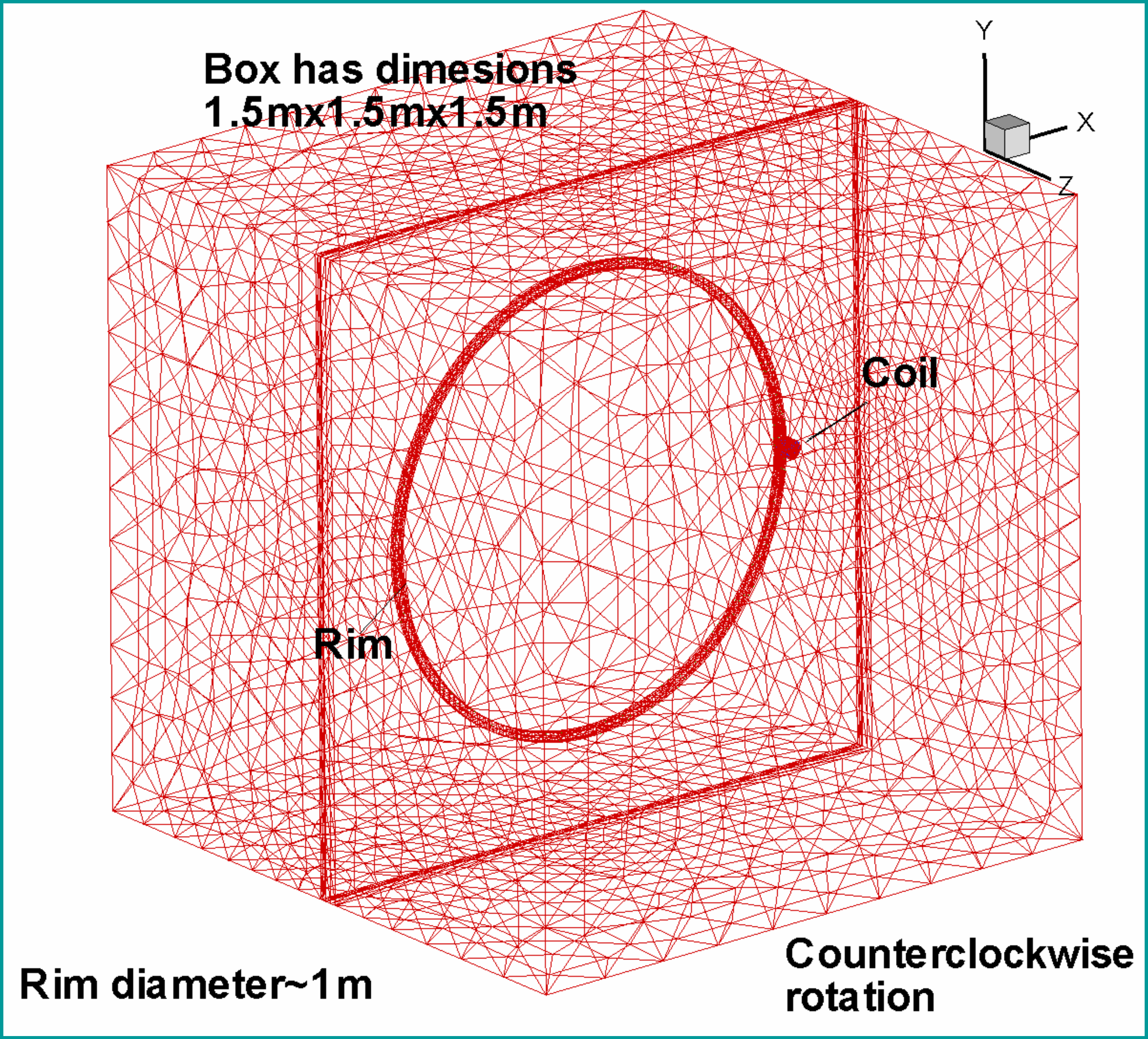
Forces

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

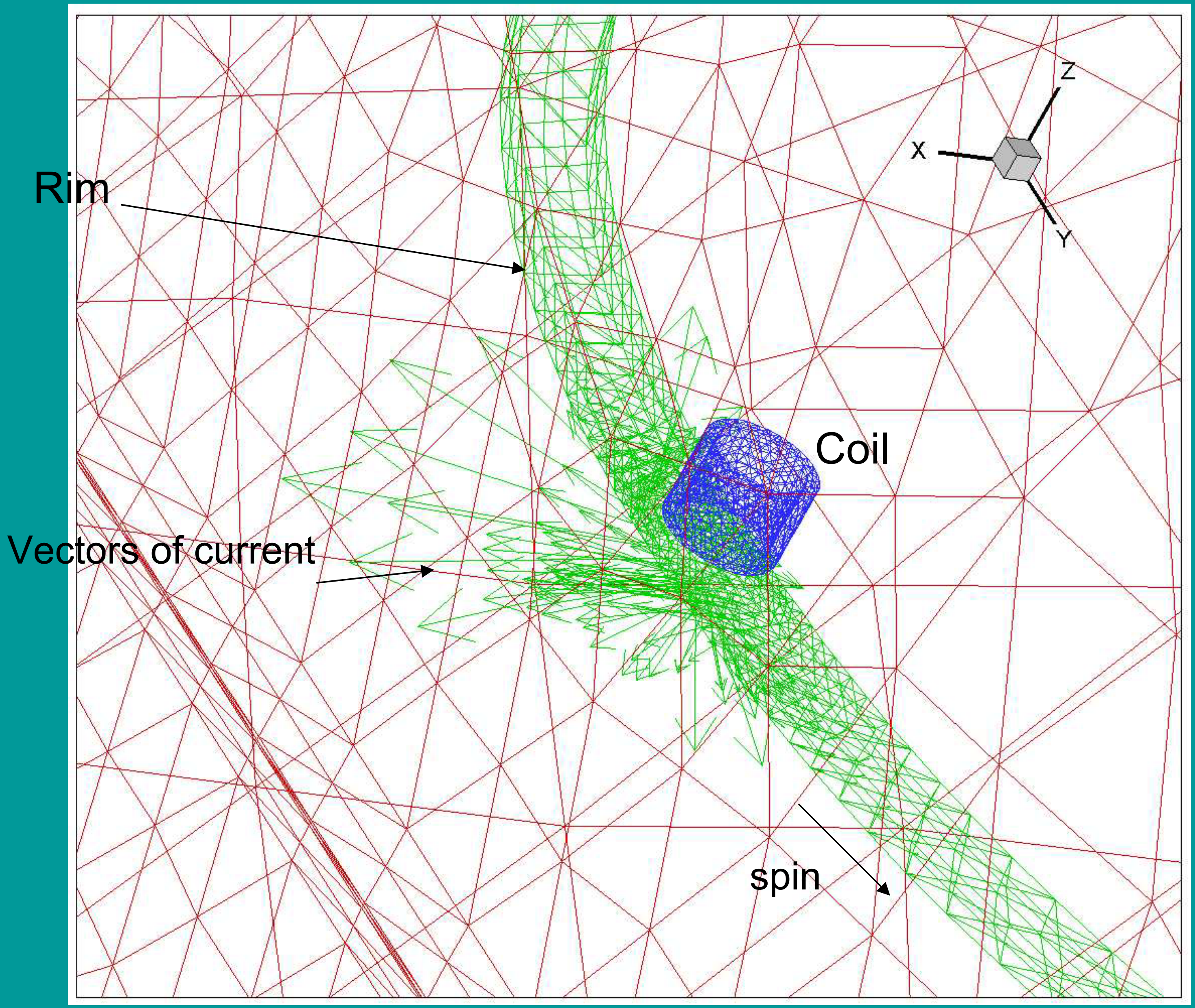
Power

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

