Fermi National Accelerator Laboratory

TM-1582
[SSC-N-601]

SSC Magnet Mechanical Interconnections*

R. C. Bossert, R. C. Niemann, J. A. Carson,
W. L. Ramstein, M. P. Reynolds, and N. H. Engler
Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois

March 1989

---

* Presented by R. C. Bossert at the 1989 International Industrial Symposium on the Super Collider (IISSC), New Orleans, Louisiana, February 8-10, 1989.

Operated by Universities Research Association, Inc., under contract with the United States Department of Energy

SSC MAGNET MECHANICAL INTERCONNECTIONS

R. C. Bossert, R. C. Niemann, J. A. Carson, W. L. Ramstein, M. P. Reynolds and N. H. Engler

Fermi National Accelerator Laboratory
P.O. Box 500
Batavia, IL 60510

ABSTRACT

Installation of superconducting accelerator dipole and quadrupole magnets and spool pieces in the SSC tunnel requires the interconnection of the cryostats. The connections are both of an electrical and mechanical nature. The details of the mechanical connections are presented. The connections include piping, thermal shields and insulation. There are seven piping systems to be connected. These systems must carry cryogenic fluids at various pressures or maintain vacuum and must be consistently leak tight. The interconnection region must be able to expand and contract as magnets change in length while cooling and warming. The heat leak characteristics of the interconnection region must be comparable to that of the body of the magnet. Rapid assembly and disassembly is required. The magnet cryostat development program is discussed. Results of quality control testing are reported. Results of making full scale interconnections under magnet test situations are reviewed.

SSC MAGNET MECHANICAL INTERCONNECTIONS

Introduction

Several full size SSC model magnets have been assembled at Fermilab.[1,2] The interconnection area is an integral part of these magnets. They have been connected to test stands and to each other in string tests.

Procedure

The interconnection is developed from the beam tube outward. The seven mechanical connections to be made are shown in Fig. 1.

Power leads and electical connections inside the cold mass are made first. The cryostat connections are then made. Order of connections with their estimated times to make in a tunnel situation are shown in Table 1:

Table 1. Interconnection Procedure

Connection:

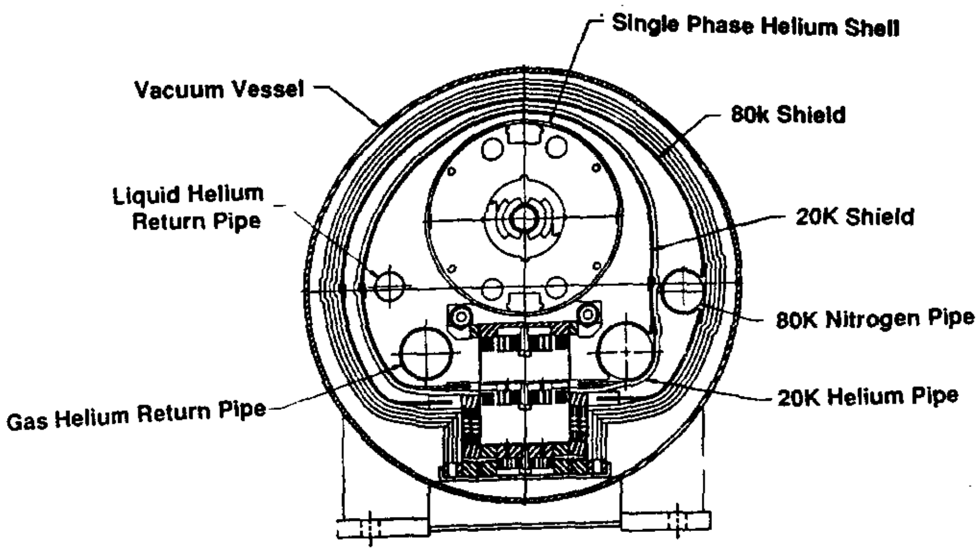
1.) Weld Beam Tube ------------	setup - 5 minutes weld - 2.5 minutes each total (2 welds) - 15 minutes
2.) Weld Cold Mass Bellows ------	setup - 5 minutes weld - 15 minutes total (2 welds) - 40 minutes
3.) Weld Shield and Return Pipes -	setup - 2.5 minutes each weld - 2.5 minutes each total (8 welds) - 40 minutes
4.) Mount, and Insulate Interconnection Shields ------	mounting - 5 minutes attaching - 10 minutes insulating - 5 minutes total (2 shields)-40 minutes
6.) Weld Vacuum Vessel --------	setup - 5 minutes weld time - 40 minutes total (2 welds) - 90 minutes

<u>Total Connection time</u>: 3 hours, 45 minutes

Disconnection:

1.) Break Vacuum Connection -------	setup time - 5 minutes cutting time - 30 minutes cleanup time - 5 minutes total (2 cuts) - 80 minutes
2.) Remove Shields and Insulation -----------------	remove shield - 10 minutes remove insulation - 5 min. total (2 shields) - 30 min.
3.) Break Shield and Return Pipes --------------------	setup time - 5 minutes cutting time - 5 minutes cleanup time - 3 minutes total time (8 cuts) - 104 minutes
4.) Break Cold Mass Connection -----	setup time - 5 minutes cutting time - 15 minutes cleanup time - 5 minutes total (2 welds) - 50 minutes
5.) Break Beam Tube Connection ----	setup time - 5 minutes cutting time - 5 minute cleanup time - 5 minutes total (2 welds) - 30 minutes

<u>Total disconnection time</u>: 4 hours, 54 minutes



The Interconnection is developed from the beam tube outward. There are seven mechanical connections to be made.

