SSC-MAG-95
SSC-N-209
LBID-1199

ARC QUAD DESIGN PROPOSED FOR FIRST MODEL MAGNETS*

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The ARC quad is designed to satisfy the following requirements:

- I = 6500 A at operating field (in series with the dipole)
- Quad must "track" the dipoles within about 1%
- 40 mm bore diameter

Cost minimization of the facility indicates that a two-layer, high-gradient design, requiring shorter length than single-layer designs, has lower cost. An additional very important benefit of a two layer design is that the 30 strand cable used in the outer layer of the dipole can be efficiently used; cable length as short as 200 ft can be used in the quad whereas 2300 ft is the minimum cable length usable in the dipole (outer layer). Tevatron experience indicates that this will significantly reduce the total cost of the quad cable by minimizing scrap cable. An efficient single layer design requires development of a new smaller cable cross section.[1]

Interlocking collars are chosen for structural support because they were successfully used in the Tevatron, have dimensional accuracy and four-fold symmetry to minimize field distortion, and have low fabrication

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cost. A 19 turn design with 10 mm collars, G = 212 T/m iron O.D. = 9 inches, and length of 3.3 m was chosen for the CDR.[2]

A recent re-design and optimization study included coil cross-sections with 19 to 24 turns, aluminum and stainless steel collars 10 and 15 mm wide, and iron O.D. up to 9 inches; the proposed design shown in Fig. 1, has 22turns, 12 mm wide collars, a gradient of 232 T/m at I = 6500 A[3,4], and is 3.0 m long. (Similar preliminary designs have been made for various cable sizes and larger bore diameters.[5]) Thickness of the cable insulation, interlayer insulation, midplane insulation, coil-collar insulation, etc., is identical to that of the dipole design.

Parameters are listed below:

Cable: 30 strands, .0255 in dia. Cu/SC = 1.8 (identical to dipole outer layer cable)

Inner Layer:

Number of turns	9
" " wedges	1
Inner radius	20.214 mm
O.R.	30.044 mm

Outer Layer:

Number of turns	13
" " wedges	1
I.R.	30.500 mm
O.R.	40.331 mm

	gradient at I = 6500 A
$\mu = \infty$	233.35 T/m
real iron	232 T/m

B_{max} at conductor: 5.29 T on inner layer

Operating temperature: 4.35 K

Strand $j_c = 2750\ A/mm^2$ at 4.2 K and 5T (no allowance for cable degradation)

j_c at 4.35 K and 5.29T: 2499 A/mm^2

j_o at 6500 A: 1841 A/mm^2

$j_c/j_o = 1.36$

The comparable value of j_c/j_o for the dipole inner layer is 1.25; therefore, this quad has 9% more design "margin" than the dipole; this is reasonable considering that there will probably be a much less extensive R&D program devoted to the quads.

Calculated field uniformity at $r = 1$ cm for $\mu = \infty$ (normalized to the quadrupole field at r = 1 cm) is given below:

Multipole	B(Multipole)/B(Quadrupole)
Quadrupole	1.0
12-pole	$.002 \times 10^{-6}$
20-pole	$.04 \times 10^{-6}$
28-pole	$.85 \times 10^{-6}$
36-pole	$.23 \times 10^{-6}$

At $I = 6500$ A, B_{12-p}/B_{4-p} increases to only 1.3×10^{-6} due to iron saturation. For 5 μm diameter filaments, the additional magnetization effect results in $B_{12-p}/B_{4-p} = -2.4\times10^{-4}$ at injection ($I = 6500$ A/20).(6)

Notches in the iron yoke are provided to accommodate the main buss conductors; for simplicity, the notch dimensions are identical to those in the dipole. A 7.5 inch iron outer diameter (as shown in Fig. 1) can be used if the notches are located at the flux separatrix at the 45 location; four are provided for field symmetry with the two "empty" notches used for liquid helium bypass channels. However, there are advantages of standardization and simplicity if the quad iron O.D. is identical to that of the dipole (10.5 inch) and this is proposed for the initial models as shown in Fig. 2.

