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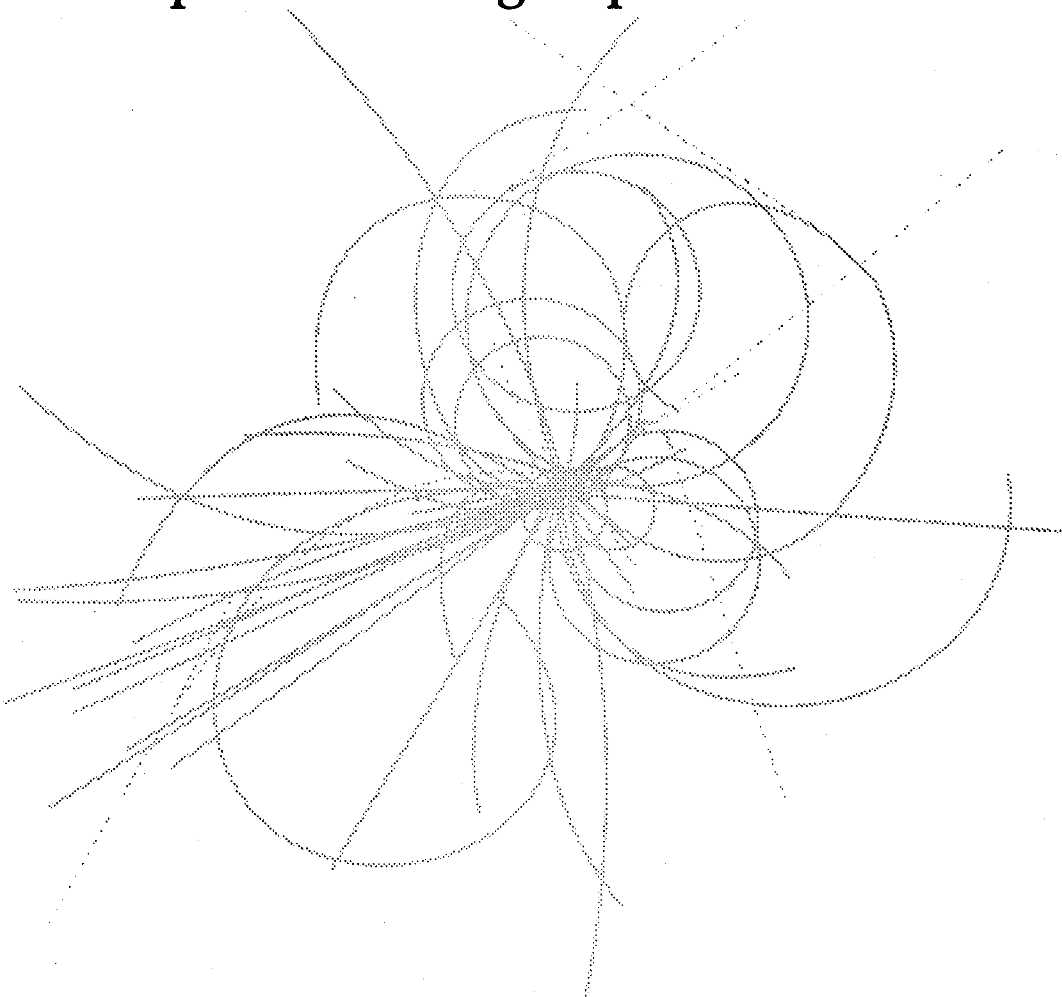

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CONCEPTUAL DESIGN OF THE SSC CRYOGENIC TRANSFER LINES

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Abstract: The SSC cryogenic system requires transfer lines for transporting cryogens between above-ground refrigeration plants and below-ground subcoolers. The transfer lines will be built in modules for convenience in fabrication, handling, and assembly. Each module of the transfer line consists of a vacuum vessel which encloses a bundle of seven cryogenic circuits at 4 K, 20 K, and 80 K. The cryostat includes an 80 K shield and a multilayer insulation (MLI) system for reduction of the heat leaks into the 20 K and 4 K circuits. Heat leaks through various paths are estimated and presented in conjunction with the basic system requirements. Discussions are provided on the design criteria, constraints, and thermal contraction handling techniques.

