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DFBX Boxes -- Electrical and Cryogenic Distribution Boxes for the Superconducting Magnets in the LHC Straight Sections*

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***Abstract*— DFBX distribution boxes provide cryogenic and electrical services to superconducting quadrupoles and to a superconducting dipole at either end of four of the long straight sections in the LHC. The DFBX boxes also provide instrumentation and quench protection to the magnets. Current for the quadrupole and the dipole magnet is delivered through leads that combine HTS and gas cooled leads. Current for the 600 A and 120 A correction magnets is provided by pure gas-cooled leads. The bus bars from the leads to the magnets pass through low leak-rate lambda plugs between 1.8 K and 4.4 K. The heat leak into the 1.9 K region from the liquid helium tank is determined by the design of the lambda plugs. This paper describes the DFBX boxes and their function of delivering current and instrumentation signals to the magnets.**

***Index Terms*—Gas Cooled leads, HTS Leads, Lambda Plug, Superconducting Buses**

I. Introduction

The DFBX distribution boxes are part of the contribution from the US to the CERN Large Hadron Collider (LHC). The US contribution to the LHC machine includes the final focusing low beta quadrupoles for interaction regions (IR) 1 2, 5 and 8 and superconducting dipoles on either side of IR 2 and 8. In IR1 and IR5, there are no superconducting dipoles. All four straight sections have LHC superconducting corrector magnets, which are located within the low beta quadrupole string. The placement of the DFBX at the ends of the LHC interaction region is shown in Fig. 1.

The DFBX connects the LHC helium cryogenic distribution system (CERN QRL) with the superconducting magnets. The cooling is supplied and returned to the LHC QRL distribution headers in four temperature ranges. There is cooling at 1.9 K for the magnets, and 4.4 K cooling for the DFBX helium tank and busses. Gas at 20 K cools the top of the 7.5 kA HTS leads, and cooling at 65 K is supplied to the shields. In addition, the DFBX provides 1.9 K cooling to the LHC beam tube. The DFBX shares a common cryostat vacuum with the superconducting magnets on either side. The LHC beam pipe passes through the middle of the DFBX.

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In addition to being an integral part of the cryogenic system for the IR superconducting magnets, the DFBX also contains the electrical leads for the all of the superconducting magnets around the DFBX. As a result, the DFBX will have up to six 7.5 kA HTS leads, fourteen 600 A gas-cooled leads, and ten 120 A gas-cooled leads. (There are four HTS leads in the DFBX for straight sections 1 and 5, and there are six HTS leads for straight sections 2 and 8.) The final electrical function of the DFBX is to act as a conduit for the electrical signals from all of the superconducting magnets to the CERN control system. Figure 2 illustrates the various cryogenic and electrical functions for a typical DFBX box found on either side of LHC straight sections 2 and 8. This paper describes primarily the electrical functions of the DFBX. The DFBX cryogenic distribution functions are described in [1].

II. The Magnets Supplied By The DFBX

On the quadrupole side of the DFBX, there are four strong focusing quadrupoles Q1, Q2a, Q2b, and Q3 that are supplied with current by two pairs of 7500 A combined HTS and gas-cooled leads. There are also four sets of correction magnets within the superconducting quadrupole string. Because the quadrupoles are close to the beam interaction zone, they are single aperture magnets. The region where the quadrupoles and the DFBX are located is a higher than normal radiation zone. Some organic materials such as Teflon can not be used in this region. The radiation levels are high enough to add extra heating into the region around the DFBX.

The corrector magnets consist of steering magnets, and correctors for sextupole, octupole, decapole, skew quadrupole, skew sextupole and skew octupole. There are seven coil sets that are powered through the 600 A gas-cooled current leads. In addition there are five coil sets that are powered through the 120 A gas-cooled current leads.

The quadrupoles and correction magnets are supplied with current and cryogenic services by the DFBX on both sides of IR1, IR2, IR5, and IR8. In IR2 and IR8 there is a superconducting dipole on the side of the DFBX away from the interaction region. A pair of 7500 A HTS and gas cooled leads in the DFBX supply current to the dipole. There are no correction elements on the dipole side of the DFBX.