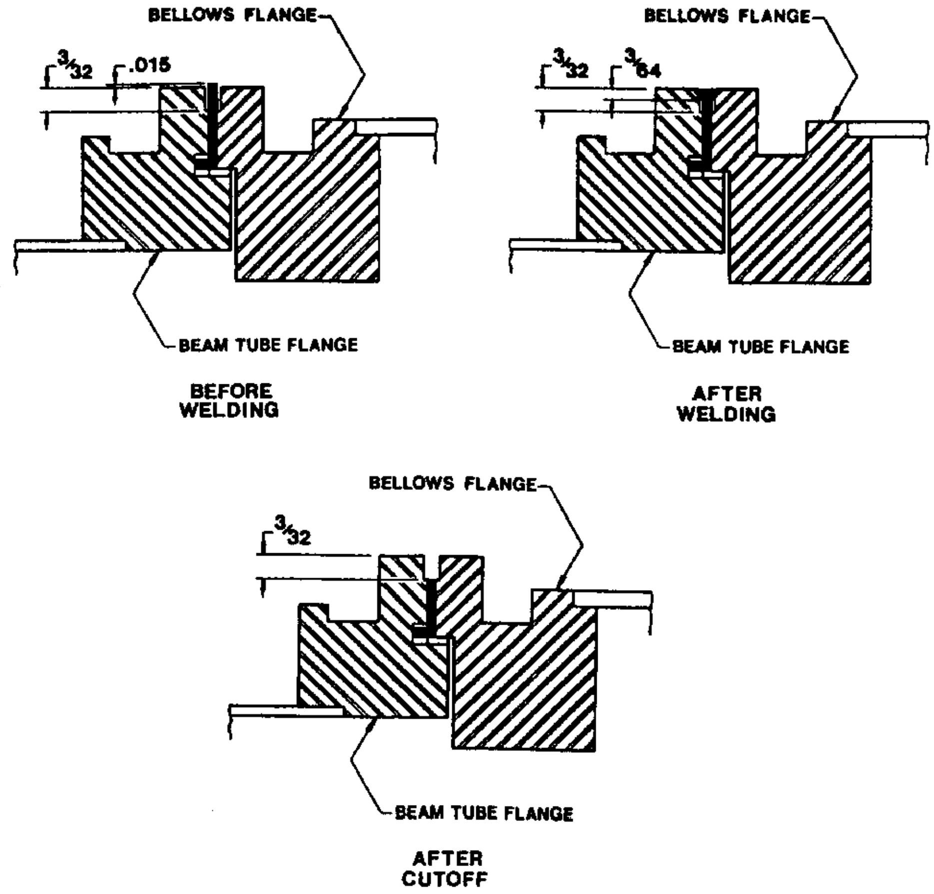
Fig. 1. Seven cryostat connections

It is obvious that a substantial amount of time will be devoted to making interconnections. Efficiency in making and breaking these connections is therefore critical.

Piping System Connections

A. Beam Tube. The beam tube is the first connection to be made. It consists of a bellows assembly with a stainless steel flange on each end. This assembly consists of two bellows of different diameters with an isolating vacuum between them. This extra vacuum space isolates the internal beam tube area from the liquid helium space, insuring a seal even if one bellows should fail. The bellows assembly is inserted between two mating flanges on the beam tubes and welded with a computer controlled weld head. Two welds are made, one on each end of the bellows. These welds are made by consuming disk shaped washers which are placed between the flanges (shown in cross section in Fig. 2). The area internal to the weld is purged with an inert gas. Nitrogen is being used as the purge gas for the beam tube connection.

The weld system consists of an orbital water-cooled welding head with a 220 V power supply. The head is made to clamp onto a pipe as shown (see Fig. 3). With minor modifications to the collets it can be made to clamp to the beam tube flanges. The tungsten electrode is driven by a rotating gear. The weld cycle has been previously programmed into the unit so that the operator has only to press a button to run the appropriate program. A typical weld program includes times and currents for the initial tack welds, upward current ramp, weld cycle, and downward current ramp. The weld cycle includes time, current and motor speeds for both the high and low end of the "pulsed" arc. Up to 99 steps (called "levels"), are available. Pre and post purge times are also programmable. A typical weld program is shown in Table 2.

