Non-linear IOTA inserts

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Design, manufacture and measurement of the phase I prototype and considerations for the phase II (full size) demonstration model

*Participants

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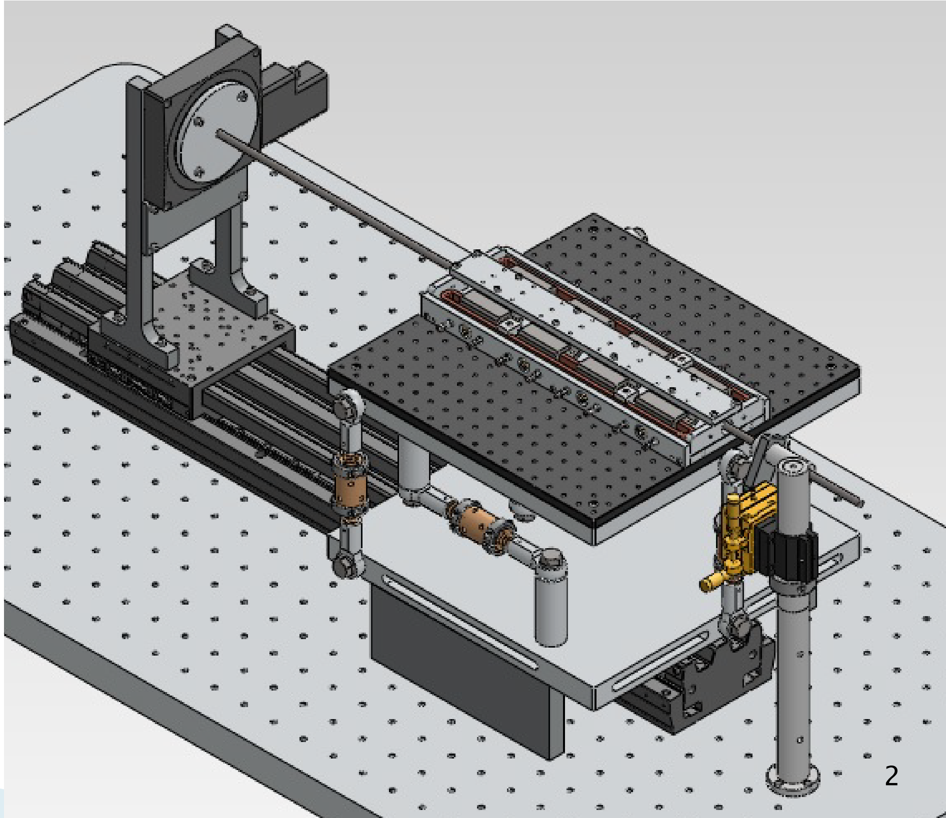


Outline

- Previous talks covered the why, so I'll cover the inserts exclusively.
- Design philosophy.
- Phase I: design, build and measure a short prototype.
  - Testing several "new to us" magnet design techniques and a new measurement system
- Phase II: design, build, measure and install a full scale demonstration model.

