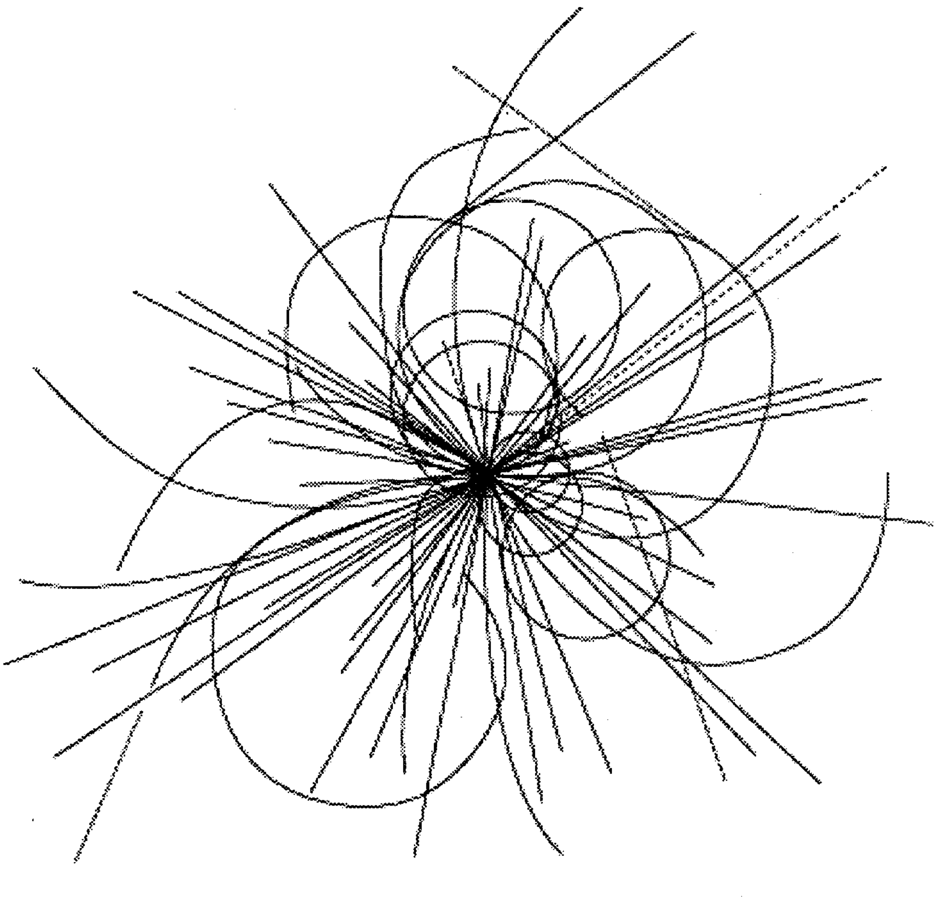
CONF-930537--121

SSCL-Preprint-267

SSCL-Preprint-267
April 1993
Distribution Category: 414

V. Tran

Corrector Magnets: Combined Structural Analysis of Collider 50 mm Aperture Ordered Wound Dipoles Interior Section



Superconducting Super Collider Laboratory

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

To be published in *Supercollider 5*

SSCL-Preprint-267

Corrector Magnets: Combined Structural Analysis of Collider 50 mm Aperture Ordered Wound Dipoles Interior Section*

V. Tran

Superconducting Super Collider Laboratory†
2550 Beckleymeade Ave.
Dallas, TX 75237

April 1993

*Presented at the Fifth Annual International Symposium on the Super Collider, May 6–8, 1993 San Francisco, CA.

†Operated by the Universities Research Association, Inc., for the U.S. Department of Energy under Contract No. DE-AC35-89ER40486.

CORRECTOR MAGNETS: COMBINED STRUCTURAL ANALYSIS OF COLLIDER 50MM APERTURE ORDERED WOUND DIPOLES INTERIOR SECTION

Vu H. Tran

Mechanical Engineering Department
Accelerator Systems Division
Superconducting Super Collider Laboratory *
2550 Beckleymeade Avenue, MS 4006
Dallas, TX 75237-3997

ABSTRACT

The 50mm aperture prototype collider ordered wound dipole corrector magnets have been modeled with finite element techniques considering the individual and combined load cases of the preloading from keys, cooldown to 4 K and the effect of magnetic forces during energizing. Results of the analysis are presented as longitudinal, transverse and shear stresses for the ordered wound coils and as maximum von Mises stress for the carbon steel outer laminations, the stainless steel inner lamination, and the carbon steel keys.

