# IMPROVED DESIGN FOR A SSC COIL ASSEMBLY SUSPENSION CONNECTION

E.T. Larson, J.A. Carson, T.H. Nicol, R.C. Niemann, R.A. Zink

Fermi National Accelerator Laboratory
Batavia, IL

## ABSTRACT

Close control of the alignment of magnets for the proposed Superconducting Super Collider (SSC) high energy physics research facility is essential for the success of this small bore accelerator. The connection of the magnet coil assembly to the cryostat suspension system presents many challenges to the cryostat designer. The resulting design must withstand shipping and seismic loads, allow axial contraction of the coil assembly, position the coil assembly center line within a 0.25 mm radius, provide rotational adjustment of the coil, resist axial quench loads, provide a bearing assembly which is tolerant to high vacuum, high radiation and cryogenic conditions, and fit within the stringent geometric constraints of the cryostat assembly. A coil assembly suspension connection which meets these criteria is described. Measurements of the effective friction coefficient, static load deflection, and component stresses are compared to the predicted performance. Experiences with a full length model of the coil assembly connection are presented.

## INTRODUCTION

Dipole magnets of the proposed Superconducting Super Collider (SSC) will require an integrated suspension system which meets the demanding criteria of low heat leak, high structural strength, precise alignment, high reliability and low cost required for this system. This paper outlines the design considerations, and test results for an improved connection between the reentrant post[1] and the dipole cold mass assembly.[2]

To date all dipole model magnets have been assembled with a cold mass connection which uses insert pins to penetrate the outer shell and contact the iron yoke within the cold mass assembly as shown in Figure 1. The insertion pins act both as fiducial and structural support members, and require a seal weld on the outer shell for each pin penetration. Parallel rods with sleeve bearings support and guide a tie bar which attaches to both insertion pins locking the cold mass in rotation and lateral position.

Difficulty in positioning the insertion pins accurately in their welded sockets, along with a lack of rotational freedom initiated the search for an improved design. Areas of the original design requiring improvement are:

A Providing angular position adjustment of cold mass during assembly
B Increasing structural support to withstand dynamic loads
C Improving bearing performance, lower wear rate, reduced stick slip binding
D Avoiding multiple weld penetrations in the cold mass outer shell.

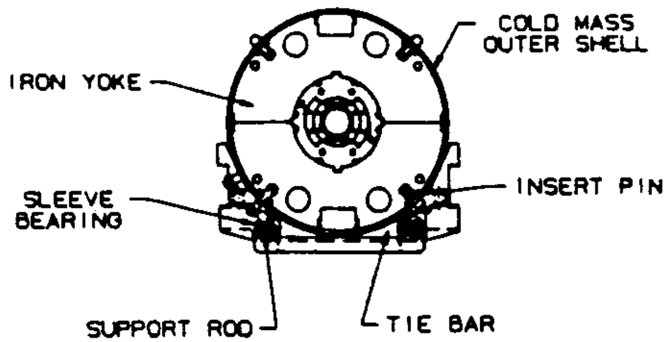


Fig. 1. Present cold mass slide connection.

An improved cold mass slide connection for SSC dipole magnets has been designed and preliminary testing completed. To date it has successfully passed loading and slide tests at or above design criteria.

## DESIGN CONSIDERATIONS

A cold mass connection must perform the following:

- A Position the magnet bore center repeatably and accurately
- B Support static and dynamic loads
- C Allow for axial contraction during cyclic cold mass cooldowns
- D Fit within the close geometry of the cryostat
- E Withstand the cryogenic and radiation environments associated with superconducting accelerator magnets

The typical layout of the improved coldmass suspension system is shown in Figure 2. Four of the five connections to the cold mass are of a sliding design, allowing both rotational and axial degrees of freedom. The center connection is fixed during assembly and locks the angular and axial position of the cold mass. Four anchor tie bars will be installed between the five reentrant posts to share the axial loads transfered from the fixed center connection to the center post.[3]

