Fermilab

TM-1349
(SSC-N-29)
0102.000
2750.000

DESIGN, CONSTRUCTION, AND PERFORMANCE OF A POST TYPE CRYOGENIC SUPPORT*

R. C. Niemann, J. D. Gonczy, T. H. Nicol,
J. G. Otavka, and M. W. Roman

September 1985

*Presented at the 1985 Cryogenic Engineering Conference and International Cryogenic Materials Conference, Massachusetts Institute of Technology, Cambridge, Massachusetts, August 12-16, 1985.

DESIGN, CONSTRUCTION AND PERFORMANCE OF A POST TYPE CRYOGENIC SUPPORT

R. C. Niemann, J. D. Gonczy, T. H. Nicol,
J. G. Otavka, M. W. Roman

Fermi National Accelerator Laboratory

Batavia, Illinois

ABSTRACT

A support member for superconducting magnets and other cryogenic devices has been designed, fabricated and structurally and thermally evaluated. The member is a cylindrical post constructed with fiber reinforced plastic (FRP) tubing and having metallic heat intercepts and end connections. All FRP to metal connections are made by mechanical shrink fitting and do not employ adhesives or fasteners. The post can operate in tension, compression and flexure or in combinations of these loads. The details of the design and construction are enumerated. Structural performance has been measured in tension and compression at 80 and 300 K and in flexure at 300 K. Creep effects on the shrink fit joint reliability are being evaluated. Thermal performance has been measured for a post with ends at 4.5 and 300 K and with heat intercepts at 10 and 80 K. The measured performance has been compared with the analytical predictions. Full scale, working, prototype posts have been successfully utilized in several model cryostats for the Superconducting Super Collider dipole magnet development program.

INTRODUCTION

As a part of the conceptual design of superconducting magnet cryostats for the Superconducting Super Collider (SSC), a post type cryogenic support has been developed, built and tested.

As a result of their function in the SSC accelerator rings, the magnets have a small cross-section; i.e., ≈5 cm bore, and are relatively long; i.e., >12 m. The magnet coil assembly must be suspended by a system that provides position stability, low refrigeration loads, high reliability, installation and adjustment ease, and low cost construction. The suspension system must provide support during magnet assembly, shipping and installation, cooldown and warmup phases, steady state operation and upset conditions.

An iron-less cosΘ magnet configuration for the SSC dipole[1,2] imposes a unique design requirement for the suspension system since magnetic forces can exist between the coil assembly and the steel vacuum vessel required for magnetic shielding. The forces are caused by an offset of the axes of the coil and vacuum vessel assemblies due to component manufacturing and assembly tolerances. Since the offset can be random, the force can occur in any direction in a plane normal to the magnet axis. The magnitude of the forces can be high; i.e., ≈3 x coil assembly static weight.

After consideration of several types of suspension systems, a cylindrical post type support was selected for the iron-less cosΘ SSC dipole[3,4].

The main features of the post are as follow:

- Load Carrying Versatility - A cylindrical section results in a support that can carry tension, compression, bending and torsional loads.
- Low Heat Leak - The use of FRP materials with effective heat intercepts results in predictably low heat leaks.
- Installation and Adjustment Ease - The post, involving only a single support member at a suspension point, simplifies installation and adjustment.

GEOMETRY

The basic elements of the post support are the tubular sections that comprise its major structure. A tubular section allows for the development of flexure and torsional stiffness while maintaining a small cross-sectional area. Depending on the geometrical and/or structural requirements, the support can consist of a single tube, stepped tubes or reentrant tubes. Possible geometries for a 300 to 4.5 K support are as shown by Figure 1.

The dimensions of the tubular elements are determined by concurrent consideration of stress, deflection, heat leak, creep and the installation geometry. For the iron-less cosΘ support, short term position stability and long term position stability; i.e., creep , were the controlling design conditions which resulted in a lightly stressed design.

In order to accommodate the axial thermal contraction from ambient (300 K) to operating (4.5 K) conditions of the coil assembly relative to the vacuum vessel the support is hinged at its ends or incorporates a slide at one end.