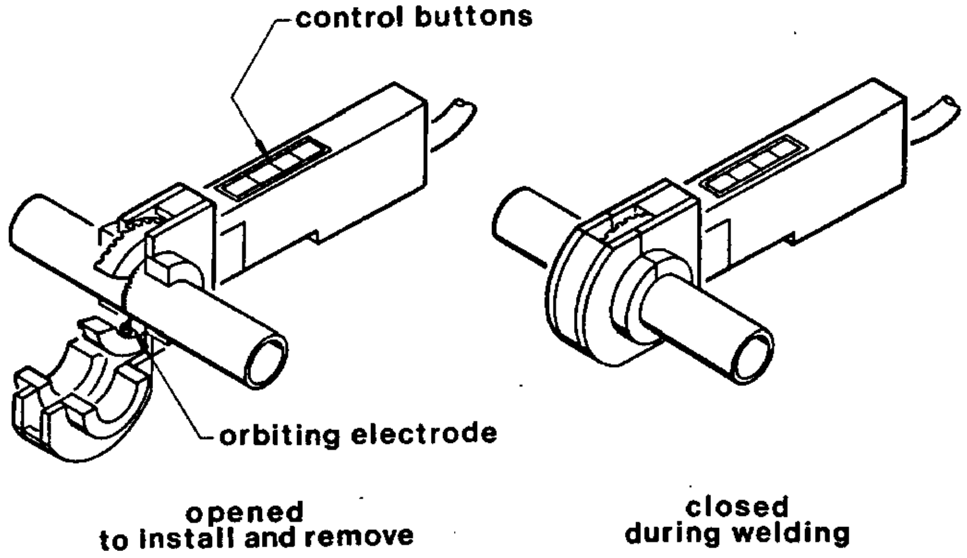


BEFORE WELDING

AFTER WELDING

AFTER CUTOFF

Fig. 2. Beam tube weld



opened
to install and remove

closed
during welding

Fig. 3. Beam tube weld head

Table 2.

Weld Procedure #1625-10/0 1 5/8 Sleeve S.S. Fermi SSC
Pre-purge gas 35.00 sec
Strike Current 20.00 amp Post-purge 20.00 sec

				--------HIGH--------			--------LOW--------		
LEVEL NO. SEC.	LEVEL TIME SEC.	CURRENT SLOPE SEC.	MOTOR SLOPE SEC.	TIME SEC.	CURRENT AMP	MOTOR RPM	TIME SEC.	CURRENT AMP	MOTOR RPM
1	14.56	7.00	4.00	0.28	89.0	0.71	0.28	27.0	0.71
2	14.56	7.00	0.00	0.28	88.6	0.71	0.28	27.0	0.71
3	14.56	7.00	0.00	0.28	88.0	0.71	0.28	27.0	0.71
4	14.56	7.00	0.00	0.28	87.6	0.71	0.28	27.0	0.71
5	14.56	7.00	0.00	0.28	87.0	0.71	0.28	27.0	0.71
6	14.56	7.00	0.00	0.28	86.6	0.71	0.28	27.0	0.71
7	14.56	7.00	0.00	0.28	86.0	0.71	0.28	27.0	0.71
8	12.00	12.00	12.00	0.15	48.0	1.42	0.15	27.0	1.42
FINAL	6.00	6.00	6.00	0.12	8.0	2.60	0.12	4.00	2.60

The beam tube is removed by cutting out the section of the consumable washer which is fused to the flanges. This cut is made by an orbital pipe cutter as shown in Fig. 4. The cutter is a two piece unit which clamps onto the pipe. It is specially designed to fit the low clearance application, as are the cutters for all the other cryostat connections. A cutting tool similar to that used on a lathe revolves around the pipe. The tool bit is attached to a ring gear which is driven by a variable speed motor. A cam feed system allows the operator to vary the tool feed from 0 to .006 inches per revolution. Both pneumatic and hydraulic motors are available. Power requiremints for air are 35 cfm at 80-100 psi. The hydraulic requirements are 4-5 gpm at 1500 psi. Air is presently being used at the test facility. It has not yet been determined which medium will be used in the SSC tunnel.

Several beam tube bellows have been welded and cut off from test stands. Clearance problems for the weld head and pipe cutter have at times been encountered, and have made hand welding and grinding necessary. We have found that alignment is critical to the welding unit. Alignment problems have not been encountered on the test stand, since the beam tube connection is used as the reference to align the magnet to the stand. Compressing the bellows to the proper length for insertion into the opening has also proved to be more difficult than was anticipated. Mechanical fixtures work, but are cumbersome and difficult to use.

<u>B. Cold Mass Connection</u>. The cold mass connection is then made. The bellows is stored on the return end of the cold mass. The technician must slide the bellows into position for welding. Bellows and sleeves are stainless steel. Again there are two welds to be made, one on each side of the cold mass bellows. These are fillet welds, with filler material to be added (see Fig. 5). The weld head for this connection is water cooled with a tungsten torch. The internal purge gas is helium. The entire weld head revolves around the pipe (see Fig. 6). It is driven by a chain which is mounted to a guide ring. The guide ring is firmly clamped to the pipe (cold mass). An automatic arc gap control keeps the tungsten electrode always at the proper distance from the weld. Filler material is fed at a controlled rate from a metal spool. All weld parameters are pre-programmed as in the beam tube weld.

The cold mass bellows is removed by cutting out the fillet welds and sliding the bellows back into the storage position. An orbital pipe cutter similar to the beam tube cutter is used to remove the welds. Whereas the beam tube cutter feeds in the radial direction (like a lathe cutoff tool), the cold mass cutter feeds in the longitudinal direction (like a turning operation). It is clamped to the end sleeve of the cold mass and runs concentric with the sleeve within .005 inches. This is achieved by use of a spring-loaded tracking module. This cut is made without lubrication, as are all the cutoff operations in the interconnection region. Air requirements for this cutter are 85 cfm at 80-100 psi. Hydraulic requirements are 8-10 gpm at 1500 psi.