INTRODUCTION

Cryogenic transfer lines are required for the SSC cryogenic system to transport cryogens between the above-ground refrigeration plants and the below-ground main ring. This work summarizes the issues pertinent to the design and performance analysis of the transfer lines. A transfer line consists of seven cryogenic circuits which are enclosed in a single cryostat. An internal suspension system supports the internal components including the cryogenic circuits, a multilayer insulation (MLI) system, and a thermal shield. Through this suspension system, the loading from the internal components is transmitted to the vacuum vessel. The capacity requirement of the internal suspension system is based on a 2g loading of all the internal components of the cryostat. Three types of internal suspension systems are evaluated. Heat leaks into the three cryogenic circuit groups (4 K, 20 K, and 80 K) through each suspension system are estimated and compared.

The main ring of the collider is divided into ten sectors and the high energy booster into two sectors. Each sector is an independent cryogenic unit with its own

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helium refrigeration plant supplying helium for the 4 K and 20 K circuits. The nitrogen supply is provided by one or two air separation plants for the entire collider. There is a nitrogen dewar for each sector which can be filled during normal operation by withdrawing liquid from the magnet nitrogen circuit. The dewars may also be filled by nitrogen trailers to serve as the nitrogen supply source during collider maintenance periods. One transfer line is required at each sector to transport helium and nitrogen required for maintaining the operating temperatures of the magnets and their thermal shields. The total length of the transfer lines for connecting the main ring to the refrigeration plants is estimated at 1,250 m (4,100 ft). The transfer lines will be built in two kinds of basic construction units, the standard module and the elbow piece. The standard modules constitute over 90 percent of the transfer lines, and the elbow pieces complete the bends at required locations. The module is approximately 12 m long and weighs 1,800 kg (4,000 lb). As depicted in Figure 1, a transfer line starts at the helium refrigeration plant building running horizontally towards the utility shaft. It continues vertically down along the shaft wall reaching the bottom of the shaft, where it runs horizontally to the subcooler coldbox. The next section of the transfer line connects the coldbox to the feed/distribution box in the cryogenic alcove located on the other side of the main ring. The ring tilt and the local topography

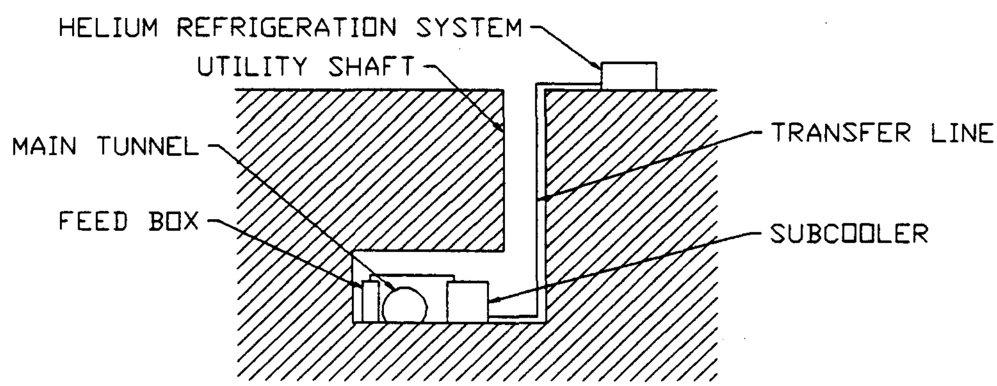

Figure 1: Schematic layout of a cryogenic transfer line

dictates that the length of the transfer line vary from sector to sector, particularly in the vertical sections. It ranges approximately between 70 m (229 ft) and 120 m (394 ft). The cryogenic circuits are designed to meet the system requirements tabulated in Table 1.

DESIGN AND ANALYSIS

The design requirements of the transfer lines include high reliability; low heat leak; easy fabrication at minimal cost; and convenience in handling, transport, assembly, and maintenance. In each standard module, an internal suspension system provides mechanical means to secure the cryogenic circuit bundle, the thermal shield, and the MLI system to the vacuum vessel. It is composed of one longitudinal and five radial supports. The longitudinal support is located at one end of the module so that the circuits can move freely at the other end to accommodate thermal contraction. The radial supports distribute the radial loading, and reduce deflection and vibration

Table 1: System characteristics

	Pressure		Temperature	Mass Flow Rate	
	Design (Bar)	Nominal (Bar)	(K)	Design (g/s)	Nominal (g/s)
4 K helium supply	20	4	4.5	400	400
4 K helium return	20	3.5	4.28	300	100
4 K gas helium	10	.8	4.0	400	300
20 K helium supply	20	3	16.5	200	200
20 K helium return	20	2	24.0	200	200
80 K liquid nitrogen	20	10	80.0	400	80
80 K gas nitrogen	10	1.3	80.0	400	350

in the circuit tubes. The radial supports are evenly spaced at 2 m intervals, corresponding to a natural frequency around 33 Hz for the circuit tubes. The external support system will provide measures to secure the entire transfer line at designated locations.