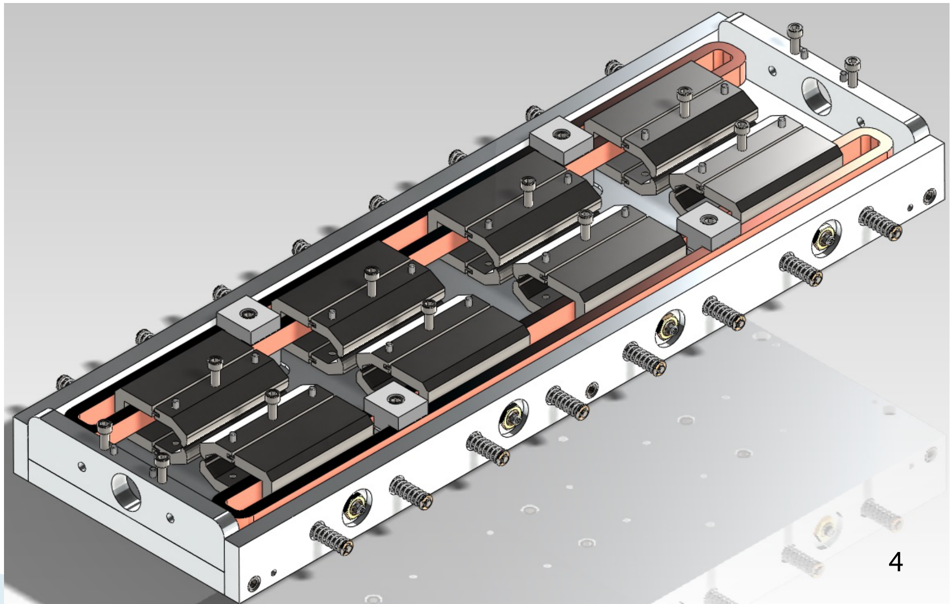
Design Philosophy I

Series expansion!

$$\Phi(x,y,s) \equiv \frac{B\rho c^2}{\beta(s)}\phi(x/\beta(s), y/\beta(s))$$

$$\phi(x_N,y_N) = t\sum_{n=1}^{\infty}\frac{2^{2n-1}n!(n-1)!}{(2n)!}\left(\frac{x_N^2+y_N^2}{c^2}\right)^n \sin\left[2n\arctan\left(\frac{y_N}{x_N}\right)\right]$$

1. Segment the magnet so that each segment is a 2D multipole magnet with β = constant
   - 20 segments
   - Excite them all with a single pair of coils
   - Tune via the reluctance of the return yokes

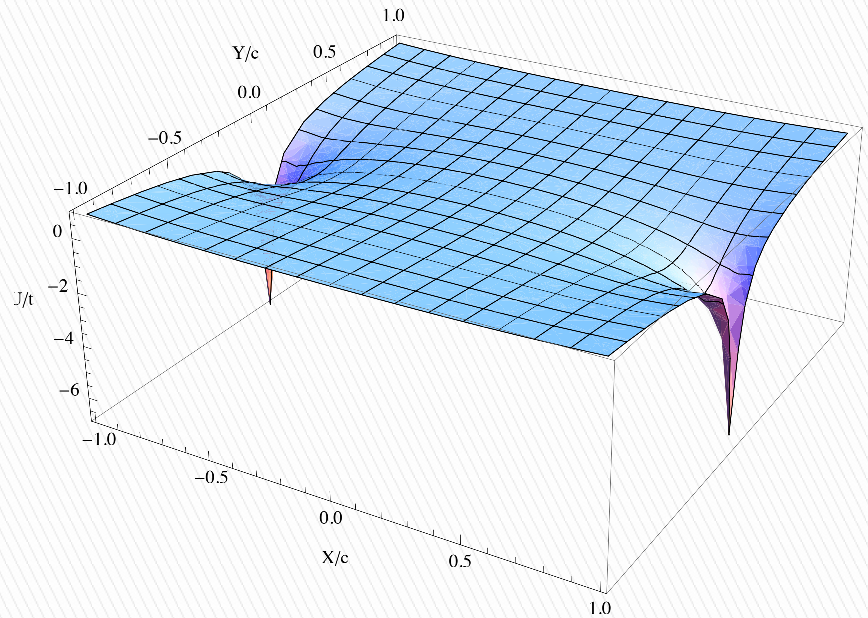


Design Philosophy II

2. Deal with the peculiarities of this potential
   - The series expansion on the previous page papers over a singularity
   - The desired good field region isn't round, for practical reasons, we desire a larger vertical region with good field
3. Use the scalar potential just like normal for quads and sexts, etc…
   - This "hammer" works so well in multipoles, try to use it here as well

