Fermi National Accelerator Laboratory

FERMILAB-Conf-91/218
SSCL-503

An Overview of the Multilayer Insulation System for the Superconducting Super Collider

W. Boroski, T. Nicol, and C. Schoo

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

August 1991

* Presented at the *XVIIIth International Congress of Refrigeration*, Montreal, Quebec, Canada, August 10-17, 1991.

Operated by Universities Research Association Inc. under Contract No. DE-AC02-76CHO3000 with the United States Department of Energy

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No de la communication / *Paper No.* 99

AN OVERVIEW OF THE MULTILAYER INSULATION SYSTEM FOR THE SUPERCONDUCTING SUPER COLLIDER

by

W.N. Boroski, T.H. Nicol, and C.J. Schoo

présenté dans le cadre du XVIII^{e} Congrès international du froid/
Written for the XVIII th International Congress of Refrigeration

Palais des Congrès de Montréal/
Montréal Convention Centre
Montréal, Québec, Canada

10-17 août 1991 / *August 10-17 1991*

XVIII^{e} CONGRÈS INTERNATIONAL DU FROID

XVIIIth INTERNATIONAL CONGRESS OF REFRIGERATION

IIF-IIR-MONTRÉAL-1991

RÉSUMÉ / *SUMMARY:*

The MLI system for the SSC is designed to meet strict performance requirements over the 25 year life of the accelerator. Thermal measurements at 80K and 20K have been used to create an MLI system that limits heat flow to design values while incorporating features that permit the use of large-scale fabrication techniques. The result is a cost-effective means of mass-producing MLI blankets of consistent geometry and thermal performance.

MOTS-CLÉS / *KEYWORDS:*

Multilayer insulation, Heat transfer, Mass production

TABLE I
Structural Properties of Candidate Materials

ORGANIC MATERIAL	POLYESTER	POLYIMIDE	POLYAMIDE
TRADE NAME†	MYLAR, REEMAY, DACRON	KAPTON	NYLON, CEREX
MOISTURE ABSORPTION	0.4% @ 50% Rh REEMAY SPUNBONDED 0.5% @ 98% Rh	1.3% @ 50% Rh ———	8.0% @ 50% Rh CEREX SPUNBONDED 3-5% @ 95% Rh
OUTGASSED MASS PER UNIT MATERIAL MASS	DACRON NET 1.1×10^{-4} g/g DOUBLE ALUMINIZED MYLAR 2.6×10^{-3} g/g	——— DOUBLE ALUMINIZED KAPTON 3.1×10^{-3} g/g 3.9×10^{-3} g/g	NYLON NET 4.0×10^{-2} g/g ———
IONIZING RADIATION DAMAGE	5.7×10^{8} RAD (50% MAX. MECHANICAL)	5.0×10^{9} RAD (50% MAX. MECHANICAL)	7.0×10^{7} RAD (50% MAX. MECHANICAL)
IRRADIATION EVOLVED GASES	3-5 ml/g @ 10^{9} RAD H_2(70%), CO_2(20%), CO(10%)	———	20-25 ml/g @ 10^{9} RAD H_2(52%), CO(20%), CO_2(12%), N_2(8%), O_2(3%)

† DUPONT DE NEMOURS & CO; REEMAY INC; JAMES RIVER CORP.

The three candidate material types are comparable in mechanical strength. However, polyamides are highly hygroscopic. This characteristic is detrimental to the performance of the cryostat vacuum system and is a principal reason for the exclusion of polyamides from the system. Also, the structural integrity of polyamides begins to degrade well below the radiation dosage of 5 x 10^5 rads predicted in the cryostat. While polyimides, and in particular Kapton, have exceptional resistance to radiation damage, for the SSC the high cost of the material does not offset its benefit. PET materials are tolerant to dosages above the levels anticipated for the cryostat. Thus, the material of choice for use in the MLI system is polyethylene terephthalate (PET), a polyester. With the availability of polyester materials, all components of the MLI system, including thread and Velcro fasteners, are polyesters.

