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Status of Suspension Connection for SSC Coil Assembly*

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ABSTRACT

Superconducting Super Collider dipole magnets require an integrated suspension system to meet the structural and thermal requirements outlined in the design criteria. Sliding suspension connections which retain the cold mass assembly during static and dynamic loading, while allowing axial motion during thermal contraction are an integral part of this magnet suspension system. Variations from the original prototype design have been tested and their performance compared. The results of these evaluations, and areas of future investigation are described.

INTRODUCTION

Dipole magnets for the Superconducting Super Collider (SSC) require an integrated suspension system which meets the demanding criteria of low heat leak, high structural strength, alignment stability, high reliability, and low cost associated with zero maintenance cryostat systems.[1]

One of the components in that suspension system is the slide connection which must transfer loads between the cold mass and the compact cryogenic supports (CCS).[2] These loads may come from shipping, quench or seismic sources. There are five connections to the cold mass, four are of a sliding design allowing rotational and axial degrees of freedom.[3] The center connection is fixed, locking the angular and axial position of the cold mass. The five connections share lateral and vertical loads, while the center connection transfers any large axial loads to the HYBAS support system.[4] During cooldown the slide connections accommodate the cold mass axial contraction, which is over 3/4" on the connection farthest from center. The slide connection provides a minimal resistance to axial motion to help reduce any large imposed bending moments on the post supports. The connections must also fit within the close geometry of the cryostat without causing thermal contact shorts, and be able to withstand the cryogenic and radiation environments associated with superconducting accelerator magnets.

Design A Experience

The original Design A version of slide connection consisted of two parallel rods with sleeve bearings which supported a guiding tie bar. This bar could slide axially while supporting small blocks which held insert pins that penetrated the cold mass skin, see Fig. 1. The insert pins acted both as fiducial and structural support members, requiring a socket to interface with the magnet iron yoke and a seal weld on the outer shell of the cold mass.

Field experience with this system demonstrated the difficulty of positioning the fiducial pins accurately and repeatedly. Only ten pins 0.25 inches in diameter support the weight to the cold mass assembly, with each pin requiring a weld and leak check step, adding to the complexity of the cold mass. The parallel rods of the slide required accurate positioning to prevent binding during axial motion, and developed high wear rates due to high contact stress between the rod and tie bar. A temporary solution was implemented when a bushing was inserted between the parts reducing friction and wear rates considerably. The bushing consisted of Teflon and lead captured in a sintered bronze matrix attached to a steel backing plate. The material, commercially known as DU, proved to be an excellent material for reducing friction and wear and could withstand the stringent environment of the cryostat. Tests were made on Design A assemblies at cryogenic temperatures to verify the performance of the DU bushings. The test results showed an increase in coefficient of friction under cryogenic conditions but the increase from 0.10 to 0.25 was acceptable, see Fig. 2.