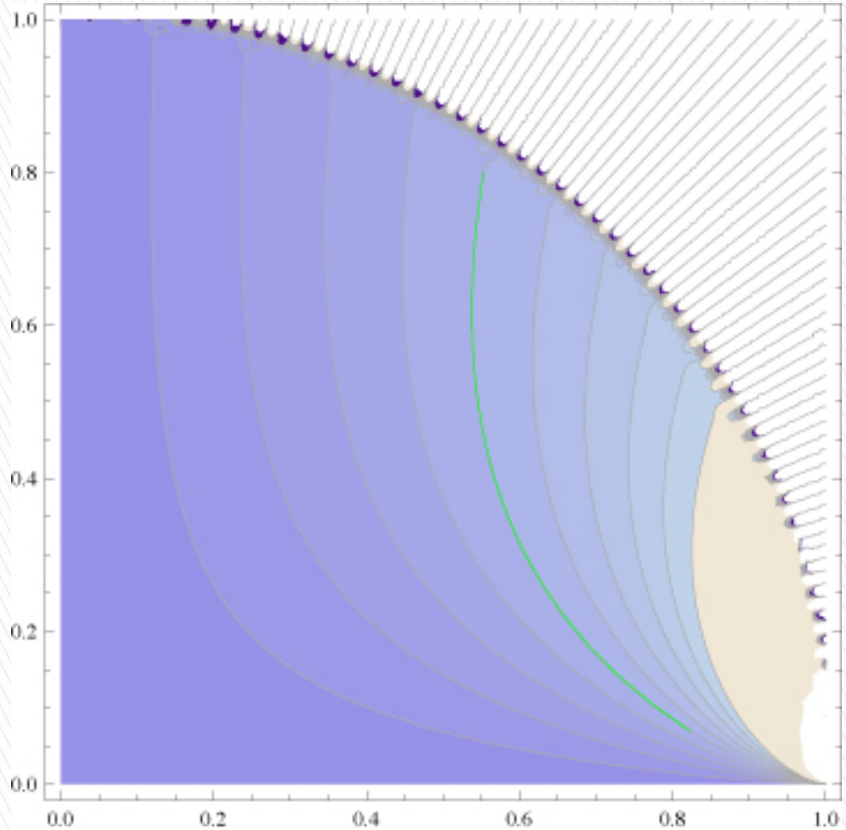
Series Expansion Hides…

- There is a pair of infinities at
  $x_N = \pm c,\ y_N = 0$
- This limits the region over which the expansion can possibly work
  $$\sqrt{x_N^2 + y_N^2} \leq c$$
- Maybe we could try to place a current there
  - who wants to mess around with an infinity?
  - Didn't seem to work well in simulation anyhow!



Full Potential

One solution to rule them all

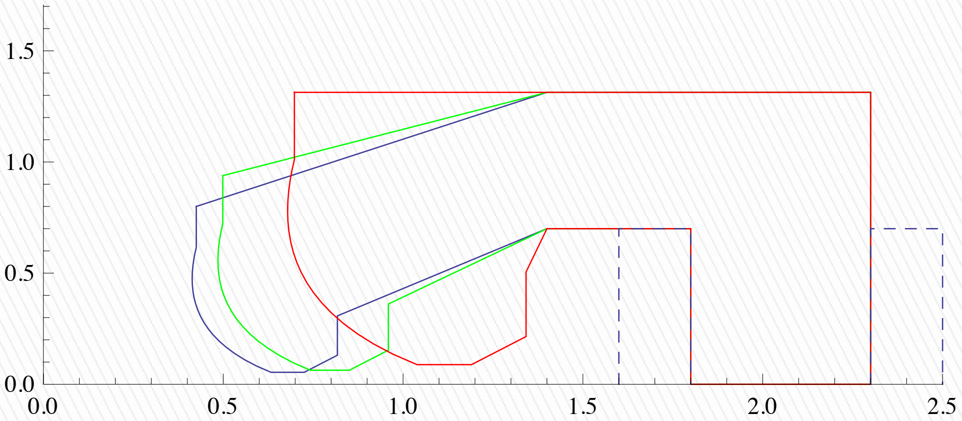


Universal Solution

- Typical multipole design
  1. Find an equipotential surface
  2. Put iron on one side of that surface
  3. Correct for edges
  4. Energize the iron with some kind of B-field source
- By finding a solution in normalized space, we can solve the equipotential problem only once