3. DESIGN OF THE MLI SYSTEMS FOR THE SSC DIPOLE CRYOSTAT

<u>80K MLI System</u> - The MLI system for the 80K shield was formulated using results from thermal performance measurements made on several MLI geometries/6,7/. Results from these measurements, presented in Figure 1, show that the MLI system with no spacer has the lowest heat flux under steady state conditions. However, this system proved sensitive to small changes in vacuum vessel wall temperature and system pressure. By comparison, while the MLI systems incorporating spacers consistently had higher heat flux values, all were within the design budget. Further, these systems were more insensitive to changing system parameters; the buffering is attributed to the volumetric heat capacity of MLI assemblies with spacer layers. Whereas the operating conditions of an accelerator can vary considerably over time, the MLI system design incorporates PET spacer layers to buffer transient effects. The resulting system will offer more consistent performance throughout the operation of the accelerator.

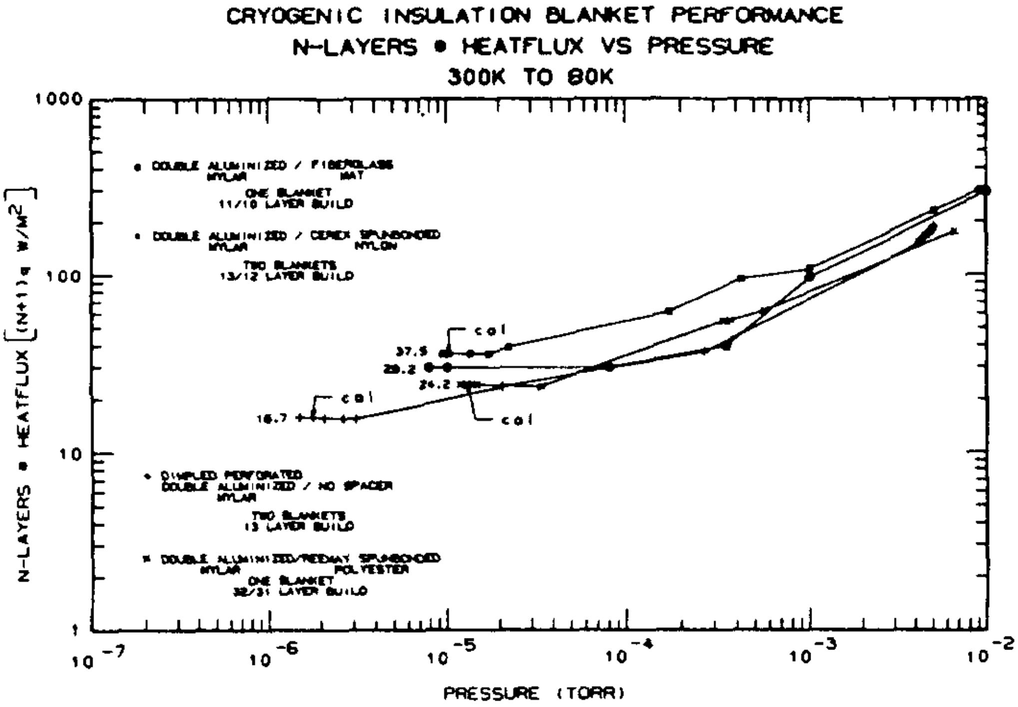

Figure 1. Thermal performance between 300K and 80K

The MLI system for the 80K thermal shield consists of two 32-reflective layer blanket assemblies for a total build of 64 reflective layers. The blankets are designated as the inner 80K and outer 80K blanket, each with a nominal layer density of 3.6 layers/mm. Figure 2 shows a cross-section view through the seam/joint area of the 80K outer blanket. The inner blanket geometry is similar with the exception of the emissivity flap. The emissivity flap covers the seam area thereby maintaining a reflective surface over the entire blanket perimeter. The flap is not required on the inner blanket as the seam area is covered by the outer blanket assembly.

The reflective layers consist of 0.03 mm thick PET film aluminized with a nominal coating thickness of 350 angstroms, or 0.9 ohms/square, per side. The reflective layers are held apart by single spacer layers of 0.10 mm spunbonded PET material. Single layers of 0.23 mm spunbonded PET cover the blanket top and bottom and serve to position the polyester hook and loop fasteners at the blanket edges. The fasteners are attached to the cover layers by sewing. A third 0.23 mm thick PET layer is located midway through the blanket assembly to separate the upper and lower 16 reflective layers. The multiple blanket layers are sewn together as an assembly along both edges of the blanket. Non-lubricated thread is used in all sewing operations.