Collar width was chosen to be 12 mm; this provides acceptable stresses that are calculated to be less than those already experienced in aluminum dipole collars. If the collar width is decreased slightly, the increase in gradient (because of smaller iron I.D.) would be about 2.2 T/m per mm of width. We believe that the lower bending stresses encountered with 12 mm collars during the assembly operation (compared to 10 mm which is deemed a minimum practical width) is worth the 1.9% lower gradient. We see no advantage at the present time of stainless steel over lower-cost aluminum; the deflections under magnetic load are very small and, we believe, will not produce a significant field distortion (must be verified).

A nearly identical 22 turn design with cable of identical dimensions (but with a lower copper fraction) is a leading candidate for a 260 T/m I.R. quad with iron adjacent to the windings. (close-in iron is unacceptable for the ARC quad because the ~8% non-linear saturation effect would make "tracking" of the dipoles more difficult). It is very advantageous that nearly identical coil dimensions will allow the same coil winding and molding tooling to be used for models of an IR quad as well as well as an ARC quad. Therefore, we propose to construct I.R. quad models soon after the ARC quad models.

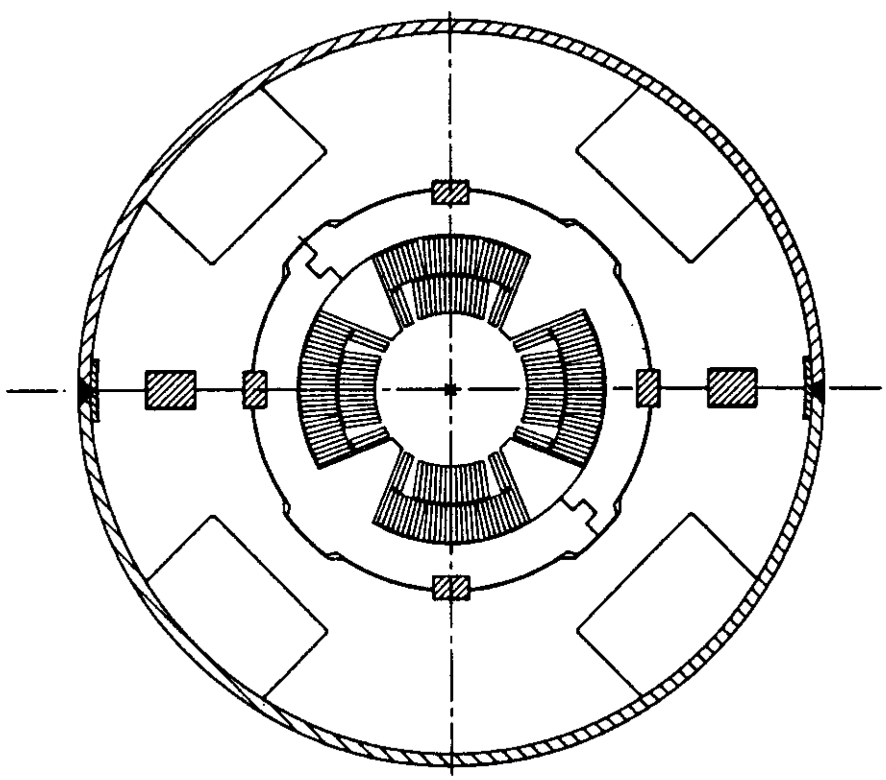
References

1. Quadrupoles: Preliminary Study, SSC-MAG-59, R.W. Meuser, 11/25/85.
2. Arc Quadrupole Design for the SSC, SSC-MAG-158, C. Taylor, 4/3/86.
3. Arc Quad for SSC-First Cut., S. Caspi and M. Helm, SSC-MAG-87 (LBID-1172), 6/19/86.

4. Finite Element Analysis of a 12 mm ARC Quadrupole Collar for the SSC, C. Peters, SSC-MAG-85 (LBID-1174), 6/17/86.

5. High Gradient Accelerator Quadrupole Design, A.D. McInturff, J.A. Carron, S. Snowdon, ICFA Panel Workshop on Superconducting Magnets and Cryogenics, Brookhaven National Laboratory, 5/12/86.