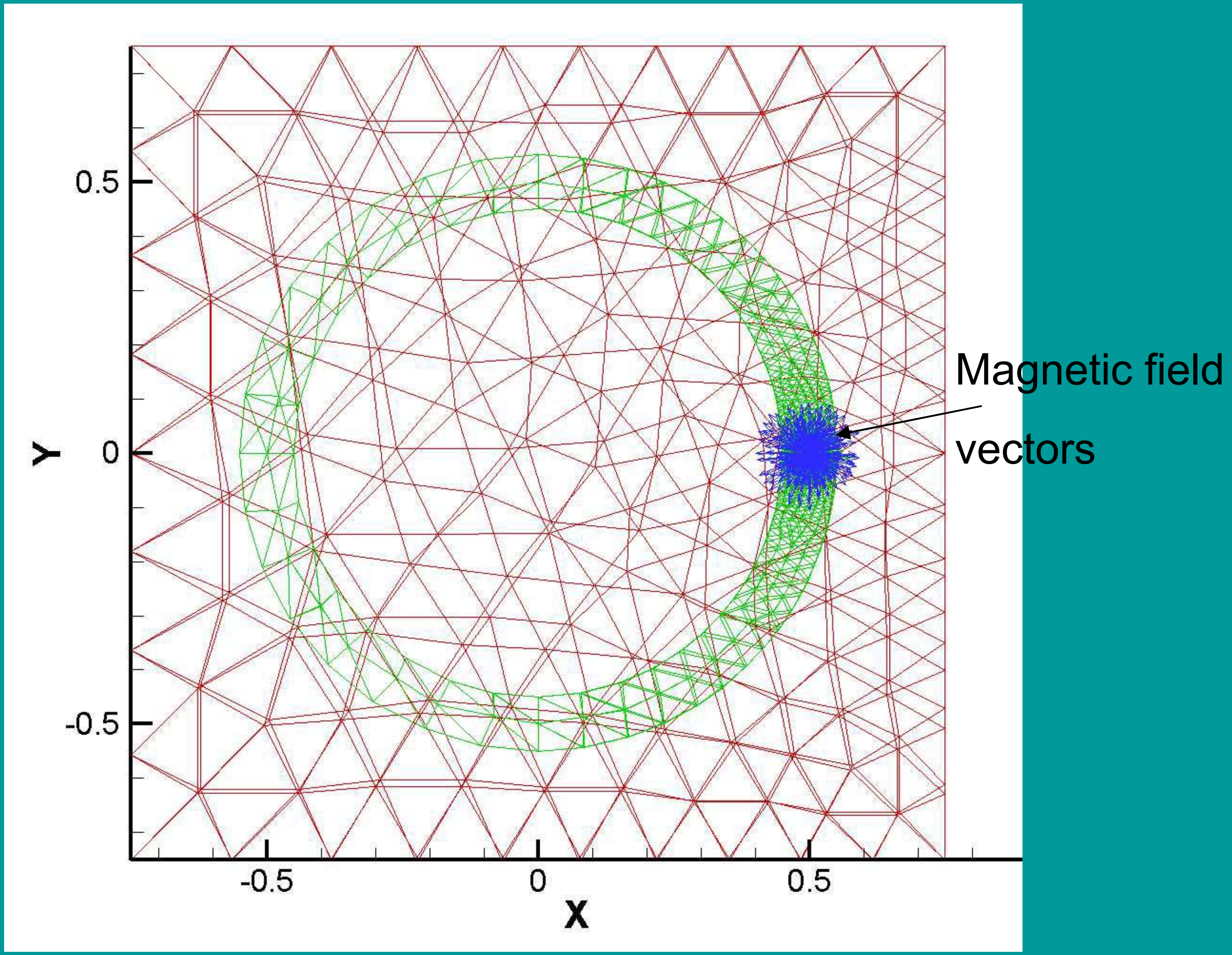
$\sigma = 2.38\cdot 10^6$ 1/ohm/m Radius ~0.5m, thickness ~1.4cm


Box has dimesions
1.5mx1.5mx1.5m
Y
X
Z
Coil
Rim
Rim diameter~1m
Counterclockwise
rotation

Mesh box.



