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HTS Solenoid Design Review

Coil Design

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Coil Design



Overview of the Presentation

- Brief and a limited review of the general requirements
- Magnetic analysis conforms to the latest engineering design
- LN₂ (77K) testing

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Component: BZ*BZ

0.0

Desired Focussing from Solenoid

Basic Requirement :

 $\int B_z^2 dz \approx 1 T^2 . mm$





OPERA-2d
Pre and Post-Processor

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0.01

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0.02



Fringe Field

- 1. Should be less than 1.5 kG (0.15 T) on the superconductor when the solenoid is <u>ON</u>.
- 2. Should be less than a few mG on the cavity when the cavity is turning to superconducting state (solenoid is <u>OFF</u> at this time).
- 3. Trap field is a concern.
- 4. Field calculations (for beam focussing, etc.) must include the influence of shielding from superconductor and mu-metal



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Earlier Design (Jan/April '06)





- There are two solenoid coils in the design.
- Smaller coil was added later on to reduce (buck) the exterior field in superconducting cavity region.
- Iron yoke plays a major role in creating field and in providing shielding.
- The two coils are connected in series.
- Small coil will also have a shunt power supply for tuning. However, model was optimized for cancellation at zero shunt.
- The analysis of this model was sent to Dmitry Kayran in April 06.
 - The focus of this review is on the coil design.
 - This model had 14 layers in both bigger and smaller coils.

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dauss

Wb m

: Ă m

S m²

w

N

: J kq



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400.0 UNITS Z [mm] Length mm Flux density : T 300.0 Field strength : A m⁻¹ Potential Wb m⁻¹ Conductivity : S m¹ Source density: A mm² Power : W 200.0 Force : N Energy : J Mass : kg 100.0 0.0 PROBLEM DATA egun-oct06-review.st Quadratic elements Axi-symmetry -100.0 R*vector potential Magnetic fields Static solution Scale factor = 1.0 -200.0 61323 elements 123106 nodes 48 regions -300.0 -400.Q 12/Oct/2006 15:38:43 Page 169 Vector Fields

• Magnetic model on this slide conforms to the latest design (Tuesday, October 10, 2006).

Current Coil Design

• It has 15 layers instead of 14 layers in both coils. Larger coil has 12 turns. Smaller coil is a double pancake coil (2 turns).

Calculations are done in two cases:

Case 1 : Bucking coil in series (as per the current engineering design).

Case 2: Bucking coil turned off.

Case 2 (without bucking coil) will be presented first.

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Coil Design



Testing In Liquid Nitrogen (77 K) Will Validate the Required Design Performance

2.6

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



We will be able to test solenoid at a current greater than the design value @77 K itself with liquid nitrogen only. No need for the liquid helium or even sub-cool nitrogen testing (significant cost saving). Lower temperature operation gives extra margin.



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2.4 Field 64K 2.2 Perpendicular 2 Ic(T,B)/Ic(77K,0) + 77K 1.8 1.6 1.4 Scaling Ratio, 1.2 0.8 0.6 0.4 0.2 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 0 Perpendicular Magnetic Field (Tesla) 2.6 **—** 50K 2.4 Field 64K 0-70K 2.2 Parallel + 77K Ic(T,B)/Ic(77K,0) 2 1.8 1.6 1.4 Ratio, Scaling 0.8 0.6 0.4 0.2

Coil Design HTS Solenoid

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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

Parallel Magnetic Field (Tesla)



Field Components at Design Field (Important for 77 K testing at LN₂)



Nominal self-field performance of conductor: 145 A (verified by measurement).

Scale factor at these field is : ~0.6 at 77 K.

Expected performance: 145*0.6= ~87 A.

Design requires <34 A at ~5K

(huge margin even for 77 K test).

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- Scale factor at 0.15 T is ~0.22.
- Expected current: 145*.22 = 32A
- This is close to the design current of 33.6 A and thus the solenoid can be tested close to the operating current.
- However, Lorentz forces will be significantly lower and different.

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Focusing in One Solenoid Case (Bucking coil turned off)

Basic Requirement : UNITS 0.016 Length mm $\int B_z^2 dz \approx 1 T^2 . mm$ Flux density Field strength : A m¹ 0.014 Potential : Wb m¹ Conductivity : S m¹ Source density: A mm² Power W 0.012 : N Force Energy : J Mass kg 0.01 -260.0 Z [mm] 8.0E-03 PROBLEM DATA -280.0 E:\opera\e-gun\oct06revie w/egun-oct06-review-0bu 6.0E-03 ck.st -300.0 Quadratic elements Axi-symmetry R*vector potential 4.0E-03 Magnetic fields -320.0 Static solution Scale factor = 1.0 2.0E-03 61323 elements 123106 nodes -340.0 48 regions -360.0 0.0 R coord 0.0 0.0 0.0 0.0 0.0 Z coord -500.0 -400.0 -300.0 -200.0 -100.00.0 -380.0 Values of BZ*BZ -400.0 12/0xt/2006 16:44:57 Page 210 Vector Fields -420.0 -440.0 0. Component: BZ*BZ 12/Oct/2006 16:43:20 Page 209 0.01 0.0 0.02 Vector Fields

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Field in Cavity Region (Bucking coil turned off)

-4.0E-04

-6.0E-04

-8.0E-04

0/0

-250.0

R coord

Z coord

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• The influence of the remnant field of the yoke will be reduced by demagnetization cycle.

• To further reduce the field on superconducting structure, a bucking solenoid is added (see next slide).

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0.0

-130.0

0.0

-90.0

0.0

-50.0

0.0

-10.0

0.0

-170.0

-210.0

Values of BZ

luadratic elem xi-symmetry Pvector poten lagnetic fields

tatic solution icale factor = 1.0

31323 elements

123106 nodes 48 regions

0.42008 18.57-40 Fase 215

Vector Fields



Focusing in Two Solenoid Case (Bucking coil turned on, in series)



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Comparison of Designs

(without bucking coil and the present design)





Whereas an earlier design (January/April 06 version) that was sent to beam physicist gave correct compensation, the engineering design in the current form clearly over compensates the field.

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Summary and Thoughts on the Present Design

Since the compensation is too much (not too little), the error, in principle, should be fixable with a redesign of the yoke (not yet built) and by taking out turns from the bucking coil. It is possible that the compensation may require non-zero shunt current even in nominal design.

Added after the review:

Two separate power supplies (as suggested by George Ganetis) gives an added benefit that it should allow the use of present bucking coil running at a different current.