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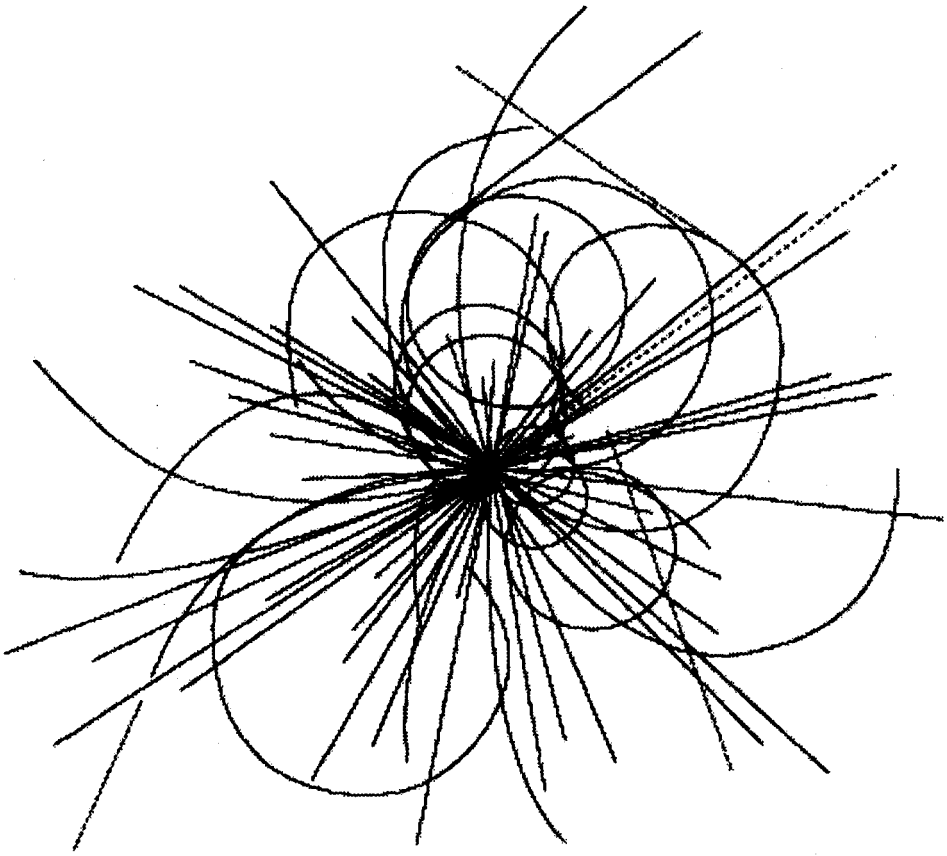

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PRELIMINARY DESIGN OF SECTOR CRYOGENIC SHAFT TRANSFER LINE SYSTEM

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INTRODUCTION

The SSC cryogenic system has an unprecedented capacity to supply cryogens at 4 K, 20 K (helium) and 80 K (nitrogen) for both normal operation and transient conditions of the collider magnets and thermal shields.[1] At each sector, the terminal element of the surface refrigeration plant is the surface distribution box (SDB). On the collider side, four half-feed spool pieces (SPRF) interface with the underground cryogenic facilities. The shaft transfer line connects the surface distribution box and the helium cold compressor box in the underground cryogenic chamber. Its reliability is vital to the operation of the SSC cryogenic system. The shaft transfer line consists of 7 cryogenic circuits enclosed in a common vacuum jacket (24 in O.D., schedule 10 carbon steel pipe). The 4 K gas helium, 20 K helium return, and 80 K gas nitrogen circuits use 4" stainless steel tubes, and the other circuits use 3" tubes. The wall thickness for all circuit tubes is 1.651 mm. The length of the shaft transfer line varies from sector to sector. It ranges from 30 to 80 meters. Each shaft transfer line is to be built in basic construction units (straight module and elbow piece) and assembled on-site. The maximum length of the straight module is 12 meters (40 ft). An isometric view of a transfer line module is shown in Figures 1. The thermal shield, covered by two MLI

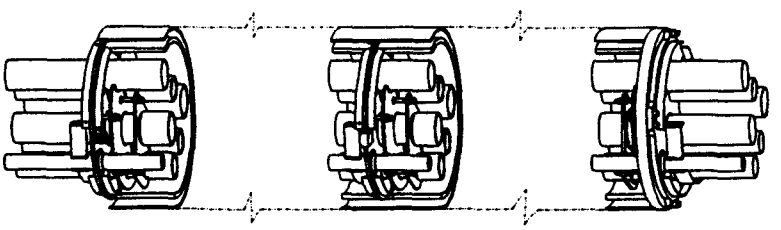

Figure 1: Isometric view of transfer line module

blankets, encloses all the circuit tubes. It is split in halves circumferentially proportional to the locations of the two nitrogen circuit tubes, and soldered to the tubes at a 0.4 m interval. Each helium circuit tube is also covered by an MLI blanket. A shaft transfer line is a single vacuum unit. A vacuum barrier is attached to each end of a transfer line to isolate the vacuum space of the cryostat from neighboring equipment. The enclosed space will be evacuated after the on-site final assembly. A vacuum pumping port is installed on every construction unit, and two pressure relief devices are installed on each shaft transfer line to protect the cryostat from being internally pressurized when a circuit leak occurs. Bellows are used at every interconnect region to accommodate thermal movement for each circuit tube. The elbow piece completes a 90 degree bend. The circuit tubes

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are bent twice within the elbow cryostat to complete the 90 degree bend. Straight tube sections between the bends make the tubes parallel to the vacuum jacket. Mittered sections compose the vacuum jacket of the elbow piece.