INTRODUCTION

The dipole corrector magnets are members of the collider ring correctors which are responsible for providing steering and closed orbit correction of the proton beams. These corrector magnets are located inside of the spool piece. This paper presents results from a finite element stress analysis of the prototype collider 50mm aperture ordered wound dipole corrector magnets. This analysis considers only the interior sections along the length of the structure - which differ greatly from the end sections. The coils for this dipole magnet structure are manufactured using ordered wound techniques. Load cases involved in the analysis include preloading from keys, cooldown to 4 K and magnetic (Lorentz) forces from energizing. The objectives of this stress analysis for the dipole structure are to determine the stresses in the ordered wound coils, the necessary shim thickness around the coils and to evaluate the capability of the outer laminations, inner laminations and keys to resist the stresses induced by reaction with the coils. The results of this analysis will be used as reference for further design of the dipole structure members - including the coils, the inner laminations, the outer laminations and the keys.

The dipole magnet structures consist of magnetic coils held in place by a series of thin, interlocking carbon steel outer laminations. Figure 1 shows two consecutive cross-sections of the dipole. The outer laminations are configured such that each cross-section of the magnetic structure along the length of the coils contains two interlocking outer lamination pieces: one above and one below the magnetic coils. Each outer lamination piece is joined to the pieces immediately in front of and

*Operated by the Universities Research Association, Inc., for the U.S. Department of Energy under Contract No. DE-AC35-89ER40486.

behind it by two continuous pins. Continuous longitudinal carbon steel alignment keys on the right and left sides of the outer laminations provide the "preload" forces necessary to hold the outer laminations in place and to exert pressure on the magnetic coils. The outer lamination sections immediately in front of and behind each individual outer lamination section are identical in geometry but are rotated 180 degrees about the vertical axis (y-axis), yielding the same external shape but a different configuration at the alignment keys. The alternating orientation of the outer lamination pieces permits the "elbow" section of each outer lamination piece keyway to be alternately placed above or below the alignment keys. Layer of Kapton are placed around the coils to act as a shim. Therefore, one of the design criteria in this analysis is to provide enough shim thickness to have the minimum stresses in the coils after cooldown to be at least greater than the maximum stresses in the coils due to magnetic forces only. This criteria should applied to each coil's local longitudinal, transverse and shear direction stresses in the coils. The ordered wound coils structure consists of continual loops of 0.381 mm (15.0 mil)-diameter superconducting Cu:Nb-Ti (2.2:1) wire insulated with a 0.076 mm (3.0 mil)-thick layer of Kapton and Dupont XMPI adhesive.

