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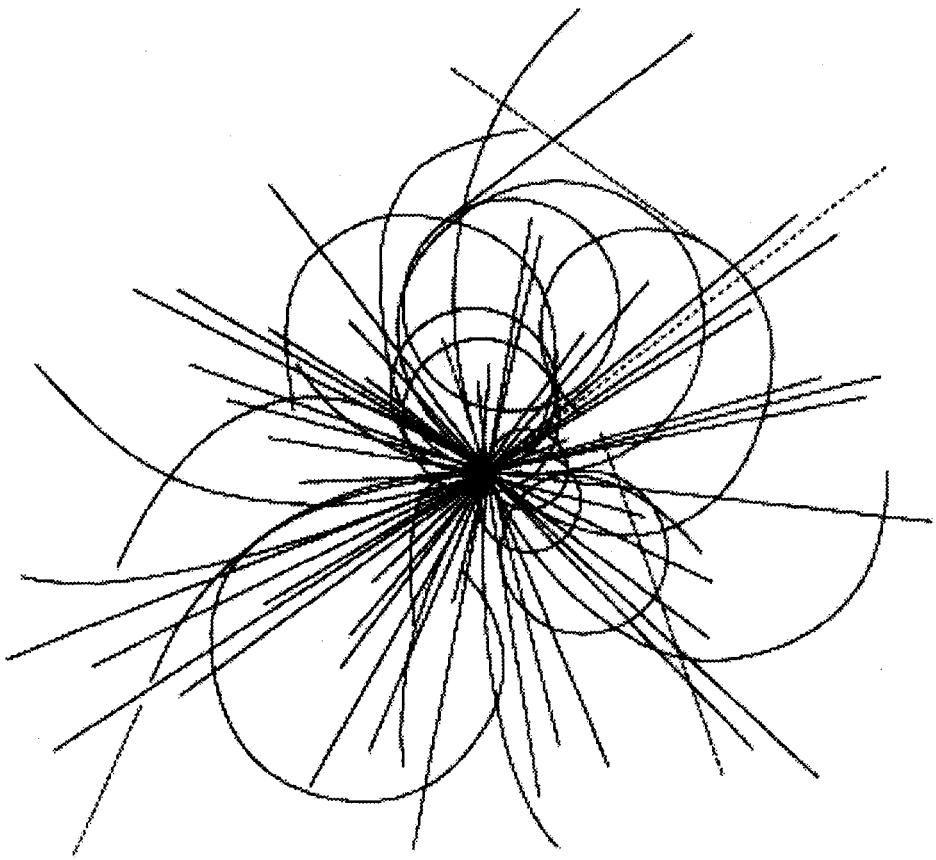

Superconducting Super Collider Laboratory

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Mechanical Analysis of the DSB Cross-Section*

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MECHANICAL ANALYSIS OF THE DSB CROSS-SECTION

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INTRODUCTION

This paper presents the preliminary mechanical finite element analysis for the SSCL designed DSB dipole magnet. This SSCL version 50 mm aperture dipole magnet is for the SSCL High Energy Booster with nineteen turns, three wedges for inner coil and twenty six turns, one wedge for outer coil, the round collar is nineteen mm thick, the yoke and the shell are adopted from the design for quadrupole QSE101.

The main purposes of this mechanical study are to ensure that there are no excessive stresses in the cold mass under different loading, to avoid coils unloading from the collar at excitation of 6500 A, to ensure collar-to-yoke, line-to-line fit after welding the shell, and also to ensure the yoke midplane gaps are closed at an operating current of 6500 A.

Therefore, the analyses performed include magnet assembly (collaring) to 69 Mpa azimuthal stress at the inner coil pole and 55 Mpa azimuthal stress at the outer coil pole; shell welding to 207 Mpa azimuthal stress in the shell; magnet cooldown to 4.25 K; and Lorentz excitation at a current of 6500 A.

FINITE ELEMENT MODEL

Analysis is performed on a quarter model since the geometry and loading are symmetrical.