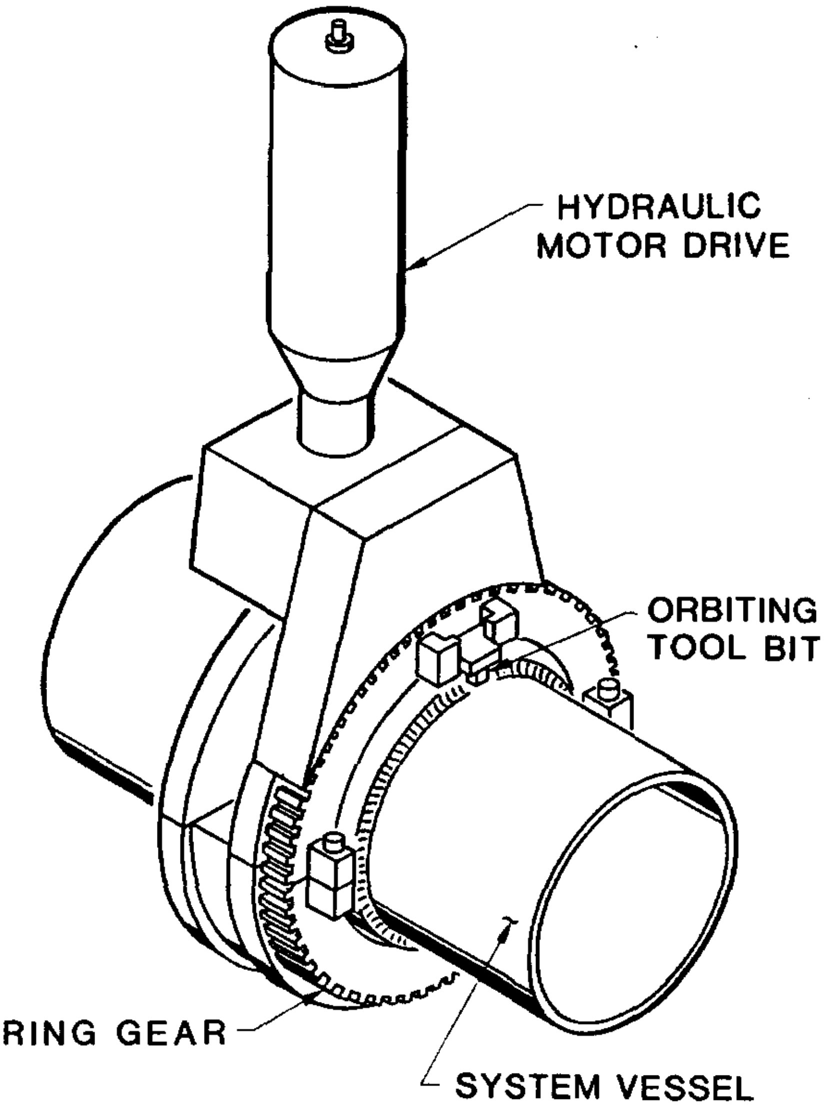


Fig. 4. Beam tube weld cutter

Cold mass bellows have been welded and cut off successfully with the automatic equipment in an interconnection mockup at Fermilab. Clearance problems have resulted in an inability to use the longitudinally feeding pipe cutter for the cold mass on the test stands. This problem will be resolved in the next cryostat iteration.

C. Shield and Return Pipes. Two shield and two helium return pipes surround the cold mass (see Fig. 1). These pipes range from 1.90 to 3.5 inches in ouside diameter. They are all welded and cut off in the same manner. The bellows for these pipes are permanently attached to the lead end of the magnet. They are welded on the return side by using a "sleeve" assembly as is shown in Fig. 7. The corner of the sleeve is melted and fused to the pipe. The sleeve serves as a consumable material for welding as well as a mechanism for aligning the pipes for the welding unit. It is stored on the bellows end flange. The technician slides the sleeve over the gap between the bellows and it's mating pipe on the return end of the magnet. A new collet must be inserted into the same weld head that was used for the beam tube. The weld head is then clamped in the proper position on the pipe. A weld program designed for the specific joint is called. Purge gas is helium for the 20K shield and helium return pipes and nitrogen for the liquid nitrogen line. After welding, the head is placed on the other end of the sleeve, and the operation is repeated. The welds are removed by longitudinal-feed orbital pipe cutters. These cutters are identical in operation to the one that is used for the cold mass, but similar in size to the one used for the beam tube. Air and hydraulic requirements are the same as for the beam tube cutter. Figure 8. shows the SSC Interconnection area with a small orbital pipe cutter mounted in position on a helium return pipe.