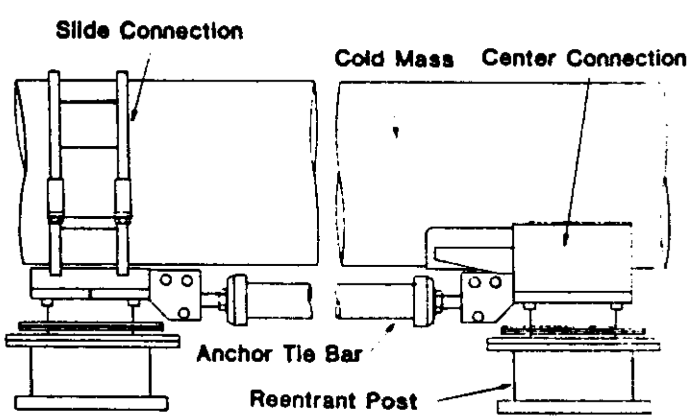


Fig. 2. Typical suspension system components.

Figure 3 shows the main components of the improved cold mass slide connection. The base sits on top of the 4 K ring of the reentrant post assembly with a split flange ring locking the base to the top of the ring. The cradle arms of the lower half contain bearing blocks which retain removable bearing pads. The outer shell of the cold mass contacts these pads to establish the position of the magnet assembly. The upper half of the connection has an identical bearing support which retains the cold mass during shipping, quench or seismic loads. The four points which contact the outer shell are located to avoid the longitudal weld seams which close both halves of the outer shell and the cut out in the iron yoke, see Figure 4. The outside diameter of the outer shell at these points is not concentric due to fabrication distortions, and therefore is not a reliable surface for alignment.

The outer surface of the coldmass at suspension points will be used as a fiducial for locating the magnet bore center. Using the surface of the cold mass as a fiducial requires referencing the outside diameter to the magnet bore center. Errors in the collared coil assembly and gaps between the collars and iron yoke are the same for any fiducial system referenced to the iron yoke. Efforts are centered on reducing the error between the outside iron yoke surface and the stainless steel outer shell surface. Two proposals for achieving this are discussed later.

Magnet alignment is critical in three directions; vertical height (y), lateral position (x), and angular position ($\theta$). Height and lateral position are to be established by alignment targets placed on complete cold mass connection/post subassemblies. Shims establish height while lateral position will be achieved by bolt clearances. When the five cold mass connection/post subassemblies are aligned in x and y the cold mass will be set into the lower connection half, measured to determine the angular offset of its average vertical magnetic plane, rotated to compensate for this offset and fixed at the center. The critical dimension in the lower half of the cold mass connection is the radius created by the bearing insert. Tolerances in the counter bore or post assembly can be removed from alignment

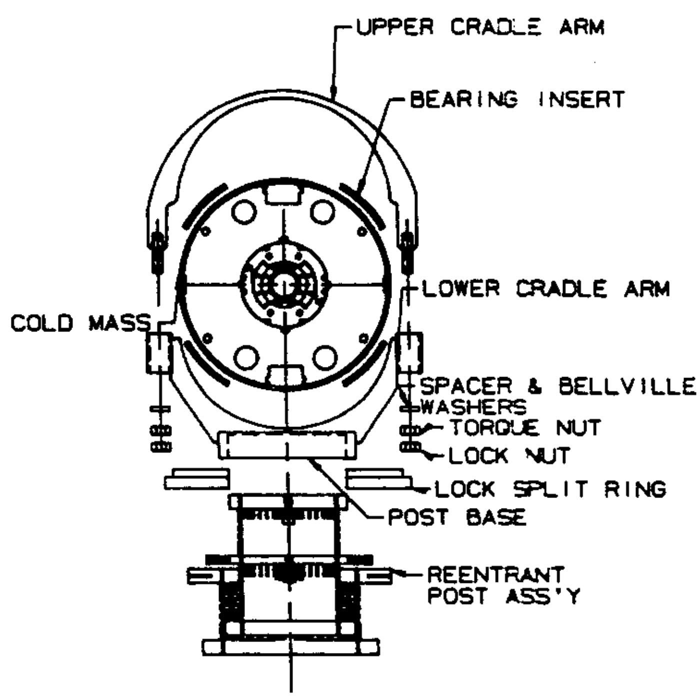


Fig. 3. Improved cold mass slide connection.

