EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

European Laboratory for Particle Physics

CERN - AT / MT Division

CERN LIBRARIES, GENEVA

CERN MT/93-04 (ESH)

LHC Note 237

CM-P00063445

**DESIGN AND CONSTRUCTION OF A PROTOTYPE SUPERFLUID
HELIUM CRYOSTAT FOR THE SHORT STRAIGHT SECTIONS OF THE
CERN LARGE HADRON COLLIDER (LHC)**

W. Cameron, B. Jenny, G. Riddone, P. Rohmig, R. van Weelderen

Cryogenic Engineering Conference (CEC), Albuquerque - 12-16 July 1993

Geneva, Switzerland

4 July 1993

DESIGN AND CONSTRUCTION OF A PROTOTYPE SUPERFLUID HELIUM CRYOSTAT FOR THE SHORT STRAIGHT SECTIONS OF THE CERN LARGE HADRON COLLIDER (LHC)

W. Cameron, B. Jenny, G. Riddone,
P. Rohmig, R. van Weelderen

CERN
1211 GENEVA 23
Switzerland

ABSTRACT

The lattice of the CERN Large Hadron Collider (LHC) will contain 384 Short Straight Section (SSS) units, one in every 51 m half-cell. A Short Straight Section is composed of a twin aperture high-field superconducting quadrupole, two combined-function corrector magnets and quench protection diodes, all operating in pressurised helium II at 1.9 K. The SSS cryostat also contains a barrier for sectoring the insulation vacuum and a Technical Service Module housing beam diagnostics, current feedthroughs and instrumentation capillaries, as well as cryogenic valves and pipework serving the local half-cell cooling loop. The helium vessel with its magnets, weighing about 6000 kg stands on two low heat inleak supports. Separate vacuum manifolds permit pumping the beam pipes every 51 m. Two thermal insulation systems, the radiative insulation and a gaseous helium cooled thermal shield, intercept incoming radiative and conductive heat. All these components must be arranged, to perform without interference and within the tight constraints of minimum transverse and longitudinal space occupancy. The design and function of the prototype SSS and its main features, covering mechanical and thermal aspects, as well as construction details, are described.

INTRODUCTION

CERN is currently undertaking design studies and development work leading towards the future Large Hadron Collider (LHC) project¹. This multi-TeV range collider will consist of a ring of twin aperture magnets using NbTi superconductors operating in a pressurized superfluid helium bath at temperatures below 2 K.

The standard arcs of the LHC ring, covering approximately 20 km of the circumference (in a total of about 27 km) are composed of standard cells repeated 192 times in the ring. One half of a standard cell, shown in Fig. 1, consists of three dipole magnets and one quadrupole magnet. Tuning and correction magnets are housed next to the quadrupole and a beam observation station (BPM) is located on the other side.

Fig. 1 : LHC half-cell layout

The present prototype Short Straight Section unit (Fig. 2) contains a twin aperture quadrupole magnet, with an aperture distance of 180 mm. A pair of tuning quadrupoles, 170 mm in diameter, and a pair of combined sextupole and correction dipoles, 160 mm in diameter, are mounted in a mechanical support structure and aligned with reference to the quadrupole by a common inertia tube which, with its end covers, forms the cold mass and the helium vessel.

The cold mass is assembled in the cryostat, which consists of a support system, the cryogenic piping, the radiative insulation, the thermal shield and the vacuum vessel. Together they form the standard section of the cryomagnet.

A vacuum barrier, bolted to the cold mass permits separation of the insulating vacuum of each half-cell.

Separated from the standard section of the cryomagnet by the vacuum barrier a Technical Service Module (TSM) is placed between the cold mass and the interconnection region of the next half-cell dipole. The TSM consists of the half-cell cryogenic control valves, the helium phase separator, the instrumentation capillaries, the electrical feedthroughs for the correction dipole magnet and a pair of Beam Position Monitors (BPM).

While providing a stable mechanical support for the magnet cold mass, the cryostat must limit the heat inleaks to a level matching the tight heat load budget of the LHC. It must withstand the thermal and mechanical transients associated with rapid cooldown and magnet quench and should favour economic manufacture on a large scale basis. The basic SSS cryostat design has been conceived together with the LHC dipole cryostat², with which it forms part of the LHC half-cell sharing the piping for refrigeration distribution.