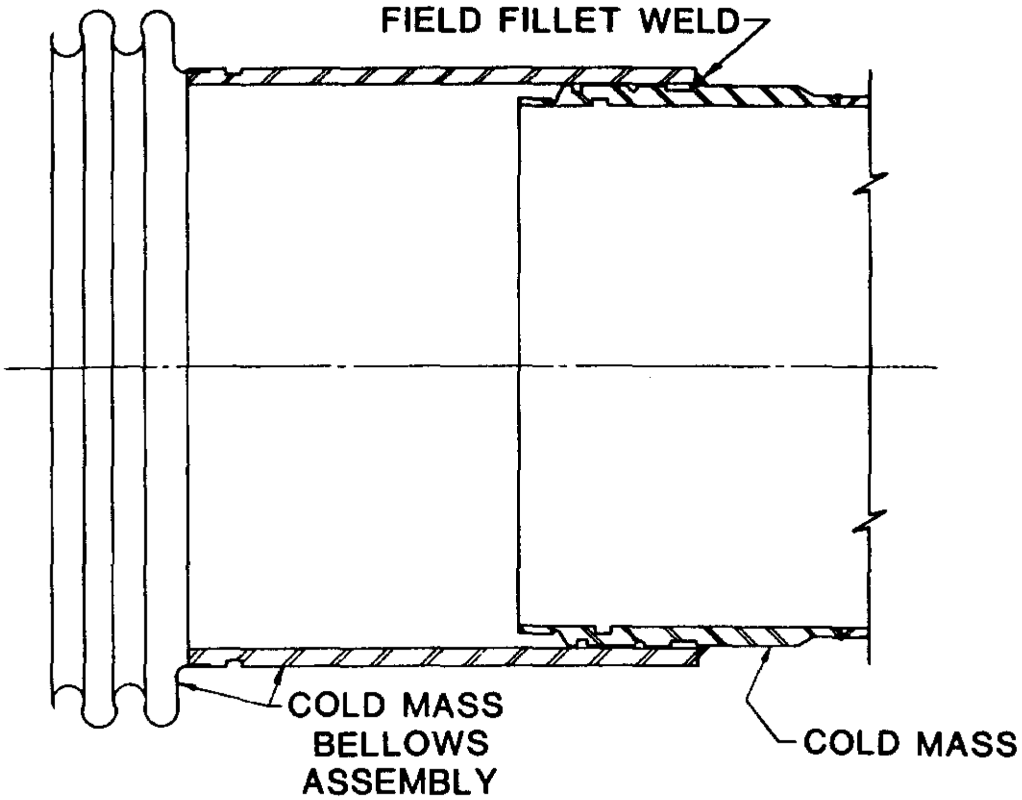


Fig. 5. Cold Mass Weld.

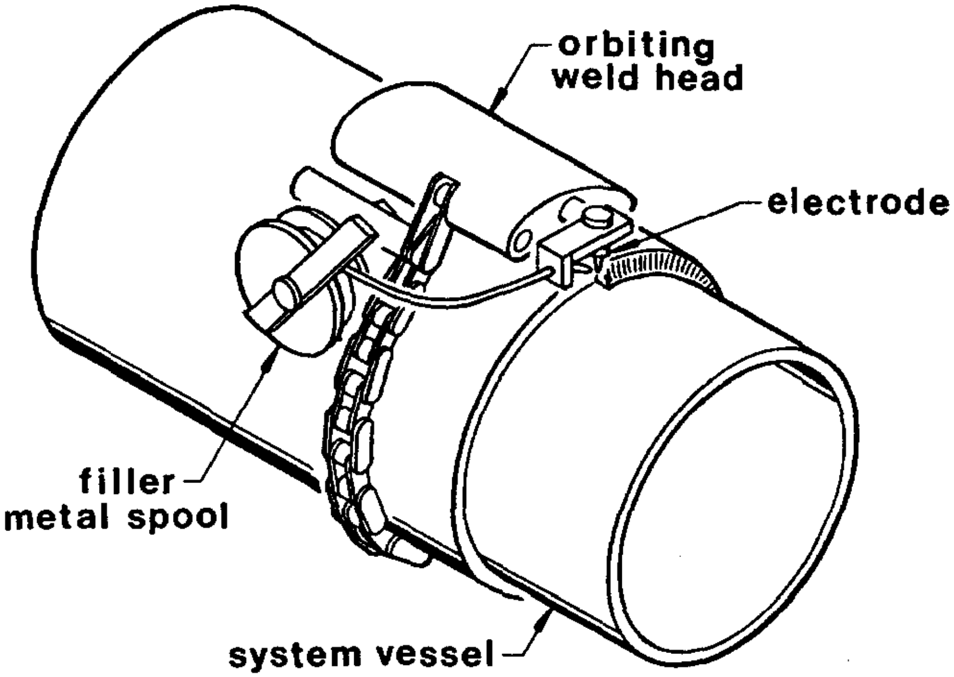


Fig. 6. Cold Mass Welding Unit

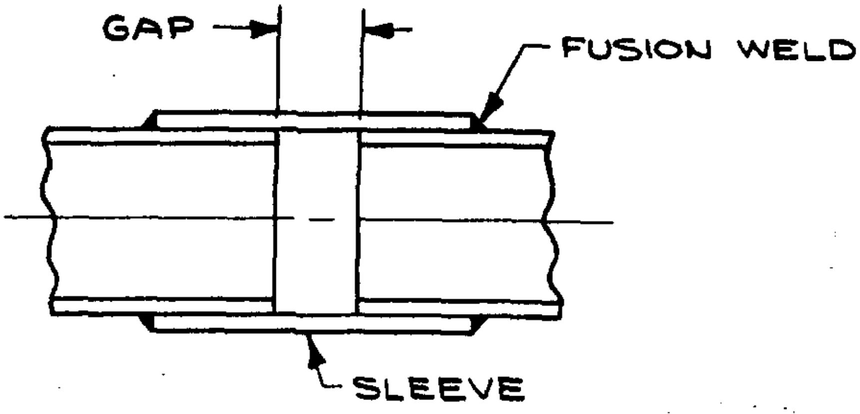


Fig. 7. Shield and return pipe weld

Many welds using the sleeve assembly have been made and cut apart at Fermilab, both on and off the test stand. This method has several desirable features. The sleeve serves to align the pipes for welding, eliminating the problem of weld programs shutting down due to pipe misalignment. Bellows compression is no longer necessary, because it does not need to be compressed into a specific slot as is the beam tube bellows. Longitudinal tolerances in pipe position are taken up by the gap between pipes, allowing a smaller bellows travel to be specified.