At each blanket edge, the upper MLI layers are sewn together from the upper cover layer through to the midlayer, with the thread terminated in the heavier midlayer material. The seam location is then incremented 7.62 cm laterally along the midlayer and the lower 16 layers sewn together from the midlayer through to the lower cover layer. This geometry is shown in Figure 2.

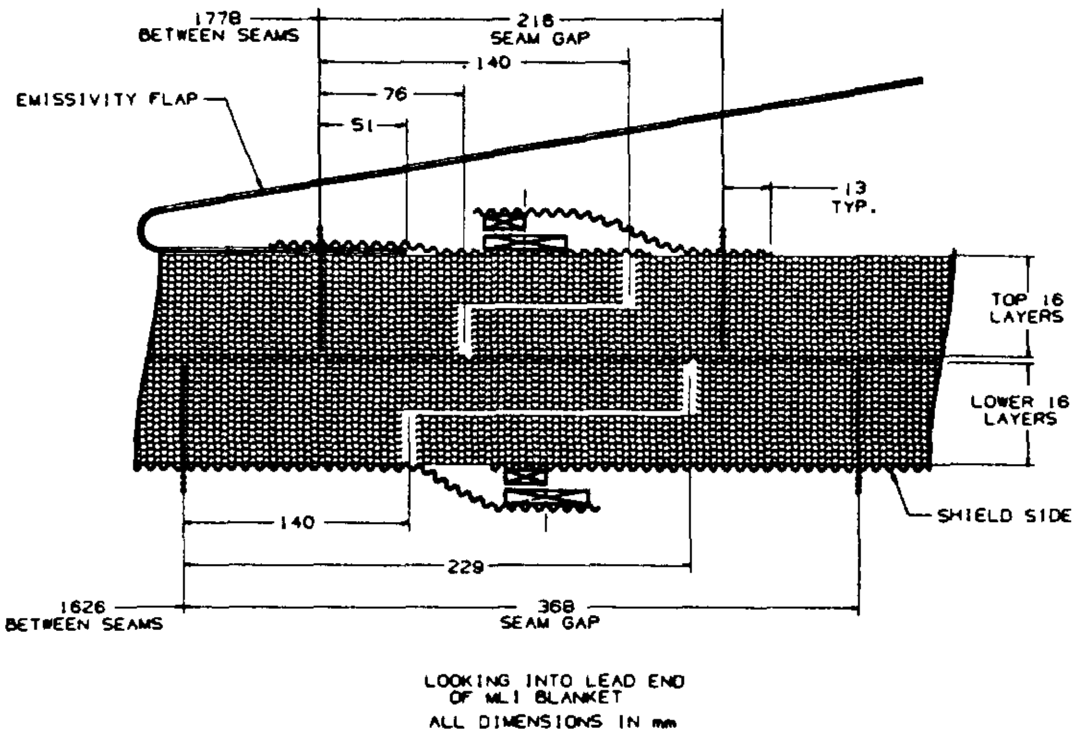

Figure 2. 80K MLI blanket cross section

The sewn seams are advantageous in the fabrication of large blanket assemblies as they hold the many layers together in a package that can be treated as a single entity during shipping, handling, and cryostat installation. Stepping the sewn seam interrupts and lengthens the conductive path through the thread, thereby minimizing the effects of the seam on overall blanket performance. Measurements on various sewn seam geometries to study this effect have shown that the stepped seam geometry meets the infrared heat load budget to 80K/7/.

<u>20K MLI System</u> - With respect to MLI on surfaces at very low temperatures, it is found in the literature that MLI is not recommended on surfaces at temperatures below 80K. Rather, it is suggested that the cold boundary be covered with aluminum tape to provide a low emissivity surface. Also, it has been reported that the addition of MLI on a low emissivity surface causes an increase in the heat transfer rate between boundary surfaces. An experimental program has been established to study MLI performance below 80K with particular interest in residual gas conduction.