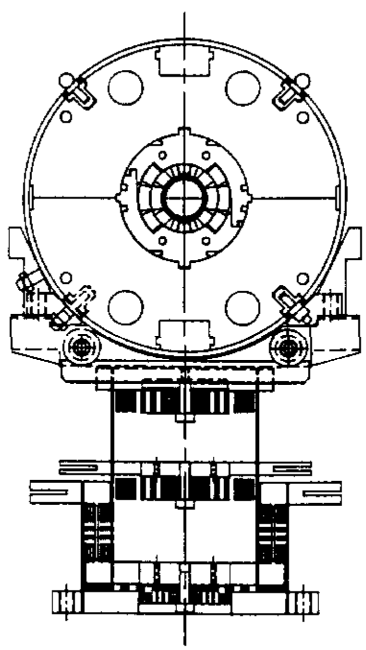

Fig. 1. Design A Slide Connection

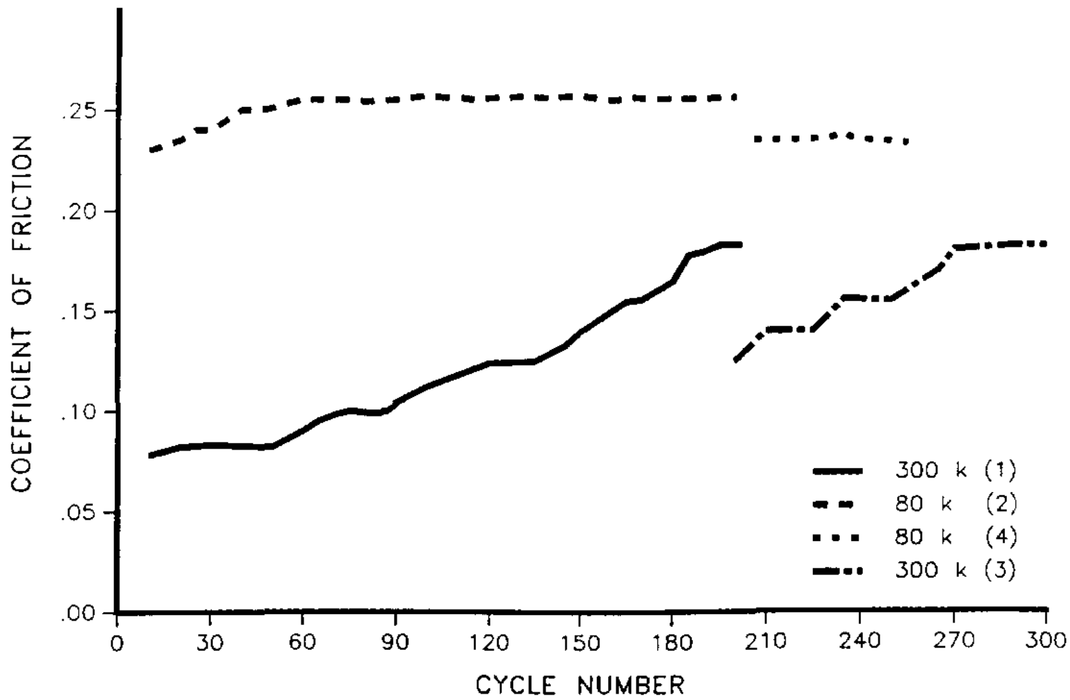

Fig. 2. Design A Friction vs. Equivalent Thermal Cycles

While the Design A version was successful in the magnets it was installed in; there were several areas of the design which could be improved upon. The following design areas were principle motivations for changing to the Design B connection.

A Eliminate the need for multiple weld penetrations in the cold mass skin.

B Improve the structural support to withstand dynamic loads.

C Improve bearing performance and reduce wear rate.

D Provide angular adjustment of the cold mass during assembly.

E Separate the alignment and support functions.

Design B Experience

Prototype models of Design B slide connections were fabricated to test the concept of applying bearings directly to the cold mass skin. The prototypes consisted of a frame assembly that would support four DU bearing pads, see Fig. 3. The frames lower half was attached to the 4K ring on the top of the CCS by a split ring bolted at four locations. The upper half of the frame contains the cold mass during loading and is attached to the lower half by four half inch bolts. Each bolt has four Belleville washers stacked in series giving an effective spring rate of 6,500 lbs/in. The washers are compressed 0.050 inches during assembly, yielding an effective preload of 1,300 lbs. These washers act as tensioning springs which maintain uniform loading of the bearings and compensate for any radial differential thermal contraction effects between the cold mass and the slide connection.

