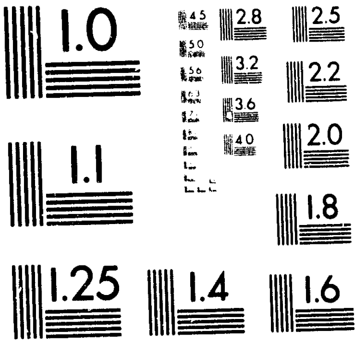
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SSCL-Preprint-427

Spool Pieces at the SSCL*

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May 1993

*Presented at the 1993 IEEE Particle Accelerator Conference on May 17–20, Washington, D.C.

†Operated by the Universities Research Association, Inc., for the U.S. Department of Energy under Contract No. DE-AC35-89ER40486.

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Abstract

The basic features of the Superconducting Super Collider lattice are the two beamlines formed by superconducting dipoles (7736) and quadrupoles (1564). The dipoles constrain two 20 TeV proton beams into counterrotating closed orbits of 86.2 km. The quadrupoles (FODO) require cryogenic cooling to LHe temperatures. This requirement isolates the main magnets from the outside world. The interface required, the spool, is a crucial component of superconducting lattice design and machine operation. There are over 1588 spools in the Super Collider. We present here SSCL spool designs which consist of 1) housing for superconducting closed orbit and multipole correction magnets, 2) cryogenic function, magnet quench protection, system power, and instrumentation interfaces, and 3) cold to warm transitions for warm magnet and warm instrumentation drift spaces.

I. INTRODUCTION

There are two superconducting cryogenic machines in the SSCL complex, The Collider and High Energy Booster (HEB). The Collider is filled with 2 TeV proton beams by the HEB. The HEB is a 10.8 km superconducting machine. The common task for the Collider and HEB is to design an interface that meets all the requirements of such large machines while maintaining costs and providing reliability in operation. The large quantities of spools and their criticality to machine operation directly effect spool production cost, reliability, and maintainability.

II. SPOOL CONCEPTS AND FUNCTIONS

There are three primary types of spools that perform all the functional requirements of the Collider and HEB. These are as follows:

The *Standard Spool* is found primarily in the arc sections of the Collider and HEB. Its principal functions are cryogenic control, quench (magnet) protection, correction magnet support, and vacuum isolation.

The *Transfer Spools* provide most of the functions of the Standard Spool in addition to their principal function of transferring the liquid cryogens and main power busses to cryogenic bypasses in warm drift regions.

The *I/O Spools* include three types, the Feed, End and Isolation Spools. These three spools have specific functions which are fundamental to the input (Feed), turnaround (End), and separation (Isolation) of cryogenics and main power throughout the Collider and HEB rings.

The primary categories of spools (Standard, Transfer, and I/O) do not contain just 5 types of spools as described above. The three primary types multiply into several variations due to limitations in space and the need for special functions in specific locations. One example is the need for a mirror image of all three types of spools. This is not satisfied by just rotating the spool 180 degrees, because the cross-section of any spool and its functions are not symmetrical. An ongoing effort exists to standardize and limit the types of spools. The obvious drivers of such an effort are design costs, spares, and maintenance.

III. STANDARD SPOOLS AND ARC CELLS

The standard spool's principal location is in the Collider and HEB arc half-cells. A Collider arc half-cell contains a main quadrupole magnet, spool, and five dipole magnets. This spools principle function is cryogenic control, quench protection and housing of correction magnets. This half-cell makes up the fundamental (FODO) cell of the Collider.

A HEB arc half-cell contains a main quadrupole magnet, spool, and two dipole magnets. This spools has the same principle function as the Collider arc spool of cryogenic control, quench protection and housing of correction magnets. This half-cell makes up the fundamental (FODO) cell of the High Energy Booster.

IV. SPOOL DESIGN

All spools provide an outer cryostat that contains plumbing, temperature shields, an inner cryostat and a beam tube. The Collider ring design has two counter-rotating rings with one above the other. Spool design for the collider must take into account that a second spool will be suspended above a Collider spool.

The HEB ring design is for a bipolar machine. This requirement of being able to accelerate protons in either a clockwise or counterclockwise direction requires the HEB spool design to consider instrumentation and control differences. The main effect takes place in the location of the Beam Position Monitor (BPM), which is housed in the spool. The requirements for the BPM that directly effect the spool design in the Collider and HEB are that the BPM must be located as close to the main quad of a half-cell as possible. In the case of the HEB a given BPM will be downstream of a main quad and upstream of the correction quads while accelerating protons in the clockwise direction. In the next phase of acceleration (counterclockwise) the same BPM will be upstream of the main quad and downstream of the spools correction packages. It turns out that operation and control correction schemes are able to handle the differences in clockwise versus counterclockwise alleviating the need for special BPM placements in the HEB. This however does not release the requirement of the BPM being positioned close to the main quad. In the Collider and HEB there are locations other than the arc cells that fail to be as straight forward. These locations such as the abort and transfer line straight sections position spools up and downstream of the main quads. This

*Operated by the Universities Research Association, Inc., for the U.S. Department of Energy under Contract No. DE-AC35-89ER40486.

requires the BPM and other components of the spools to a mirror image.