D. Vacuum Shell. The vacuum shell connection is shown in Fig. 9. The weld and cutoff prodeedure is similar to the cold mass connection, except that the shell material is carbon steel instead of stainless. The bellows is stored on the return end of the vacuum vessel. The technician slides it into position. The same weld head is used as the cold mass. The appropriate weld program is called, and the fillet weld is made. The weld is removed by a longitudinal-feed pipe cutter of the proper diameter. Air and hydraulic requirements are the same as that for the cold mass cutter.

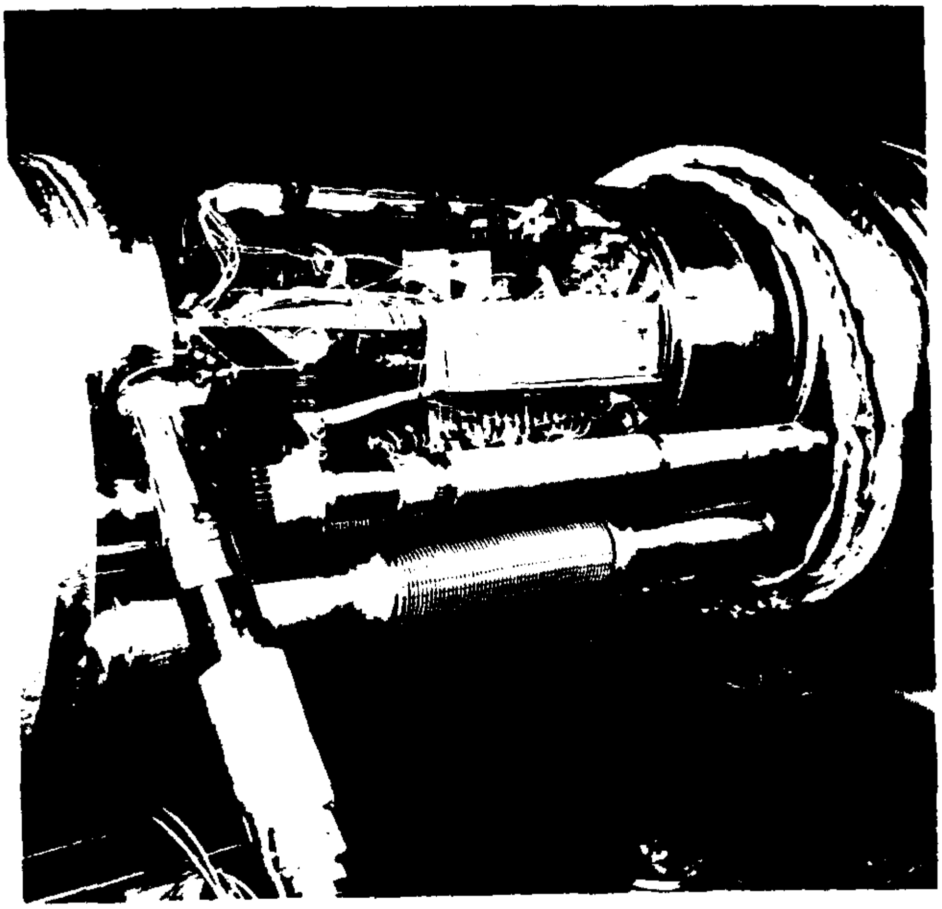


Fig. 8. SSC interconnection area

No vacuum vessel connections have yet been made by this procedure. An o-ring connection is presently being used at the Fermilab cold magnet test facility.

Bellows

Bellows are required for all interconnection joints. The bellows are installed in their compressed state and expand to compensate for the contraction of the cryostat when cooled down. They also accomodate any differences in position, both axially and radially, of the magnet ends. They must function at the temperatures dictated by their particular system. All but the vacuum bellows must be non-magnetic. They must satisfy the SSC magnet requirement of 20 thermal cycles with a reasonable safety factor. Specifications concerning pressure, longitudinal travel, axial offsets, and physical dimensions must be met. Table 3 lists the specifications for the interconnection bellows presently being used.

Bellows are made of 316L stainless steel. This material offers a good combination of mechanical strength, weldability and corrosion resistance.

A quality assurance testing program for SSC bellows and welded joints has begun. Testing of welded joints has not yet taken place. One bellows of each type except the vacuum bellows has been tested. The bellows that were tested were made of 321 stainless steel. An earlier cryostat design used this material. The 316L should have improved extension-compression cycle life. A more comprehensive test program using the 316L bellows will be initiated. Twenty samples of each type will be tested. After this testing is complete, the test program will be reevaluated. Table 4 shows the procedure and results of the testing completed to date.

Table 3. Bellows Specifications.

System	Inside Diameter	Outside Diameter	Travel	Maximum Pressure	Maximum Axial Offset	Minimum Life Cycles
Beam Tube	1.600	3.125	3.0	300 psi ext. 1*10e11 torr int.	not specified	1000
LHe Ret.	1.50	1.875	2.125	300 psi int. 0 external	.100	1000
80K Shield	2.375	3.250	3.125	300 psi int. 0 external	.100	1000
He Gas Ret.	2.709	3.500	2.125	300 psi int. 0 external	.100	1000
20K Shield	3.000	3.875	3.125	300 psi int. 0 external	.100	1000
Cold Mass	11.80	12.80	2.125	300 psi int. 0 external	.040	1000
Vacuum Vessel	26.00	28.00	1.37	75 psi int. 15 psi ext.	.200	not specified

(all dimensions in inches)

Table 4. Bellows Testing.