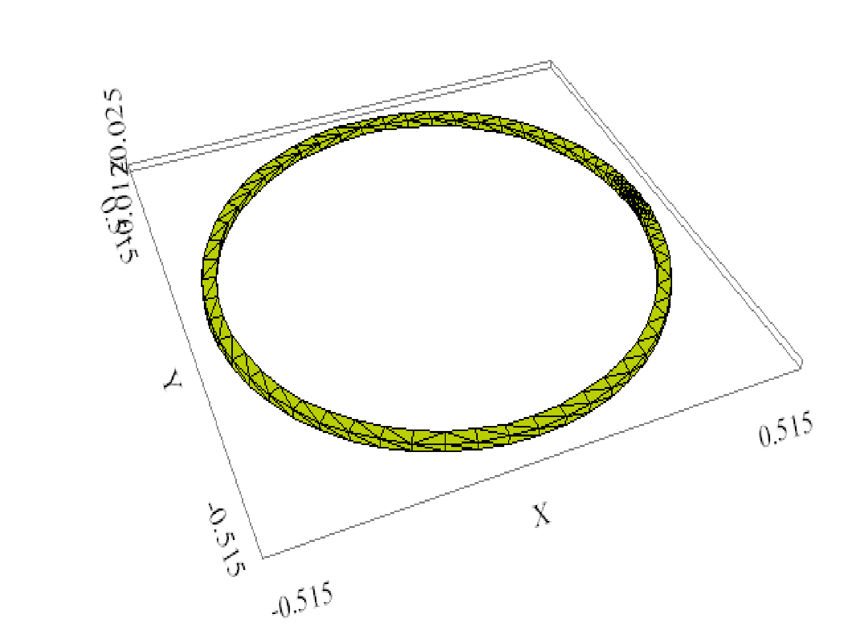
A bit more detailed picture. Mesh is denser in vicinity of coil

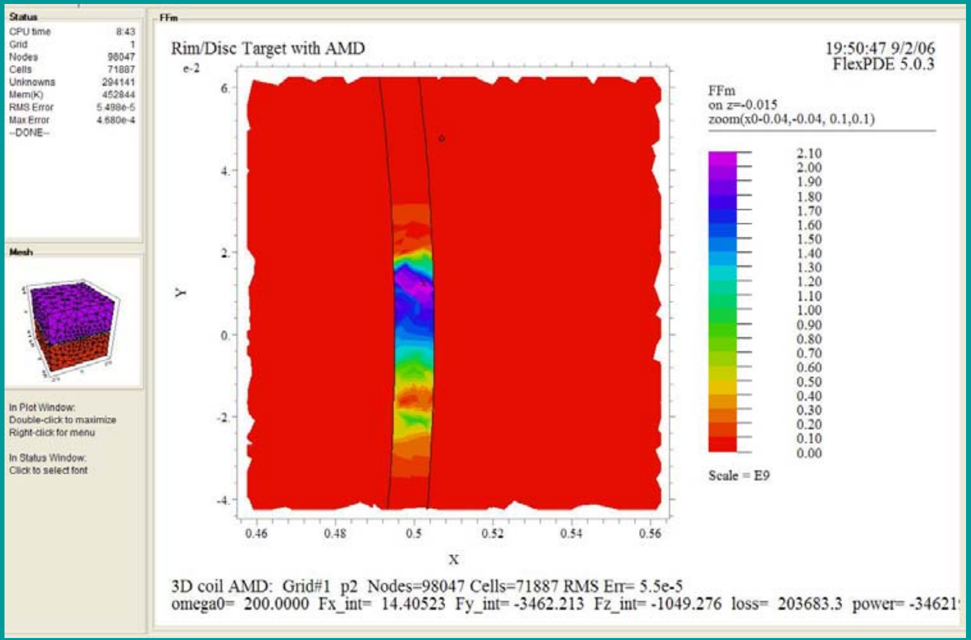


Top view. Rim with intermediate width. Dimensions are in meters.

