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Short Straight Sections in the LHC Matching Sections (MS SSS): An Extension of the Arc Cryostats to Fulfil Specific Machine Functionalities

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The LHC insertions require 50 specific superconducting quadrupoles in the matching sections, operating either in 1.9 K superfluid helium or in boiling helium at 4.5 K. These magnets are assembled together with corrector magnets in cold masses, and are inserted in individual cryostats to form the MS Short Straight Sections (MS SSS). The variety of quadrupoles and corrector magnets leads to 10 families of cold masses, with lengths ranging from 5 to 12 m and weights ranging from 60 to 140 kN. The MS SSS need to fulfil specific requirements related to the collider topology, its cryogenic layout and the powering scheme. Most MS SSS are standalone cryogenic and super-conducting units, i.e. they are not in the continuous arc cryostat, and therefore need dedicated cryogenic and electrical feeding. Specially designed cryostat end-caps are required to close the vacuum vessels at each end, which include low heat in-leak Cold-to-Warm transitions (CWT) for the beam tubes and 6 kA local electrical feedthrough for powering the quadrupoles. This paper presents the design of the MS SSS cryostats as an extension of the arc cryostat's design [1-3], to achieve a standard and consequently cost-effective solution, and the design solutions chosen to satisfy their specific functionalities.

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SHORT STRAIGHT SECTIONS IN THE LHC MATCHING SECTIONS (MS SSS): AN EXTENSION OF THE ARC CRYOSTATS TO FULFIL SPECIFIC MACHINE FUNCTIONALITIES

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Abstract

The LHC insertions require 50 specific superconducting quadrupoles in the matching sections, operating either in 1.9 K superfluid helium or in boiling helium at 4.5 K. These magnets are assembled together with corrector magnets in cold masses, and are inserted in individual cryostats to form the MS Short Straight Sections (MS SSS). The variety of quadrupoles and corrector magnets leads to 10 families of cold masses, with lengths ranging from 5 to 12 m and weights ranging from 60 to 140 kN. The MS SSS need to fulfil specific requirements related to the collider topology, its cryogenic layout and the powering scheme. Most MS SSS are standalone cryogenic and super-conducting units, i.e. they are not in the continuous arc cryostat, and therefore need dedicated cryogenic and electrical feeding. Specially designed cryostat end-caps are required to close the vacuum vessels at each end, which include low heat in-leak Cold-to-Warm transitions (CWT) for the beam tubes and 6 kA local electrical feedthrough for powering the quadrupoles. This paper presents the design of the MS SSS cryostats as an extension of the arc cryostat's design [1-3], to achieve a standard and consequently cost-effective solution, and the design solutions chosen to satisfy their specific functionalities.

LHC INSERTIONS AND QUADRUPOLES

The optics scheme in the 8 LHC insertions is mainly dictated by their specific function: 4 are dedicated to the high-luminosity experiments, 2 for beam cleaning, 1 for RF cavities, and 1 for the beam dumps. The integration of the main quadrupoles (MQ and MQM, the arc quadrupole and insertion quadrupole respectively) with the corrector magnets in common cold masses, yields 10 different combinations of cold masses in the MS SSS, as shown in Table 1.

Table 1: MS SSS Cold masses

Cold mass/position	Magnets	T°	Cold mass Length (mm)	Cold mass weight (kN)	No. Units
Q7 IR4	MQM + MCBC	1.9	5345	58	2
Q5, Q6 IR4 Q4, Q5 IR6	MQY + MCBY	4.5	5345	58	8
Q7 IR3, 7	MQ + MQTL + MCBC	1.9	6620	74	4
Q5, Q6 IR1, 5	MQML + MCBC	4.5	6620	83	8
Q4 IR1, 5	MQY + 3 MCBY	4.5	8020	93	4
Q7 IR 1, 2, 5, 8	2 MQM + MCBC	1.9	8995	111	8
Q6 IR2, 8	MCBC+MQML+MQM	4.5	10400	123	4
Q6 IR3, 7	6 MQTL + MCBC			123	4
Q4 IR2, 8, Q5 L2, R8	2 MQY + 3 MCBY	4.5	11355	141	6
Q5 R2, L8	2 MQM + 3 MCBC	4.5	11355	141	2

MS SSS CRYOSTATS

Main Cryostat Parameters

The SSS cryostats have been designed to house the variety of cold masses listed above, applying the solutions adopted in the arc cryostats as far as possible, for obvious reasons of standardisation and consequent cost effectiveness. In particular, some main features could be kept identical to those in the arc cryostats: diameter and thickness of the vacuum vessels, cross section of the thermal shields, the multilayer insulation blankets and composite material support posts.

However, to cover the full cold masses range of lengths and weights, their cryostats have been adapted in the main dimensions detailed in Figure 1.