Proceedure:

1.) Initial Leak Check
2.) 50 cycles at nitrogen temperature
3.) Vacuum Leak Check
4.) Hydrostatically pressurized to 20 atmospheres internally
5.) Hydrostatically pressurized to 25 atmospheres internally
6.) Vacuum Leak Check
7.) Repeat steps 2 through 6 until bellows fails or until 1000 cycles is reached.

Results:

Bellows	Cycles to Failure	Bellows Material
LHe Return	175	321 Stainless
He Gas Return	459	321 Stainless
20K Shield	No Failure at 600	321 Stainless
80K Shield	100	321 Stainless
Cold Mass	No Failure at 100	321 Stainless

Interconnection Shields

The 20K and 80K thermal shields must continue through the interconnection area. Thermal shield "bridges" are installed for this purpose. The shield bridges are mounted as shown in Fig. 10. The top half is placed over the space between the two magnet shields. It is supported by the magnet shields. The bottom half is then hinged into the top half as shown. Predrilled rivet holes are matched on the other side. Rivets then hold the halves together. The shield bridge is "thermally attached" to the magnet shield on one side and overlapped, but not attached on the other. The thermal attachment presently consists of a series of small fillet welds as shown. A crimped connection is under consideration for future models. The overlap allows the shields to move with respect to each other when they contract by 2.75 inches during cooldown.

The shield bridges are each made of .062 inch thick 1100-0 aluminum. This material is very soft and easy to form. It is also extremely high in thermal conductivity at 20 and 80 K. Since the shield bridges are thermally attached on one side only, and not attached to the 20K and 80K pipes, the temperature gradient through them is different than that on the magnet shields. It is longitudinal, and significantly longer than the azimuthal path for the shields inside the magnet. A material with higher conductivity than the 6061-T6 aluminum of the magnet shields is therefore necessary. Although not strong enough to use for the magnet shields, 1100-0 aluminum is structurally sufficient for the short bridge in the interconnection area.

Insulation

The shield bridges must be insulated. They are insulated in exactly the same manner as the shields inside the magnet.[3] Junctions between the magnet and the interconnection insulation blankets are made by aluminum tape. The blanket junction is made in a "stairstep" configuration as shown in Fig. 11. No provision for magnet shrinkage in the interconnection area is necessary. This has been accomodated for in the cryostat body.

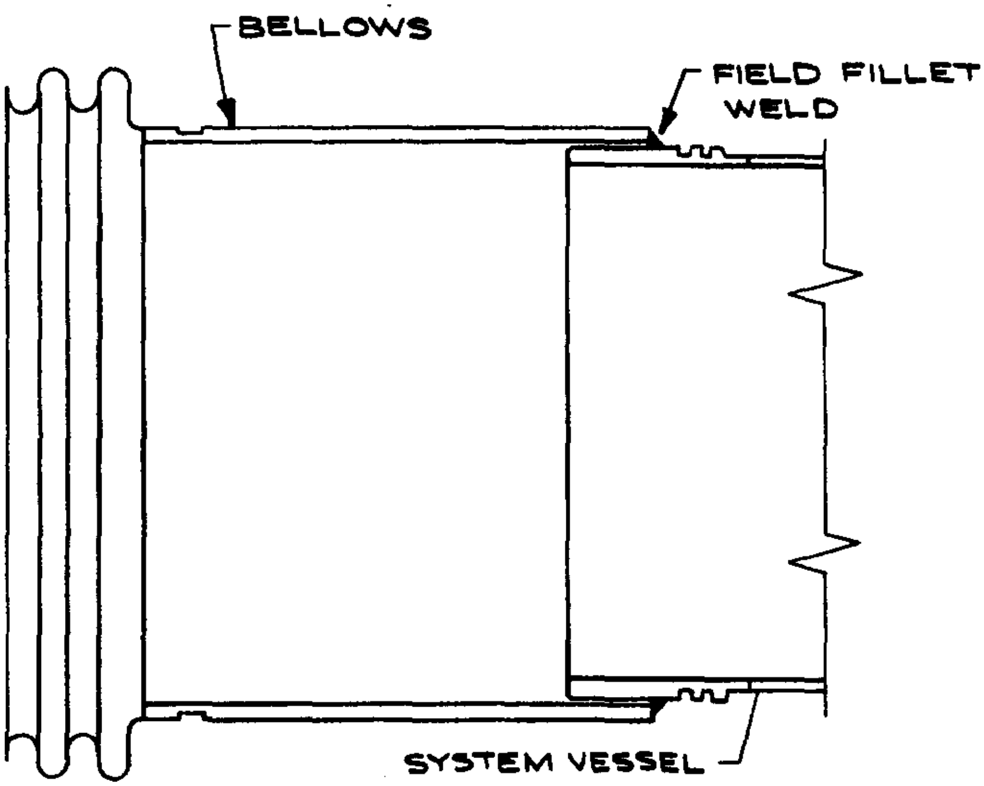
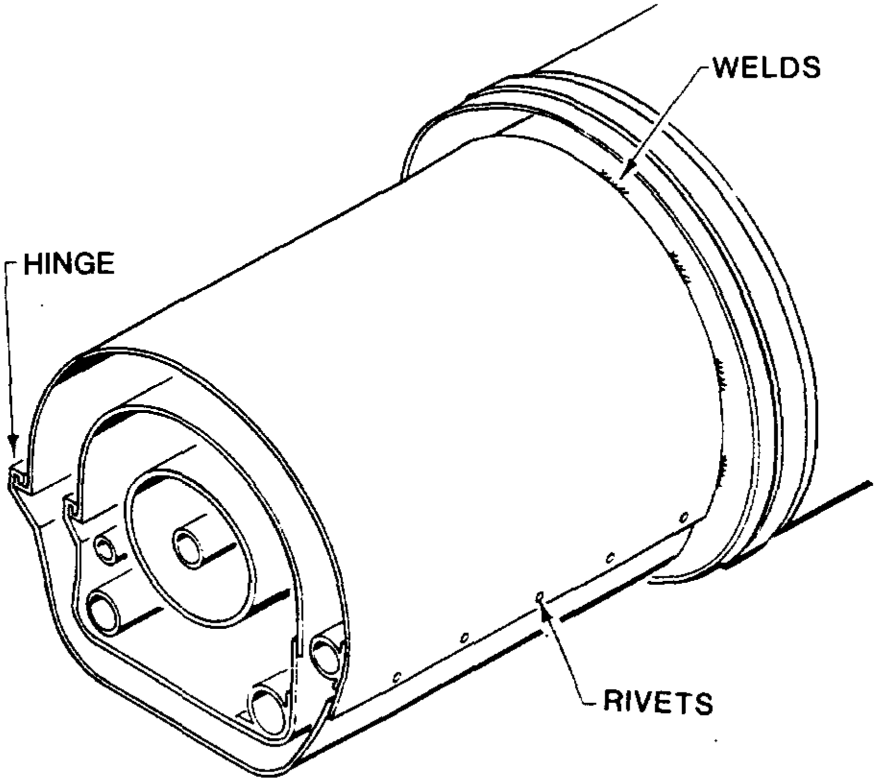


