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Conceptual design of the Cryogenic Electrical Feedboxes and the Superconducting Links of LHC

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Abstract

Powering the superconducting magnets of the LHC arcs and long straight sections is performed with more than 1000 electrical terminals supplying currents ranging from 120 A to 13'000 A and distributed in 44 cryogenic electrical feedboxes (DFB). Where space in the LHC tunnel is sufficient, the magnets are powered by locally installed cryogenic electrical feedboxes. Where there is no space for a DFB, the current will be supplied to the magnets by superconducting links (DSL) connecting the DFBs to the magnets on distances varying from 76 m to 510 m.

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Conceptual design of the Cryogenic Electrical Feedboxes and the Superconducting Links of LHC

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INTRODUCTION

The LHC will include several thousand superconducting magnets operating either at 1.9 K in superfluid helium or at 4.5 K in saturated helium, powered with electrical currents ranging from 60 A to 13 000 A. Most magnets are installed in 8 continuous strings of magnets in the arc regions of LHC, but a certain number of superconducting magnets are also required between the arcs, in the long straight sections and in the final focusing regions of the LHC (inner triplets), close to the main experimental areas. CERN will supply 16 cryogenic electrical feedboxes (DFBAs) for the arcs and 28 feedboxes for the long straight sections (DFBMs and DFBLs) while the 8 feedboxes for the inner triplets (DFBXs) will be supplied in the framework of the US-LHC collaboration and are described by Zbasnik et al. [1].

When the integration of a DFB is not possible close to the superconducting magnets, the magnets are powered through superconducting links (DSL) that connect the DFBs and the superconducting magnets on distances varying from 76 to 510 m.

CRYOGENIC ELECTRICAL FEEDBOXES

Powering the LHC will require 3 families of cryogenic electrical feedboxes:

- The DFBAs, connected to each end of the LHC octants, ensuring also the mechanical and cryogenic functions of arc termination. There are 16 DFBAs in the LHC.
- The DFBMs, powering standalone magnets in the long straight sections. There are 23 DFBMs in the LHC, located in the LHC tunnel, alongside the magnets that they power.
- The DFBLs, powering the superconducting links. They also supply the cryogenic fluids to the DSLs. There are 5 DFBLs in the LHC, located in underground caverns close the LHC tunnel.

The main function of the DFBs is to transfer high currents from room temperature cables to superconducting busbars via current leads. The current leads are gas cooled devices designed to transfer high currents with limited transmission of heat to the 4.5 K liquid helium in which the busbars are immersed [1]. The types of DFBs and the types of current leads and their respective number for each type of DFB are listed in Table 1. Table 2 shows the total number of current leads required for the LHC.

Table 1 List of the DFBs and their current leads

DFB type	Number	Type of leads (nb/DFB)
DFBA	16	13kA (2-6), 6kA (12-15), 600A (44-62), 120A(0-4)
DFBM	23	6kA (3-5), 600A(4-12)
DFBL	5	6kA (0-5), 600A(0-44), 120A(0-12)

Table 2 The current leads for the DFBs

Type of lead	Number
13'000 A	64
6'000 A	258
600 A	692
120A	196

The DFBs also ensure other functions which are not directly related to the electrical powering but are crucial for the operation of LHC, like terminating the LHC arcs for the DFBAs and supplying the cryogenic fluids to the superconducting links.

Design of the DFBs

In addition to providing a number of functionalities for the LHC operation, the DFBs design must take into account the very stringent constraints of the LHC tunnel (geometry, radiation, transport, etc.) and must also allow the in-situ exchange of the current leads in all long straight sections of the LHC.

The DFBs are of modular design: they are assembled from two families of current leads modules, assembled together with interface modules and other specific equipment that depends on the requested configuration (see Figure 2 and Figure 3).

The high-current module integrates 13 kA and 6 kA leads while the low-current module integrates 6 kA, 600 A and 120 A leads. The number of leads and their arrangement is different for each DFB but the same basic design is used for all modules. The current lead modules support the leads and the busbar system and integrate the cryogenic circuits for their operation. To power the magnets, the busbars pass trough specially developed cryogenic superconducting feedthroughs. Big removable doors allow a good access to the cryogenic piping and to the electrical connections.