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

Geometry of rim



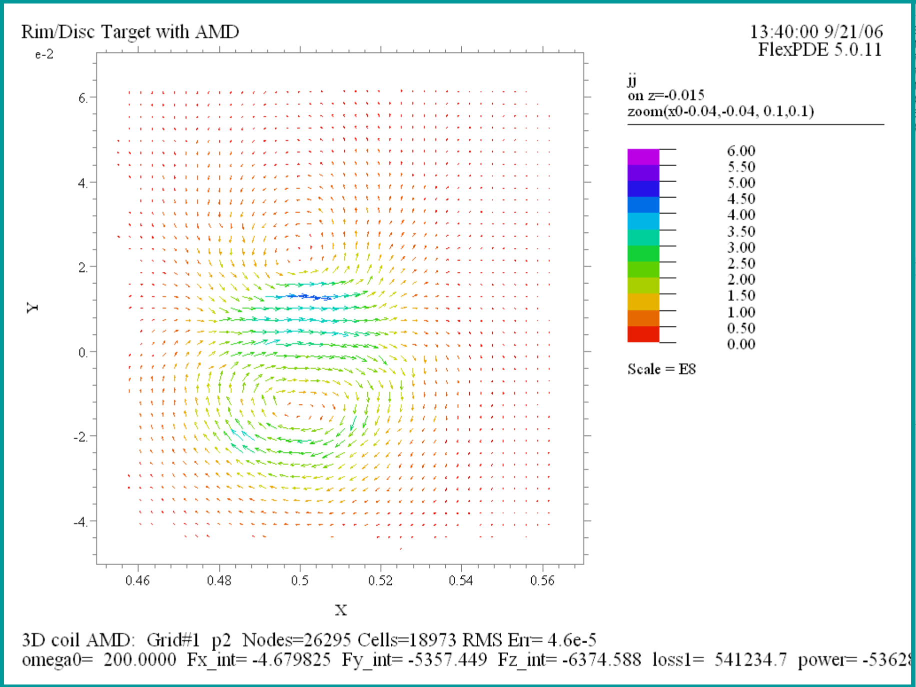


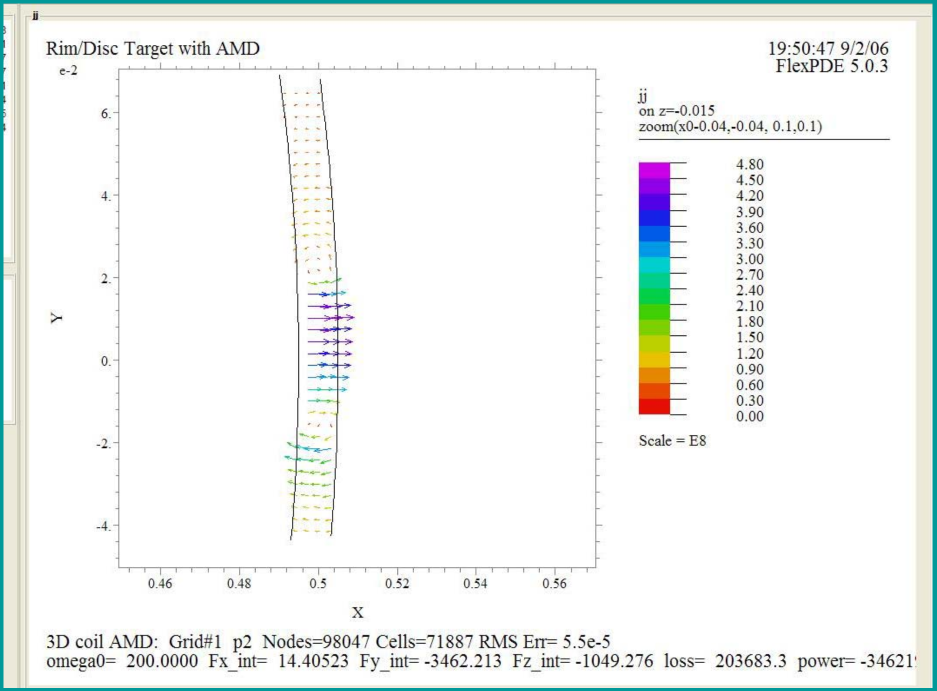
Thickness of rim ~0.4 rad length

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





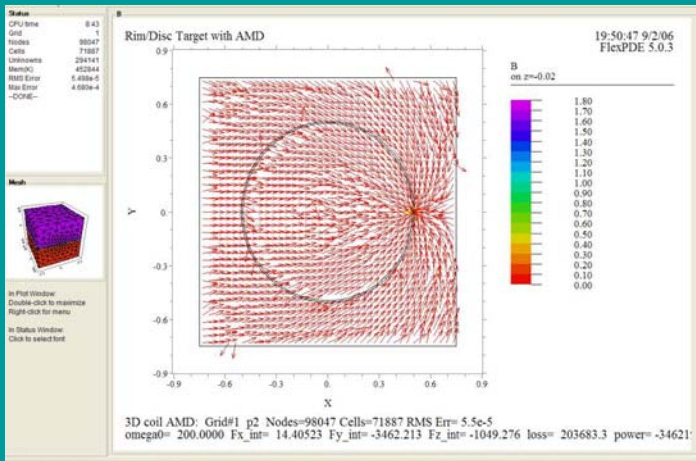
Current distribution inside wide rim

Current distribution inside narrow rim

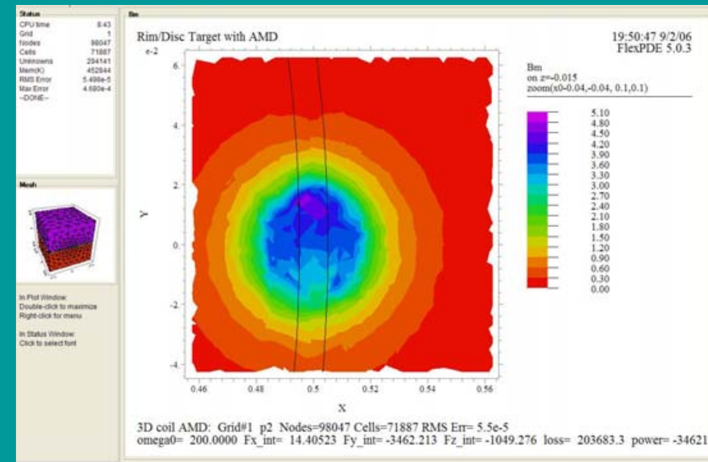
Center of coil located at x=0.5;y=0. One can see, that the field is dragged by spinning metal. As there is an attenuation, this transverse field varying into depth.

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.

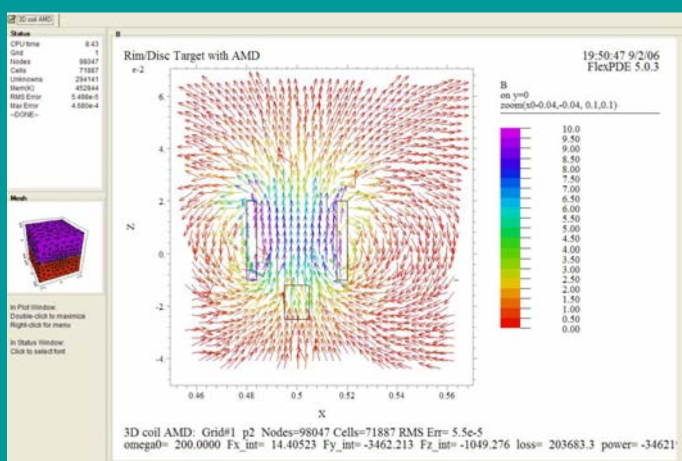


Top view to the vector field

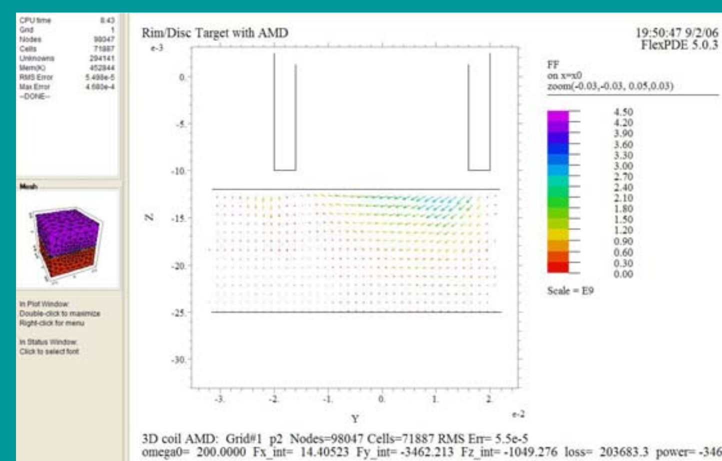


Contour plot of field amplitude.

