Improving Magnetic Materials for RCS Cavity Tuners

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IPAC-21 – MOPAB366

Overview

- Rapid Cycling Synchrotrons (RCSs) require cavities with large tuning range
- Tried and true large frequency range tuning is achieved by the use of magnetic (non-conductive) materials – ferrite/garnet where permeability varies as a function of magnetic bias current
- The tuning material is the main source of RF power loss – this is due to the imaginary part of the permeability, or $\tan\delta = \mu''/\mu'$
- Within an LDRD and with the company National Magnetics, we are exploring new materials and heat treatment recipes that help to decrease the losses.
- National Magnetics is manufacturing/improving the materials using modified mixing recipes and heat treatment procedures.
  - FNAL will perform the sample testing in the frequency range of interest

Biasing Scheme

- Except for a few isolated examples, wide range tuners have been built using ferrite with a parallel bias (bias field parallel to RF B field)
- The effective permeability is different in these two cases:

$$\mu'_{\parallel} = \frac{\partial B}{\partial H} \qquad \text{parallel biased}$$

$$\mu'_{\perp} = \frac{B}{H} \qquad \text{perpendicular biased}$$

- For low loss, one would bias the material close to saturation; but for parallel bias, this gives a tiny tuning range
- Most ferrites like NiZn cannot be biased to saturation with a realistic bias system
- Thus we are exploring perpendicularly bias garnet – National Magnetics AL800
- Improvements on such materials have not been explored since the SSC days; we are exploring this

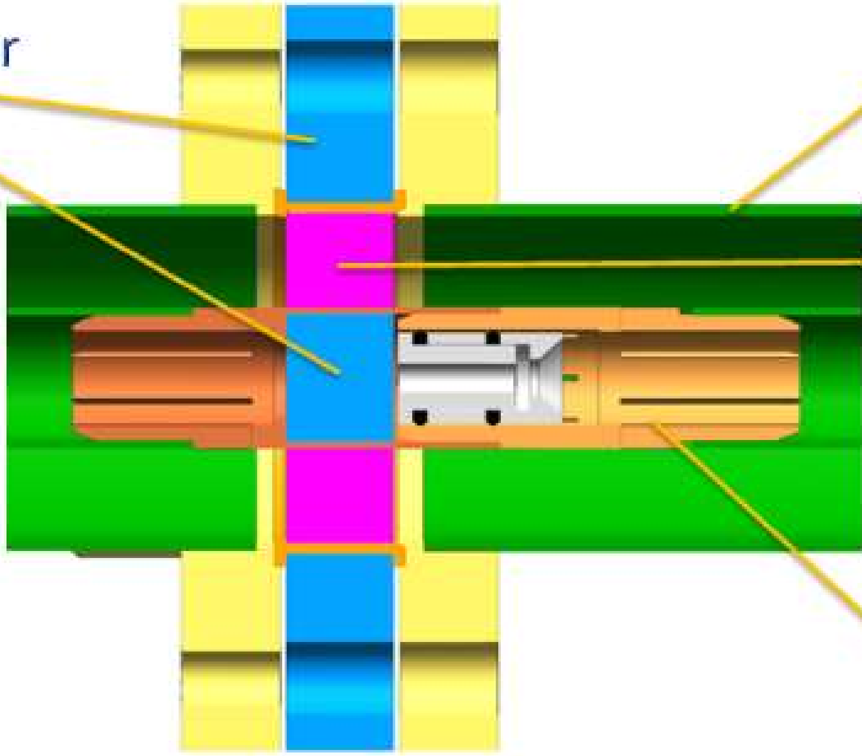
National Magnetics Manufacturing Plans

- Change composition of garnet material (three different trial mixtures)
  - Make ~15 rings of each type
  - For 3 compositions, sinter under 8 psi of pressurized O_2
  - Hot isostatic pressing of above
- National Magnetics will perform their usual QC tests and measurements on the samples
  - Their measurements are not in our frequency range of interest; need to do our own measurements
- Aim is to reduce ΔH, the gyromagnetic line width, ~10%
  - ΔH is related to $\tan\delta$

