THERMAL PERFORMANCE OF THE LHC SHORT STRAIGHT SECTION CRYOSTAT

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Abstract

The LHC Short Straight Section (SSS) cryostat houses and thermally protects in vacuum the cold mass which contains a twin-aperture superconducting quadrupole magnet and superconducting corrector magnets operating at 1.9 K in superfluid helium. In addition to mechanical requirements, the cryostat is designed to minimize the heat in-leak from the ambient temperature to the cold mass. Mechanical components linking the cold mass to the vacuum vessel such as support posts and an insulation vacuum barrier are designed to have minimum heat conductivity with efficient thermalisations for heat interception. Heat in-leak by radiation is reduced by employing multilayer insulation wrapped around the cold mass and an actively cooled aluminium thermal shield. The recent commissioning and operation of two SSS prototypes in the LHC Test String 2 have given a first experimental validation of the thermal performance of the SSS cryostat in nominal operating conditions. Temperature sensors mounted in critical locations provide a temperature mapping which allows a crosscheck with the calculated temperature values and thermal performance. Moreover the measurements allowed a validation of the efficiency of the employed thermalisations. This paper presents the experimental results for the thermal performance of cryostat components and gives a first comparison with the design values.

1 INTRODUCTION

The eight arcs of the LHC lattice contain in total 360 Short Straight Sections. The SSS assembly is a cryostat housing a helium vessel, the so-called cold mass, containing a twin-aperture superconducting quadrupole magnet and two pairs of superconducting corrector magnets, operating in 1.9 K superfluid helium.

The SSS cryostat consists of two main parts; the standard section cryostat section with the cold mass and the technical service module (QQS) housing the beam position monitor (BPM), the instrumentation feed-through system (IFS) and the dipole corrector feed-through (DCF). Depending on the SSS variant [2], the QQS contains in addition an insulation vacuum barrier, a helium phase separator and a jumper connection to the external cryogenic distribution line.

2 THERMAL DESIGN

The cryostat heat loads are caused by radiation and solid conduction in mechanical components linking the cold mass to the vacuum vessel. The radiation heat in-leak is minimized by employing multilayer insulation (MLI) and solid conduction to 1.9 K is minimized by intercepting heat to the cryogenic lines E (50-65 K) and C' (4.6-20K).

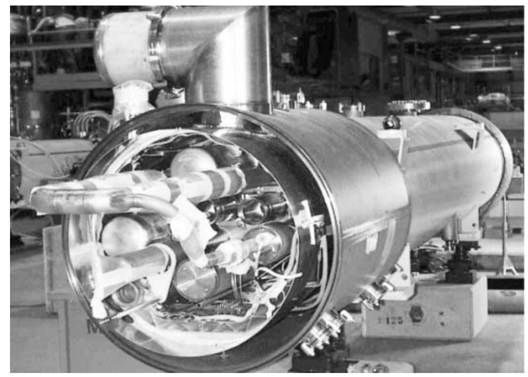

Figure 1: LHC Arc Short Straight Section Prototype.

2.1 Multilayer insulation

The MLI design consists of pre-fabricated blankets made of 6 μm thick polyethylene reflective films coated on each side with 400 Å of aluminium and interleaved with polyester spacer nets. A thermal shield, operating at 50-65 K, is equipped with two superposed blankets of 15 layers each and the cold mass is equipped with one blanket of 10 layers (Fig 2.). The QQS module and the insulation vacuum barrier are equipped with several carefully adapted MLI blankets and pads. For the ease of installation, the MLI blankets are equipped with Velcro™ fasteners allowing an edge-to-edge installation of the blankets, thus avoiding an overlapping thermal short-circuit of their cold and warm sides. For mechanical strengthening, the inner- and innermost reflective films are reinforced by polyethylene nets glued onto their inner sides.

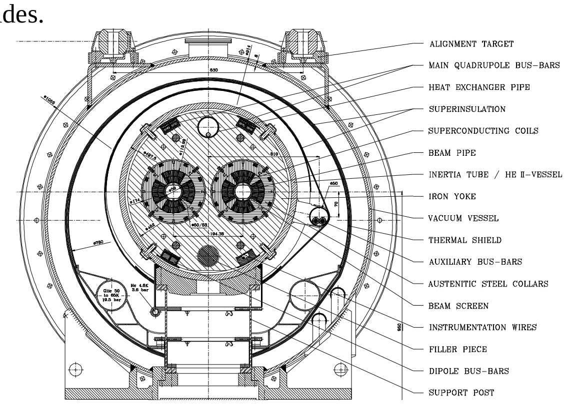

Figure 2: SSS cryostat cross-section.