Drag is seen here

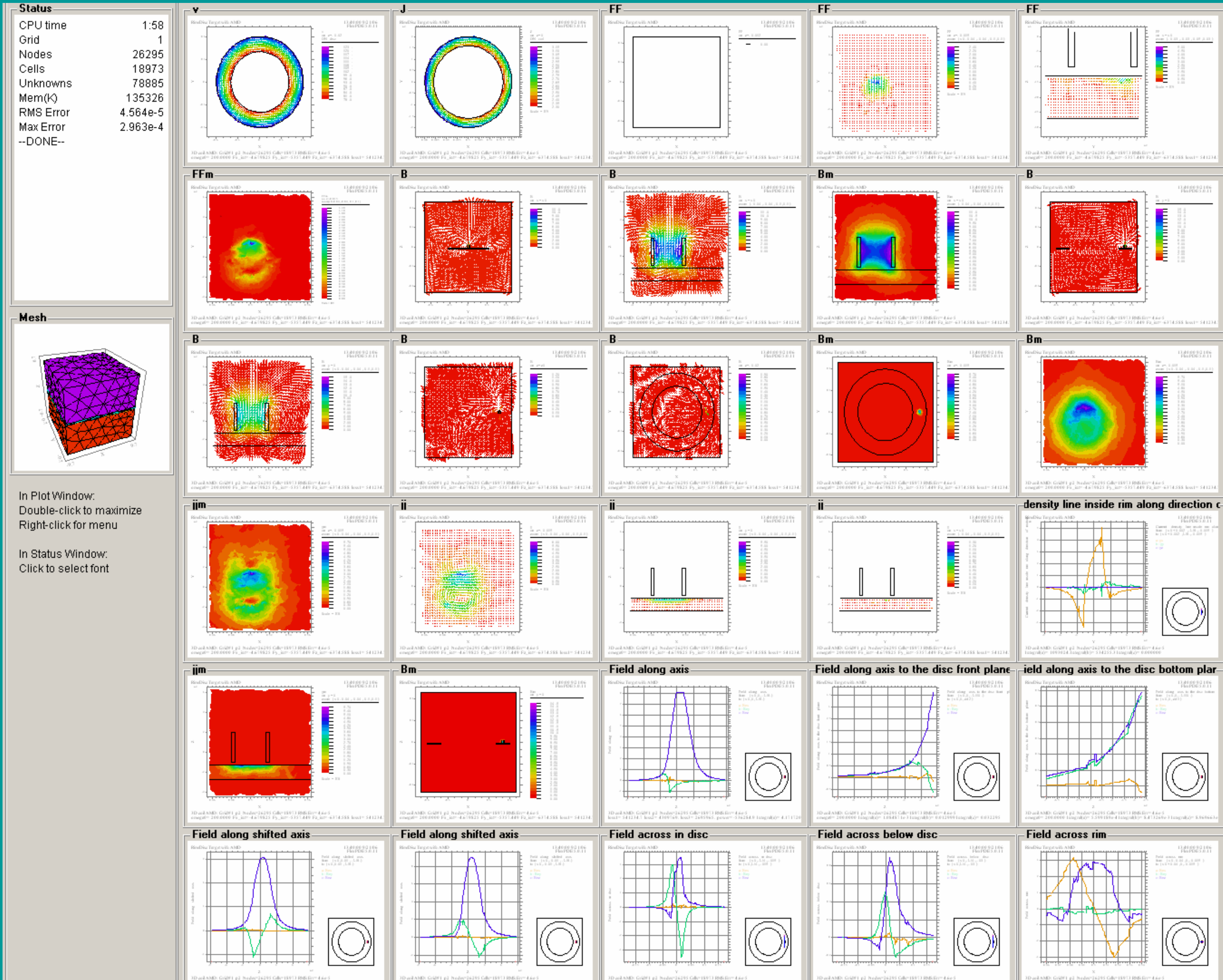


Fields in cross section through the center of coil



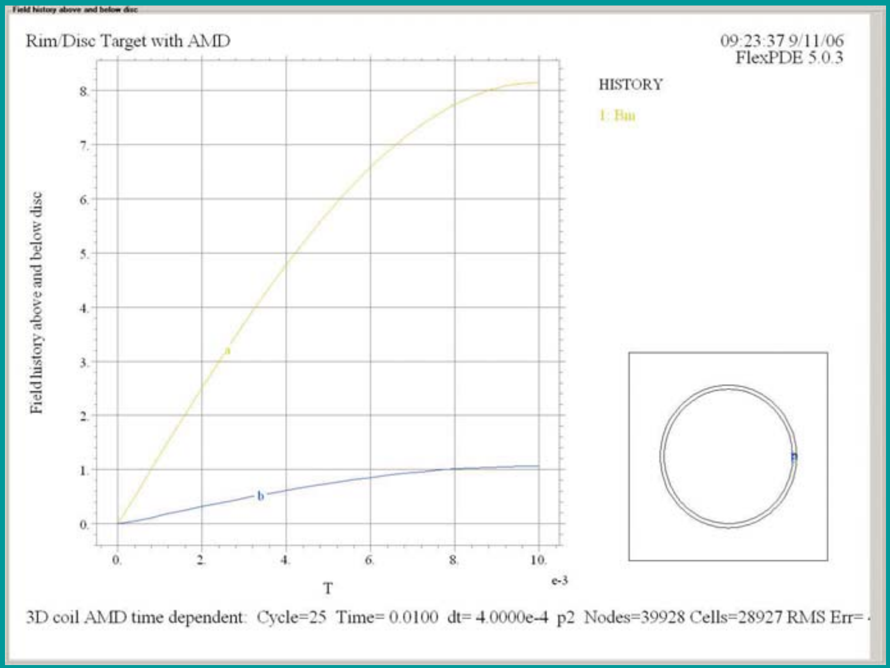
Forces in cross section YZ plane through the center of coil

Palette output for wide rim

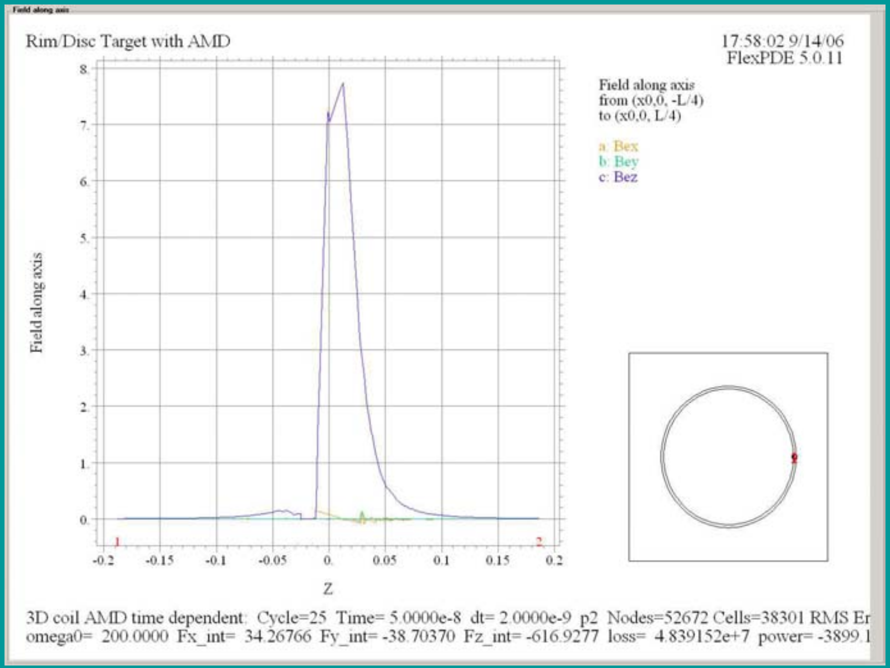


We investigated pulsed feeding also.