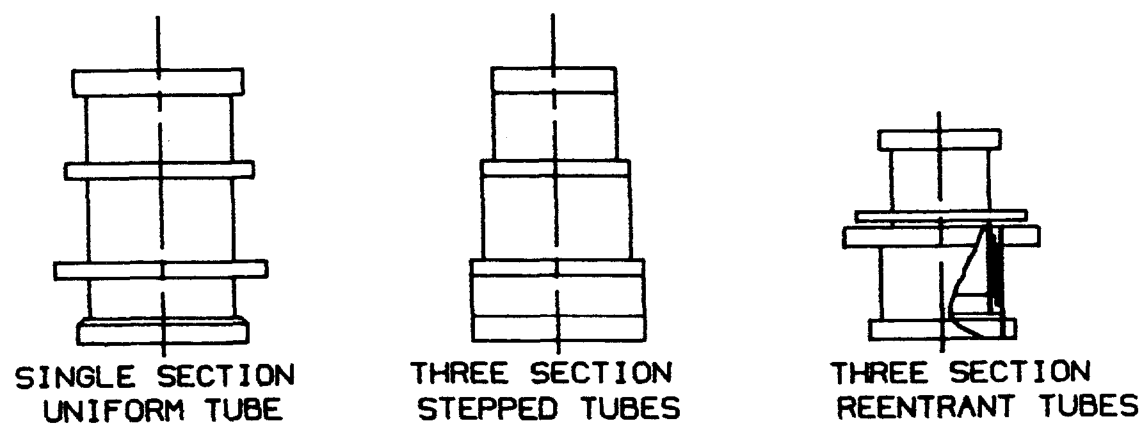


Fig. 1. Post support geometries

JUNCTIONS

A post type support requires junctions between the FRP tubing and the metallic connections. The junctions must be able to effectively transmit tension, compression, bending and torsional loads. In order to ensure position stability, the junction must not slip either axially or tangentially when loaded to design conditions. The junctions must be highly reliable in both the near and far terms.

After consideration of several joining methods; i.e., bonded, screwed, pinned, etc., it was decided to incorporate a shrink fit type junction. The junction is accomplished by shrinking the tube onto a central metallic disc or ring and then shrinking a metallic ring over the tube. The attributes of the shrink fit junction are as follow:

- Non-invasive - The tubing is not machined or penetrated, but only clamped between the metallic elements.

- Controlled Strength - The strength of the junction can be controlled by material selection, amount of interference employed and surface treatment of the mating surfaces.

- Operating Temperature Range - By proper selection of materials, e.g. stainless steel for the inner disc and aluminum for the outer ring, the junction becomes stronger as it becomes colder due to the added clamping afforded by the differential thermal contraction of the members.

- Heat Intercept - The junction provides a tightly clamped, reliable connection between the tubing and metallic heat intercepts.

- Manufacturability - The junction involves the assembly of machined components with routine procedures.

INTERNAL THERMAL RADIATION

By its nature, a post support is subject to internal thermal radiation. This internal radiation can significantly affect the thermal performance of the support and must be controlled. Effective control can be achieved by the use of multilayer insulation internal to the post structure.

PERFORMANCE EVALUATION

As a part of the iron-less cosθ magnet cryostat development program, a post type support was designed, built and evaluated both structurally and thermally. Posts were installed and operated in two cryostat models; i.e., a 6m Magnetic Effects Model (3 posts) and a 12 m Heat Leak Measurement Model (5 posts).

<u>Geometry.</u> The post evaluated employed a single tube configuration with connections to 300, 80, 10 and 4.5 K. The post was designed, essentially, to the criteria for the iron-less cosθ magnet cryostat. The post geometry is as shown by Figure 2 and its construction details are as given by Table 1. Ten post assemblies were manufactured.