There are two types of interface modules: DFBAs are connected to the LHC arcs with an interface module called "shuffling module". It ensures the arc termination functions and also allows the rerouting of the busbars to the current lead modules. It shall withstand all vacuum and pressure forces due to its position at the end of the arc, while ensuring a very precise positioning of the beam pipes. Its support system is designed to allow realignment in LHC operating conditions. It also provides the supports of the high-current module. DFBL are connected to the superconducting links and to the cryogenic fluid supply with a specific interface module, whose function is essentially to distribute the busbars and cryogenic piping.

A summary of the basic configurations for the 3 types of DFBs is shown in Figure 1. All DFBs are built by combining the two types of current lead modules and interface equipment specific to each DFB in the combinations shown in Figure 1. The resulting typical design of the DFBAs (1 shuffling module and 1 or 2 current moduels), the DFBMs (1 low-current module) and of the DFBLs (2 low-current modules side by side and 1 interface module to the DSL) are shown in Figure 2 and Figure 3..

A view of the DFBA located at the left side of IR8, therefore powering sector 7-8 of LHC, is shown in Figure 2. This DFBA is a typical example of the above cited modular design and consists essentially of:

- An interface (shuffling) module
- A high-current module, placed besides the beam pipes. connected to the shuffling module and integrating a jumper connection to the cryogenic distribution line of LHC [2]
- A low-current module.

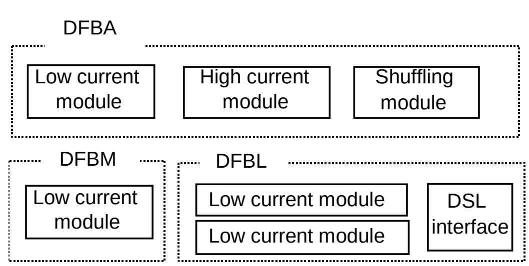

Figure 1: Schematic representation of the DFB configurations

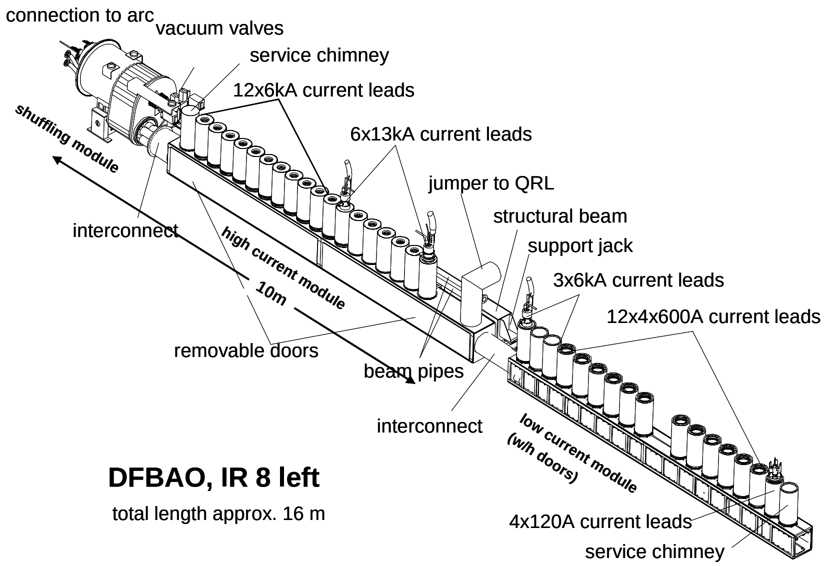

Figure 2: DFBA of IR 8 left, powering sector 7-8 of the LHC.

SUPERCONDUCTING LINKS

When the integration of a DFB close to the magnets is not possible, the electrical current is transferred from the DFBs to the LHC magnets through superconducting links (DSL).

Five DSLs will be needed for the LHC. One of them will be exceptionally long, about 510m in length without any intermediate branches. It will link the 3 km long continuous cryostat of accelerator magnets of Arc 3-4 of the LHC to a current feed box located in UJ33 some 510 m away. Besides its power transmission function, the link will also need to provide the cryogens for this current feed box. An additional four, significantly shorter, links will be used at points 1 and 5 of the LHC machine to bring power from current feed boxes to individual magnet cryostats (Q6, Q5 and Q4D2). Each of those four links will be about 76 m in length with two intermediate branches, roughly 3 m in length, to individual magnet cryostats. A summary of the characteristics of the superconducting links of LHC is shown in Table 3.