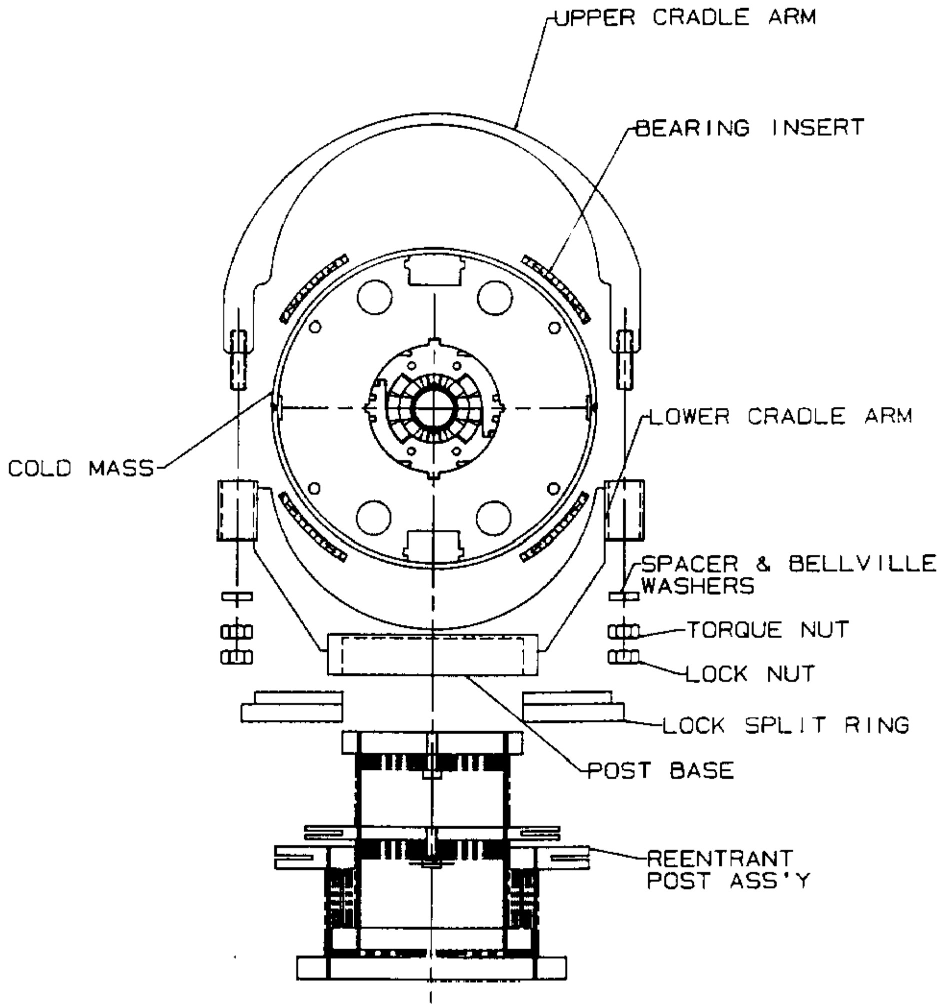

Fig. 3. Prototype Design B Slide Connection

Since DU bushings had proven themselves in the Design A slide connections it was logical to use them in Design B but with a larger contact surface to reduce localized wear effects noted in Design A. The bearings were offset 45 degrees from the vertical and horizontal planes. The cold mass has distortions in these planes due to features in the iron yoke and welding techniques used during assembly. These locations were selected to minimize any effect these distortions might have on alignment and bearing performance.

The DU material requires a nominal 20 micro inch contact surface finish for optimum performance. Tests on short machined mandrels proved that unacceptable friction and wear would result from surfaces which did not meet the 20 micro inch criteria. Concern over surface finish initiated a search for material to use in the cold mass skin. Stainless steel sheet with a stock "2B" finish met the surface finish criteria and was available as a standard product. Use of the Design B concept would require better surface finish on the cold mass outer skin than was presently being provided by the stock 3/16" plate already in use.

DEVELOPMENT AND TESTING PROGRAM

The prototype assemblies were tested at all the load levels specified in the design criteria and successfully passed these tests.[3] These prototype Design B assemblies used very thin sections in the vertical plane due to the geometric constraints of the cryostat. This resulted in distortions from welding during assembly.

As a result of these problems investigations were made into developing a cast version of the assembly in order to avoid any assembly welding, and to provide a complex stock geometry for machining that would minimize scrap. The material selected for the castings was CF 8, a stainless steel having composition and properties that closely match 304 series stainless. The cast versions were of similar geometric cross section as the prototypes, but the thin framework was eliminated in favor of a more uniform section that could be easily cast, see Fig. 4.