Measurements have been conducted to study the effects of infrared radiation and residual gas conduction on insulating schemes near 20K. The experimental setup has been previously described/8/ and thus only a brief overview is offered. All test samples were installed on an OFHC copper drum with an outer surface area of 0.36 m^2. The temperature of the copper drum, dubbed the Cold Plate, can be varied from 7K to 50K. The warm boundary is fixed near 80K by an OFHC copper shield secured to the bottom of an LN_2 reservoir. The inner surface of this 80K shield is covered with 3M No. 425 aluminum tape to provide a low emittance surface simulating the aluminum 80K shield of the cryostat. Heat transfer in the system is measured using a heatmeter; insulating vacuum is measured with two independent Bayard-Alpert nude ionization gages.

The measurement program has been tailored to address conditions found in the SSC cryostat. To this end, one series of measurements was conducted with 3M No. 425 aluminum tape installed on the outer surface of the Cold Plate. The objective was twofold: 1) simulate the cryostat condition of two aluminum surfaces facing one another; and 2) study the effects of varying gas pressure on systems with no MLI. The second series of measurements measured the performance of a 10-reflective layer MLI blanket installed on the Cold Plate. Reflective layers were 0.03 mm thick Mylar aluminized with a nominal coating thickness of 600 angstroms, or 0.45 ohms/square, on each side. Reflective sheets were held apart by sets of three spacer layers of 0.10 mm thick spunbonded PET mat. The additional spacer layers decreased the blanket layer density to 1.6 layers/mm. Finally, the MLI test blanket incorporated the stepped seam/stepped joint geometry previously described for the 80K system.

Figure 3 presents results from these measurements. At pressures below 4.0E-6 torr the measured heat flux into the cold surface is below the design budget for both test schemes. However, as the pressure increases the system with no MLI experiences a rapid increase in heat transfer to the cold boundary. This is in direct contrast with the rate of heat transfer increase seen through the MLI blanket. These results show that the MLI blanket does in fact impede heat transfer through residual gas conduction, and serves to maintain a lower overall heat flux as the pressure increases.

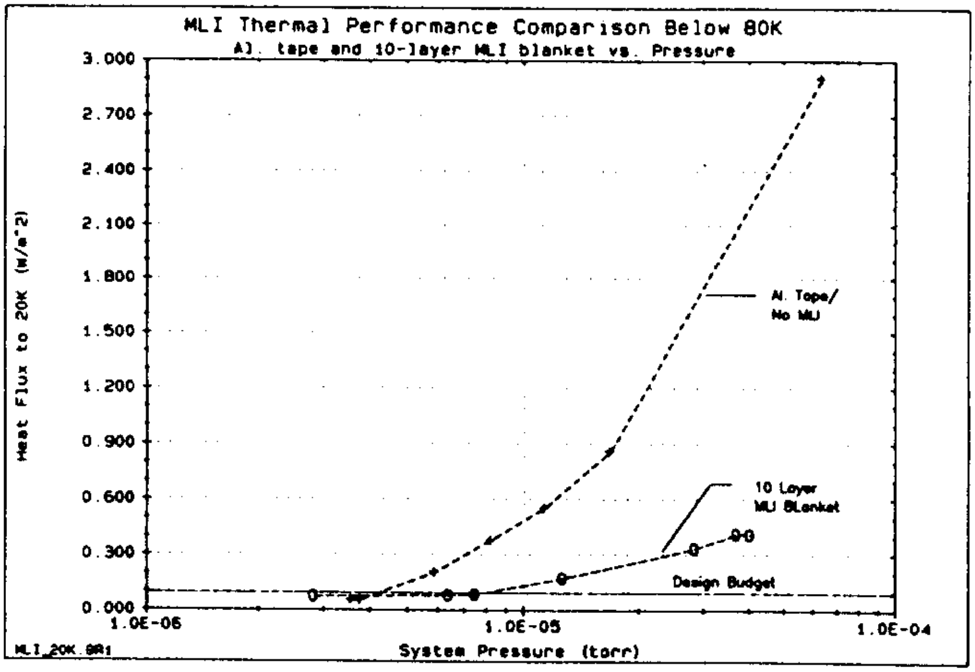

Figure 3. MLI performance from 80K to 20K

It must be noted that there is some question as to the actual pressures being measured in the calorimeter. Using equations for radiant energy exchange and residual gas conduction by Scott/9/, values of predicted vs. measured heat flux were calculated using measured temperatures and pressures and are presented in Figure 4. Since redundant thermometers verified measured temperatures and the heat leak measurement method accuracy was verified with calibration heaters, a calculation is also presented which plots a predicted pressure given measured temperatures and heat load.