Model Assumption[1]

* The model assumes plane stress analysis
* All materials are linearly elastic, except that plasticity is considered for the collar. The coils are orthotropic in radial and azimuthal directions both for Young's Moduli and thermal coefficient. The Young's Moduli for the inner coil are higher than that for the outer coil due to the stiffness increment caused by curing the inner coil twice.

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* Young's Modulus for each material at 4.25K is higher than that at room temperature
* All contact surfaces are assumed frictionless or bound
* No interferences exist between coil turns and wedges
* The front collar is spot welded with the back collar, so that the displacements of front and back collars in the horizontal midplane are the same radially, but the same magnitude in the opposite direction azimuthally, also similarly in the vertical plane
* Lorentz forces are calculated with infinite permeability iron.
* Half collaring prestress is modeled by specifying coil midplane displacement, another half by specifying an interference between coils and collar at pole planes.

Material Properties[1]

	Elastic Modulus	**Thermal Coefficient**
Inner Layer Insulated Cable	Room Temperature Eazim = 11,000 Mpa Eradial = 17,600 Mpa Cold Temperature Eazim = 13,200 Mpa Eradial = 18,320 Mpa	αazim = 1.40e-5 (1/K) αradial = 1.53e-5 (1/K)
Outer Layer Insulated Cable	Room Temperature Eazim = 10,000 Mpa Eradial = 16,000 Mpa Cold Temperature Eazim = 12,300 Mpa Eradial = 17,120 Mpa	αazim = 1.40e-5 (1/K) αradial = 1.53e-5 (1/K)
Copper wedge, Brass Shoe, Brass Key	Room Temperature E = 120,000 Mpa Cold Temperature E = 150,000 Mpa	α = 1.11e-5 (1/K)
Kapton	Room Temperature E = 3,000 Mpa Cold Temperature E = 3,810 Mpa	α = 2.00e-5 (1/K)
Intercoil Spacer	Room Temperature E = 10,000 Mpa Cold Temperature E = 12,300 Mpa	α = 1.8e-5 (1/K)
Nitronic 40 Stainless Steel	Room Temperature E = 195,000 Mpa Eplastic = 40,000 Mpa yield stress = 620 Mpa Cold Temperature E = 206,700 Mpa	α = 0.92e-5 (1/K)
Iron Yoke	Room Temperature E = 205,000 Mpa Cold Temperature E = 211,000 Mpa	α = 0.698e-5 (1/K)
Stainless Steel Shell	Room Temperature E = 195,000 Mpa Cold Temperature E = 206,700 Mpa	α = 1.073e-5 (1/K)

RESULT

Table 1. Inner and outer coil average azimuthal stresses; collar horizontal and vertical deflections at pole under various loading

Loading Condition	Pole Stress (Mpa)		Collar Deflection (mm)	
	Inner	Outer	Horizontal	Vertical
Collaring	69.7	54.8	0.0264	0.0995
Welding to 207 Mpa*	85.9	68.0	0.00655	0.0586
Cooldown to 4.25 K*	56.5	51.2	0.0324	0.0459
Energization to 1000 A*	55.7	50.6	0.0331	0.0454
Energization to 2000 A*	53.3	49.0	0.0353	0.0441
Energization to 3000 A*	49.3	46.2	0.0388	0.0418
Energization to 4000 A*	43.7	42.3	0.0431	0.0387
Energization to 5000 A*	36.7	37.4	0.0486	0.0347
Energization to 6000 A*	28.0	31.4	0.0554	0.0297
Energization to 6500 A*	23.1	28.0	0.0593	0.0268

Table 2. Collar to yoke contact force; midplane yoke to yoke contact force and minimum and maximum gap under various loading

Loading Condition	Collar-Yoke Contact F (N)		Yoke-Yoke		
	Horizontal	Vertical	Contact F (N)	Max. Gap (mm)	Min. Gap (mm)
Welding to 207 Mpa	942	1012	0	0.0488	0.0353
Cooldown to 4.25 K	165	332	1590	0	0
Energization to 1000 A	172	327	1594	0	0
Energization to 2000 A	198	315	1607	0	0
Energization to 3000 A	244	297	1625	0	0
Energization to 4000 A	312	274	1649	0	0
Energization to 5000 A	400	246	1678	0	0
Energization to 6000 A	511	213	1712	0	0
Energization to 6500 A	578	198	1728	0	0

Where deflection "*" is calculated as:

Deflection = $R.\alpha.dT$ - Abs. Dfl.

