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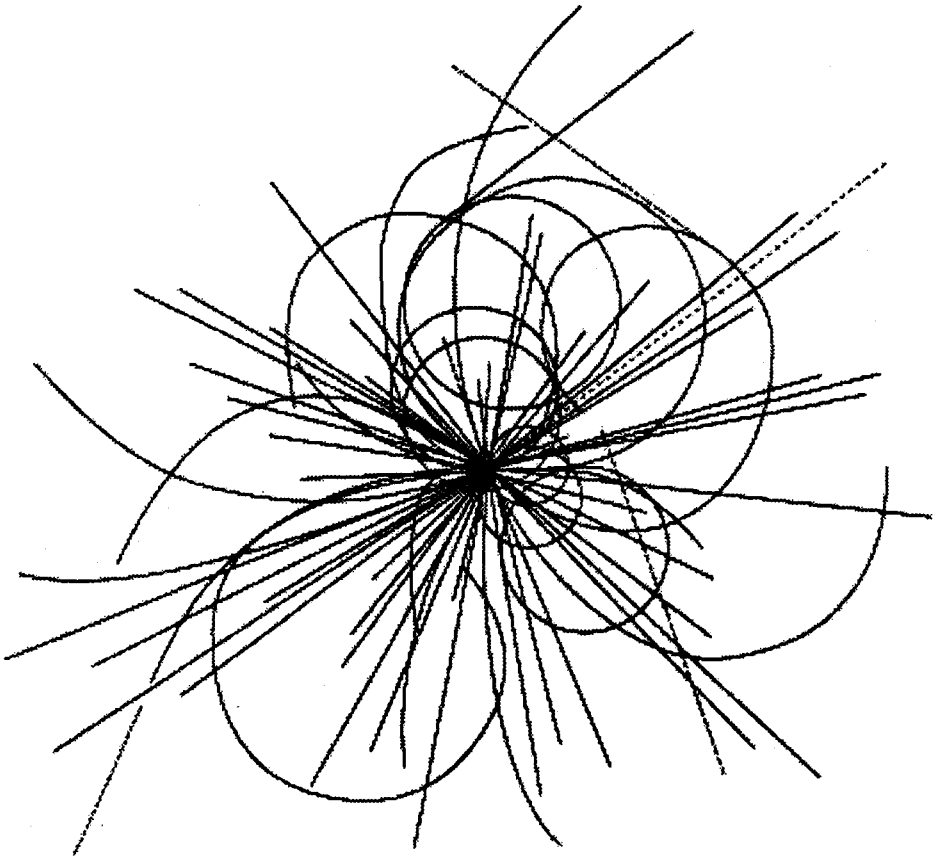

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THE DESIGN AND DEVELOPMENT OF A SINGLE PIECE, SANDWICH TUBE COLDMASS SUPPORT POST FOR THE SSC COLLIDER DIPOLE MAGNETS

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ABSTRACT

This paper presents the design and development of the single piece, carbon/epoxy syntactic core sandwich tube support post concept for the 13-m and 15-m Collider Dipole Magnet (CDM). The engineering studies focus on balancing the structural and thermal requirements for the structure, and most importantly the implicit requirement of "Designing for Producibility." Results from these studies, as well as the development program plan, will be presented.

INTRODUCTION

The SSC CDM coldmass and cryostat thermal shielding is supported within the vacuum vessel by support posts. There are five posts supporting the 15-m dipole; four posts support the 13 meter dipole. The support posts are required to meet very rigorous structural, thermal and geometric requirements. The structural requirements for the support posts include the static and dynamic loadings during transportation and handling of the magnet, as well as the introduction and maintenance of the induced cold mass curvature (sagitta) loads. The four outboard support posts of the 15m CDM accommodate sliding hardware to mechanically isolate the thermal contraction of the coldmass from the vacuum vessel. This sliding hardware is at the (300 K) support post base. The center support post is the geometrically fixed support between the coldmass and vacuum vessel.

The support posts thermally isolate the 4 K coldmass, the 20 K inner thermal shield, the 80 K outer thermal shield, and the 300 K vacuum vessel. The limited space between the coldmass and vacuum vessel requires designing the support post with a short thermal length. The significance of this thermal path is the primary design driver for the configuration. Therefore, optimization of the structure is directly associated with thermal performance of the support post material system.

The initial design and development efforts for the CDM support post were performed at Fermilab[1] in support of the 40 mm CDM development. The design began evolving from the complex re-entrant post configuration to a simpler nested tube concept. The nested tube concept is composed of a carbon/epoxy cylinder existing in the thermal path between the 4 K coldmass and the 20 K inner thermal shield; and a fiberglass/epoxy tube existing between the 20 K and 300 K thermal paths. The two tubes are connected by a single lap shear bonded joint which is loaded between an interference fit external

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external (shield) attachment ring, and an internal support disk located at the 20 K intercept. The support post mechanical attachments at the 4 K, 80 K, and 300 K intercepts are consistent with the 20 K attachment (interference fit metal external-ring to internal-disk). The configuration takes advantage of the low thermal conductivity of the carbon/epoxy material below 20 K, and the low thermal conductivity of the fiberglass/epoxy above 20 K.