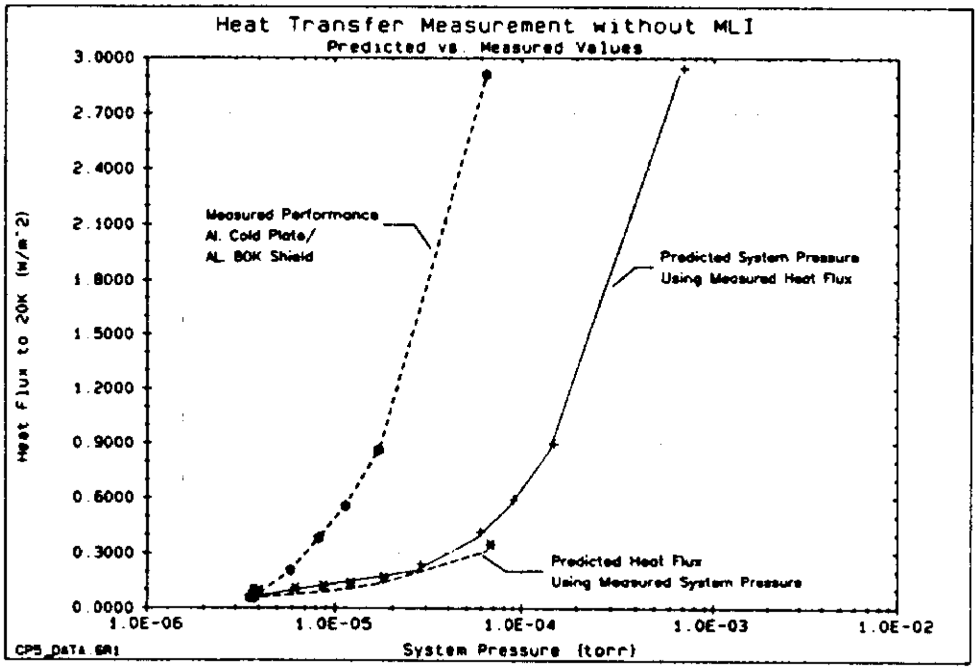

Figure 4. Predicted vs. Measured Values with No MLI Installed

The graph illustrates the large disagreement between predicted vs. measured values of heat flux as the pressure increases. Since the measurement methods are considered valid, one explanation is that the pressure between the 80K and 20K surfaces in the calorimeter is different from the pressure being measured at the vacuum vessel wall. It should hold that this pressure be lower due to cryopumping onto the colder surfaces. However, it must be noted that the method of increasing pressure in the system is through system outgassing with the vacuum pump valved off. Due to the high conductance in the system, it is conceivable that if the larger sources of outgassing are in the innermost areas, then a pressure gradient through the cryostat of one decade in the molecular flow regime is not unreasonable. This is still under investigation.

Due to this uncertainty, the data it must be qualified as qualitative rather than quantitative in the increased pressure region. Still, the data is useful in establishing the benefit of an MLI blanket on gas conduction shielding at pressures above 1E-6 torr. Thus, with the support of these measurements, the blanket design specified for the 20K MLI system incorporates 10 reflective layers of PET film aluminized with a nominal coating thickness of 600 angstroms per side. The reflective layers are held apart by sets of three spacer layers of 0.10 mm spunbonded PET material. Single layers of 0.23 mm spunbonded PET cover the blanket top and bottom to position the polyester Velcro fasteners. The multiple layers are sewn together along both edges of the blanket.

At each blanket edge, the upper MLI layers are sewn together from the upper cover layer through to the middle three layers of 0.10 mm PET material, with the thread terminated in the three middle layers. The seam location is then incremented 7.62 cm laterally along the midlayer, and the lower MLI layers are sewn together from the middle three layers through to the lower cover layer. The resulting geometry is shown in Figure 5.

