SUPER MAGNETS FOR INTERACTION REGIONS

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Introduction

The two basic methods for bringing about main ring and energy doubler beam collisions have been investigated and reported by Diebold and Collins.¹ Since the 50 meter length of straight section is a formidable limitation in both the "kissing" and "transposed" geometry, the question has arisen: Can interaction region magnets be superconducting? If the answer is yes, then higher field magnets can be shorter, leaving more room for detectors. Not only must these magnets have a large aperture, but they must also satisfy various requirements such as allowing space to shield one beam from the magnetic elements of the other (in the case of independent magnets for each beam) and having magnetic field quality sufficient to handle 8 GeV injected beam in the main ring in the case of a common magnet such as the magnet "C" in the "kissing" scheme. A rough estimate of the cost of such supermagnets is given below as an aid to the selection of interaction geometry.

Design

After looking at various possibilities it was decided that magnet "C" of the "kissing geometry" (see Figure 2 of Diebold and Collins) would be the best magnet to investigate. We have

carried through a preliminary design for the two-dimensional cross section. The magnet can essentially have any desired length (22-ft long doubler dipoles have been shown to have no important length effects), and the cross section is shown in Figure 1. The design criteria was 9 in. of "good-field" region. Since the doubler dipole magnets have 2-in. of good field region for a 3-in. conductor bore, this represents a scaling factor of 4.5 and a conductor bore of $13\frac{1}{2}$ in.

The same 23 strand Rutherford-type cable as used in the doubler dipoles is assumed. This cable, with outer dimensions of approximately 0.050 in. x 0.300 in., typically carries 5000 amps at 50 kG. For the doubler magnets the cable is "key stoned" (changing the 0.050 in. dimension to 0.044 in. on the inner radius and 0.055 in. on the outer) to approximately match the 3 in. coil bore. Due to the larger bore here the keystoneing would be considerably less ($\sqrt{2}$ mils) or perhaps zero with the turn-to-turn insulation being compacted into a trapezoid during molding to compensate for the rectangular conductor.

This design has 141 turns on each half of the inner shell and 85 turns on the outer. The shell angles of 72.5° and 41.7° are approximately the same as for the doubler dipoles and are selected to minimize the 6-pole and 10-pole coefficients. At 4500 amps this design gives a central field of 44.77 kG; this is about 83% of the short sample current carrying capability, a conservative value.

Other details which can be seen from Figure 1 are as follows:

1. The iron shield has an inner radius of 15.1 in. and an outer radius of 30.2 in. It is warm and below saturation.
2. The field contribution from iron is 8 kG.
3. The space between the coil and iron is 7.7 in., more than adequate for coil support collars of stainless steel, liquid nitrogen temperature shield, and coil centering supports of "low-heat-loss" design.

Scaling to Other Sizes of Super Magnets

The above exercise substantiates the following scaling rules which can be used for similar large aperture magnets. We use as scaling parameter the coil bore compared to that of the doubler:

$$R = \frac{r_{C \text{ mag}}}{r_{\text{doubler}}} = \frac{6.75 \text{ in.}}{1.5 \text{ in.}} = 4.5 .$$

1. Two layers or shells of doubler cable are required with about the same azimuthal coverage, independent of R.
So, $\propto R$ for the amount of superconducting wire.
2. Forces per unit length to constrain the superconductor; $\propto R$ strong enough, but may need $\propto R$ preloading! This may mean a different approach for preload such as aluminum coil collars which load coil structure due to differential thermal contraction. Longitudinal thermal expansion coefficient match could be accommodated by use of matched "bore-tube" and intermittent coil collars with a longitudinal preload clamp system similar to Escar dipoles.

3. Displacement force: 1.1 lbs/inch length/mil offset, independent of R. Thus, the stiffness of the coil centering supports need be no greater than for the present ED/S magnets. Since the manufacturing tolerances may be somewhat looser for the large magnets discussed here, the strength or yield point of the supports may need to be increased somewhat to allow for larger unintentional displacements of the superconductor center from the iron center. Such an increase in strength would presumably result in a somewhat larger heat leak across the suspension.
4. Stored energy $\propto B^2 \times \text{Vol}$ or $\propto R^2$. As an example, a 9 in. good field interaction region magnet of length equal to an energy doubler dipole would have ≈ 0.5 megajoules $\times 4.5^2 = 10$ megajoules of stored energy, the equivalent of a string of 20 energy doubler dipoles. This would require additional safety lead taps or quench inducing resistors to distribute the quench wave over a larger volume of superconducting coil in order to protect the coil from high temperature during a quench. Other changes such as increasing the Cu to superconducting ratio from present 1.8 to 1 should be investigated.

Outer dimensions: $\propto R$. As an indication of the accuracy of these scaling rules, we note that 60.4 in./15 in. ≈ 4.0 compared to $R = 4.5$. The radial space required by the conductor remains constant, slightly breaking the $\propto R$ scaling.

5. Iron; $\propto R^2$.

Preliminary Cost Estimate

We use as a starting point the latest energy doubler dipole cost experience which is given below:

Unit Cost in Kilodollars for
22-ft Long Dipole (in quantity
of 25)

Cryostat parts	6.9
Coil parts	4.3
Yoke parts (including stamping)	1.4
Yoke steel	<u>1.8</u>

Parts Subtotal 14.4

Superconductor (4800 ft at \$2/ft)	9.6
Coil labor	3.3
Cryostat labor	3.6
Yoke labor	<u>0.4</u>

Labor Subtotal 7.3

Total 31.3

Tooling 160

A rough estimate for a 9 in. good field super magnet, with the same 22 ft. length as a doubler magnet, would then scale as follows:

Cryostat parts (xR) dominated by end effects	$6.9 \times (4.5) = 31$
Coil parts (xR^2) due to change in preload system	$4.3 \times (4.5)^2 = 87$
Yoke parts (xR)	$1.4 \times (4.5) = 6.3$
Yoke steel (xR^2)	$1.8 \times (4.5)^2 = 36.5$
Superconductor (xR)	$9.6 \times (4.5) = 43.2$
Labor (xR)	$7.3 \times (4.5) = \underline{33.9}$

Total ~240

The tooling estimate at this time can only be at best a guesstimate. Equipment which is already on hand for energy doubler dipole magnet fabrication and assembly would undoubtedly be modified for this work rather than starting from scratch. We take \$400,000 as a rough tooling estimate. Several magnets of this design could be produced for this one-time investment.

Future Work

1. Programmable correction coils required for 8 GeV beam.
2. Quench protection study.
3. Coil collar clamp system design.
4. Comparison design for conventional magnet with cost comparison for construction and operation.

Acknowledgments

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References

1. R. Diebold and T. Collins, "Crossing Geometry for Main Ring on Doubler Collisions," memo serving as background material for this Summer Study (May 1977); see also the paper in these proceedings with the same title.