Fig. 9. Vacuum shell connection



Fig, 10. Interconnection Shields

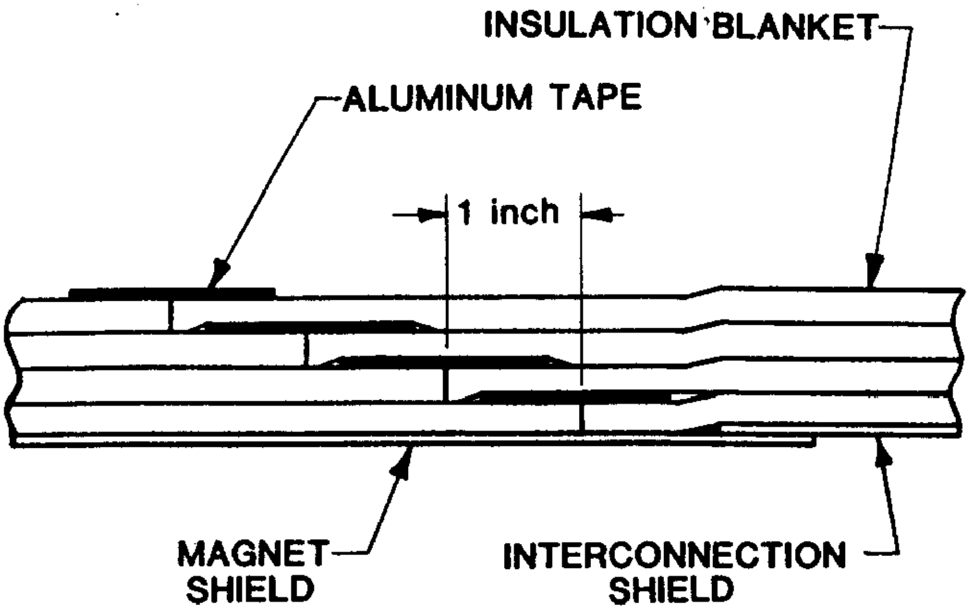


Fig. 11. Insulation Joint

Interconnection Model

Fermilab constructed a full size interconnection model for the initial cryostat design. It has been used to practice connecting and disconnecting magnets. The model has several flaws: 1.) It is not located in a full size tunnel cross section. 2.) It consists only of one magnet, not two stacked vertically as is in the real tunnel. 3.) No electrical connections are included in the model. 4.) It is a static model, representing only the warm, installed position of the magnet.

The model is fine for practicing welding and cutoff. It does not, however, have the ability to replicate the movements within the interconnection due to thermal contraction. Design of a new model which corrects these deficiencies is underway.

CONCLUSION

The magnet interconnection area consists of many interrelated systems. The initial design and testing has been completed. Continuing development is necessary including verification of times involved in making interconnections, testing of components, and leak checking under tunnel conditions.

REFERENCES

1. Niemann, R.C., et al., "Superconducting Super Collider Second Generation Dipole Magnet Cryostat Design," Applied Superconductivity Conference, August 22-25, 1988, San Francisco, Ca.

2. Engler, N.H., et al., "SSC Dipole Magnet Model Construction Experinece," presented at the 1987 Cryogenic Engineering Conference, St. Charles, IL, June 14-18, 1987.

3. Gonczy, J.D., et al., "Multilayer Insulation (MLI) in the Superconducting Super Collider a Practical Engineering Approach to Physical Parameters Governing MLI Thermal Performance," presented at the International Superconducting Super Collider Symposium, New Orleans, LA, February 8-10, 1989.