The Single Piece Composite Tube Approach

Since the design of the support post is cost driven (8000 dipole magnets with five support posts each for the collider) the implicit design requirement is "Designing for Producibility." This means that the ability to minimize hands-on fabrication processes will reduce the support post assembly costs (since the material costs are relatively fixed). Operations such as fabricating two separate tube structures (fiberglass and carbon/epoxy), machining land areas for dimensionally restrictive interference fit locations on the tube, preparing and bonding the lap shear joint region, etc. contribute significantly to the cost of the support post assembly. Minimizing, or eliminating any of these steps provides a substantial program cost reduction.

Since composite materials provide the thermal and structural capabilities required for the support post, and metal attach hardware is required for assembly, the decision becomes which design features of the Fermi two-piece can be optimized to reduce manufacturing complexity (which translates into lower costs). The chosen optimization locations were the tube composition/configuration, and the interference fit.

The initial design work at General Dynamics Space Magnetics (GDSM) focused upon determining the thermal conductivities of a selection of candidate post materials. Since the thermal budget requirements for the post structure are restrictive, only composite (non-metal material) structures can be considered for use. Epoxies, and more importantly micro-balloon filled epoxies, have lower thermal conductivities than glass or carbon fiber filled epoxies. Intuitively, chopped fiber filled epoxy will have lower conductivities than long fiber filled epoxies, but chopped fiber composites have significantly lower compression strengths, have brittle (failure) behavior at cryogenic conditions, and are more susceptible to creep. Long-fiber reinforced epoxies provide the necessary strength and stiffness to meet the structural requirements of support post while still maintaining thin cross-sections to minimize thermally conductive paths.

Point of Departure Configuration

Figure 1 is a diagram of the Support Post assembly. The support post assembly is composed of a single piece carbon/epoxy, syntactic core sandwich cylinder of a constant thickness (2.5 mm). There are three plies of carbon/epoxy cloth on the Internal Diameter (I.D.) side of the tube, a 0.76 mm ply of glass micro-balloon filled epoxy (syntactic core) center, and two plies of cloth on the tube Outer Diameter (O.D.) Although the constant thickness provides structural overkill for the 4 K to the 80 K regions of the post (lower bending induced loads) the configuration allows simplified fabrication requirements.

The internal support disks, as well as the 4 K and 300 K external rings are made of 304LN CRES. The 20 K and 80 K intercept rings are made of 6061-T6 aluminum. The 20 K and 80 K intercept regions (external rings) are used to support thermal shielding, and the cryogenic return piping (and hardware) for the coldmass. The interference-fit internal disks (304LN) are required to distribute end loads into the post cylinder, and to allow load carrying at the 20 K and 80 K intercepts.

The tube is fabricated by wrapping carbon/epoxy cloth onto a cylindrical mandrel to form the three skin plies at the tube I.D. — the three I.D. plies are applied in a continuous wrap. All skin plies are wrapped under mechanical loading (follower roller) to eliminate entrapped air. Syntactic core film is then wrapped over the I.D. skin build-up. Finally, additional carbon/epoxy cloth is wrapped over the syntactic core to form the two O.D. plies of the tube.

The tube rolling approach to fabrication allows multiple tubes to be fabricated at one time. The cured tube is cut into the 177.8 mm (7 inch) lengths required for the post. Achieving the continuous wrapping of the skin plies allows the possibility of creating a quasi-automated process for tube fabrication. Tube wrapping allows flexibility in material orientation (material direction placed parallel with load direction), and provides a low life cycle cost due to the high rate of material that can be processed.

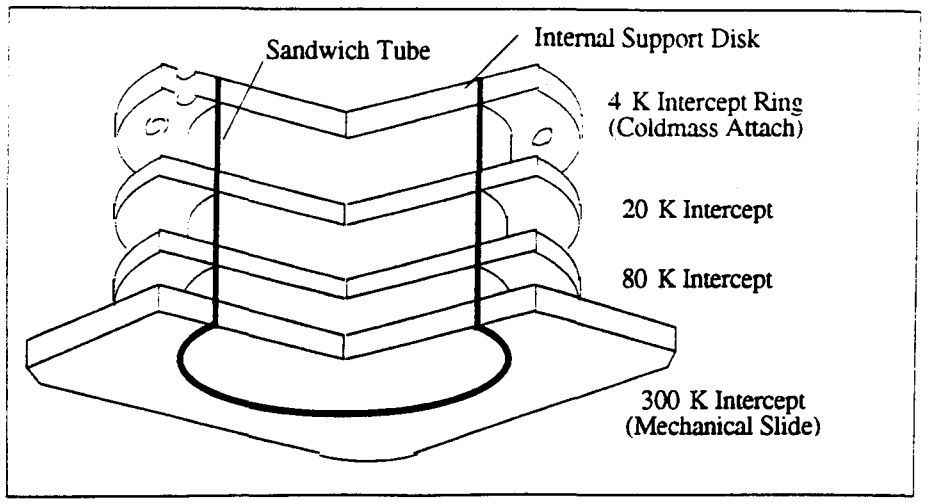

Figure 1. CDM support post assembly.