CERN is currently building a lattice half-cell (test string) comprising about 50 m of the magnetic structure of LHC.

Fig. 2 : Short Straight Section layout

Standard cell focusing magnets

The helium tightness is obtained by small covers welded on the outside of the tube covering the bolts and pins. Figure 3 shows a cross section of the quadrupole in its cryostat.

The main quadrupoles of each ring are powered in series with the dipole magnets. The dipole correctors are excited independently and have low current cryogenic leads in each TSM. The multipole correctors are grouped into families and each family is connected in series by superconducting bus bars.

Fig. 3 : Cross-section of the LHC Prototype Quadrupole with its cryostat

Magnet constraints imposed on the cryostat

The quadrupoles are first order points in the LHC alignment process. To match with the tight beam orbit requirements the cryomagnet mechanical structure must guarantee stable and reproducible positioning.

The quadrupole with its inertia tube provides mechanical support and reference for the corrector magnets and the BPM. The alignment of these corrector magnets with reference to the quadrupole is obtained by supporting plates with a fitted key system, similar to that of the quadrupole and which positions the corrector magnets in the inertia tube.

Held in place by longitudinal spacer rods, the support plates also locate the bus bars with their expansion loops, mounted in insulating covers.

On the prototype of the test string, the support plates, with the correctors replaced by iron dummies, hold the quadrupole protection diodes (Fig. 4). For the final design the diodes will be assembled such that their replacement without dismounting the SSS is possible.

The prototype quadrupole, manufactured and measured apart, is contained already in its part of the helium vessel. After assembly with the extension tube, housing the corrector magnets, and the end flanges it forms an entirely welded enclosure designed to withstand the pressures (design value 2 MPa) associated with rapid cool down and magnet quench.

Magnet and cryostat alignment

Alignment plugs, machined together with the precision pin holes, serve as mechanical references to the magnet axis, once the cold mass is closed.

Two support posts, essentially a filament wound epoxy glass column glued between stainless steel plates⁶, transfer the magnet and helium vessel load onto cylindrical seats of the vacuum vessel. As well as the cold mass load, the front support post will also restrain the 4000 daN axial force of the vacuum barrier during half-cell vacuum testing. To allow for the differential thermal contraction between the cold mass at 1.9 K and the vacuum vessel at ambient temperature, the rear support post slides longitudinally on a low friction polyethylene plate while the front one is fixed.

Reference targets, adjusted on the vacuum vessel support points, and a level gauge enable alignment of the cryomagnet in the half-cell. Reproducibility measurements of the magnet position during thermal cycles will be made on the test string by electronic sensors.

BEAM POSITION MONITORS

For measurement of the beam position and the diagnostics of its dynamic behaviour transverse Beam Position Monitors (BPM) are mounted close to the quadrupole magnet on the outside of the cold mass. One vertical and one horizontal 0.3 m long BPM, prealigned in a

Fig. 4 : Longitudinal section of the prototype SSS

common fixture, are positioned by alignment jigs with reference to the inertia tube plugs and thus to the mechanical axis of the quadrupole. Welded into the beam pipes they form part of the LHC beam vacuum system. Held in position by an adjustable support, the BPMs are thermalized to 4.5 K.

INSULATION VACUUM AND VACUUM BARRIER

After an initial pump-down with turbomolecular pumps backed with a roughing pump, a pressure of 10^{-1} Pa (10^{-3} mbar) will be achieved.

Cryopumping by the cold surfaces at 1.9 K ensures an insulation vacuum quality of better than 10^{-3} Pa (10^{-5} mbar). This will provide good thermal insulation and minimise the effect of any residual leaks between the beam vacuum and the insulation vacuum.

Vacuum barriers mounted between cold mass and TSM limit the effects of helium leaks, facilitate leak detection and pump-down from atmospheric pressure. During the installation of the LHC, they enable independent testing of the half cells for higher installation rates.

Two designs are followed for the conception of the vacuum barrier.