This work summarizes the preliminary design of the shaft transfer line. Operating modes dictating the design criteria are addressed. System requirements, design constraints, and results of design analysis conducted on key elements are also discussed.

DESIGN

The design and nominal pressure, temperature, and mass flow rates for the seven cryogenic circuits of the shaft transfer line are presented in Table 1.† The design also needs to meet certain

Table 1: Shaft transfer line system requirements

Cryo. Circuits	P		T	Flow Rate	
	Design (bar)	Nominal (bar)	(K)	Design (g/s)	Nominal (g/s)
4 K He supply	20	4	4.5	400	400
4 K He return	20	3.5	4.3	400	100
4 K gas He	10	1	4.0	400	300
20 K He supply	20	3	16.5	200	200
20 K He return	20	2	24.0	200	200
80 K liquid nitrogen	20	10	80.0	400	80
80 K gas nitrogen	10	1	80.0	400	300

strength and heat leak requirements. The longitudinal support is designed to withstand a 2 g loading in all directions. The elbow support is designed for hydrostatic, hydrodynamic, and thermal loadings. Design pressures are used to calculate the hydrostatic loading. The estimated heat leaks into the cryogenic circuits per unit length are shown in Table 2. Pressure relief devices protect the vacuum

Table 2: Estimated heat leak per unit length

Heat Leak Budget (W/m)		
4 K circuits	20 K circuits	80 K circuits
0.0984	0.328	3.94

jacket against excessive internal pressure in the vacuum space of the cryostat. Temporary covers are required to protect the interior of the cryostat from damage and contamination at both sides of the modules and elbow pieces during transport. Lugs for handling are installed on the vacuum jacket before a module can be shipped. Appropriate procedures are to be developed for proper transport, handling, and assembly.

The straight module internal suspension system holds the internal elements (circuit tubes, thermal shield, and MLI blankets) and transmits the loading to the vacuum jacket. The suspension system consists of one longitudinal and four radial supports. The longitudinal support anchors the internal elements to the vacuum jacket at one end of the module. Each circuit tube is welded to a stainless steel collar which is bolted to the longitudinal support. One of the radial supports is installed at the opposite end to the longitudinal support, the rest are located at even intervals in between. They restrict the radial movement of the circuit tubes. Three caster modules are attached to the free end radial support to allow longitudinal movements. The internal suspension system for the elbow piece consists of two supports with one at each end of the elbow piece. Both supports are anchored to the vacuum jacket. Due to the 90 degree bend and the use of bellows for circuit tube interconnections, the supports will experience both hydrostatic and hydrodynamic loadings in various operating modes. Within an elbow piece, the thermal movements of the circuit tubes are accommodated by their flexures. Stainless steel brackets are attached to all internal supports to support the MLI blankets. The blankets are secured to the brackets using barbed snap-on type

†The actual mass flow rates of the nitrogen circuits could deviated from these figures substantially, depending on the final design of the nitrogen system.

nylon fasteners at designated locations. The stress analysis of the internal suspension system is performed using a finite element analysis package ViziCad by Algor, and the results are presented elsewhere[4]. The external suspension system holds the shaft transfer line at two locations on each module. It is to be designed for the operating mode which produces the most severe loading.[‡] All external supports will provide means for three-dimensional adjustment.

The temperature in the surface building (utility shaft head house) is in the range of 0° to 50°C. The controlled collider tunnel temperature is at 80° ± 5°F. The assessment of the thermal stress level in the vacuum jacket is based on the the differential of thermal expansion between the vacuum jacket material (carbon steel) and the utility shaft wall (concrete). The thermal stress will be below 1,500 psi for a temperature difference of 50°C, which falls well below the allowable level. Appropriate spring factors need to be incorporated in the external suspension system design to reduce thermal loading. Attachment to the vacuum jacket is required for external support and handling. The surface area of the attachment to the module vacuum jacket for external support and handling is sized in such a way that a 2 g loading of the module can be supported at one location.