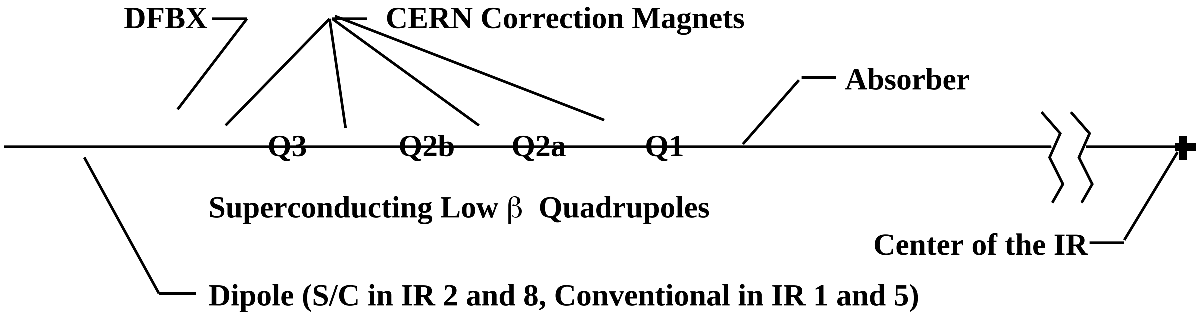

Fig. 1. The location of the DFBX with respect to the low beta quadruples (Q1, Q2a, Q2b and Q3) and the outboard dipole.

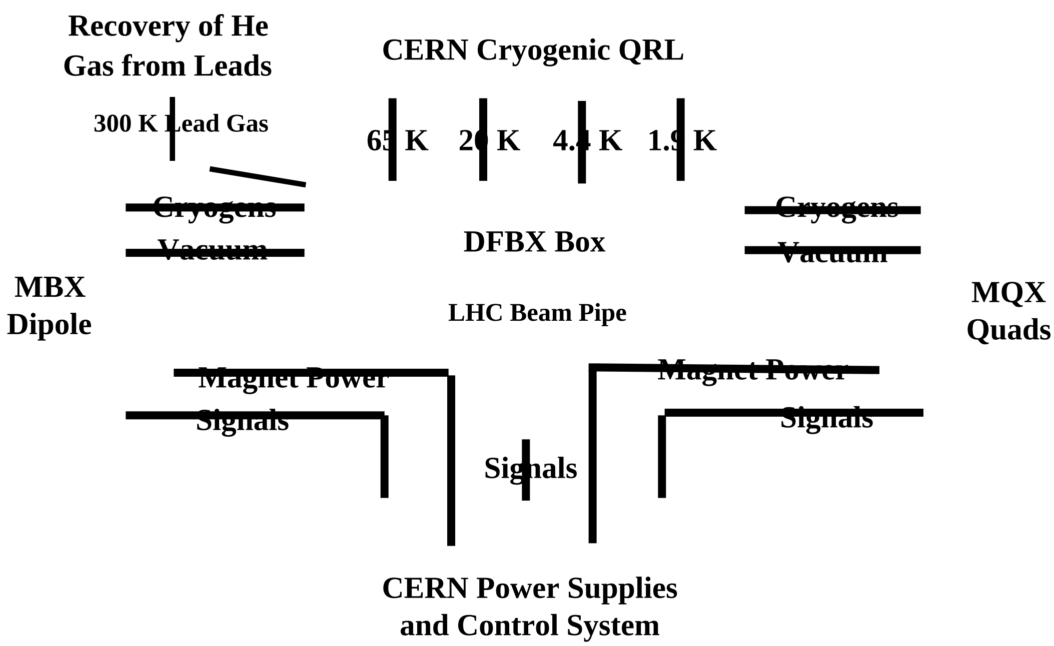

Fig. 2. A functional diagram for the DFBX around interaction regions 2 and 8. Helium at 65 K is used to cool the shields. 20 K helium is used to cool the gas-cooled part of the combined gas cooled and HTS leads. 4.4 K helium cools the liquid helium tank, and 1.9 K helium is connected to the S/C quadrupoles on the MQX side of the box and the S/C dipole on the MBX side of the box.

III. HTS Leads and Gas Cooled Leads for the DFBX

The DFBX boxes in IR2 and IR8 will have six 7.5 kA HTS leads (four leads for the low beta quadrupoles and two leads for the dipole). In IR1 and IR5, the DFBX will have only four HTS leads (for the low beta quadrupoles only). The HTS leads for the DFBX were made by Pirrelli in the United Kingdom. The lower part of the HTS lead is connected to a Nb-Ti bus that is in the 4.5 K helium bath within the DFBX helium tank. The upper end of the HTS leads and the gas-cooled leads are by conduction to the helium tank and by 20 the K helium gas that comes from the CERN cryogenic QRL system (see Fig. 2). A PEEK (Poliehterehterketone) plastic seal separates the helium-tank 4.4-K liquid helium-bath and the 20 K gas source that connects to the base of the HTS lead chimney. This seal keeps the 20 K helium from flowing into the 4.4 K region and 4.4 K helium from flowing up the gas cooled portion of the 75.kA leads. The upper part of the HTS lead assembly is a gas-cooled lead using helium gas from the 20 K source. The refrigeration needed to cool the combined HTS gas-cooled leads is a factor of four lower than needed to cool 7.5-kA gas-cooled leads. The 7.5-kA HTS lead is the lower part of the lead assembly is shown in Fig. 3.