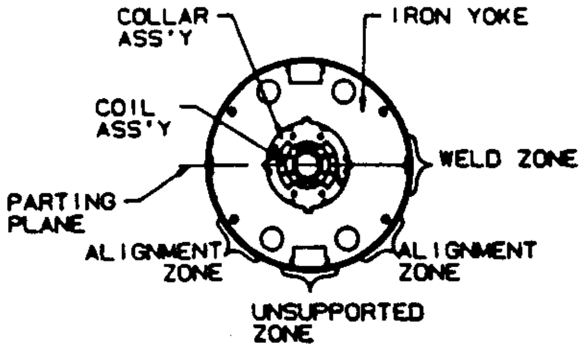


Fig. 4. Cold mass alignment zones.

error by shims and lateral positioning. The upper half of the slide connection gives structural strength for dynamic loads, but does not establish alignment, therefore it does not have high fabrication tolerances.

The magnet assembly is subjected to shipping, quench and seismic loads which are transfered to suspension components through the cold mass connections. Load handling criteria are shown in Table 1.[4] The five connections share the lateral and vertical loads, while the center connection alone transfers the axial load. The only axial load the slide connections see is the result of axial forces transfered through the bearing pads during cooldown.

During the 300 to 4 K cooldown the 17 meter coldmass shrinks 51 mm overall. The center connection being fixed causes the supports farther from center to see greater relative axial motion. The connections 3.454 meters from center see 10 mm axial motion while the connections 6.908 meters from center experience 20 mm axial contraction. This axial motion must be permitted while minimizing the axial reaction load in the bearings; and subsequent bending moment imposed on the reentrant post assembly. Reducing axial reaction loads also prevents large post deflections and potential binding or misalignment. The design is based on 70 thermal cycles occuring during the life of a magnet.[5]

The SSC cryostat cross section, Figure 5, has small clearance in the vertical direction due to insulation requirements, post geometry, etc. For this reason the cold mass is positioned as close to the top of the post as practical with a minimum thickness in the upper arm half to avoid thermal shield interference. Insulating standoffs are installed on the upper arm halves to minimize thermal conduction if the 20 K insulation shield should contact the cold mass connection.

The design must withstand the anticipated radiation over a twenty year life of $6 \times 10^6$ rad, and operate in an insulating vacuum of $1.33 \times 10^{-4}$ Pa.

## TEST EXPERIENCE

Prototype design models have been fabricated and preliminary testing of the structural and sliding performance has been completed. The model assemblies are wrought stainless steel weldments which provide a slotted land for the bearing pad to set into. The bearings are a laminated steel backed plate with a lead/teflon mixture impregnated into sintered bronze on the plate surface, which are rolled into

Table 1. Load Handling Criteria

| Load | | Direction | G's |
|---|---|---|---|
| 7,250 | kg | X (lateral) | 1 |
| 14,500 | kg | Y (vertical) | 2 |
| 10,875 | kg | Z (axial) | 1.5 |

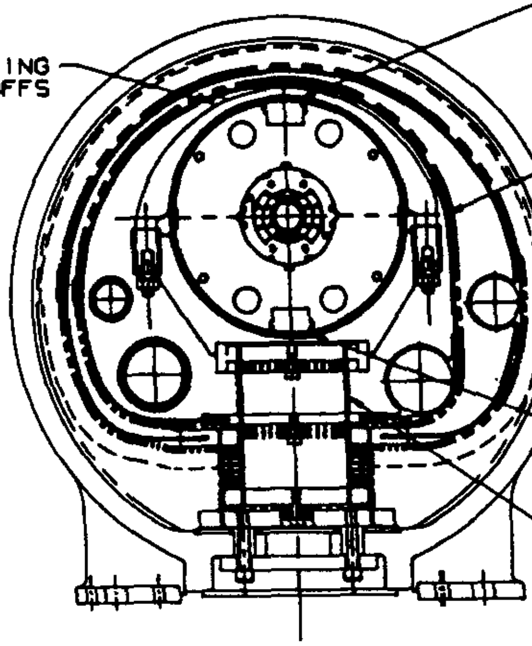


Fig. 5. SSC cryostat cross section.