Return to real space

- To make the universal solution useful
  - Extend the top up to increase the good field region in y to $y \lesssim 0.8\ \beta^{1/2} c$ (found with 2D sims)
  - Cut off the corner near $x = \beta^{1/2} c$
  - Put in a return yoke so that a coil can be added.
- Add reluctance gap

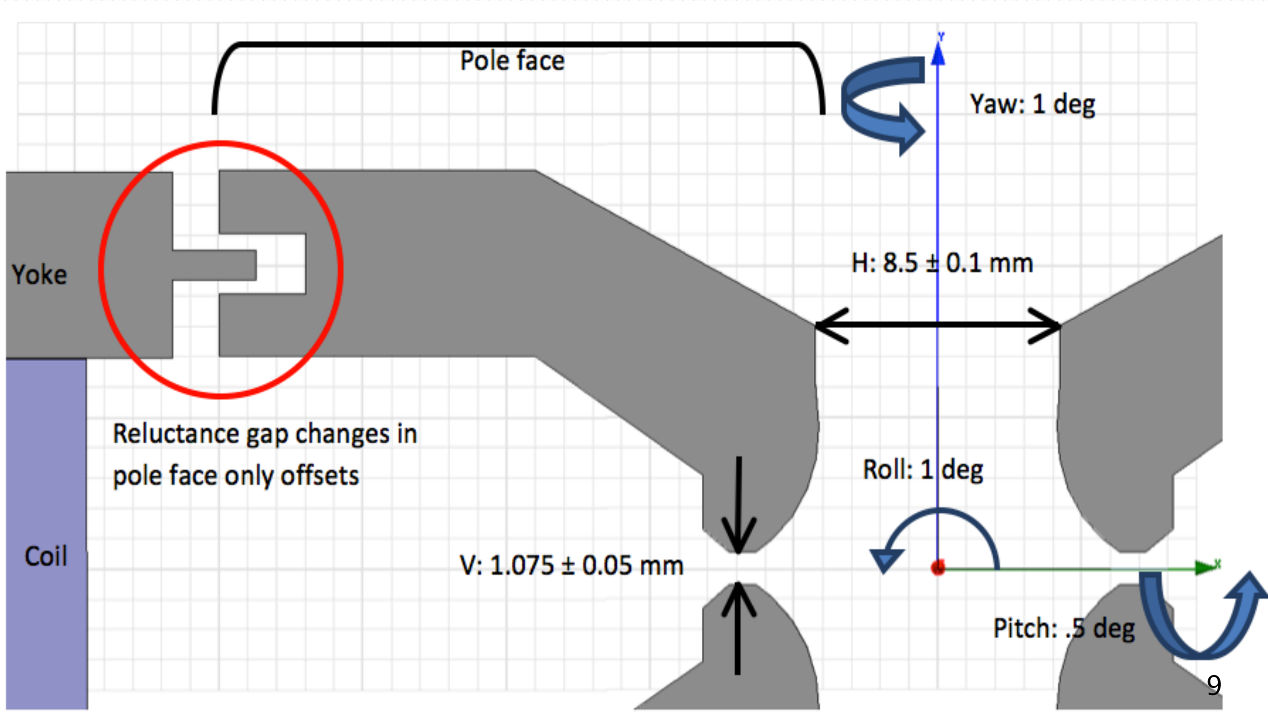


Segments 1,5 and 10