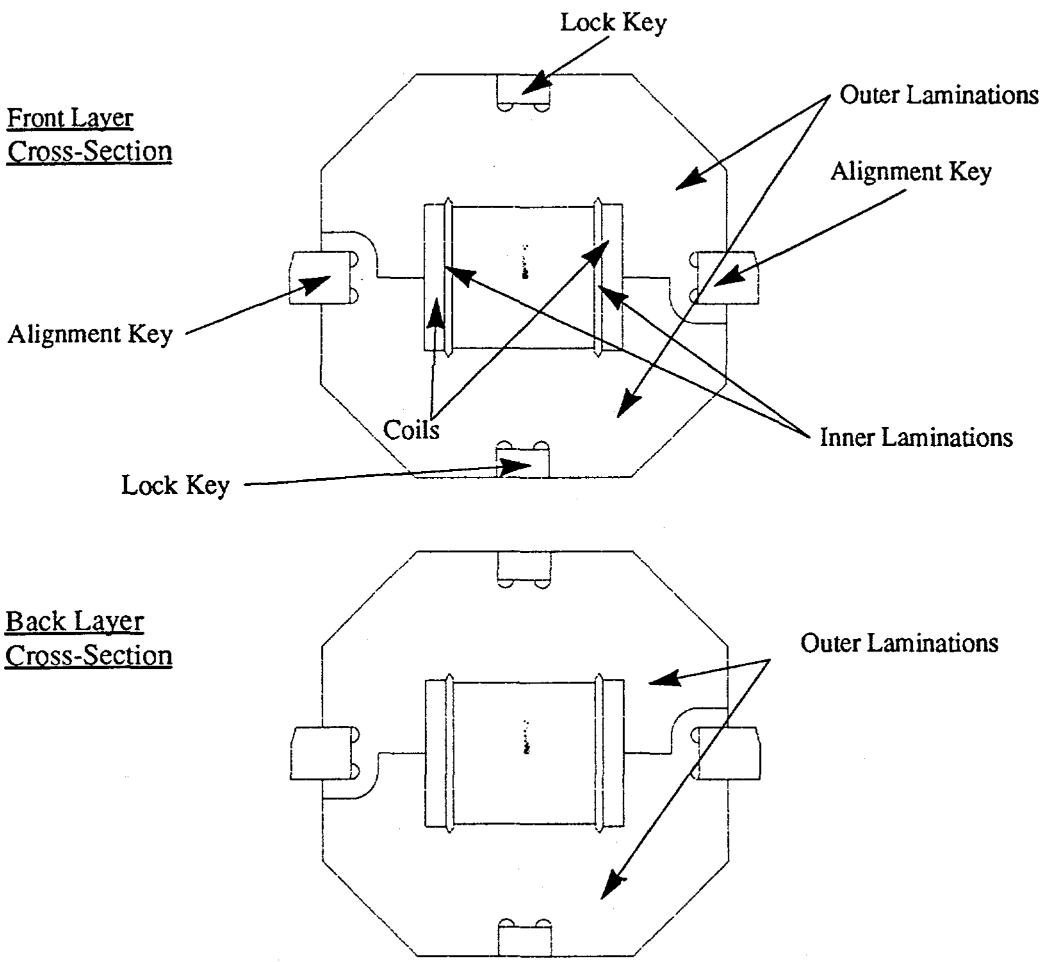


Figure 1. Collider 50mm Aperture Ordered Wound Dipoles - Front and Back Layer Cross-Sections

MODEL CONSTRUCTION

The magnet assembly is modeled as a two-dimensional finite element system. The model consists of two adjacent layers of outer laminations (each consisting of a top and bottom outer lamination piece from the same cross-section) hereafter referred to as the "front" and "back" outer laminations. To get the correct loading from the keys, the two layers of the outer laminations are modeled with two-dimensional plane stress elements. The front and back outer laminations are linked only with coupled nodes at each of the four continuous pin locations. Gap elements having a positive gap distance to act as a interference are used to join the coils to the outer laminations (gap elements only transmit compression load not tension load). These positive gap distances represent the thickness of the shim around the coils. All other gap elements between various parts are given a zero value. The coils, inner lamination and keys are constructed from two-dimensional plane stress elements. Material properties used in this model are shown in Table 1. Material properties for the ordered wound coils are obtained from testing and analysis.

Table 1. Material Properties

Materials		Carbon Steel	304L Stainless Steel [1]	Ordered Wound Coil
Young's Modulus (psi)	T = 293 K	30.0×10^6	27.6×10^6	200,000
	T = 4 K	30.6×10^6	29.2×10^6	300,000
Poisson's Ratio	T = 293 K	0.292	0.29	0.346
	T = 4 K	0.292	0.2788	0.339
Thermal Expansion [2] Coefficients, (K^{-1})		0.685×10^{-5}	1.059×10^{-5}	1.4×10^{-5}
Yield Tensile Strength (psi)	T = 293 K	25,000	58,900	N/A
	T = 4 K	54,000	79,400	N/A
Ultimate Tensile Strength (psi)	T = 293 K	42,000	95,500	N/A
	T = 4 K	65,000	241,000	N/A

LOADING CASES

Preload Case

As mentioned previously, the preloading case experienced upon assembly is simulated by assigning to all the gap elements around the two coils an overlapping gap distance to represent the shim thickness. All material properties for the preload case are referenced to 293 K.

Preload and Cooldown Case

The combined analysis of the preload and the cooldown uses the same model as does the preload alone except that the model is assigned an initial temperature of 293 K and a final temperature of 4 K to represent the cryogenic state after the cooldown has occurred. All material properties for the combined analysis are given at the reference temperature of 4 K.