<u>Structural Evaluation.</u> Prior to the manufacture of the model posts, prototypes of the 300, 80, 10 and 4.5 K junctions were made and tested. Six 80/10 K junctions were operated in both tension and compression to 10,000 Kg loads; i.e., machine limit, at both 300 and 80 K. The samples

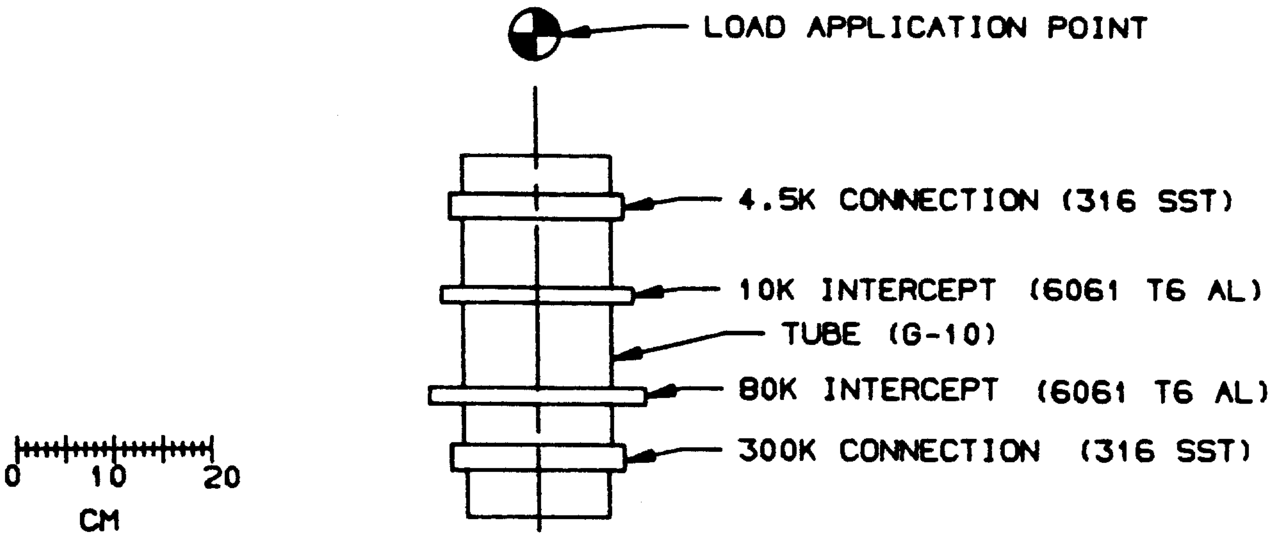


Fig. 2. Test post support

Table 1. Model Post Details

ELEMENT	MATERIAL (1)	L (mm)	OD X t (mmxmm)	300K RADIAL INTERFERENCE (mm)	CONTACT PRESSURE (MPa)	σ_R (MPa)	σ_T (MPa)
. 300 K Connection							
- Disc	316SST	25.4	146.6				
- Ring	316SST	25.4	203.2x 25.7	0.635	175.0	175.0	483.4
. 300 - 80 K Tube	G10	42.9	152.4x 3.2	-	-	-	-
. 80 K Intercept							
- Disc	6061T6Aℓ	12.7	146.7				
- Ring	6061T6Aℓ	15.9	221.4x 34.5	0.368	67.7	67.7	258.2
. 80 - 10 K Tube	G10	85.7	152.4x 3.2	-	-	-	-
. 10 K Intercept							
- Disc	6061T6Aℓ	12.7	146.7				
- Ring	6061T6Aℓ	15.9	196.0x 21.8	0.432	64.1	64.1	243.2
. 10 - 4.5K Tube	G10	42.9	152.4x 3.2	-	-	-	-
. 4.5K Connection							
- Disc	316SST	25.4	146.6				
- Ring	316SST	25.4	203.2x 25.7	0.635	175.0	175.0	483.4

exhibited no axial slippage and no signs of mechanical damage. The tests of three of the samples were repeated after a period of ten months with no change in the results. One 300/4.5 K junction was operated in tension to 10,000 Kg load; i.e., machine limit, at both 300 and 80 K. The samples exhibited no axial slippage and no signs of mechanical damage.