The vacuum vessel is made of 609.6 mm (24 in) schedule 10 carbon steel pipe. Stainless steel tubes sizing from 50.8 mm (2 in) to 101.6 mm (4 in) are used for the cryogenic circuits. The 80 K thermal shield will be rolled out of copper sheet. The internal radial support consists of three disks of composite material, and the longitudinal support is constructed using stainless steel plates and corrugated shells. In the interconnect region, the circuits are joined by stainless steel bellows to accommodate thermal contractions.

Vacuum Vessel and Vacuum Barrier

The stress analysis on the vacuum vessel is based on the pressure range, concentrated stresses at both internal and external supports, and buckling criteria for the vessel as a slender shell.

The transfer line at each sector will be an independent vacuum unit. Vacuum barriers will be installed at both ends of a transfer line to isolate the transfer line vacuum space from that of the connecting subcooler coldbox in the tunnel and feed/distribution box at the surface. The barriers also serve as the local longitudinal supports for the internal components. The cross section of a vacuum barrier is shown in Figure 2. Three stainless steel plates are used to support the three cryogenic circuit groups. They are thermally set at nominal temperatures of 4 K, 20 K, and 80 K, and connected by two sets of concentric stainless steel shells. An additional set of shells anchors the 80 K plate to the vacuum vessel. The operating vacuum level of the cryostat will be maintained below 10^{-6} torr.

Internal Suspension and External Support Systems

The internal suspension system supports the circuit tubes, thermal shield, and MLI blanket by transmitting the loading from these internal components to the vacuum vessel. As shown in Figure 3, a radial support consists of three circular composite disks. Each disk supports one of the three cryogenic circuit groups. The disks are separated and supported by stainless steel rods which transmit the loading from the 4 K disk to the 20 K disk, and then to the 80 K disk. A set of rollers is attached to

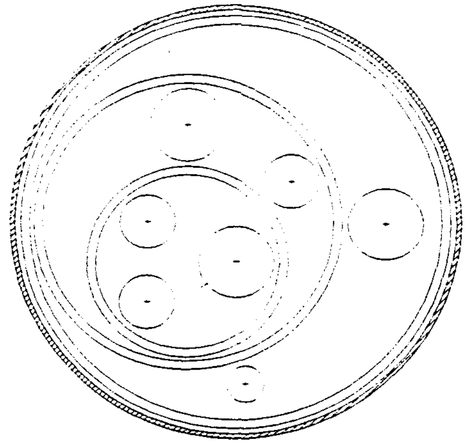

Figure 2: Vacuum barrier for transfer lines

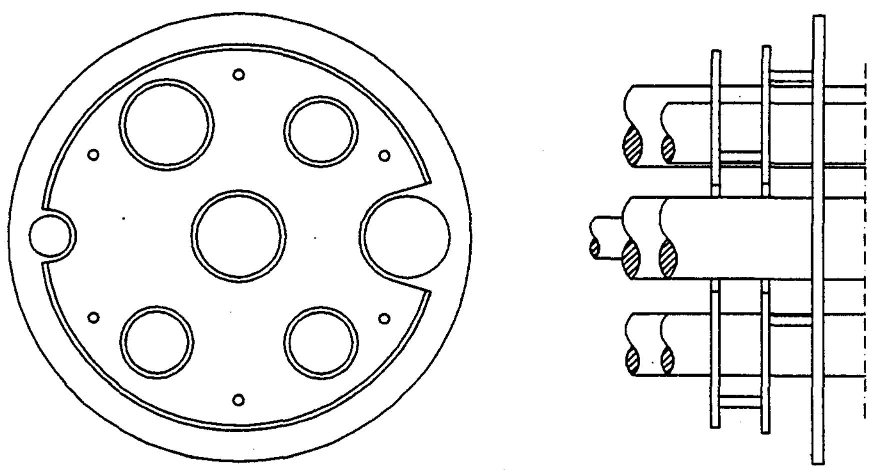

Figure 3: Disk-type suspension system

the 80 K disk in such a way that the disk can slide longitudinally within the vacuum vessel following the thermal movement of the 80 K tubes. The 80 K circuit tubes are secured to the 80 K disk, while the 4 K and 20 K tubes are allowed to move freely within the 4 K and 20 K disks in the longitudinal direction.