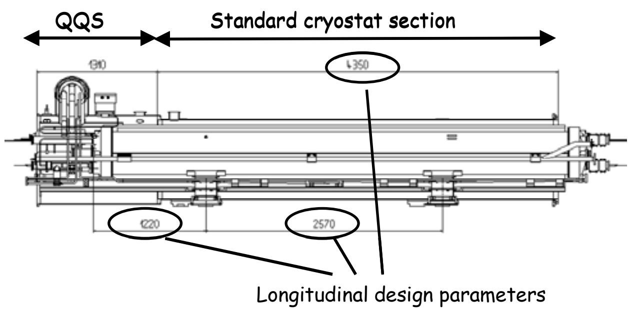

Figure 1 : Main cryostat design parameters for an SSS

Fortunately enough, in all cases the cold masses weight and length fall in between those of an arc SSS and an arc cryo-dipole.

The supporting system is similar to that of the arc SSS, an isostatic two-point supporting of the cold mass onto the vacuum vessel. To limit the longitudinal thermal contraction movements of the cryogenic piping, the support closest to the technical service module (QQS) housing the cryogenic connection to the distribution line fixes the cold mass to the vacuum vessel. In this way, all the complex, lengthy and expensive integration studies already done for the QQS of the arc SSS, could be largely reused to cover the MS SSS. The other support post allows free longitudinal sliding of the cold mass onto the vessel, while keeping its transverse positioning accuracy, thanks to a close fit sliding key. The spacing of the support posts was defined to minimise the vertical sagitta of the main magnet under the self-weight of the cold masses. For the longest and heaviest cold masses, the addition of a third supporting point was necessary, thus leading to an hyper-static solution requiring a more complicated assembly. The vertical position of the cold mass under the central support post needs to be adjusted by adequate shimming during SSS assembly, as in the case of the arc cryo-dipoles. Table 2 summarises the maximum vertical deflections calculated for the various configurations, whereas Figure 2 shows an example of the calculated deflection for the cold masses of SSS in Q4 and Q5 in IR2 and 8.

Since the magnets in the 36 MS SSS from Q6 to Q4 do not require super-fluid helium cooling and are not part of the 1.9 K cryogenic circuit of the continuous arc cryostat, these units operate in boiling helium at 4.5 K. Despite their operating temperature of a few K higher, the same thermal design of the 1.9 K cryostats [4] was adopted. The MS SSS feature the same thermal shielding and radiation multilayer insulation of the arc cryostats, with the exception of the 5-10 K thermalisations of the support posts which were suppressed as being useless.

Table 2: Calculated vertical deflections of cold masses

	Q8,10	Q9	Q4 IR1,5	Q7	Q4,5
Mean of the vertical displacement on the Quadrupole(s) length	-252 μm	-306 μm	- 268 μm	-353 μm	-291 μm
Maximum sagitta on quadrupole(s)	116 μm	106 μm	44 μm	59 μm	32 μm
Sagitta on the quadrupole connection side	116 μm	106 μm	42 μm	44 μm	32 μm
Sagitta on the corrector connection side	181 μm	224 μm	217 μm	228 μm	79 μm

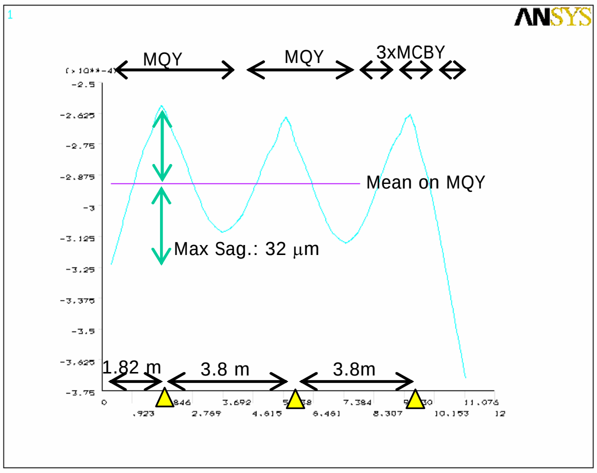

Figure 2: Calculated deflections for Q4 & Q5 in IR2 & 8.

Specific Features

In addition to the variety of cold masses, the MS SSS have to cope with very specific features required by the topology of the machine, the cryogenic layout and the powering schemes. The 36 SSS from Q6 to Q4 are standalone cryogenic and super-conducting units, i.e. they are not in the continuous arc cryostat and therefore need dedicated cryogenic and electrical feeding. 4.5 K boiling helium requires that the filling of the magnets with helium is done from the higher most point of the cold masses to avoid the accumulation of gas around the magnet superconducting coils and inefficient cooling. Considering that the LHC machine stands in a 1.4% inclined plane, the QQS with its cryogenic feeding needs to be conveniently positioned and oriented depending on the tunnel slope at the SSS location. The SSS therefore need to be assembled accordingly, introducing an additional variant in the types of SSS. Furthermore, end-caps to close the vacuum vessels at each end are required, equipped with Cold-to-Warm Transitions (CWT) to provide low heat in-leak feed-through of the beam tubes [5].