final form. This self lubricating bearing material, like other bearings, requires a surface finish of 0.50μm or better for optimum performance. The bearing is rated for service at 4 K, and has low outgassing in high vacuum. Higher radiation resistant bearing materials such as polyimides and molybdebum disulfide coatings are being investigated, but because of availability and ease of fabrication laminated steel bearings have been chosen for prototype models.

The slide connection deflection under static loading has been measured and the results are shown in Table 2. Values represent the cold mass center deflection relative to the slide connection base, with post deflections subtracted out. Induced stresses are less than 25% of material yield point. The outside of the cold mass is 9 mm from the post top ring, while the upper arm has a 10 mm gap between its top point and the thermal shield avoiding interference. The two halves of the connection interlock in a guided slot to increase strength during lateral loading. The halves are bolted together with stainless steel bellville washers acting as tensioning springs and preloaded to a total of 550 kg for the four springs. This allows for any differential thermal contraction between the connection and cold mass, and provides a uniform preload in the bearings.

A full length cold mass has been tested in static ambient conditions to monitor bearing response to cyclic axial displacement at full load. A double acting hydraulic cylinder was used to measure axial load while moving the cold mass in the axial direction. Substituting a slide connection at the normally fixed center support allows axial displacement of 25 mm in each direction. The surface finish of the cold mass was improved to 0.50μm at the five support locations. Figure 6 shows the axial actuation force vs equivelant thermal cycles for the full length cold mass installed with 3 mm center to end sagitta. The 70 cycle design life, and

Table 2. Slide Connection vs Load.

| Load | Direction | Deflection |
|---|---|---|
| 4,500 kg | -Y Vert. Down | 0.8 mm |
| 3,000 kg | +Y Vert. Up | 1.8 mm |
| 2,250 kg | X Lateral | 1.3 mm |