An opportunity to test the prototype slide connections came when magnet D0004 was made available for mechanical tests, after manufacture it was found to be defective. Sections of the cold mass skin were removed and replaced with 2B finish material to provide a suitable surface to test the prototype Design B slide assembly. The center connection which is normally fixed was replaced with a sliding connection, thus allowing the entire cold mass to be moved axially. Ambient tests were made to determine the performance of the slides on this full scale model. Axial motion which simulated successive thermal contraction cycles was provided by a hydraulic actuator. The force required to move the assembly, the deflection of the CCS and slide connections, and the amount of wear the DU bearings experienced were all noted during the testing. Figure 5 plots the force to move the assembly vs. the number of simulated thermal cycles. Deflection of the CCS's was uniform indicating equal distribution of axial loads, with negligible deflection of the slide connection itself relative to the CCS. There was visible transfer of the outer layer of DU material to the surface of the cold mass skin, considered normal during the break in of the bearing. This transfer establishes a free moving layer between surfaces that enhances performance.

Since the cryostat is over 58 feet in length, with a very long time constant to reach thermal equilibrium, it was impractical to do full length cryogenic tests of the slide connections at liquid helium temperatures. Therefore, tests were designed to demonstrate the feasibility of the slide connections performance under simulated cryostat conditions using a short sample cryostat which was fabricated specifically for the task. This would yield the necessary data for evaluation at a reasonable cost, allowing extrapolation to liquid helium conditions. These tests were designed to measure the changes in performance under vacuum at $1x10^{-6}$ torr, and at liquid nitrogen temperature, since the majority of material property changes and thermal contraction effects have occurred by 80K. A short mandrel that simulated the cold mass was cooled to 80K in a short dewar. External hydraulic actuators would allow axial motion to be induced at cold temperatures and thus simulate hundreds of thermal cycles in a short time frame. The tests showed that the effective coefficient of friction dropped slightly under vacuum, before cooling, and the coefficient of friction increased by a factor of 3 at 80K, see Fig. 6. There was a slight decrease in friction under vacuum, which could be attributed to a drier environment, but the overall effect is less than 10 percent. The cast versions provide an extremely stable foundation for the bearing pads, reducing the deflection of the upper half and subsequently reducing the sliding resistance by more than 30%. This is a significant improvement over the prototype Design B. The coefficient of friction remains stable over several hundred cycles, the actual number of cooldowns for magnets is estimated at 20 or less over the life of the accelerator. These test results are consistent with earlier data taken on DU bushings used in the Design A version. The results of these cold tests indicate an effective coefficient of friction of 0.30 at helium operating temperatures, which translates into lateral forces of 1300 lb. per support point when the cold mass is cooled to operating temperature. This lateral force is well within the capability of the CCS suspension system which is rated for 3,150 lb lateral loads at each support point.[4]