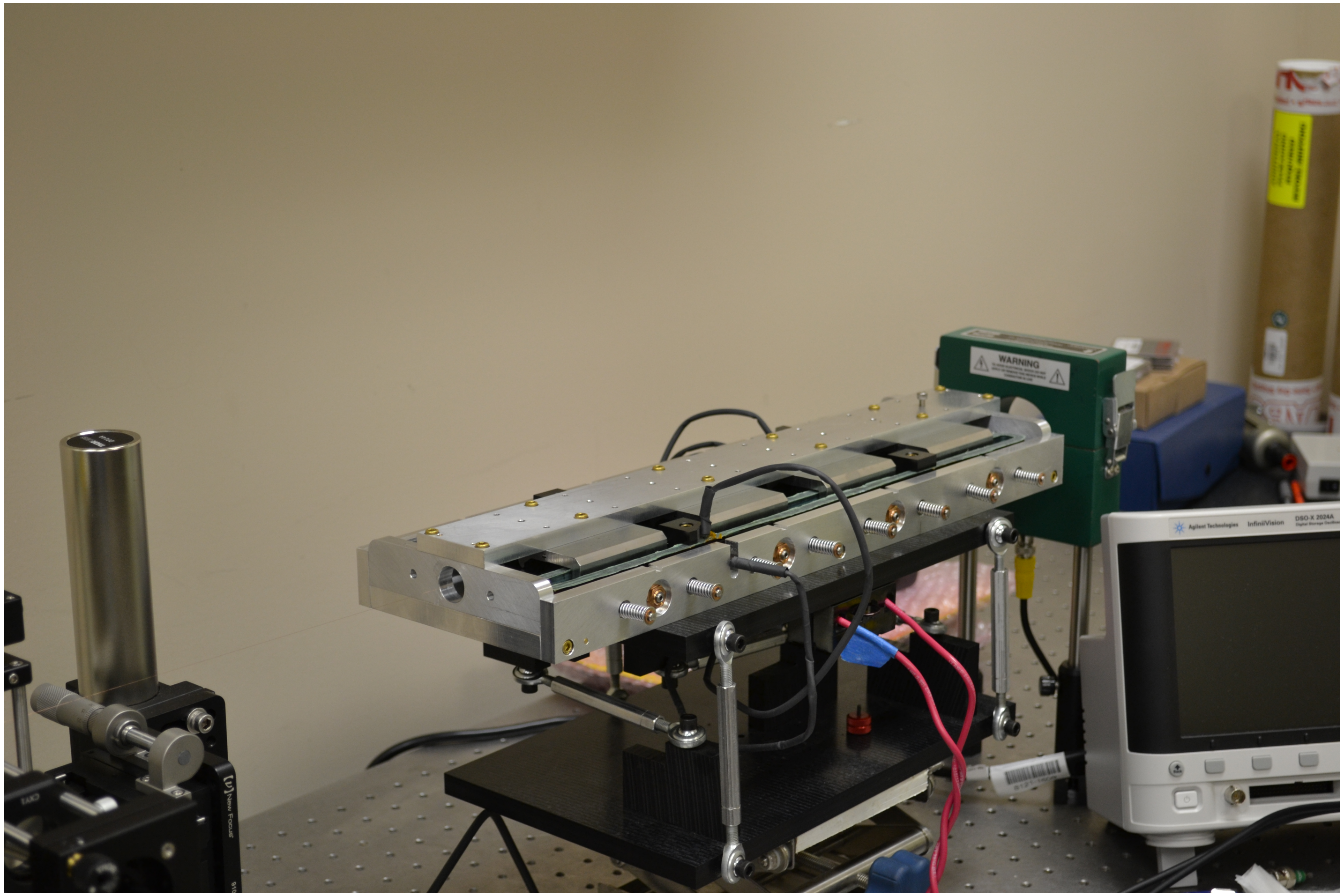
Error Tolerances

- Preliminary tolerances:
  - Co-axial to 50 μm
  - Less than 1% deviation from ideal field
- Manufacturing tolerances set via 3D simulation
- This makes a tolerance table we think we can hit

- Want to maintain the good field region from the 2D simulations:
  - $y \lesssim 0.8\ \beta^{1/2}\ c$
  - $x \lesssim 0.6\ \beta^{1/2}\ c$