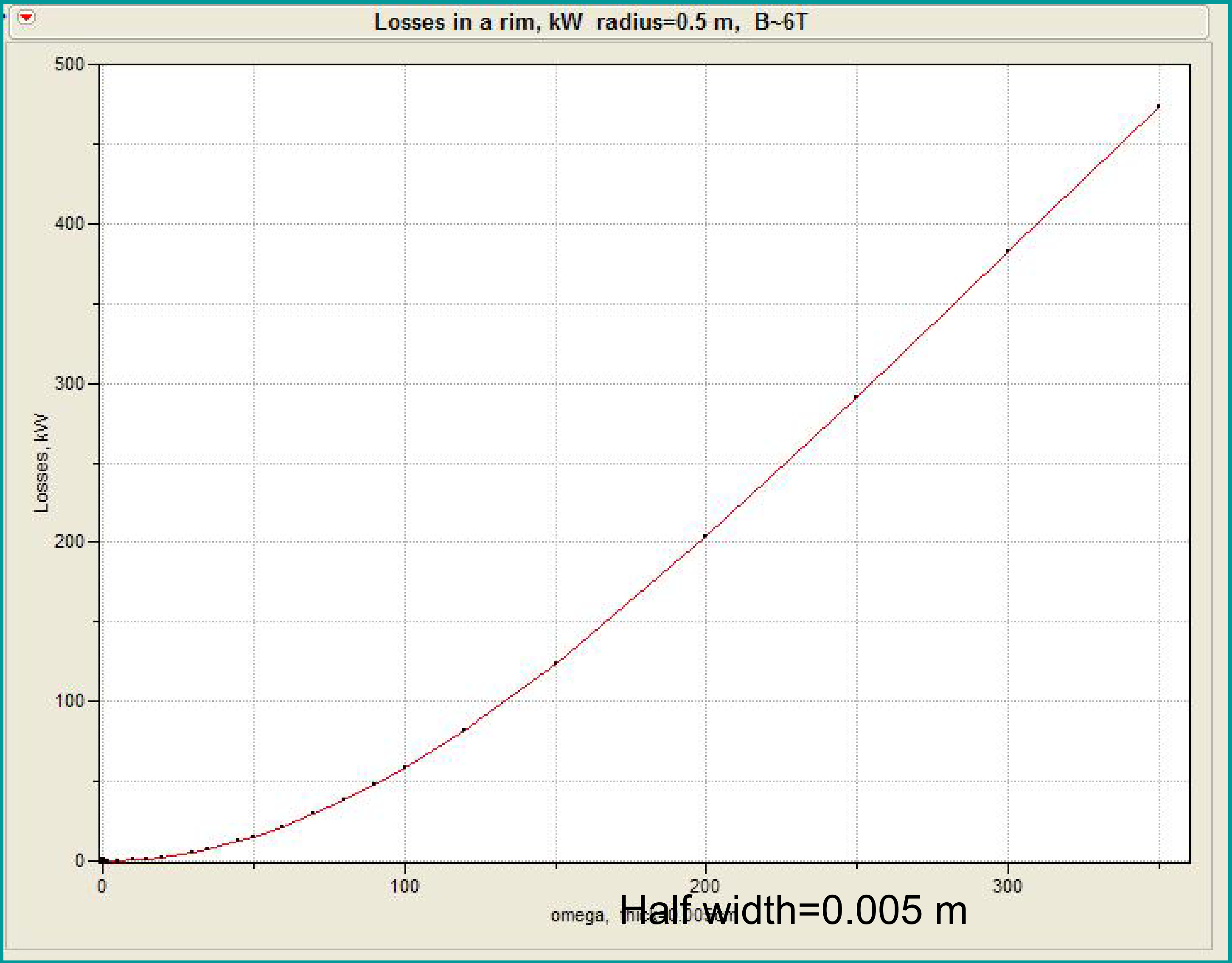
Range zero-top rise time within 50 nsec-20 msec.