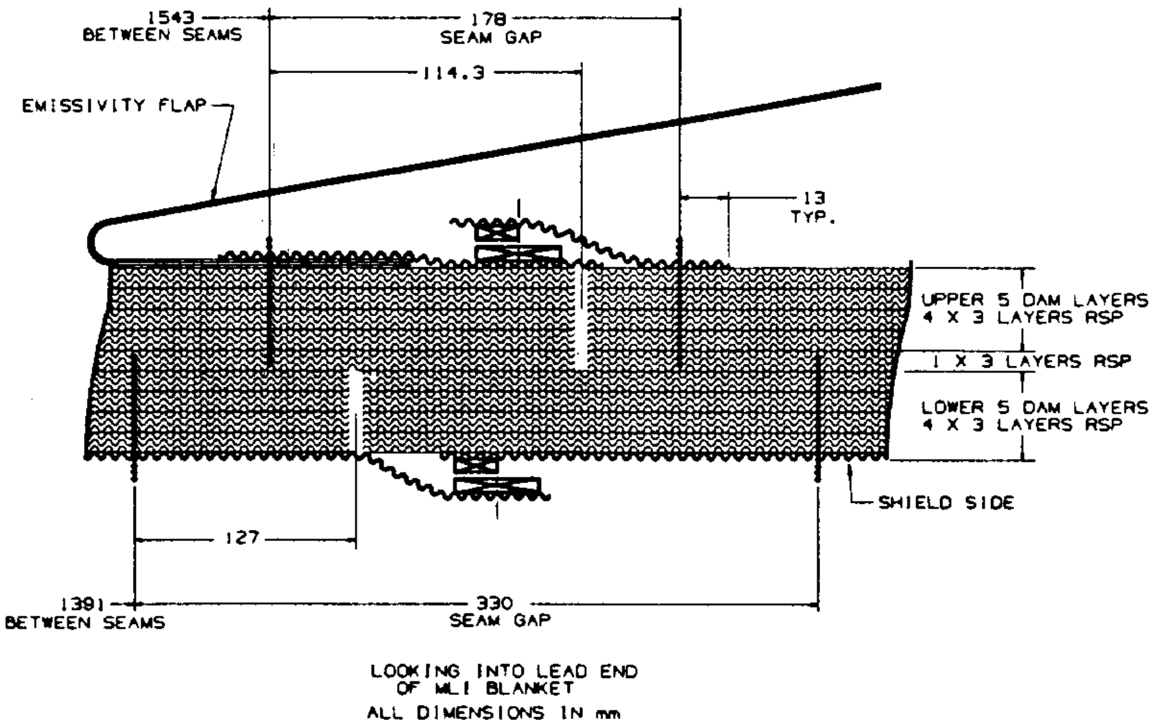

Figure 5. 20K MLI blanket geometry

Cold Mass MLI Geometry

Radiation heat transfer between 20K and 4K is almost negligible. However, this region is very sensitive to changes in insulating vacuum levels. Results from computer modeling show that the presence of a 10-layer blanket on the cold mass appreciably reduces the heat leak into the cold mass at pressures above 10^{-6} torr/10/. Thus, the primary function of the cold mass blanket is to impede residual gas conduction between 20K and 4K.

The MLI system for the 4K cold mass consists of a single 5-layer blanket that is spirally-wrapped twice around the cold mass for a total build of 10 reflective layers. The cold mass blankets do not employ hook and loop fasteners or heavy cover layers. Rather, they are held in place with 7.62 cm wide adhesive-backed aluminized polyester tape. The MLI layers are sewn together near both edges of the blanket during blanket fabrication. During cryostat installation, one sewn seam is cut off as the blanket is wrapped onto the cold mass. The remaining sewn seam serves to maintain interlayer registration while holding the assembly together.

4. METHOD OF FABRICATION

A large diameter winding apparatus is used to fabricate the MLI blankets for the cold mass and thermal shields. The apparatus consists of a rotatable mandrel having a 5.5 meter fixed diameter with an outer surface that is crowned with a convex cross-section. Adjacent supply spools hold the reflective and spacer materials. The function of the apparatus is to wrap the appropriate number of layers from the supply spools around the fixed mandrel. When the appropriate number of layers are wrapped onto the mandrel for a given blanket thickness, the materials are cut away from the supply spools. Since each layer wrapped increases the circumference of the mandrel, each successive layer is slightly greater in length then the preceding layer. Thus, the blanket fabrication method provides integral material to accommodate thermal contraction to cryogenic temperatures.