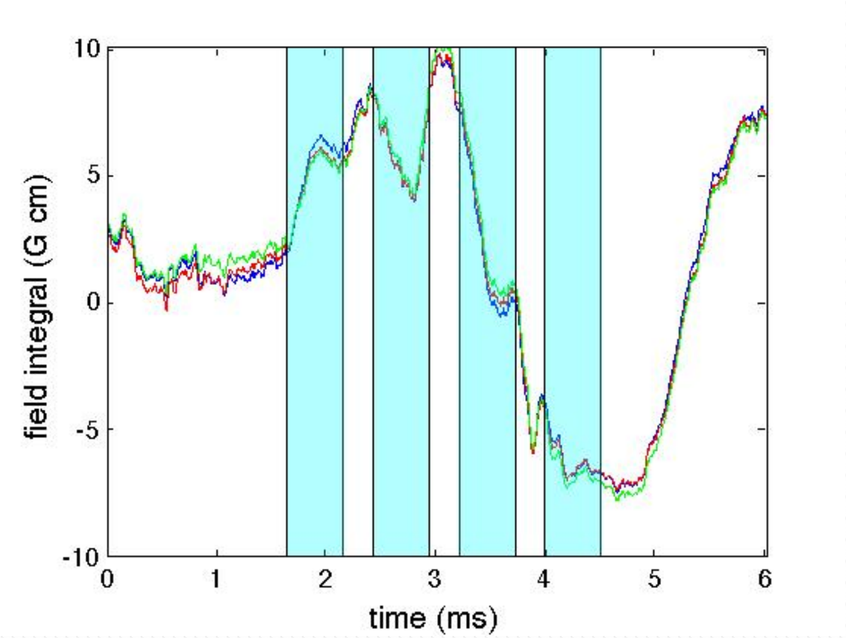


The result



Pulse Wire Axis Measurement

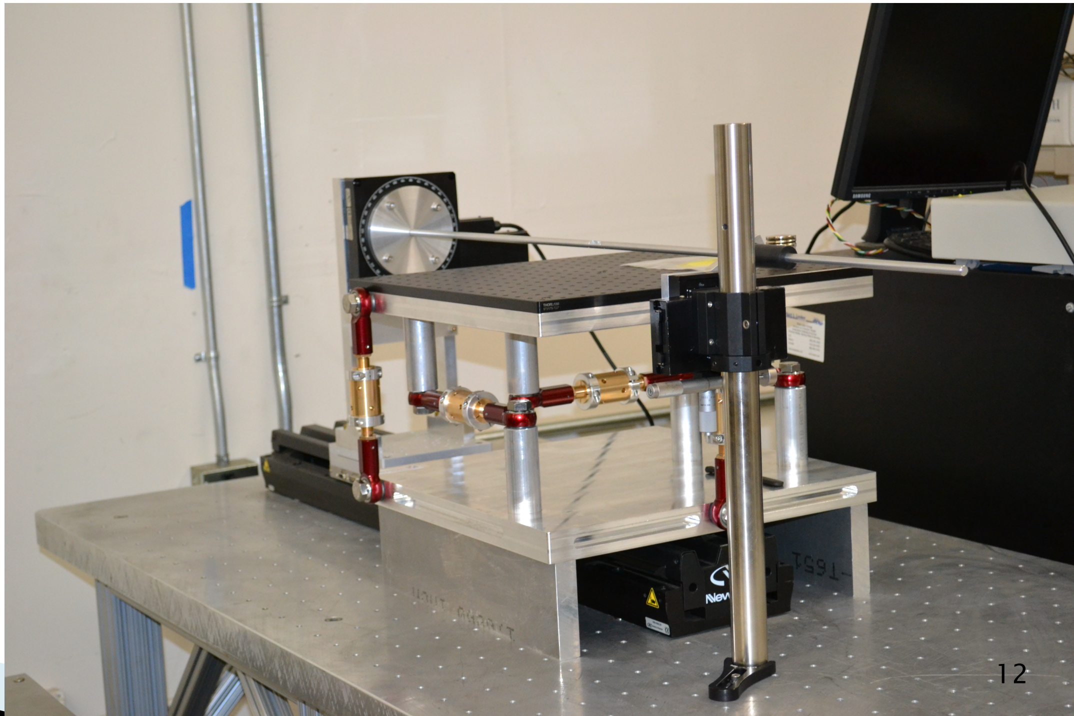
- In principle, this method can tell us whether the axes of each of the four sections is common
- The wire won't deflect if they have a common axis
- Sort of worked – vibrating wire might work better