Fermilab Testing

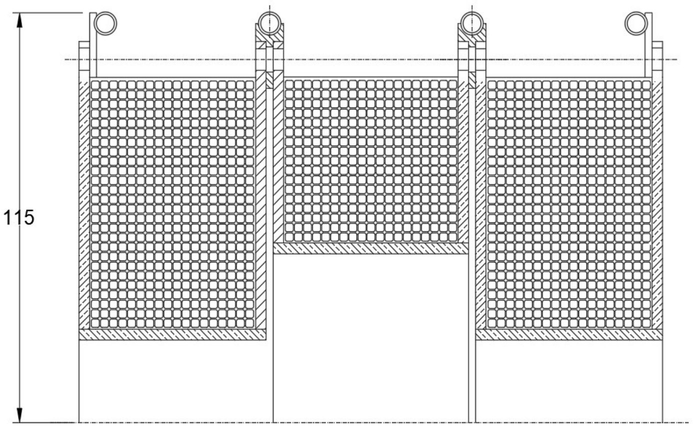
- We have attempted to measure garnet losses previously, but it is difficult and the test setups need to be improved – this is one key part of this LDRD
- After much simulation and design iteration, we are building a test setup
- Need for simulation - Very important to make the fields as uniform as possible
  - Difficulty is exacerbated by small deviations having a large effect on the results
    - This also makes the mechanical design complicated
- The design is based on 1⅝" coaxial geometry which is heavily modified for the particular issues at hand

Test Fixture (bias solenoid not shown)



Extract complex ε and μ from network analyzer S-parameter measurements

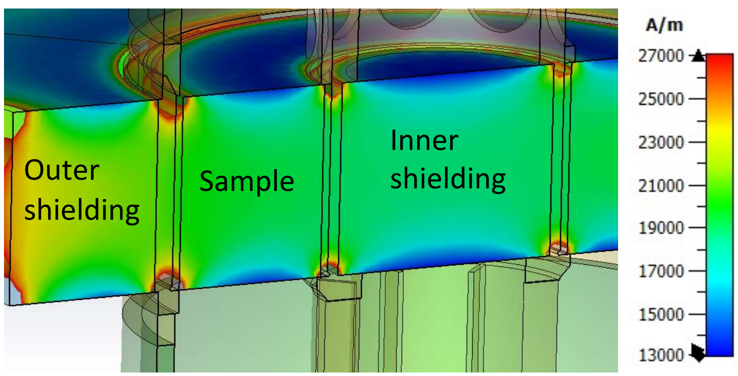
Pictures



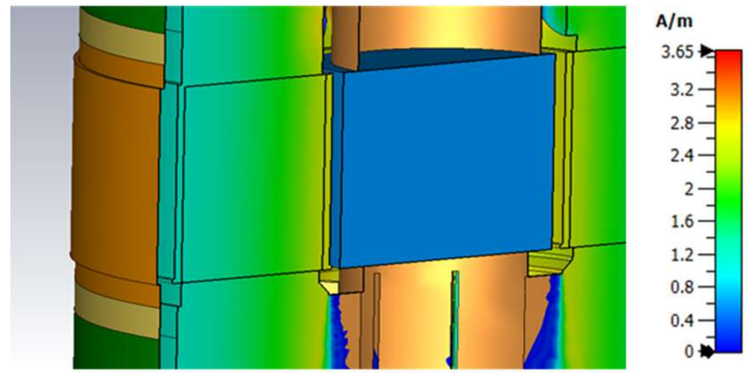
Solenoid - coils are wound using #11 square copper wire; 468 turns on the outer coils, 323 turns on center coil

Simulation

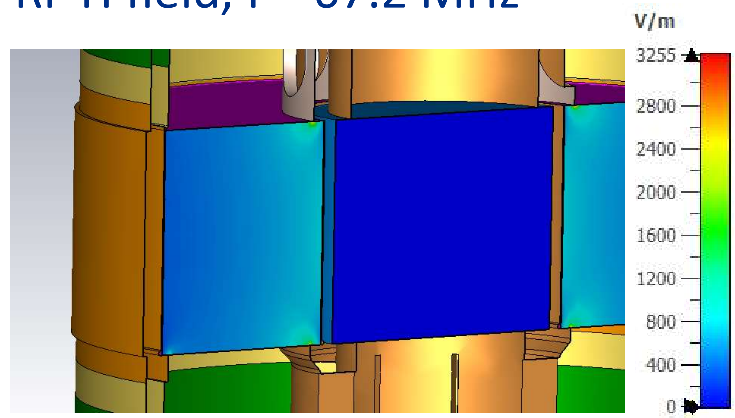
- Method to extract complex ε and μ was proposed by Weir but shown in [7] that even small errors on coax/sample dimensions can result in significant errors
- Made walls and gaps as thin as possible, used magnetic ‘shielding’for field uniformity $\rightarrow$ made mechanical design complex
- Field uniformity is good, though not perfect



Bias field, external field 63662 A/m



RF H field, f = 67.2 MHz



RF E field, f = 67.2 MHz

Conclusions

- We are in the process of building a test fixture which we have designed to measure the complex permeability in AL-800 garnet
- National Magnetics is in the process of delivering batches of samples improving upon the initial material
- We will begin testing as soon as the fixture is complete

Thank you