A. General Components, Cryogenic Piping

The Standard spool contains many pipes, valves, power leads, and instrumentation. This is because it is the principle interface into the superconducting rings. Table 1 lists the basic components of a standard spool.

Table 1
Standard Spool Requirements

Beam tube with connections
Beam tube vacuum port
Beam tube vacuum valves – warm
Beam Position Monitor (BPM)
BPM mounting interface to cryo pipe #1
Beam Position Monitor lead interface
Safety lead pair with quench stopper
Lead port correction element-6 pair, 83 A avg
Lead port instrumentation function (2)
Quench vent valve 1-phase to 20 K He
Valve cool-down / warm-up
Relief valve-cryostat to outside
Relief valve-liquid helium to outside
Relief valve-liquid helium return to outside
Relief valve-gaseous helium return to header
Relief valve-liquid nitrogen to outside (2)
Cryostat vacuum pumpout ports w/ valves (2)
Cryostat vacuum barrier
Cryo pipe #1-liquid helium cold mass
Cryo pipe #2-liquid helium return
Cryo pipe #3-gaseous helium return
Cryo pipe #4-20 K He
Cryo pipe #5 80 K Nitrogen
Cryo pipe #6 80 K Nitrogen
Shields-20 K and 80 K
Multilayer Insulation-20 K and 80 K
Insulation vacuum instrumentation
Correction element supported in cryo pipe #1

The Collider and HEB spool cryogenic piping requirements are the same as the cryogenic piping requirements of their respective main dipole and quadrupole magnets. The HEB pipes are defined in Table 1.

The spools as a component of the Collider and HEB are limited to the rate at which heat can be put into the cooling system. These rates are part of a budgeted amount based on cryo plant specifications. The standard spool heat load budgets are given in Table 2.

Table 2
HEB Standard Spool Heat Load Budget

Load Type	Liquif.	4 K	20 K	80 K
	g/s	Watts	Watts	Watts
Static Heat	0.072	2.73	15.71	57.87
Dynamic Heat		0.29		
Total	0.072	3.02	15.71	57.87

B. Vacuum Barriers

The standard spool within the HEB has two configurations. The differences are the vacuum barrier and recooler components. Due to design envelope limits and the complexity and size of both a vacuum barrier and recooler, only one of these components can be in a single HEB spool. The Collider spool has a longer design envelope than the HEB and is able to contain both a vacuum barrier and recooler in the same spool. There is a design requirement that a cryogenic machine maintain a vacuum to certain levels within the inner and outer cryostats of all the magnets, spools and drift spaces. By design the vacuum chambers of adjacent magnets and cryogenic components are connected. The vacuum barrier is a component that breaks up the cells of a machine into manageable vacuum chambers. Several design requirements for the vacuum barrier are opposing. The vacuum barrier must be robust enough to withstand fault conditions with atmospheric pressure on one side and evacuated conditions on the other side, and at the same time the heat leak requirements of the barrier want as little mass for heat flow. The vacuum barrier must be able to separate the insulating vacuum between the lead and return end of the spool. This allows for separate vacuum domains in each half-cell of the Collider and each cell of the HEB. All spools have two separate operating vacuum systems. The beam tube vacuum is the principle system and operates at or below 10^{-7} Pa. The other system is the cryostat insulating vacuum which is required to operate at or below 10^{-4} Pa. The systems are independent and maintained by flowing cryogens around and through the respective evacuated spaces. The vacuum requirements are maintained by cryo-pumping. This is the improvement of a vacuum by means of the adsorbtion of condensable gases on cold surfaces. Liquid helium at 4.2 K flows around the outer surface of the evacuated beam tube and cryo-pumps. The insulating vacuum is maintained by the 20 K helium and 80 K nitrogen gas which flow through the cryogenic pipes in thermal contact with the 20 K and 80 K shields which cryo-pump. At start-up vacuum is achieved by mobile pump carts that pull a vacuum on the beam tube and insulating chambers until cool down with cryogens enables a cryo-pumping condition.