Other design options evaluated include a post-type suspension system and a sleeve-type suspension system, which are shown in Figure 4. In the post-type suspension design, three S-shaped cylindrical composite shells are used to support the internal components. They are integrated by two stainless steel shells. The sleeve-type suspension design uses a single stainless steel plate at 80 K, which supports all the circuit tubes. Each 20 K tube is secured to the plate by a set of sleeves, and the 4 K tubes are attached to the same plate as a bundle.

The performances of the various internal suspension systems are compared and the systems are judged by their structural integrity and heat leak resistance. Among the systems evaluated, the sleeve-type design offers the best structural integrity and reliability. However, this design has the highest heat leak into the 4 K circuits. The

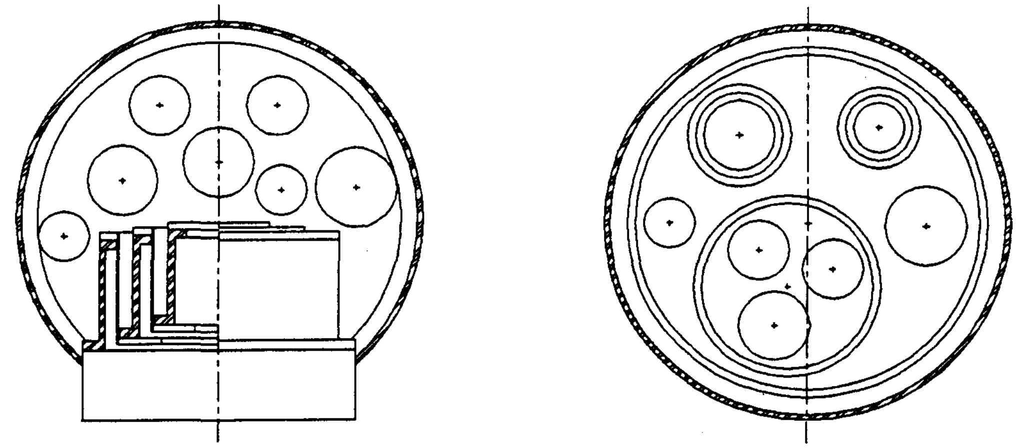

Figure 4: Post-type and sleeve-type suspension systems

post-type suspension requires penetrations in the vacuum vessel, which is an undesirable feature for the transfer lines since it reduces the available cross-sectional area for the tubes. Each internal suspension system is structurally designed to meet the same loading requirement. The differences in building material and in construction geometry lead to a variation in heat leaks into the three cryogenic circuit groups. The estimated conductive heat leaks into the cryogenic circuits are set forth in Table 2.

Table 2: Heat leaks for different internal suspension systems

Support	Heat Leak (W)		
Type	4 K	20 K	80 K
Post	.0123	.259	2.038
Disk	.0408	.62	5.95
Sleeve	.4289	.4052	10.41
Vacuum Barrier	.0225	.8472	10.73

Each transfer line module will be supported externally at two locations to distribute the loading. The external support system will provide means for position adjustment in three orthogonal directions at the final assembly. Additional external attachments are also needed for handling, transport, and assembly.

Interconnections

In the interconnect region where two adjacent transfer line units will be joined, each circuit tube will be connected with a bellows to accommodate the thermal contraction. This is accomplished by compressing the bellows at ambient temperature to a certain degree at the final assembly, such that when the circuit reaches its operating temperature, the bellows will assume a length which reduces the tensile stress in the bellows. The thermal shield and MLI blanket are bridged in the interconnect region. The bridging shield overlaps with the joining shields on both ends. The layers of the MLI system are preferably interwoven to produce a smooth transition. A sleeve type joint will be welded between the two joining vacuum vessels to make up the gap after all the internal components are properly joined and leak-tested.

Elbow Pieces

The transfer lines require 90° bends at several locations. Each bend causes a change in the orientation of the cross section of the cryostat with respect to the center line of the vacuum vessel. This orientation change does not have any impact to the standard modules, as each of them can be rotated at the final assembly to match the required cross section. However, it dictates that each elbow piece have a different cross section with respect to the plane in which the elbow lies.

Another important issue concerning the elbow piece is its internal longitudinal support. Since bellows are used to handle thermal contractions in the cryogenic circuits, the tensile stress in each circuit tube at the bend due to the static pressure and hydraulic hammer has to be localized within the elbow piece. The longitudinal support for an elbow piece is primarily sized for this loading.