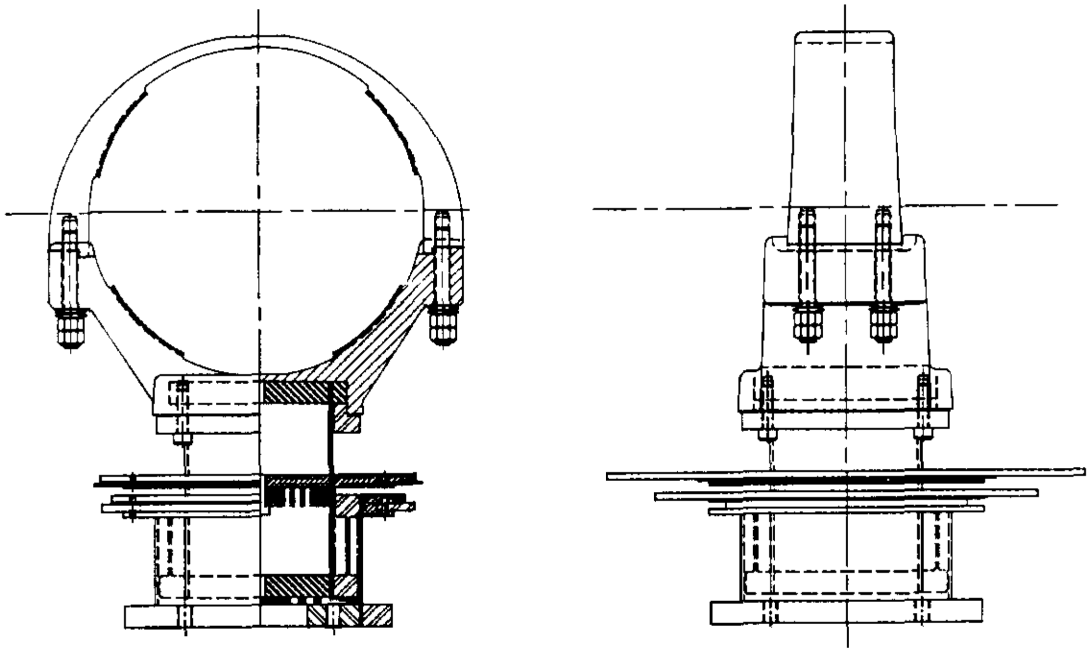

Fig. 4. Design B Slide Connection Casting

Tests of the outgassing rate of the slide connection were made to establish the magnitude of gas influx into the vacuum system. A high vacuum chamber was used to measure the pressure rate of rise for cast versions of the slide connection. The assemblies were cleaned in solutions of freon and ethyl alcohol to remove surface contamination, but no other cleaning steps were taken. The 80 liter vessel experienced a pressure rate of rise of 5.5×10^{-9} Torr/sec with the connection at 300K resulting in an outgassing rate of 2.43×10^{-7} W/m^2.[5] This is in the normal range for stainless steels which have no bakeout or other special surface treatments. Since the surface area of the connection is small in comparison to the vacuum vessel, and the outgassing rate at operating temperatures is negligible compared to room temperature conditions, the connection does not impose a significant load to the vacuum system.