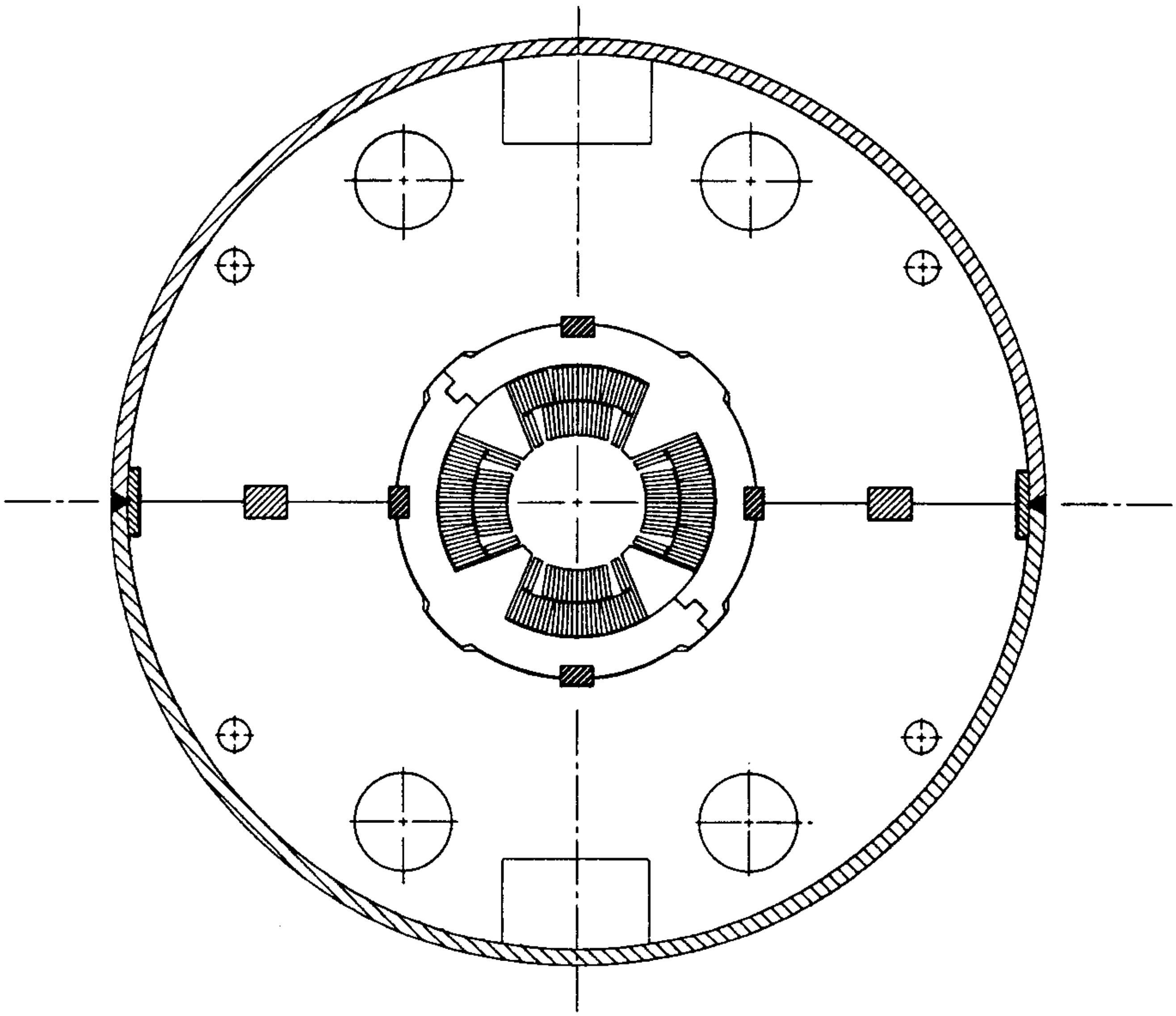
6. Residual Field Generated by the Quadrupole Magnets M6499 SSC-MAG-94, M. Green, 4/8/86. (Larger than given in LBID-1151 because of higher J_c superconductor and higher gradient of current design.)



SSC ARC QUAD

(7.5' DIAMETER YOKE)

Fig. 1.



SSC ARC QUAD

(10.5" DIAMETER YOKE)

Fig. 2.