For the GDSM support post the basic premise is to eliminate all toleranced machining operations for the sandwich tube prior to assembly. The thermal intercept ring inside diameters are machined to slip over the as-fabricated tube O.D. A nominal 0.38 mm (0.015 inch) gap between the tube O.D. and the ring I.D. is filled with an aluminum filled structural adhesive. The adhesive is "buttered" onto the mating surfaces of tube and rings prior to ring installation. The I.D. of the rings are machined with a slight taper to allow the adhesive to fill the radial gap between the tube and ring during ring placement. The adhesive is cured while the rings are constrained in a tool to achieve controlled positioning. Structurally, the cured adhesive taper acts as a wedge lock during loading.

The internal disk outside diameters are dimensioned to be approximately 0.38 mm (0.015 inch) larger than the as-cured tube I.D. The internal support disks are cryo-installed (liquid nitrogen cooled to reduce dimension) into the bore of the ringed tube. The disks are held in place until the disks warm. As the disk warms, the enlarging disk O.D. creates the interference fit for the disk/ring/tube system. The interference fit of this configuration requires the internal disk to be the only precision toleranced (interference) surface. The sandwich tube I.D. remains consistent and repeatable due to the fabrication process selected.

DEMONSTRATION PROGRAM

A structural and thermal demonstration program has been identified to examine critical features of the material and assembly of the support post at the coupon, component and CDM assembly level. The program is streamlined to provide timely information for the optimization of the single piece sandwich tube support post design and fabrication.

The initial structural demonstration for the support post consists of the fabrication and compression test of sandwich cylinder coupons (0.762 mm length) to determine the typical ultimate strengths at room temperature (300 K), and liquid nitrogen (80 K) temperature. The objective of this test is to determine appropriate lamination and cure parameters which will be incorporated into the support post assembly.

A flat panel of the sandwich is used to test the in-plane shear strength of the sandwich cross-section at 300 K and 80 K temperature. The shear test method is the Iosipescu Shear test.

The support post assembly test program will demonstrate the quasi-production configuration support post in bending and shear to limit load at 300 K, followed by compression loading (limit and ramp-up to failure) at 300 K and 80 K.

The bending/shear test utilizes an angle plate fixture to cantilever the support post assembly in the test machine. The post assembly has a load fixture fastened to the top of the post for load application at the coldmass centerline location. The load applied represents the predicted worst-case combined sagitta load and 0.5g lateral acceleration (limit) loading induced in the post. The load will be applied for 5 cycles at 300 K. Assemblies will then be loaded in uniaxial compression to 123.6E6 N (28000 lb) for five cycles at both 300 K, and 80 K; then be loaded uniaxially to compression failure at both 300 K and 80 K respectively.

The 4 K/300 K intercepts rings will be demonstrated during the bending/shear limit loading. However, a separate test configuration is used to demonstrate the typical failure load capacity of the structural-adhesive/shrink-fit interface of the 20 K/80 K thermal intercept attachment. The test is performed at 300 K only.

Thermal properties for the support post tube material are being developed from 300 K to 20 K. Thermal conductivity and expansion testing is to be performed on the carbon/epoxy cloth material, the core material, and the sandwich material. The data will be used to update the thermal analysis for the cryostat system.

Development of the long term creep characteristics of the support post tube will not be performed at the component level. For the specific application of the support post assembly if creep were to occur it would manifest itself as lost sagitta, as measured by the beam tube. Laser alignment measurements will be taken after cryostat assembly on the first prototype magnets to determine if support post creep exists.

CONCLUSIONS

This paper has presented the basic design and development parameters for the single piece sandwich tube support post configuration. The development work is continuing at General Dynamics Space Systems (GDSS). Currently, the structural test results have more than satisfied the requirements for the CDM. However, the final cross-sectional configuration for the support post will be based upon the combined thermal/structural test results. Specific areas for optimization include reducing the number of skin plies, or terminating skin plies at specific thermal intercept zones (the current configuration uses a constant thickness tube along the full length of the support post); or utilization of fiberglass/epoxy material between 20 K and 300 K intercepts. Table 1 lists the preliminary thermal analysis results for heat leak of the 15 m CDM cryostat with a four-ply carbon/epoxy, syntactic core sandwich support post.

Table 1. Preliminary Thermal Analysis

Thermal Intercept	Cryostat Total Thermal Budget (watts)	Cryostat Total Heat Leak (watts)
80 K	37	40
20 K	5.06	4.80
4 K	0.36	0.27

Since the GDSS support post was designed with producibility in mind all optimization concepts do not affect the lamination, cure, or assembly processes/features of this configuration.

ACKNOWLEDGEMENTS

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