The vacuum barrier of the prototype SSS consists of two double and corrugated stainless steel tubes, separated by an eccentric disc (Fig. 5). The outer flange will be at ambient temperature, the inner one at 1.8 K, and the various traversing tubes between 4.5 and 75 K. To minimise thermal losses, the thickness and the length of the tubes are optimised. The corrugations withstand the buckling pressure and increase the thermal length.

At the same time a vacuum barrier made of composite materials is being developed together with industry, with the aim of obtaining a low cost product for the LHC project.

During installation of the LHC, the barrier has to support atmospheric pressure either on one side or the other, depending which half-cell is helium leak tested.

Under normal operation of the LHC, no differential pressure will act on the barrier, (vacuum on both sides). When cooling down to 1.9 K, the front cover of the cold mass moves, due to thermal contraction, 3 mm in the longitudinal direction and 0.75 mm radially, while the support posts shrink 0.5 mm in the vertical direction. The barrier, attached to this cover, will follow these movements.

To reduce the heat inleak at 1.9 K, a copper ring, brazed on the outer edge of the eccentric disc and thermalized to pipe E, intercepts the heat flow at about 70 K. Therefore the temperature distribution in the barrier will be non linear between the outer and inner flange. The calculation of the thermal stresses (Von Mises) shows that the maximum values of about 8 daNmm^{-2} are near the outer edges of the disc (Fig. 6).

CRYOGENIC FUNCTIONAL REQUIREMENTS

Each half-cell will include a Technical Service Module (TSM), integrated in the SSS cryostat. The TSM must distribute the necessary cryogenic fluids at various temperature levels during cool-down, warm-up and operation of the accelerator magnets. During operation it must stabilise the magnet temperatures at less than 1.9 K.

Fig 5 : Vacuum barrier for the prototype SSS

Fig. 6 : Von Mises thermal stresses

The cryogenic flow scheme of a half-cell is represented in Fig. 7. The corresponding TSM piping and valves are shown in Fig. 8 and 9.

The function of valves and pipes are described by order of increasing temperature levels.

The magnets operate in static baths of pressurized superfluid helium at 1.8 K and 0.1 MPa (1 bar), through which heat is transported by conduction to a linear cold source constituted by a heat exchanger tube threading its way through the string, and in which heat is absorbed quasi isothermally by gradual vapourization of flowing saturated superfluid helium.

Helium at 2.2 K and 0.1 MPa (1 bar) is taken from line A. It undergoes a Joule-Thomson expansion at valve TCV1 after which the 1.8 K saturated helium is transported via a small tube inside the heat exchanger tube to the far end of the half-cell. When flowing back it vapourizes as it extracts heat from the magnets⁷. The 1.8 K saturation temperature is maintained by pumping line B connected to the phase separator.

This phase separator will collect the liquid expelled from the heat exchanger tube after a magnet quench. This liquid will then be used to subcool the liquid taken from line A before the Joule-Thomson expansion valve TCV1.

Fig. 7 : Flow scheme of half-cell cryogenics

Fig. 8 : Technical Service Module

Fig. 9 : TSM mock-up

The safety valve at the TSM is mounted between the 1.9 K magnet cold mass and the discharge line D. Line D is dimensioned to cope with the liquid and gas expelled from the magnet string in case of a quench of the complete half-cell.

Valve CFV is used to fill the magnet cryostats with pressurized helium at 4.5 K and 0.23 MPa (2.3 bar) from line C, after which it will be closed during normal operation.

To protect the cold mass at 1.9 K from heat influx due to synchrotron radiation or an eventual beam loss beam screens will be included in the final design of the SSS to intercept this heat at a higher temperature level: 4.5-20 K. Beam screens are however not installed in the SSS prototype. In the final design they are cooled by forced flow of supercritical helium, tapped from line C. The helium flow is controlled as a function of outlet temperature (maximum 20 K) by valve TCV2. The gaseous helium flow is then returned to the low pressure side of the octant refrigerator through line D.

Thermal shielding at 4.5 K and 50-75 K is provided by lines C, E, and F.