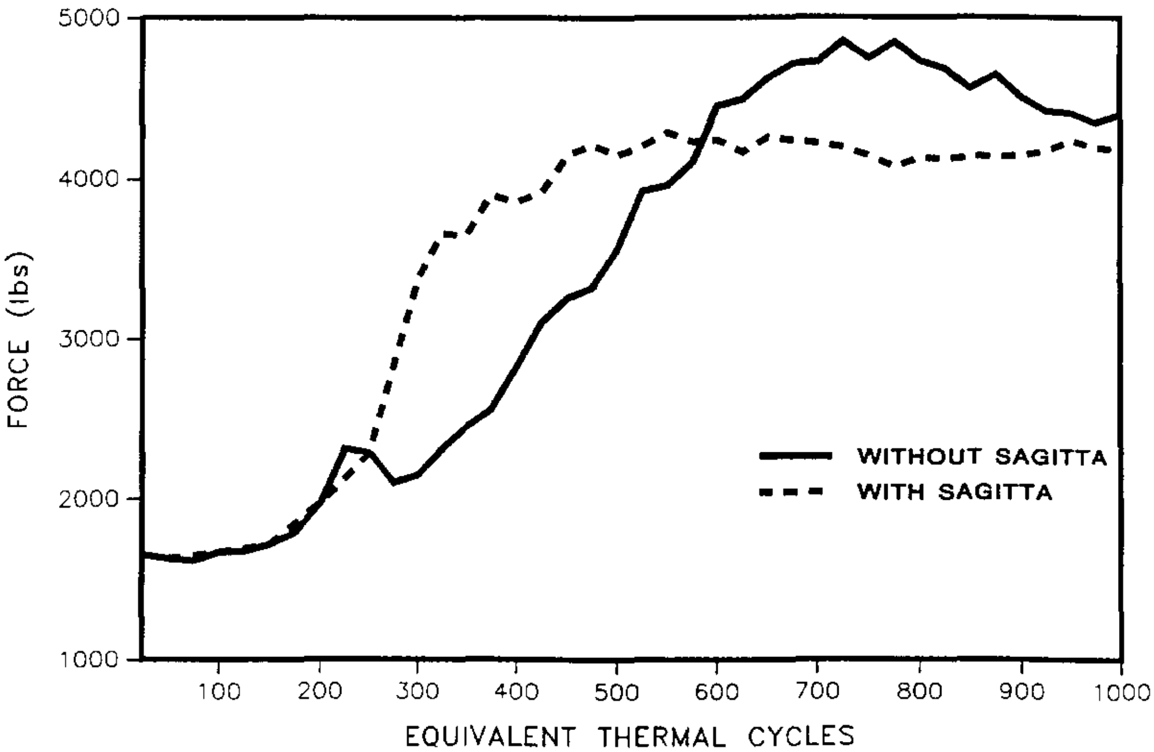

Fig. 5. D0004 Full Length Slide Tests

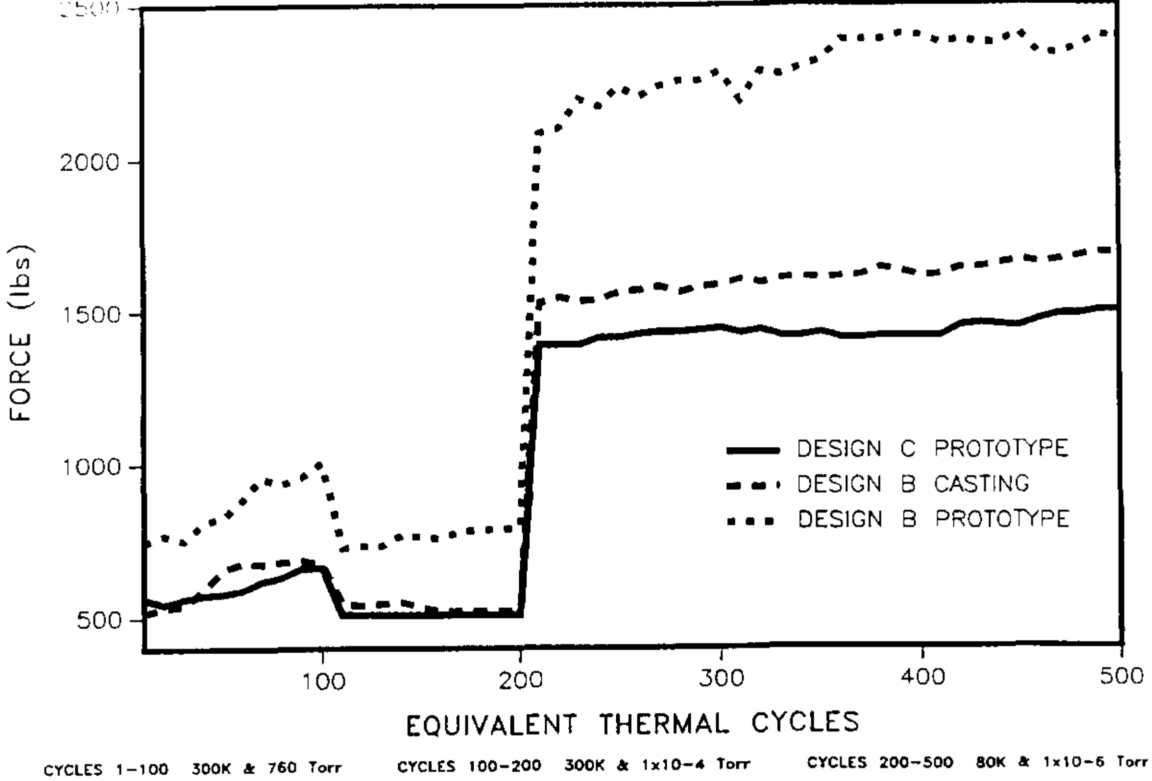

Fig. 6. Cold Slide Test Comparison

Heat leak measurements of the slide connection and CCS were made to quantify any changes which the slide connection might contribute. The heatmeter showed slightly higher heat leak which could be attributed to residual gas conduction effects. The 5-8 mW addition is small compared to the 120 mW budgeted heat leak to 4.5K.[6]