2.2 Magnet support system

The support system (Fig. 2) for the cold mass consists of two low heat in-leak column type support posts in glass-fibre reinforced epoxy resin [6]. Each support mounts two aluminium heat intercept plates glued onto the columns at intermediate positions. The thermalisation of the lower heat intercept is made by flexible aluminium multi-foil straps welded onto the thermal shield. The thermalisation of the upper heat intercept is made by a cast aluminium plate integrating the stainless steel line C'.

2.3 Insulation vacuum barrier

The insulation vacuum barrier, welded between the cold mass and the vacuum vessel, has the function of dividing the LHC insulation vacuum in separate compartments (each 214 m long). It is a stainless steel leak-tight welded structure, composed of two concentric corrugated cylinders and one internal bellows linked together by a thermalised central plate. A high purity copper ring brazed onto the stainless steel central plate and thermally linked to the aluminium cryogenic line E by a copper-aluminium brazing ensures the required heat interception.

To minimize the radiation heat in-leak, cylindrical MLI blankets are installed between the corrugated cylinders and bellows. The design study has shown that MLI protection (in particular of the internal bellows) is essential to keep the heat in-leaks within the budget.

2.4 Other components

Additional heat in-leaks are caused by the feed-through pumping tubes for the beam vacuum, beam screens, a beam position monitor (BPM), current lead feed-throughs (DCF) for the dipole corrector magnets, the instrumentation feed-through system (IFS) and a helium phase separator with its piping in the QQS module.

2.5 Heat load budget

The budgeted static heat loads to a SSS containing jumper connection and insulation vacuum barrier are shown in table 1 [7].

Table 1: Static heat load budget (in W) in a SSS.

Component	50-65 K	4.6–20 K	1.9 K
Standard Section Cryostat			
Thermal shield radiation	12.1		
Radiation to cold mass			0.47
Beam vacuum tubes	1.2		0.21
Support posts (two)	14.4	0.84	0.09
Beam screen			0.06
Technical service module QQS			
Thermal shield radiation	3.0		
IFS			0.54
Insulation vacuum barrier	11.6	0.029	0.43
BPM		0.46	0.30
DCF	5.2	1.22	0.27
Phase separator, piping	0.01	0.12	0.05
Total	**47.5**	**2.7**	**2.4**

The budgeted radiation heat in-leaks through the MLI are based on reference values of 1.1 W/m^2 from 293 K to 50-65 K and 55 mW/m^2 from 50-65 K to 1.9 K, applying safety factors in areas with complex geometry. Recent MLI tests made at CERN [3] suggests that the radiation heat in-leak in the standard section cryostat does not exceed 0.8 W/m^2 from 293 K to 50 K and 5 mW/m^2 from 50 K to 1.9 K.

The budgeted heat loads of the support post are based on a calculation model, benchmarked with experimental testing [5]. The budgeted insulation vacuum barrier heat loads are based on a dedicated thermal calculation model [4].

3 EXPERIMENTAL RESULTS

The recent commissioning and operation of the LHC Test String 2 have given a first experimental validation of the thermal performance of the SSS cryostat in nominal cryogenic conditions. Phase 1 of the LHC Test String 2 has been operating with a continuous LHC lattice cryostat comprising two prototype Short Straight Sections interleaved by three LHC dipole cryomagnets.

Figure 3 shows the temperatures in the SSS3 during the first cool down in August-September 2001. Table 2 summarises the measured average temperatures after nominal operation temperatures are reached for the cold mass, line C' and line E.

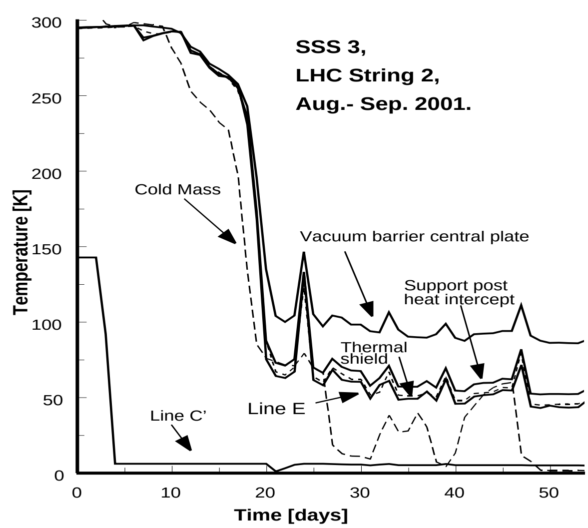

Figure 3: Temperature mapping in the SSS3.