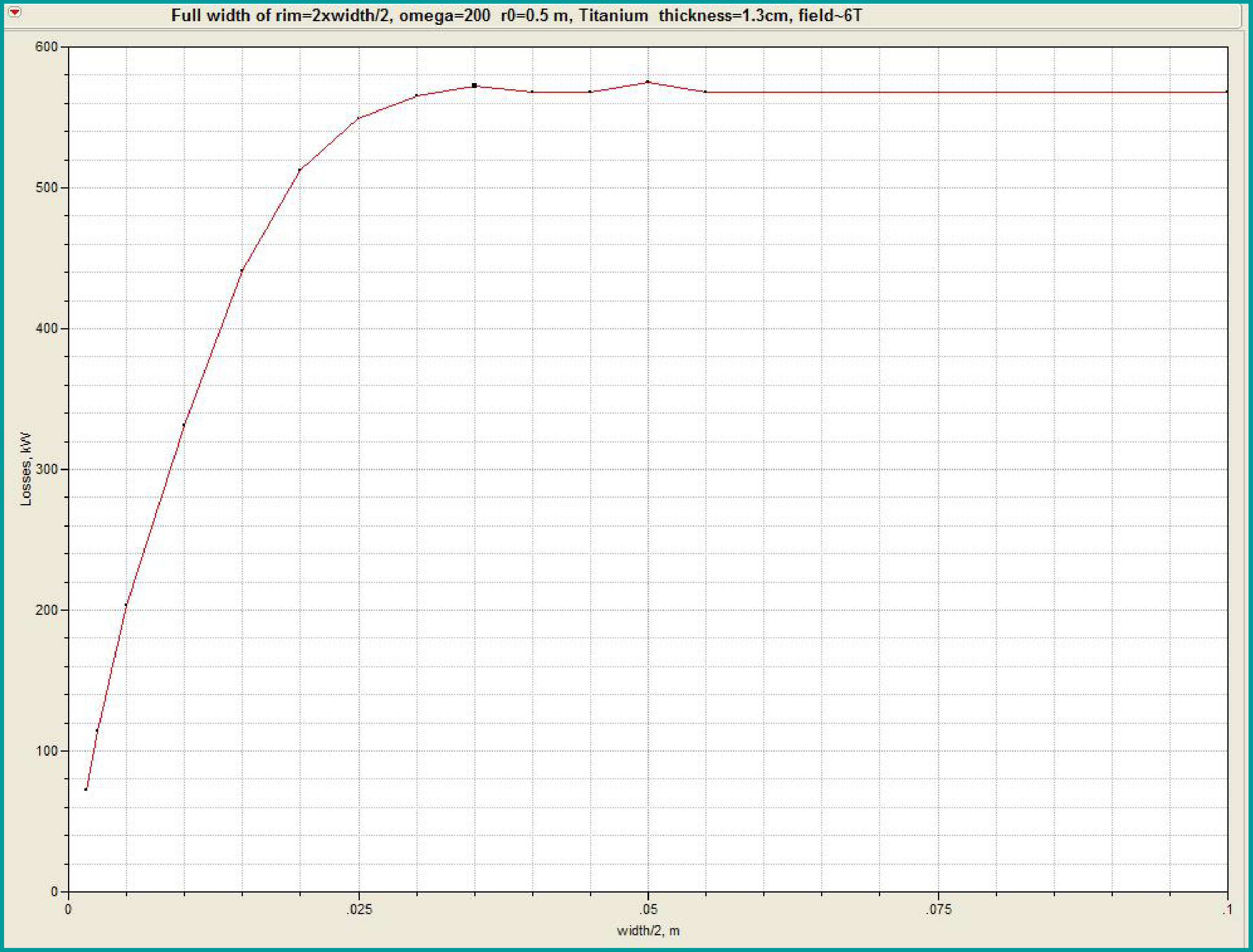
Field history below and above rim for 10 msec pulse duty (from zero to the top)



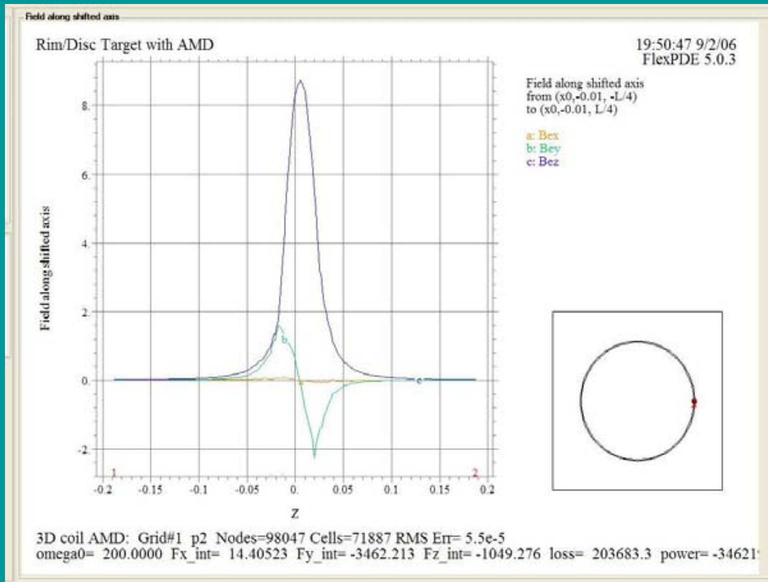
Field elevation along axis at 50 nsec pulse duty. AMD philosophy is not working for short feeding pulse