The cryostat serves for the purpose of reducing the heat leaks into the cryogenic circuits. Refrigeration for the thermal protection is available at 20 K and 80 K. Considering the structural simplicity and reliability, only one thermal shield (gauge 19 copper sheet) at 80 K is used. The thermal contact is established by soldering the shield to the 80 K tubes. Numerical analysis indicates that the circumferential temperature variation in the thermal shield is less than 1 K. Two MLI blankets are used over the thermal shield. The blanket design is similar to that for the dipole magnet cryostat.[5] Each blanket has 20 layers of alternating double-sided aluminized mylar and spunbonded polyester spacer. Velcro strips are attached to the blanket to secure the blanket over the thermal shield. An MLI blanket of 20 layers is applied to each helium circuit tube. The internal suspension system interrupts the continuity of the MLI system at each support assembly. To prevent any see-through between the vacuum jacket and the helium circuit tubes, a smaller MLI blanket is used to bridge the gap between two neighboring MLI blankets at these locations. Each shaft transfer line is a single vacuum unit. It is isolated from the neighboring equipment by two vacuum barriers at the ends. A vacuum pumping/leak detection port is provided at each interconnect region. The design vacuum level of the cryostat is 1×10^{-6} torr measured at the inner surface of the vacuum jacket. This vacuum level is to be maintained even at the presence of a minor leak (a helium leak rate less than 10^{-6} std cm^3/s). The vacuum space is rough-pumped to 1.0×10^{-4} torr and then cryopumped. The cryopumping essentially involves solidification and adsorption of residual gas particles on surfaces at cryogenic temperature by means of van der Waals' forces. Both the thermal shield and the 80 K circuit tubes will be cryopumping after the system cool-down. When a specific pumping speed (pumping speed per unit area) S/A = 14 l/s-cm^2 is used for the 80 K surfaces, sufficient cryopumping power will be available for the condensible gas constituents due to the outgasing of the surfaces in the cryostat. Cryosorption, a physical adsorption process which also relies on van der Waals' forces, is adopted for vacuum retention purpose. Since the equilibrium pressure of adsorbed gas particles is far lower than the corresponding saturation vapor pressure,[6] particles of the gas constituents difficult to condense (neon, hydrogen, and helium) have to be adsorbed in sub-saturated conditions. Activated charcoal is used as the adsorbent in a cryogenic getter. The getter has an enclosure (shroud) to block the condensable gas especially water vapor particles. This enclosure also serves as a thermal shield to prevent direct radiative thermal communication between the getter adsorbent and warmer surfaces in the cryostat. The getter module, bolted to the 4 K gas helium circuit tube to obtain mechanical support and refrigeration, is located in the interconnect region on the radial support side. The quantity of charcoal to be used in each getter is calculated based on the assumption that the average thermal cycle of the collider is one year. The getters are to be regenerated every time the system is warmed up. In the event when substantial internal leak occurs , a turbo pump will be connected to the cryostat for continuous pumping to maintain the vacuum level at 1.0×10^{-4} torr.

Copper thermal shorting straps are used to maintain temperature boundary conditions of 20 and 80 K at various locations for both longitudinal and radial supports. The maximum temperature drop through one strap is less than 2 K. The vacuum barrier primarily consists of three groups of concentric shells and plates, each holds the circuit tubes at the same temperature level(4, 20, or 80 K). The length of the shells is around 300 mm. Copper plates are soldered to the 20 and 80 K plates to intercept heat leaks into the helium circuits. Table 3 lists the heat leaks into the cryogenic circuits through the composite design option of the internal suspension system.

Two reclosing type pressure relief devices (one at each end of a transfer line) are installed on the vacuum jacket to protect the cryostat against accidental pressure rise. The cracking pressure

[‡]Depending on the final design of the bellows, this operating mode could be either the design operating or the CCWP mode.

Table 3: Heat leaks into cryogenic circuits through supports and vacuum barrier

Support/ Barrier	Heat Leak (W)		
	4 K	20 K	80 K
Radial	0.038	0.39	2.6
Longitudinal	0.047	0.62	6.3
Bend	0.062	0.89	9.1
Vacuum barrier	0.023	0.85	10.7

of the relief devices and the maximum allowable pressure in the cryostat are set at 5 and 15 psig respectively. The relief devices are sized for 400 g/s of liquid helium totally vaporized and warmed up to ambient temperature. Each pressure relief device is sized adequately for venting alone. The second relief device is for redundancy purpose. Each pressure relief device is equipped with a protective device for accidental blockage at the inlet to ensure uninterrupted venting.

At the final assembly, a number of construction units (straight modules and elbow pieces) are to be field-connected to form a complete shaft transfer line at each sector. The cryogenic circuits are to be joined by bellows. The alignment tolerance of the circuit tubes is 3 mm between center lines. Before the installation of the thermal shield and MLI system, all cryogenic circuits are to be helium leak-checked using a mass spectrometer. The vacuum jacket interconnection is accomplished using a section of split shells (clam shells). The structure and installation methods of the interconnect region determine the required clearance between the shaft transfer line and the utility shaft wall. This clearance will be kept under 6 inches in order to reserve an adequate drop zone area in the utility shaft. Orbital welder heads will be used whenever possible for the interconnection of the circuit tubes. A longitudinal cutter will be used for the removal of the interconnect section of the vacuum jacket for repair.

SUMMARY

Since the conceptual design of the shaft transfer line was presented in 1992, design effort has been concentrated on narrowing down the design alternatives. After evaluating and comparing various design options, a preliminary design of the sector cryogenic shaft transfer line is concluded. The design requirements and the results of design analysis are quantitatively presented. Open issues are addressed, and further improvement is expected and will be integrated into the final design of the sector shaft transfer line.

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