C. Recoolers

The recooler is a component in the spool. It is a heat exchanger that takes 4.25 K liquid helium at its inlet and cools it to 4.0 K at the outlet. The recooler is designed to perform at 100 watts @ 4 K. The LHe return line supplies the recooler shell. This liquid helium is sent through the recooler valve and into the fill port of the recooler. The GHe that is produced by expansion across the valve is vented to the GHe return line. As a component of the spool the recooler maintains the cryogenic temperatures required for balance operation throughout the circumference of the Collider and HEB.

D. Quench Stopper / Quench Suppressor

Quenches are the localized increased resistance within a magnet that produces heat and propagates throughout the magnet and ring if left unchecked. Worst case quenching would destroy a magnet. The quench stopper stops the quenches from propagating by directing heat conduction through the bypass lead to the outside of a quenching half-cell. The quench system as a whole includes instrumentation which senses a quench in a local main magnet and initiates a quench stop sequence. The events include the diversion of the propagating quench heat and power on the bus around the quenching half-cell.

E. Correction Magnets and BPM

The Collider and HEB have requirements for correction of closed orbit errors both linear and higher order multipoles. The Spool is required to provide a means of housing and operating these superconducting correction magnets. There is a requirement for Corrector Element Power Leads (CEPL) to power and control the corrector fields. The spool must support the superconducting correctors by means of cooling with liquid helium and alignment and support by rails fiducialized to the spool and BPM. These alignment tolerances require state of the art manufacturing and a fiducialization that will allow alignment to the closed orbit beam when the spool is installed in the tunnel. The Beam Position Monitor (BPM) resides in the interconnect region of the spool. This is outside of the inner cold mass, but as close to the leading end of the corrector package rail support.

V. SPOOL TYPES

First draft effort at detailing, exceeded 20 types of spools for the Collider and HEB. The Collider counted a quantity of over 1580 spools and the HEB over 340 spools. An ongoing effort to lesson the quantity of types is critical to reliability, design costs, and the quantity of spares that would have to be purchased and stored. The types, quantities, and component functions of the HEB spools are listed in Table 3.

A. Transfer Spools

As defined in Section 2.0, Spool Concepts and Functions, the principal purpose of the Transfer Spools is the transportation of liquid cryogens and the main power busses to the cryogenic bypasses. This occurs in areas where warm drift regions are needed. This spool is a T box, where the cryogens and power busses leave the ring to a bypass cryostat. It has the typical interconnect joining from the previous cold magnet, and then routes the cryogen plumbing and power busses at a 90 degree angle. There is a cold to warm transitional interconnect that has just the warm beam tube continuing down the rings closed orbit. The straight sections are the locations in the ring that require warm drift sections. These warm sections contain kickers and warm magnets for beam abort, injection, and transfer to Collider. The warm sections also contains Radio Frequency (RF) cavities for acceleration of the proton beams. The table in Section 4.0 Spool Types, shows the various configurations and functions of spools that can be of the transfer type.

Table 3
High Energy Booster Spools

Spool	Rec	Length	Type	Left BPM	Right BPM	Quantity
SPRA	yes	3.675 m	Standard		x	136
SPXA	no	3.675 m	Standard		x	135
SPXAx	no	3.675 m	Standard	x		007
SPR4A/ SPR4a	yes	4.675 m	Standard	x	x	008
SPR4T/ SPR4t	yes	4.675 m	Transition	x	x	006
SPR5T/ SPR5t	yes	5.000 m	Transition	x	x	008
SPRAT/ SPRAt	yes	3.675 m	Transition	x	x	010
SPRE	yes	7.350 m	End Spool	x		002
SPRF	yes	7.350 m	Feed Spool	x		002
SPRI	yes	7.350 m	Isolation	x		002
SPXAR/ SPXAr	no	3.675 m	Return	x	x	002
SPX1R/ SPX1r	no	1.000 m	Return			017
SPX1T/ SPX1t	no	1.000 m	Transition			007

B. Feed, End (Return Box), and Isolation Spools

In addition to the same functional requirements as the standard spool, the Feed spool performs the functions as the main connection for power and cryogens to the power control and cryogenic plants. The End spool performs the turn around of power and cryogens for a cryogenic sector. The cryogenic sector is the portion of a ring maintained by a given cryogenic plant. The Collider has 10 cryogenic plants and the HEB two. The Isolation spools are placed periodically around the Collider and HEB rings to allow for isolation of cryogenic sectors in various maintenance, warmup, and cooldown modes. The Return Box is a variation of the End spool which allows for turnaround of cryogens and power in warm drift areas. The cryogens are only redirected in this case to the cryogenic bypass where they then continue in the nominal flow direction.

VI. ACKNOWLEDGMENTS

The authors would like to thank D. E. Johnson, E. Kindler, J. Austin, D. Strube, E. Cleveland, D. Bryant, G. Shuy, and V. Yarba for their continued support on this design effort.

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