The ten model posts were proof tested prior to installation. The proof testing consisted of tension to 5,000 kg load at both 80 and 300 K and bending at 300 K with a lateral 1350 kg load ≈46 cm above the 300 K pivot. One post was loaded in bending 2050 kg at 300 K. The model posts exhibited no axial slippage and no signs of mechanical damage. The models were also load cycled at 300 K to determine their tensile and flexural moduli.

In addition to evaluations as components, the posts have been evaluated in the two cryostat models. The posts were installed and operated as designed. The models were subjected to repeated cooldowns and warmups, steady state magnet operation and upset; i.e., coil quench, conditions. The cooldown motion of the coil assembly axes afforded by the hinged 300 and 4.5 K ends agreed well with predicted performance. No structural changes in the suspension systems were determined.

In order to predict the longterm stability and thus reliability of the shrink fit junction, creep tests of the 300 K/4.5, 80 and 10 K junctions are in process. Creep is being measured at 40.5 ° C which corresponds to the maximum specified magnet storage temperature. The measurements incorporate strain gages to monitor the axial flow of the tube material and the change in diameter of the metal clamping ring.

Apparatus is being assembled to measure the creep of the epoxy fiberglass tubing when loaded as per the design. Static compressive loads of 6 and 12% of the compressive ultimate strength will be employed.

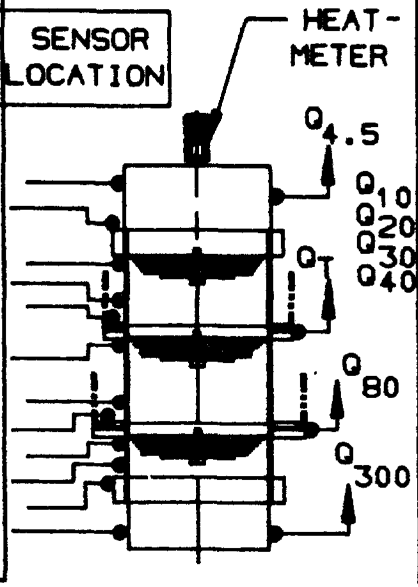
Thermal Evaluation. A model post, instrumented with temperature sensors, was installed and evaluated in a specially configured heat leak measurement dewar.[5] The post ends were at 300 and 4.5 K with intercepts at 80 K and 10 K. The heat intercepting approximates "ideal" conditions since it provided thermal contact between the intercept rings and the heat sinks around the entire perimeter of the rings. The heat flow to 4.5 K was measured by means of heat leak meter.[6,7] The heat leak and temperature distribution results are shown in Table 2. The measured and predicted temperature profiles and heat leak to the cold end were in good agreement. The measured heat leak of 25 mW to 4.5 demonstrated that small heat leaks to 4.5 K can be achieved with conventional materials and methods. The thermal connection afforded by the shrink fit connections is very good as evidenced by the close correlation of the measured temperature of the intercept and tube section above the intercept.

One of the three 6 m Magnetic Effects Model[8,9] posts was instrumented with temperature sensors in a manner identical to the post evaluated in the heat leak measurement dewar. Since the Magnetic Effects Model was known to be thermally lossy due to the several high heat gain mechanical motion penetrations, no attempt was made to evaluate the heat leak. The post temperature instrumentation indicated a higher ΔT between the intercept ring and its heat sink than predicted for an "ideal" connection. For the 10 K intercept $\Delta T \approx 8.5$ K and for the 80 K intercept $\Delta T \approx 21.2$ K. The difference is attributed to the relatively poor connection afforded by the four copper braid strap thermal links employed in the Magnetic Effects Model. More conservative design of thermal links is essential in order to attain the performance capabilities of supports.