In total, a family of 6 main types of cryostats of different lengths are needed to cover the full range of MS SSS. Figure 2 shows the variety of MS SSS, including the additional variants introduced by the cryostat end-caps for the standalone SSS. However, summing up all the specificities introduced by either the cold masses or the specific features of the SSS, a total of 32 cryostat variants is reached.

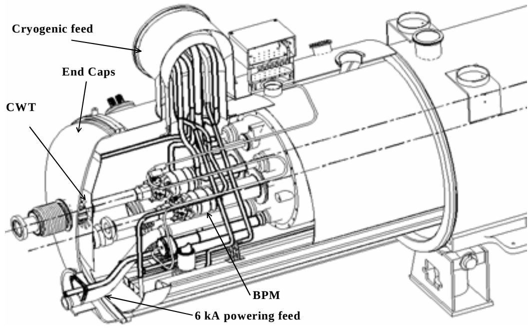

Figure 3: Technical Service Module

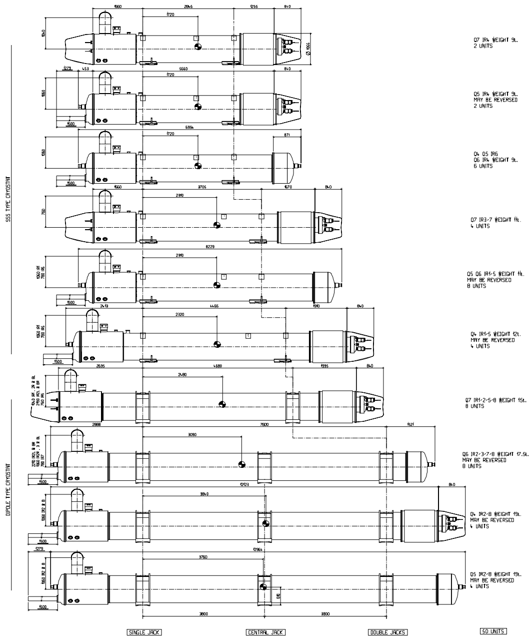

Figure 4: Main types of MS SSS.

Assembly tooling

The assembly of the various cold masses in the vacuum vessels required the development of two specific benches. One is used for the assembly of the shortest MS SSS with 2 supports, and is similar to the arc SSS bench. The introduction of the cold mass into the vacuum vessel is obtained by lifting the cold mass from its extremities and rolling it with trolleys through the vacuum vessel. The other bench was developed for the MS SSS with 3 supports. In this case, the cold mass length and weight does not allow lifting from the extremities. The cold mass is therefore towed, and slides on sledges through the vacuum vessel while standing on its 3 support posts (Figure 5).

The assembly of the QQS can be carried out using most of the positioning stands developed for the arc SSS, though it requires complementary equipments to cover all specific cases.

Figure 5: MS SSS Assembly benches: SSS with 2 supports (left), SSS with 3 supports (right).

PROCUREMENT OF COMPONENTS AND ASSEMBLY OF THE SSS

The manufacture of most of the cryostat components, in particular vacuum vessels, thermal shields, MLI, could be negotiated with the contractors already producing similar components for the arc cryo-dipoles and SSS. As a consequence, CERN could limit costs because of the re-use of existing production lines and specific tooling in the companies. In addition, profiting from the confirmed experience of the firms, the usually lengthy production start-up was avoided. No major technical problem was experienced, and the first components started being delivered to CERN mid 2004.

Following the assembly of the first cold masses at CERN, the production of the first MS SSS will start in June ’05. The assembly of the 50 MS SSS is planned to follow the sequence of installation in the LHC tunnel, and will continue until the end of 2006.

SUMMARY

Some 32 cryostat types are required to cover all specificities of the 50 MS SSS. Most of the design experience made on the arc SSS could be extended to these units. In particular, the cross section features of the cryostats could be kept, allowing re-use of standard arc components. Design provisions were made to cope with the different lengths of the vacuum vessel, thermal shields and MLI. The design of the cryostat components is terminated and the procurement of the components is in progress. Dedicated assembly tooling was developed, but mainly derived from the tooling already in use to assemble the arc SSS and cryo-dipoles. The assembly of the first MS SSS will start at CERN in June ’05, and will continue until the end of 2006.

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