$dT = 293 - 4.25$ K

R = collar outer most radius at horizontal and vertical directions

α = thermal coefficient

Abs. Dfl. = absolute deflection of the point from ANSYS analysis

Here, $R.\alpha.dT$ are 0.1998 mm and 0.1838 mm in vertical and horizontal directions.

In this analysis, the stretching stress in the collar near the key way is about 720 Mpa.

For the comparison of this round collar design with an anti-oval collar design, the analysis for the anti-oval collar with 0.1 mm total ovality is performed also. The results show that there is no contact between collar and yoke, which means that collar is free to move inside the yoke, but they are in contact at operating current. Some experts insist on collar to yoke contacting all the time after cooldown in order to reduce the risk of quench due to the movement of the collar inside the yoke, others consider that no contact between the collar and the yoke after cooldown and at low excitation currents is acceptable as long as they contact each other at operating current.

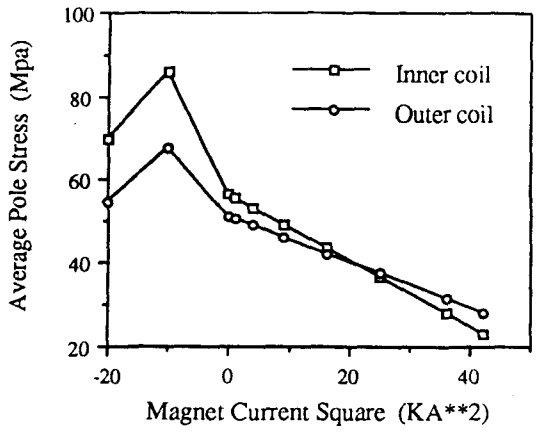

Figure 1. Calculated average azimuthal pole stress pole stress for round collar

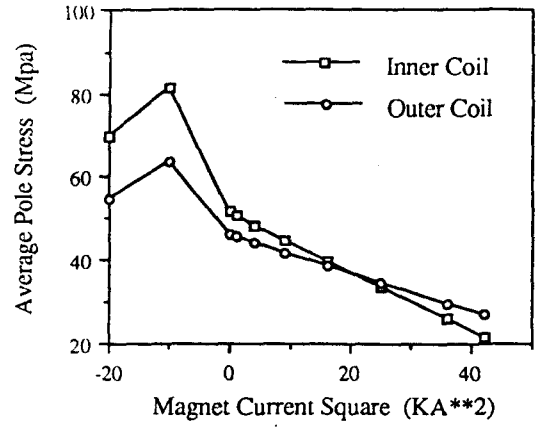

Figure 2. Calculated average azimuthal for anti-oval collar

From the data in Table 1, the calculated average azimuthal pole stress for a coil under different loading is shown in Figure 1. The same type of curve for the anti-oval collar is plotted in Figure 2. As can be seen in the figures, the pole stress for the round collar is only several Mpa greater than the corresponding one for the anti-oval collar.

CONCLUSION

From the ANSYS model analysis, it is clear that coil prestresses are far away from unloading at operating current; that yoke and collar are in tight contact after welding and remain in good contact after cooldown and excitation to 6500A; also that the yoke midplanes contact after cooldown and thereafter, although there is no any contact between them after welding.

However the analysis also shows that the tensile stress in the collar near the key way is over yielding stress after collaring, but this would not effect the overall mechanical performance of the magnet, since it is in a highly localized area.

According to this analysis, DSB with round collar would perform similarly to the collider dipole in mechanical aspects.

ACKNOWLEDGMENTS

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REFERENCES

1. J. Turner, G. Spigo, Y. Chen: Mechanical Analysis of the QSE101 Cross-Section, March, 1992