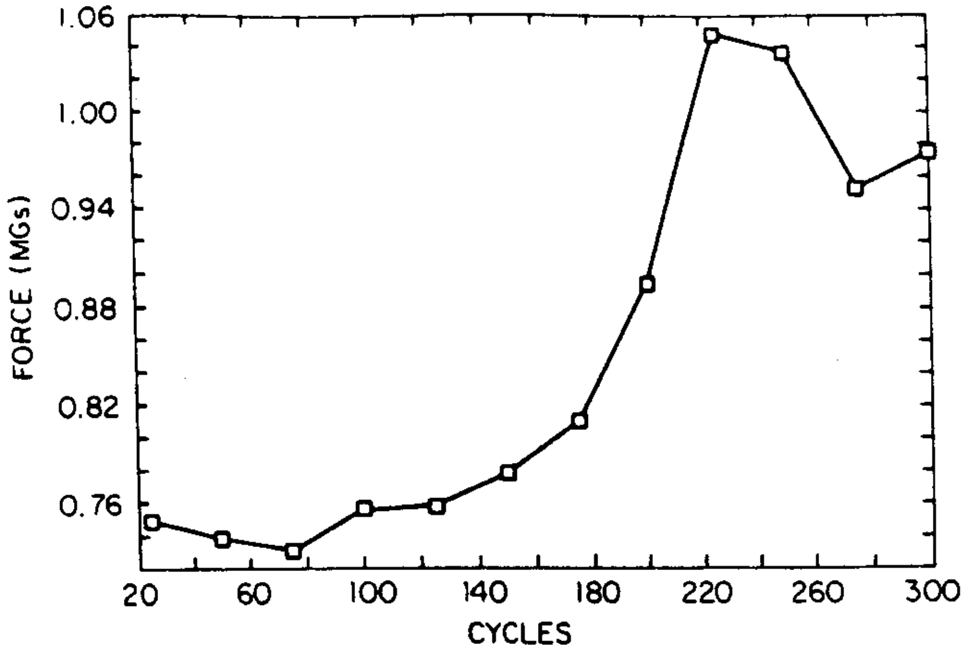


**Fig. 6. Full length test data.**

endurance factor of 4 result in test runs with a minimum of 280 cycles. The peak measured force of 1050 kg is distributed over five supports resulting in 210 kg per post. Initial cycles are 25% lower than this. The post has been designed to withstand 1450 kg loads without the assistance of anchor tie bars. By monitoring the deflection of the post assemblies and comparing them it was possible to determine axial load distribution. As expected the distribution was essentially equal throughout the testing, averaging 1 mm peak deflection at the top post ring. This deflection will be reduced considerably when the anchor tie bar system is installed.[3]

## TEST PLANS

Several areas of the design are undergoing further investigation, they include:

A Measurement of connection response at cryogenic and vacuum conditions
B Measurement of bearing materials at cryogenic and vacuum conditions
C Alternate connection fabrication methods (High production)
D Cold mass outer shell fabrication techniques

A short magnet model is being fabricated to allow cryogenic testing of the connection and alternate bearing materials. Cooldown and transient thermal response will be measured, and provisions will be made to allow axial actuation through an external hydraulic cylinder. Bearing life, change in coefficient of friction and post deflection will be key areas of investigation.

Alternate bearing materials must withstand high radiation, have structural strength at cryogenic temperatures, low outgassing at high vacuum, and low friction coefficient. Polyimide bearings with 15% molybdenum disulfide added will be tested in the short magnet model to compare performance with laminated steel backed bearings. Low friction coatings and other surface treatments will be applied to stainless steel bearing pads and tested as well.

The complete slide connection support structure is being fabricated as a sand casting in test batches to determine feasability for high production. Tests for structural strength and integrity, vacuum outgassing, and fracture toughness at cryogenic temperatures will be performed on test parts to qualify the method. Economic and performance comparisons will be made between castings and welded assemblies.

Two techniques for fabricating the cold mass outer shell are being investigated. Using the external surface of the cold mass as a fiducial requires referencing the outer shell surface to the magnet bore center. Investigations are centered on reducing the tolerance between the outside iron yoke surface and the cold mass outer shell surface. One proposal for achieving this relies on minimizing the thickness variation in the steel used for forming the outer shell, and creating sufficient tension in the outer shell during longitudal weld seam shrinkage to eliminate gaps between the iron yoke and shell. The other method relies on machining the outside diameter of the shell after forming and welding, referencing the cutting head to a contact point on the iron yoke surface. Both methods must be capable of producing high quality surface finishes to enhance bearing performance. Tests of each method are being developed and implemented to allow quantitative comparison.

## CONCLUSIONS

A slide connection for SSC magnets which addresses all the design criteria has been built and successfully passed structural and sliding tests. Completion of the remaining test program will verify the integrity of the connection for use in future model magnets.


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## REFERENCES


1. R.C. Niemann, et al., Design, construction and performance of a post type cryogenic support, in: "Advances in Cryogenic Engineering," Vol. 31, Plenum Press, New York (1986), p. 73.

2. C.E. Taylor, et al., A 6.4 tesla dipole magnet for the SSC, in: "Advances in Cryogenic Engineering," Vol. 31, Plenum Press, New York (1986), p. 25.

3. T.H. Nicol, R.C. Niemann and J.D. Gonczy, SSC magnet cryostat suspension system design and performance, in: "Advances in Cryogenic Engineering," Vol. 33, Plenum Press, New York (to be published).

4. SSC Central Design Group, Superconducting super collider magnet system requirements, "SSC-1000," October 1986.

5. SSC Central Design Group, Superconducting super collider magnet system requirements, (to be published).