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High Temperature Superconductor (HTS) Solenoid Status

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Summary and Action Items of Last (Sept. 1, '05) Presentation

Summary

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- A broad set of parameters of High Temperature Superconductor (HTS) solenoid were established
- Several designs were examined that satisfied the basic focussing requirements $\int B_z^2 dz \approx 1 T^2$. *mm*
- Solenoid design without yoke was preferred at that time to avoid/minimize residual field from magnetized iron yoke
- Order for Superconductor placed

Action Items:

- Shielding from Nb/Ti flange
- Magnetization of mu-metal shield
- Field map for beam dynamics calculations



Overview of this Presentation

- Residual field calculations and minimization (significant effort)
 - □ Shielding from NbTi Flange
 - □ Magnetization of Mu-metal shield
- New Design
 - □ Large magnetization of mu-metal forces yoke over solenoid □ Maximum field in iron minimized (plus a demagnetization cycle to further reduce residual field)
 - □ Field measurements to ensure low residual field
 - □ New design offers many advantages (just good luck)
- Results of detailed calculations (field map obtained)
 Action item
- Superconductor shipped/received



Initial design of HTS Solenoid



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Fringe Field Requirements

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Reminders from the last presentation:

- 1. Should be less than 1.5 kG on the superconductor when the solenoid is ON.
- 2. Should be less than a few mG on the cavity when the cavity is turning to superconducting state (solenoid is OFF at this time).
- Iron around solenoid reduces the field on superconductor when solenoid is ON.
- But the iron gets magnetized during the powering. In that case we must make sure that the residual field of iron is below a few mG when the cavity is becoming superconducting.
- A few mG is a very low field! Consider yoke degaussing cycles and/or some sort of shield. Write proper procedures and make sure that these procedures are followed during operation.
- A solenoid "without iron" (hence no residual field from magnetized iron) that keeps field on superconductor below ~1.5 kG (when it is fully powered), would significantly simplify operation.



Incorporation of Nb/Ti Flange in Superconducting Shielding Calculations

Nb/Ti flange, in additional to Nb pipe, provides very good shielding. Field remains well below 0.15 T (smaller in the corners too, where perhaps higher can be tolerated)

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Mu-metal Shield (and its magnetization)

If there is no yoke over solenoid, the fringe field causes a large magnetization of mu-metal shield

(without mu-metal shield)



Based on initial discussions with experts,

0.8 T is too large of a field in mu-metal.



Increase in the Thickness of Mu-metal to Reduce Maximum Field

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We considered even a factor of 4 or more increase in the thickness of mu-metal (too expensive) to deal with the fringe field of solenoid, but the field in mu-metal remain too large.





Investigation on Use of Bucking Coil

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Several configurations of bucking (reverse) coils were examined but none found attractive.





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Model and Field Without Iron Yoke Over Solenoid





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Negligible fringe field from solenoid.

is nearly zero.

Model and Field With **Iron Yoke Over Solenoid**



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Guiding Principle of New Solenoid Design (within the same overall space)





Optimized Model of the HTS Solenoid

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Field in the Yoke Iron (Small)

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Desired Focussing from Solenoid

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Field Components Experienced by electron Beam



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Magnitude of Field (at design current) in Cavity (and beyond)

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Note: The maximum field in the cavity at the design current is $\sim 1 \text{ mT}$. At zero current, we shall have much smaller field (the source is residual magnetization of iron yoke or mu-metal).

Residual field should be low since the iron yoke over solenoid is not highly magnetized. Additional component of the software will be purchased for such calculations. Moreover, iron demagnetization cycles are planned. As a part of our test program, we would run demagnetization cycles, to determine if they are necessary during the operation.

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Magnetic Shielding by Mu-metal and Superconductor

Field in sc cavity structure at the design current

(note a small maximum, ~ 0.23 mT or ~ 2.3 G)

Field in mu-metal at the design current (note a small maximum, ~0.01 T or ~100 G)

180.0 180.0 Z [mm] 160.0 Z [mm] 160.0 140.0 140.0 120.0 120.0 100.0 100.0 80.0 80.0 60.0 60.0 40.0 40.0 20.0 20.0 0.0 0.0 -20.0 -20.0 -40.0 -40.0 -60.0 -60.0 -80.0 -80.0 -100.0 -100.0 -120.0.0 -120.0.0 40.0 80.0 120.0 160.0 200.0 240.0 280.0 320.0 36 40.0 200.0 240.0 280.0 320.0 80.0 120.0 160.0 - 36 R [mm] R [mm Component: BMOD Component: BMOD 4.78019E-03 3.29281E-05 9.52745E-03 1.18278E-04 .00703E-06 2.35548E-04



Performance Test Considerations in the Earlier Model (No Yoke)

2.6

2.4

2.2

2

1.8

1.6

14

1.2

•

0.8

0.6

0.4

0.2

2.6

2.4

Λ

Ic(T,B)/Ic(77K,0)

Ratio, I

Scaling |

Superconducting



We can still test solenoid at the design current with nitrogen only, need sub-cool (~70 K) nitrogen (significant cost saving over helium testing). Lower temperature gives extra margin.



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-64K

-64K

0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2

Perpendicular Magnetic Field (Tesla)



Testing In Liquid Nitrogen (77 K) Only Can Validate the Design Performance

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Magnetic model has also been optimized to reduce the perpendicular field in the superconductor



We can now test solenoid at the design current with liquid nitrogen at 77 K only. No need for liquid helium (significant cost saving) or even sub-cool (55 K - 77 K) nitrogen (more savings). Lower temperature just gives extra margin.





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- In the present design, the inner radius of the iron yoke, rather than the inner radius of the coil, determines the focussing field. This means we can use split iron and a large radius coil (wound over a separate tube) that can be slid over all flanges, etc.
- This significantly, simplifies the overall construction and management of the project as there is a nice hand-off (we do not have to include flange, plating of beam, tube, etc.).
- These are significant advantages in terms of the construction of the solenoid and its integration with the overall project.



SUMMARY

- The present design seems to satisfy the requirements.
- Field in the mu-metal and iron yoke are small.
- Residual field will be further reduced with a demagnetization cycle. This will be a part of our overall design verification test.
- All testing can be done at liquid Nitrogen. This simplifies the overall testing at a much lower cost.
- The overall construction is simplified with a better defined hand-off.
- We are ready to move ahead to complete the project in a timely manner as soon as we receive OK.