Design of the DSLs

The DSL consist essentially of cryogenic, vacuum-insulated, transfer lines housing one or more superconducting cables. Superconducting links are used for several circuits with current ranging from 120 A to 6kA. Nominal operation temperatures will be from 4.5 K to 6 K for the part which houses the cable, and about 76 K for the heat shielding. Cross sections of the 510 m DSLC is shown in Figure 4. In the DSLs, thermal contraction compensation will be performed by elbow-shaped metallic hoses at each

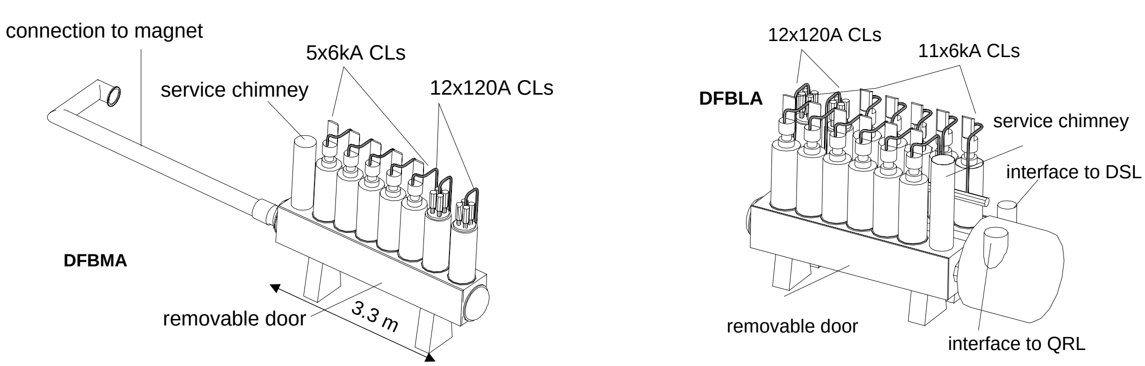

Figure 3 View of the typical configurations of DFBMs and DFBLs

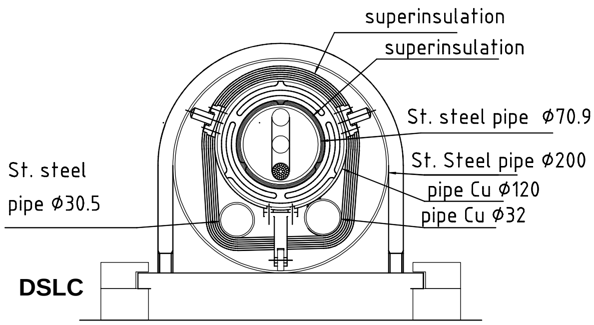

Figure 4: cross sections of the 510 m DSL

Table 3 : List of the DSLs

DSL type	length [m]	SC cables number	SC cables rating [A]
DSLA, DSLB,	76	12	600
DSLD, DSLE		12	6000
DSLC	510	44	600

branch for the shorter types (76 m) and by a combination of bellows for the cryogenic piping and a distributed "waving" of the superconducting cable for the longer type (510 m).

PROJECT STATUS

An intensive development program has been carried out for validating the design of the DFBs and of their subsystems. Several models of the cryostats, vacuum envelopes, busbar feedthroughs [4], interconnects and other components have been built and successfully tested. The first two DFBs are currently under construction at CERN for a first installation in the LHC during the first half of 2005. The remaining DFBs will be produced under the responsibility of an external contractor. The installations will follow the construction of the LHC, ending at the end of 2006. It is planned to test one of the series DFBAs during the second quarter of 2005.

After a specification, pre-design and tendering phase, an order has been placed with European industry in March 2004 for the production and installation of the superconducting links. It is planned to test a 30 m model of the 510 m DSL during first quarter of 2005. The first 76 m DSL (DSLA) will be installed in the LHC tunnel in the second quarter of 2005, the 510 m DSLC installation being planned during the first quarter of 2006.

CONCLUSION

The complex task of powering the LHC superconducting magnets in the very limited underground available space will be performed with a combination of locally installed cryogenic electrical feedboxes and the use of superconducting links for the locations where the space limitations do not allow the installation of DFBs.

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