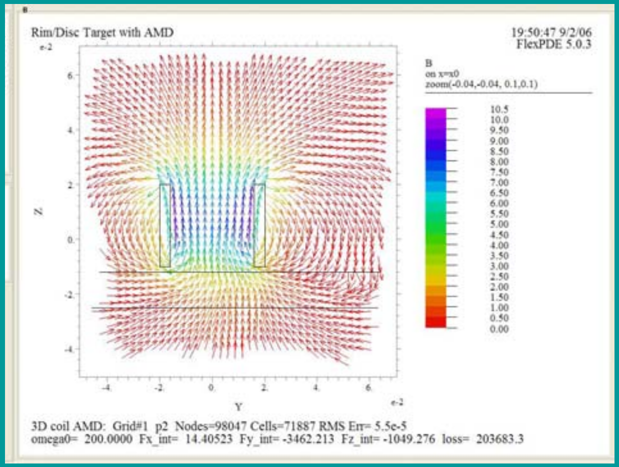


Losses as function of rotation speed Ω

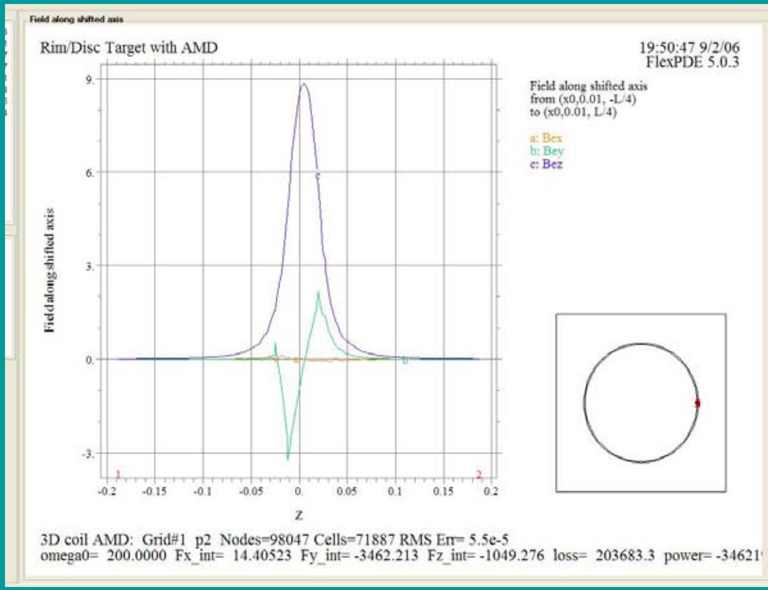


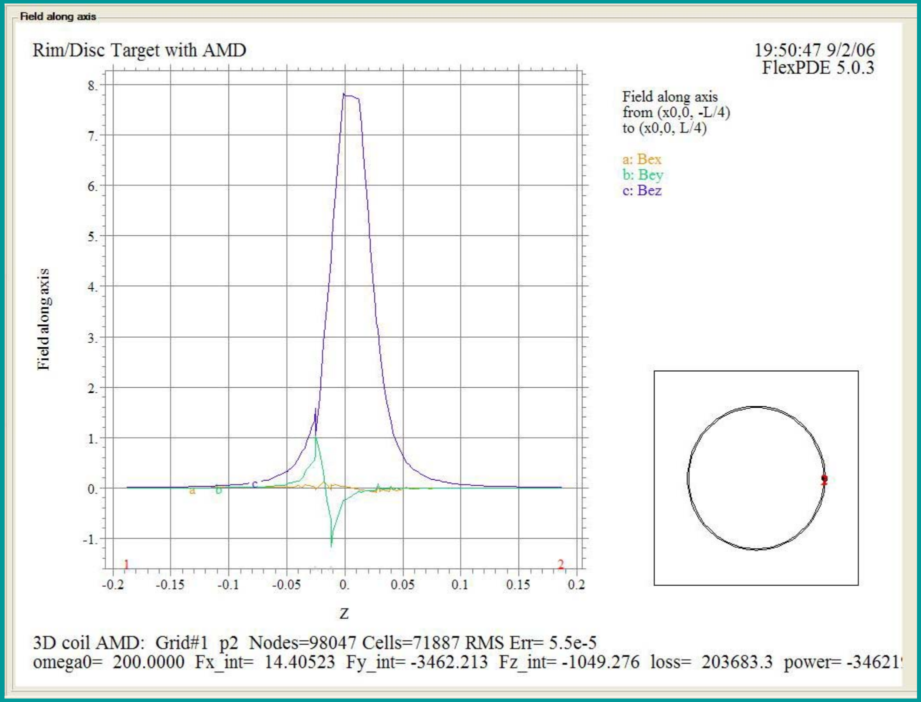
Losses as function of width of rim. After reaching the width of coil, power does not change, naturally. For narrow rim the power is dropping proportionally to the width.





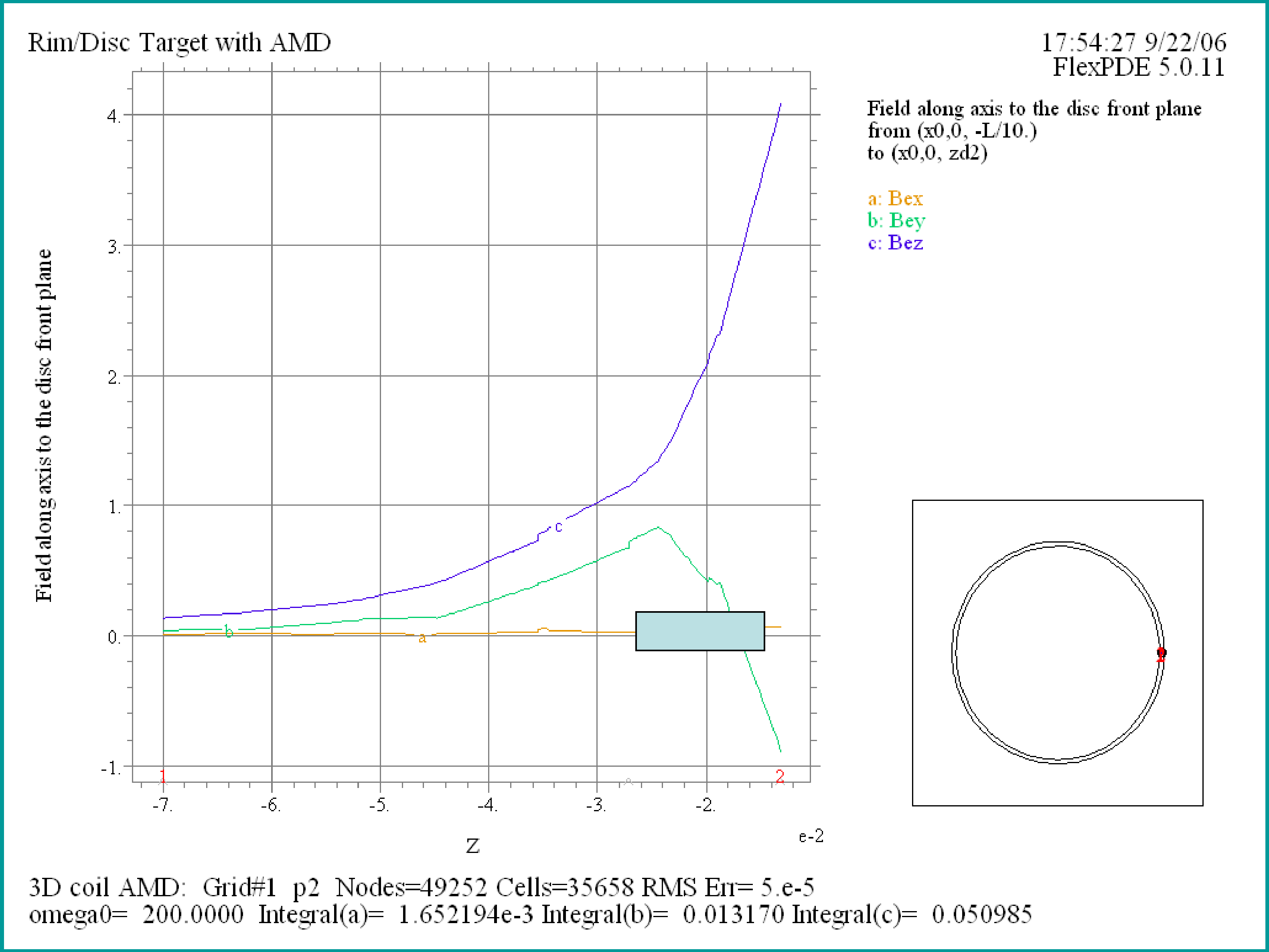
Metal is moving to the right





Inside metal, strong currents are running

Magnetic fields induced in target sweep the beam



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

CONCLUSIONS

Fields induced in rim have significant values. Typical integral ~ 1Txcm 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 ~3Txcm → Angular spread~ 0.3-1 rad for the beam

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

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

Pulsed feeding indicate worsen situation for long time pulsing. Investigated ~20msec 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