ALIGNMENT AND SUPPORT

The Design A version of the slide connection combined the alignment and support functions by supporting off the fiducial insert pins. This created problems since the pins were not designed to carry high loads and the slide connection assembly tolerances were held to alignment fixture levels ±0.001". The Design B version allows one to separate the alignment and support functions. The fabrication tolerances are relaxed on the slide connection to ±0.010" and the fiducial inserts shifted axially 6" from the support points. The fiducials presently in use are the same as Design A but are now independent of the support system. While Design B fabrication tolerances are relaxed the support must still repeatably position the magnet center within five mils, relative position stability is now the objective versus absolute position accuracy. The new cold mass assembly tooling being fabricated at FNAL is not operational, so the insert pin method used in the original BNL tooling is still being used for alignment. When the new FNAL tooling is available there will be no penetrations in the cold mass skin and the external features of the cold mass will be the fiducial reference. This will allow a full length reference versus a five position reference for magnet alignment.[7]

PROGRAM HISTORY

To date there have been seven cryostats assembled using the Design A slide connection, one using the prototype Design B version, and four using the final Design B version. Table 1 lists the magnet assemblies which have used each version of the slide connection.

Table 1

Magnet Assemblies	Design Version
HLM II, D0001, D0002, D000X DD000Z, DD0010, DD0012	Design A
DD0014	Design B Prototype
DD0011, DD0013, DD0015, DD0016	Design B Casting

FUTURE DIRECTIONS

During assembly of Design B cryostats several problems have occurred with interferences between the upper half of the slide connection and the inner 20K shield. Stand-offs made of G-10 were installed to minimize thermal shorts at these interference points. A new upper half of the connection was prototyped which would provide a nominal 3/16" profile above the cold mass skin. The design uses rolled sheet stock welded to mounting blocks which can be directly interfaced with the existing lower half of the slide connection, see Fig. 7. The rolled plate has four holes which pick up tabs on the DU bearings. The tabs are formed by rolling back the DU itself, creating a captured geometry when installed between the cold mass and the upper half of the connection. The existing design uses a recessed pocket in the casting to capture the bearings, requiring two machining steps. The same method of capturing the bearings using tabs can be applied to the lower half. Tests of the new low profile upper half, in conjunction with the cast lower half, have shown even lower resistance to axial motion. The design is seen as a candidate for the Design C cryostat.

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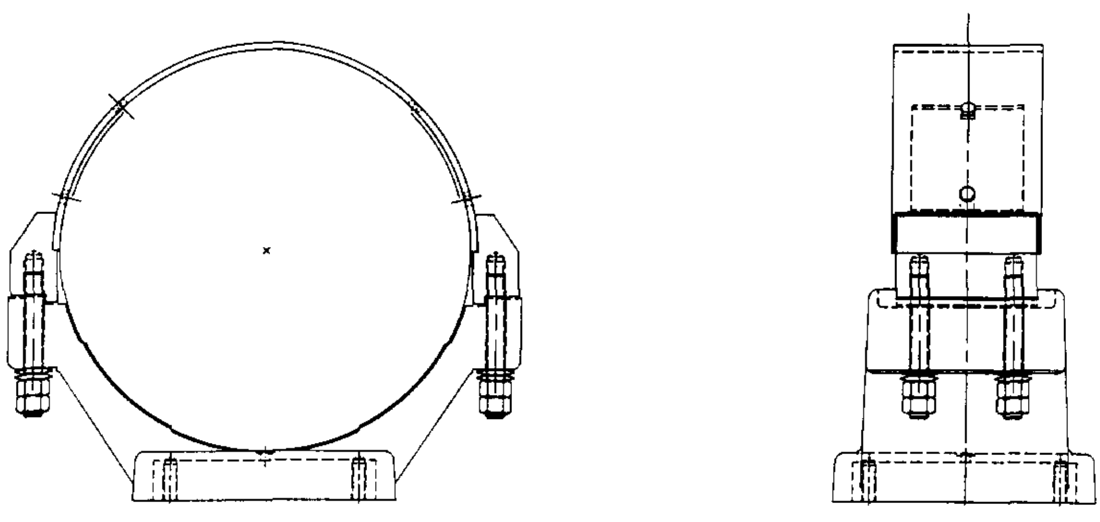

Fig. 7. Design C Prototype Slide Connection

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