Thermal Shield and MLI System

A single thermal shield operating at liquid nitrogen temperature is adopted to intercept the heat leak into the helium circuit bundle. It is mechanically supported by, and thermally anchored to, the 80 K circuit tubes. Its thickness is determined by the buckling criteria for the horizontal sections, where the shield bears the total weight of the MLI system, and by the allowable temperature difference across the shield.

The thermal contact between the shield and the circuit tubes is established by soldering (copper to stainless steel). The maximum length of each thermal shield piece is limited by the thermal contraction differential between copper stainless steel within the temperature range 300 K to 80 K. This problem can also be resolved by running a nitrogen trace line along the shield without attachment to the 80 K lines. In this way, the conflict between the structural support and thermal contact is eliminated as they are uncoupled and treated separately.

The heat flux intercepted by the thermal shield causes a circumferential temperature variation in the shield. The maximum temperature difference in a 1 mm thick copper shield is approximately 1 K. An MLI blanket of sixty layers is applied over the 80 K shield and secured to the internal suspension system. Escape paths are provided for the gas molecules trapped between insulation layers to ease the vacuum-pumping effort. Each helium circuit tube is wrapped with ten layers of MLI to further reduce the heat leak.

Hydrodynamics

Two major aspects of hydrodynamics in the transfer line design are the total pressure drop through each circuit, and the static and dynamic loading on the internal suspension system. Considering the pressure drop, geometrical constraint, and economics, the circuit tubes are sized and listed as follows:

- 4 K helium supply (76.2 mm O.D. × 1.65 mm wall)
- 4 K helium return (76.2 mm O.D. × 1.65 mm wall)
- 4 K helium gas return (101.6 mm O.D. × 1.65 mm wall)
- 20 K helium supply (76.2 mm O.D. × 1.65 mm wall)

- 20 K helium return (101.6 mm O.D. × 1.65 mm wall)
- 80 K liquid nitrogen (50.8 mm O.D. × 1.24 mm wall)
- 80 K vapor nitrogen (101.6 mm O.D. × 1.65 mm wall)

The design pressure drop and heat leak per unit length for each circuit are presented in Table 3. The last two columns in the table list the site-specific total pressure drop and heat leak of each circuit for the N15 sector. At an elbow piece, the static pressure in a circuit tube exerts an internal tensile stress in the wall of the circuit tube. This stress will be transmitted along the circuit tube to the bellows in both directions unless the loading is localized within the elbow. The internal longitudinal support of an elbow piece has to withstand this loading to protect the adjacent bellows. This support will also absorb the dynamic loading due to the momentum change of the flowing cryogen at the elbow. On the other hand, the static loading is allowed to transmit along the vacuum vessel, and the dynamic loading is localized and transmitted to the external supports for the elbow piece.

Table 3: Pressure drop and heat leak for the transfer lines

	Pressure Drop Pa/m	Heat Leak W/m	Δp at E1 Pa	$\dot{q}$ at E1 W
4 K helium supply	9.28	.005	1114	1.37
4 K helium return	4.86	.005	583	1.37
4 K gas helium	18.61	.005	2233	1.37
20 K helium supply	3.69	.014	443	22.3
20 K helium return	17.13	.014	2059	22.3
80 K liquid nitrogen	16.77	1.079	2012	280
80 K gas nitrogen	62.52	1.079	7502	280

SAFETY DEVICES AND INSTRUMENTATIONS

Each transfer line will be equipped with emergency pressure relief devices to guard the vacuum vessel against any accidental internal pressure build-up. The pressure relieving requirements for the cryogenic circuits are covered by relief devices for both above-ground and below-ground cryogenic equipment. A vacuum-pumping port is provided at each module, and will also be used for leak detection and diagnosis. On the prototypes, temperature sensors are to be installed on the internal suspension system at designated locations to verify the estimated heat leaks.

SUMMARY

The requirements for the SSC cryogenic transfer lines have been investigated. The resulting conceptual design has been outlined in this work. Prototypes of the transfer line module and elbow piece will be built and tested prior to mass production. Testing of the prototypes will concentrate on the performance of the internal suspension system. The structural integrity and thermal performance of the suspension system will be examined and compared with the theoretical predictions.

REFERENCES

1. H.H. Bednar. *Pressure Vessel Design Handbook*, 2nd Ed., Van Nostrand Reinhold Company Inc., New York (1986).

2. P.R. Smith and T.J. Van Laan. *Piping and Pipe Support Systems*, McGraw-Hill, Inc., New York (1987).