Table 2. Post Support Thermal Performance

TEMPERATURE (K)		
DESIGN	MEASURED TEST DEWAR	MEASURED MAGNETIC MODEL
4.5	6.3	8.3
4.5	6.4	8.4
5.9	7.7	9.6
9.1	9.2	12.6
10.0	10.1	13.2*
21.7	25.1	30.2
74.1	77.9	91.2
80.0	83.6	101.2
139.1	149.2	154.6
266.7	237.3	251.5
300.0	278.9	281.6
300.0	282.6	284.5

SENSOR LOCATION



HEAT LEAK (mW)	
DESIGN	MEASURED TEST DEWAR
21 **	25 ***
80 **	88 ***
153 **	158 ***
240 **	243 ***
307.3	———
4231.8	———
4559.2	———

* HEAT SINK AT 4.7K
** HEAT LEAK TO 4.5K FOR INTERCEPT TEMPERATURE OF 10, 20, 30, AND 40K
*** VALUES CORRECTED TO 4.5K COLD END

The five uninstrumented 12 m Heat Leak Model[10,11] posts were installed in a manner identical to those of the Magnetic Effects Model. The measured vs. predicted heat leaks to 4.5 K were in good agreement when the predicted value was corrected to account for the high 10 K thermal link Δ T experienced in the Magnetic Effects Model. The results are as given by Table 3.

CONCLUSIONS

A post type support is a viable suspension element for cryogenic applications. The support performance can be readily calculated and shows good agreement with measured performance. The support employs common materials and geometries and should be manufacturable in a straightforward manner.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the contributions of M. Kuchnir who developed the heat meter and of W. Boroski, M. Frett and D. Validis who constructed the apparatus and participated in the structural and thermal evaluations.

The work as presented was performed at Fermi National Accelerator Laboratory which is operated by Universities Research Assn. Inc., under contract with the U. S. Department of Energy.

Table 3. 12 m Heat Leak Heat Predicted and Measured Heat Leak Center Section

	CASE	HEAT LEAK [W/m]		
		To 80 K	To 10 K	To 4.5 K
Predicted	°12 m Model - 5 Single Tube Supports - 10 & 80 K Intercepts	2.46	0.190	0.011
Predicted	°12 m Model - 5 Single Supports - 20* & 80 K Intercepts	---	---	0.037
Measured	°12 m Model	2.79	0.190	0.051

* Adjustment made on the basis of Magnetic Effects Model instrumented post performance.

REFERENCES

1. Reference designs study group on the superconducting super collider (U.S. Department of Energy, May, 1984), DOE/ER-0213.

2. A. D. McInturff, et al., Model magnet studies, IEEE Trans. on Magnetics MAG-21 478 (1985).

3. R. C. Niemann, et al., Cryogenic design of a superconducting 5 T dipole magnet for the superconducting super collider, in: "Proc. Tenth Intl. Cryo. Engr. Conf.," Butterworth, Guildford, UK, 1984) p. 74.

4. R. C. Niemann, et al., "Superconducting super collider 5T dipole magnet cryogenic design, "IEEE Trans. on Magnetics" MAG-21 986 (1985).

5. J. D. Gonczy, et al., Heat leak measurement facility, in: "Advances in Cryogenic Engineering," Vol. 31, Plenum Press, New York (to be published).

6. M. Kuchnir, Apparatus to measure thermal conductance, in: "Cryogenics," 20 203 (April 1980).

7. M. Kuchnir, J. D. Gonczy, J. L. Tague, Measuring heat leak with a heat meter, in: "Advances in Cryogenic Engineering," Vol. 31, Plenum, New York (to be published).

8. R. C. Niemann, et al., Experimental evaluation of design of a cryostat for an iron-less cosθ ssc magnet, in: "Trans. on Mangetics-Proceedings 1985 Particle Conf. (to be published).

9. N. H. Engler, et al., 5CMϕ no iron cosθ ssc 6m magnetic effects test program, in: "Advances in Cryogenic Engineering," Vol. 31, Plenum Press, New York (to be published).

10. R. C. Niemann, et al., Experimental evaluation of design features of a cryostat for an iron-less cosθ ssc magnet, in: "Trans. on Magnetics-Proceedings 1985 Particle Conf. (to be published).

11. R. J. Powers, et al., 5cm, no iron ssc dipole 12 m model cryostat thermal performance, in: "Advances in Cryogenic Engineering," Vol. 31, Plenum Press, New York (to be published).