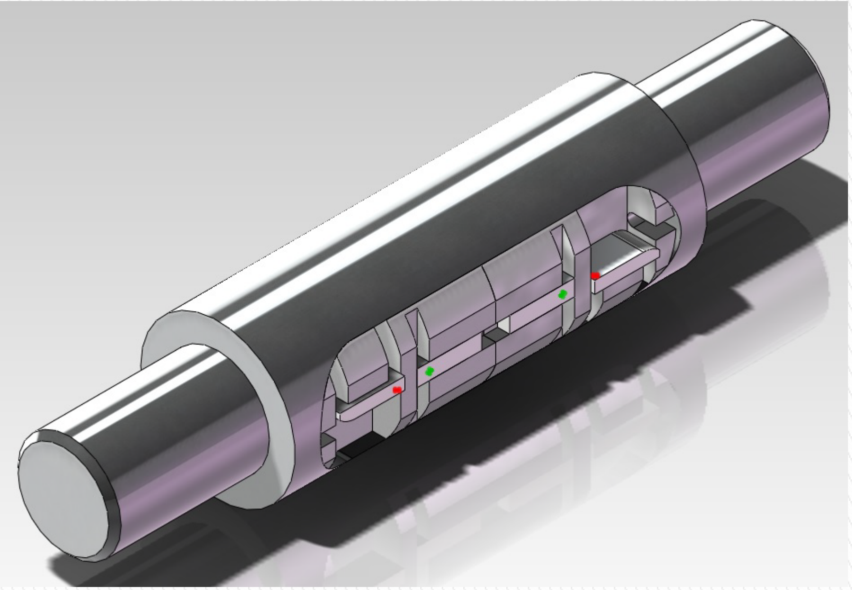
3 measurements

Measuring this structure

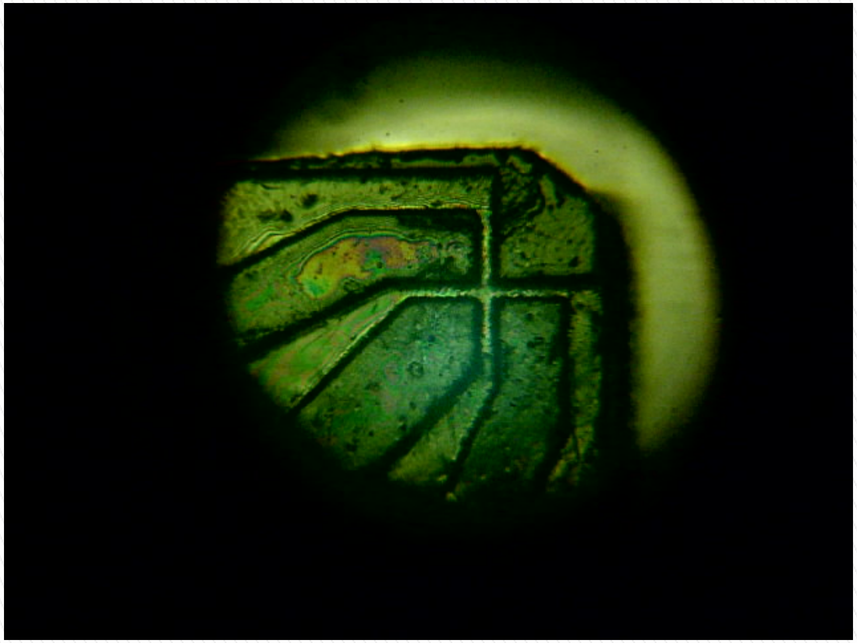
- The design has very narrow openings transversely, how do you measure it?
- "New to us" method: push and pull a set of tiny hall probes through
- Uses the a natural coordinate system for the structure
- Currently being commissioned