Magnetic Forces Case

To complete a magnetic stress analysis of the model, a separate magnetic analysis must first be conducted. The magnetic analysis is performed using a somewhat simplified version of the dipole model. The magnetic analysis is concerned only with the location and the magnetic properties of dipole structure components; therefore, the model used in the said analysis contains only the geometric and physical description of the individual components and does not require the use of gap elements. The wire in the coils are given a current density of 4.0297×10^8 A/m^2 at 100% of short sample current, but only 66% is required for operation current. The forces on the nodes of the coils are computed in the magnetic analysis and then inserted into the standard dipole model. A finite element analysis is then performed on the standard model with the magnetic forces alone to determine the influence of the magnetic forces on each component of the dipole structure.

Preload, Cooldown and Magnetic Forces Case

To complete the final combined analysis, the standard dipole model is subjected to the simultaneous loadings of the preload, cooldown and magnetic forces. Once again, a finite element analysis is performed to determine the stresses on the individual components of the coil structure due to the three combined loading cases.

STRESS ANALYSIS RESULTS

In order to have the minimum stresses in the coils after cooldown to be at least greater than the maximum stresses in the coils due to magnetic forces only, the finite element analysis shows that a shim thickness of 4 mils must be used along the two shorter lengths of the two coils. These results are shown on Table 2. As shown in Table 2, for the coils the first value is the minimum and the second is the maximum, thus showing the range of stresses in the coils. The longitudinal and transverse directions are defined along the longer and shorter length of each coil, respectively. The transverse stresses in the coils did not meet the design criteria in this analysis due to the inadequate design of the inner laminations. Even if shims were added to the longer lengths of the coils, this will not produced the necessary transverse stresses in the coils. A new design of the inner laminations should be studied to induce transverse stresses into the coils. Stresses in other parts of the dipole are all less than the material tensile yield strength.

Table 2. Stress Levels for Collider Ordered Wound Dipoles

Loading Cases		Preload of Keys shim = 4 mils *	Preload of Keys & Cool Down to 4 K	Magnetic Forces Only $I = 66\% \ I_{ss}$ or $110\% \ I_{op}$	Preload of Keys & Cool Down to 4 K & Magnetic Forces
Coils Min : Max Stress (psi)	$\sigma_{transverse}$	-289 : 4	-5 : 9	-269 : -53	-284 : -53
	$\sigma_{longitudinal}$	-796 : -632	-370 : -343	-200 : -17	-509 : -314
	τ_{shear}	-38 : 38	-4 : 4	-11 : 11	-16 : 16
Carbon Steel Outer Laminations Maximum von Mises Stress (psi)		9,600	4,700	830	4,200
Carbon Steel Keys Maximum von Mises Stress (psi)		2,400	1,200	370	1,100
Stainless Steel Inner Laminations Maximum von Mises Stress (psi)		1,700	50	60	50

* shim thickness between the two shorter lengths of coils and outer laminations

CONCLUSION

The finite element analysis for the collider ordered wound dipole corrector magnets shows that the stresses induced in the various magnet components under the specified load conditions are well within the acceptable range of allowable material strengths. The coils in this dipole design are loaded only in the longitudinal direction of coils. To help prevent transverse movement of the coils, future designs of the dipoles structure should include inner laminations capable of exerting pressure on the sides of the coils. It should be noted that different values for the material properties of coils will greatly effect the design and analysis. Therefore, accurate values of coils material properties must be obtained for further design and analysis. It should also be remembered that this analysis considers only cross-sections from the interior of the structure in a two-dimensional frame. As the cross-sections at the ends of the dipole structure differ significantly from those in the interior, additional analyses must be performed to evaluate their behavior.

REFERENCES

1. Richard P. Reed and Alan F. Clark, eds., *Materials at Low Temperatures*, American Society for Metals, Metals Park, Ohio, 1983, page 8.1.3-2.
2. Neil A. Olien, Ed., *LNG Materials and Fluids, Second Supplement*, Prepared by Cryogenics Division, Institute for Basic Standards, National Bureau of Standards, Boulder, Colorado, 1979, page 95.