While the line E is at 50 K, the temperature measured at the upper part of the standard section thermal shield is 52 K, which confirms its welded thermalisation. The extremity thermal shield temperatures are measured to 54 K respectively 59 K, indicating heat in-leak to the standard section thermal shield from the upstream QQS section and the downstream magnet interconnection zone.

A temperature sensor mounted at the beam vacuum tube feed-through indicates a temperature of 57 K, confirming the correct welded thermalisation to the thermal shield.

For the support posts, the temperatures measured confirm the correct thermalisation of the heat intercepts, with the upper plate indicating a temperature of 9 K while the line C' is operating at 5 K and the lower plate indicating a temperature of 59 K while the line E is operating at 50 K. This is a re-confirmation of the results from previous experimental tests [5].

Table 2: SSS3 average temperatures after cool down.

Line C'	**5 K**
Support post upper heat intercept	9 K
Line E	**50 K**
Support post lower heat intercept	59 K
Beam vacuum tube thermalisation	57 K
Vacuum barrier thermalisation ring	90 K
Vacuum barrier central plate	92 K

For confirmation of the thermalisation of the insulation vacuum barrier (Fig. 4) temperature sensors have been mounted on its thermalisation copper ring and on the stainless steel central plate. While the line E temperature is 50 K, the lower part of the central plate indicates a temperature of 92 K and the thermalisation copper ring at the same level indicates a temperature of 90 K. This confirms a good thermal connection between the copper thermalisation ring and the central plate but at the same time it indicates that the thermalisations to the line E are not performing as expected.

Based on the experimental results, the actual heat in-leak in the insulation vacuum barrier has been assessed by using the measured temperatures as boundary conditions for the thermal calculation model [4]. The result shows a heat in-leak to the cold mass of 0.57 W and of 9.4 W to the line E (compared to a assumed heat loads of 0.27 W to the cold mass and 11.6 W to the line E, calculated with a line E reference temperature of 50 K with an assumed ΔT of 5 K to the central plate).

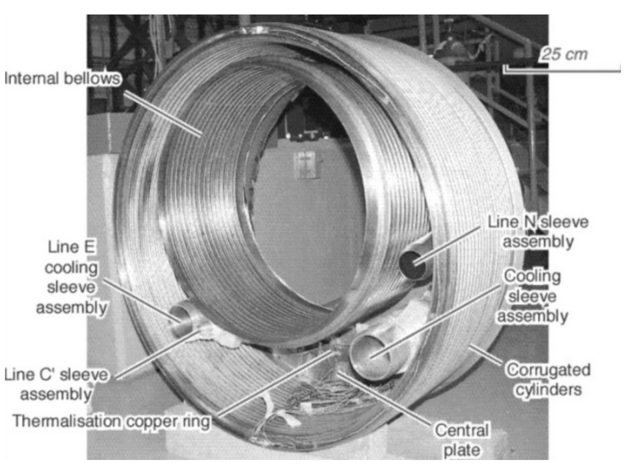

Figure 4: Insulation vacuum barrier.

An ongoing additional experimental qualification of the line E thermalisations to be used for the series insulation vacuum barriers, have preliminary confirmed a good thermal bonding of the brazing between the aluminium cooling sleeves and flexible copper straps, showing a ΔT of some 2 K while absorbing the maximum nominal heat load of 3 W per thermalisation.

4 CONCLUSION

The recent commissioning and operation of the LHC Test String 2 have allowed a first experimental validation of the SSS cryostat in nominal cryogenic conditions. Mapping of temperatures in cryostat components, such as thermal shield, support posts and insulation vacuum barrier have validated the temperature levels and allowed comparison with values from the design study. The heat intercepts on cryostat components, made by welding and brazing, have been experimentally validated, confirming correct thermalisation of support post and beam vacuum feed-through. Further investigation for the insulation vacuum barrier thermalisation is required. A final experimental validation of the global heat in-leak to the LHC lattice cryostat will be made in future dedicated tests in the LHC Test String 2.

ACKNOWLEDMENTS

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