Each blanket is bound together by sewing through the blanket with a lock-stitch set at 1.5 stitches per cm. The sewn seams are made by rotating the blanket through a stationary sewing machine while the blanket remains on the mandrel. This method serves to lock in the extra material for thermal contraction while fixing the mean layer density of the blanket. Once the sewing operation is complete, a single cut is made across the blanket parallel to the mandrel axis. The assembly is then removed from the mandrel.

Since the perimeter of the mandrel is slightly larger than the required length of the blankets, the resulting MLI blanket has sufficient length and width for an SSC shield or cold mass assembly. Additionally, the sewn seams serve to insure three-dimensional uniformity and stability, controlled layer density, and interlayer cleanliness. Finally, the seams fix interlayer registration to maintain blanket edge alignment during shipping, handling, and cryostat installation.

5. CRYOSTAT INSTALLATION

During cryostat assembly, each MLI blanket is wrapped around the shield such that the edges of the blanket overlap to form the stepped, butt-joint connection illustrated in Figures 2 and 5. The effect of the joint on thermal performance is decreased by staggering the blanket penetrations; there are 24 uninterrupted layers at any point along the 80K shield and 5 uninterrupted layers at any point along the 20K shield. To further reduce the effects of the blanket joint on thermal performance, the inner and outer seams are staggered on the cryostat.

Blanket installation begins by securing opposite ends of the inner blanket lower cover layer to each other by full engagement of the hook and loop fasteners. As the lower cover layers are overlapped and secured, perpendicular alignment marks are superimposed, thereby confirming a cylindrical blanket assembly along the cryostat length. The MLI layers between the sewn seams are then joined along the cryostat length using the stepped butt-joint. As the blanket edges are drawn together, tension on the blanket is taken by the sewn seams and cover layers; material located in the greater blanket area between sewn seams is isolated from the tension by the seams. The joint configuration is completed by full engagement of the upper cover layer hook and loop fasteners over the joint area. The resulting blanket installation is secured from opening by the closure of the two hook and loop fasteners. Thermal testing of the fasteners showed that the connection became more secure during cooldown to 77K due to the thermal contraction of the hook/loop connection.

The outer blanket is installed in a similar manner. However, the outer cover layer of the outer blanket must be removed to uncover the outermost reflective layer of DAM. Additionally, the emissivity flap must be folded over the heavy spacer material covering the seam area to provide a low emissivity surface to thermal radiation.

6. SUMMARY

The MLI system meets the design requirements set forth for the SSC dipole cryostat. Measurements conducted on the subsystems document the thermal performance of the design geometry and qualify the systems for inclusion into the cryostat assembly. A cost-effective method of mass-producing MLI assemblies has been successfully developed. The benefits of this technique include 1) a reduction in overall fabrication time; 2) a reduction in the number of personnel required to fabricate a finished product; 3) elimination of layer by layer handling; and 4) control of dimensional parameters such as layer density and edge registration. The fabrication technique allows each blanket assembly to be treated as a single component at cryostat assembly. Additionally, Velcro closures remove decision-making from the production floor and insure that each blanket assembly is installed in a like manner. Through the benefits of the MLI system design, consistent thermal performance will be established throughout the accelerator.

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Isolation Multicouche Pour le Supercollisionneur Supraconducteur (SSC)

RESUME: L'isolation multicouche (MLI) pour les cryostats des dipoles du supercollisionneur supraconducteur (SSC) doit a la fois répondre a de strictes spécifications concernant le budget thermique du cryostat et maintenir l'intégrité de l'isolation durant toute la vie de l'accélérateur estimée a 25 ans. Cette isolation comprend différentes couches installées sur des parois a 80, 20, et 4 Kelvin. Nous présentons ici une revue des différentes configurations géométriques et des différents matériaux que nous avons ensisagés. Nous discutons en détail la solution actuellement retenue en nous basant sur des mesures que nous avons faites des performances thermiques des écrans a 80 et 20 Kelvin. Nous présentons également les techniques qui peuvent être employées pour produire en masse des isolations multicouches de géométrie constante a des coûts raisonnables Enfin, nous décrivons les paramètres de notre design qui pourront être utilisés pour controler la qualité de l'isolation multicouche durant la production des cryostats.