HEAT INLEAK CALCULATIONS

The calculation of the heat inleak of the LHC prototype short straight section cryostat and its interconnection region takes only conduction and thermal radiation into account. Not accounted for is the superfluid helium leakage through the safety valve seat between the cold mass and the 4.5 K discharge line D.

Table 1 shows the calculated heat load of the main components of the prototype SSS and its interconnection region. The cryogenic components of the TSM include the vacuum vessel, the thermal shield, the valves TCV1, TCV2, CFV, the phase separator and the cryogenic pipes.

The thermal shield and the radiative insulation are covered with layers of reflective aluminized polyester (Mylar) film : 30 layers for the thermal shield and 10 layers for the radiative insulation⁸. Moreover, there are several other blankets between the vacuum barrier.

Heat intercepts at 50-75 K have been considered for the pumping manifold, the instrumentation feedthroughs, the vacuum barrier, the valves and the BPM cables.

Due to its complexity, the specific heat inleak of the SSS is significantly higher than the current dipole cryostat.

FIRST HALF-CELL STRING TEST

Simulation of realistic operation conditions, in particular the cryogenic performance, of a lattice half-cell will be investigated in the LEP assembly hall SM18. The test string will consist of one short straight section and up to four 10 m dipoles. Assembly of the first Prototype Short Straight Section will start in Autumn 1993, after reception of the main quadrupole, designed, manufactured and measured at CEA/France.

TEMPERATURE		50-75 K	5-20 K	1.9 K
Main Cryostat	Radiative insulation		0.11	0.41
	Thermal shield	26.26		
	Support posts	12.08	1.21	0.09
	Beam vacuum pumping manifold	0.91		0.01
TSM	Cryogenic components	5.16	0.13	0.50
	BPM	2.00		0.58
	Safety valve	0.36		0.40
	Instrumentation feedthroughs	0.43		0.24
Vacuum barrier		9.16	0.18	0.65
SSS Subtotal		56.36	1.64	2.88
Interc. Region	Radiative insulation		0.01	0.05
	Thermal shield	3.11		
SSS and Interconnection region Total		59.47	1.65	2.93

Table 1 : Calculated global heat inleak (W) in steady state conditions for the LHC prototype SSS

ACKNOWLEDGEMENTS

The authors wish to thank the members of the teams involved in the conception and design of the LHC Short Straight Section. Special thanks to P.E. Faugeras, Ph. Lebrun, N. Siegel and A. Mathewson for their fruitful discussions during the conception phase of the project. Many thanks also to R. Chritin, G. Foffano, Y. Nikitin, T. Renaglia and Ph. Trilhe from the design team and to T. Kurtyka for his FEM calculations..

REFERENCES

1. The LHC Study Group, "Design Study of the Large Hadron Collider (LHC)", CERN 91-03, May 1991.
2. J-C. Brunet, J. Kerby, Ph. Lebrun, P. Rohmig, B. Szeless, L.R. Williams, "Design of the LHC Prototype Dipole Cryostats", Cryogenics 1992 volume 32 ICEC Supplement.
3. J-M. Baze et al., "Design and fabrication of the prototype superconducting quadrupole for the CERN LHC project", IEEE Trans. on Magn., January 1992 volume 28 pages 335-337.
4. H. Bidaurre et al., "Design and fabrication of the prototype superconducting tuning quadrupole and octupole correction winding for the LHC project", IEEE Trans. on Magn., January 1992 volume 28 pages 342-345.
5. A. Ijspeert et al., "Test results of the prototype combined sextupole dipole corrector magnet for LHC", presented at ASC92, Chicago, August 1992, CERN LHC Note 201.
6. M. Blin, H. Danielsson, B. Evans, M. Mathieu, "Design, construction and performance of superconducting magnet support posts for the Large Hadron Collider", presented at this conference
7. A. Bézaguet, J. Casas-Cubillos, Ph. Lebrun, M. Marquet, L. Taviani, R. van Weelden, "The superfluid helium model cryoloop for the Large Hadron Collider (LHC)", presented at this conference
8. T-C. Nast, D-J. Frank, I.E. Spradley, "Investigations of multilayer insulation at low boundary temperatures", ICEC-11, Berlin, West Germany, 22-25 April 1986, pages 561-564.