Hall Probe Details



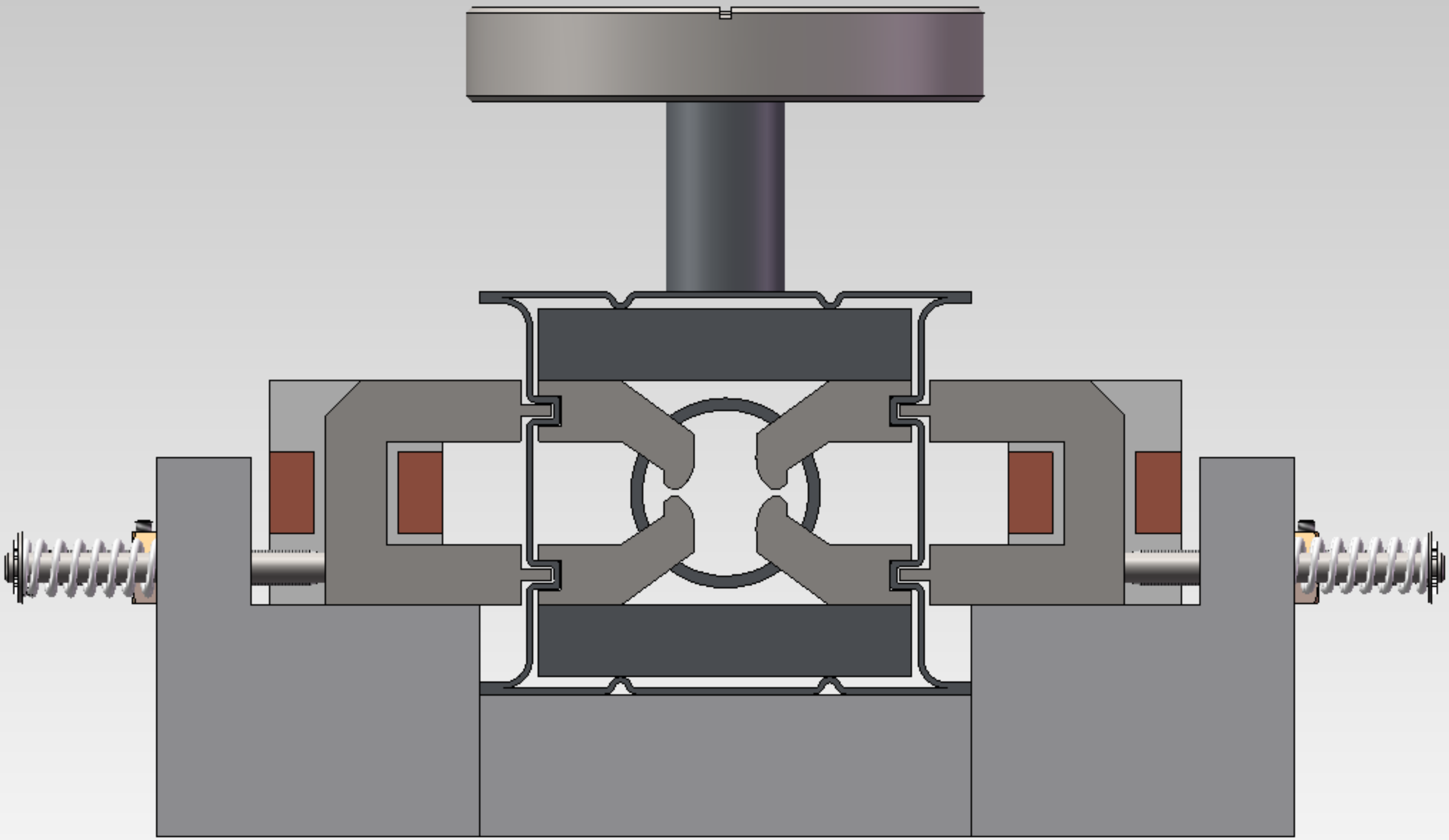
Probe Assembly



Microscope Image of Probe

Demonstration Model

- Expand the 4 segment prototype to all 20 segments
- Motorize the return yokes or power each segment separately
- Will measurement system scale up?
- Vacuum chamber is a really tough part
  1. Everything in vacuum
  2. Everything out of vacuum
  3. Poles in vacuum, yokes out of vacuum
- Leaning toward everything out of vacuum



Summary

- 4 segment prototype was designed, manufactured and a measurement system is being commissioned
- The design philosophy appears promising
- Particle tracking with the simulated fields is on-going, will use measured fields when available
- The largest remaining open question is how to integrate the vacuum system.