The fourteen 600-A gas cooled leads will be in three of the four gas-cooled lead chimneys (in groups of six, six and two). All ten 120-A gas-cooled leads are designed to be installed in the fourth chimney. An assembly of six 600-A gas cooled leads is shown in Fig. 4. Electrical heaters operating at 24 V will keep the terminals from frosting.

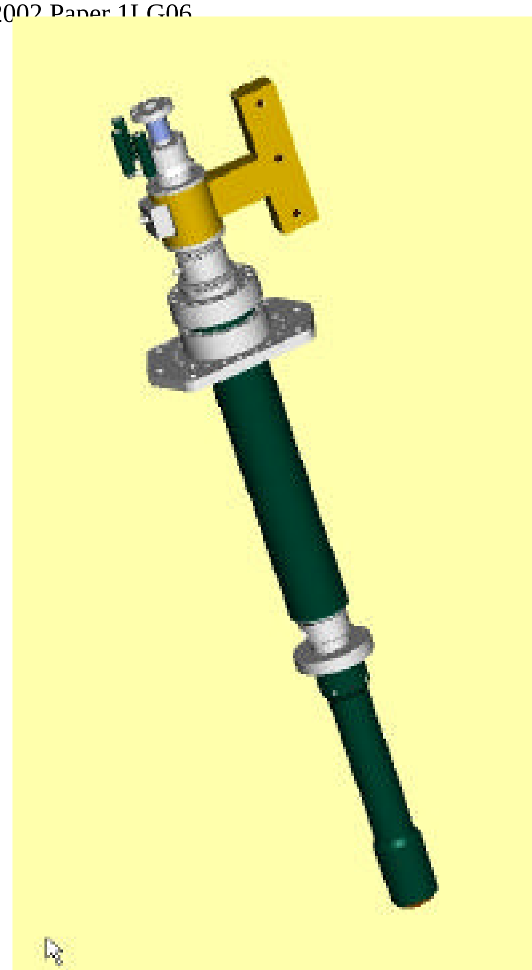

Fig. 3. A schematic representation of a 7.5-kA HTS lead combined with a gas-cooled lead between 50 K and 300K. The gas-cooled lead is above the center flange; the HTS lead is below this flange.

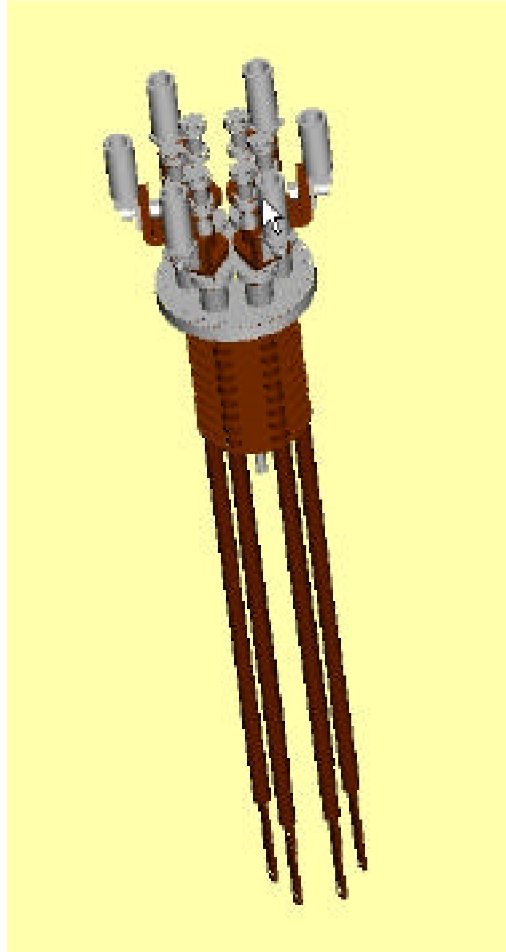

Fig. 4. An Assembly of six 600-A gas-cooled leads that goes into a 150-mm diameter DFBX lead chimney. The bars from the bottom of the leads are superconducting bus bars.

The correction coil lead assemblies will be purchased item that will assembled into the DFBX boxes. The gas cooled leads will feed directly into the 4.4 K helium tank that provides cooling for the buses and the correction magnet gas cooled leads. The correction coils are small and of low inductance. As a result, the correction magnet gas-cooled leads are specified to operate for only 60 seconds without helium flow.

IV. Magnet Busses, Lambda Plugs, and Bus Ducts

The lower part of the leads are in a 4.4 K liquid helium bath at about 1.2 bar. The superconducting quadrupoles, the corrector magnets, and the dipole operate in a bath of sub-cooled 1.9-K helium at a pressure above 1 bar. During normal operation, the pressure difference between the 4.4 K helium tank and the 1.9 K magnet cryostat is small. During a quench, the pressure in the magnets can reach 20 bar. The magnet busses must pass through a leak tight lambda plug that can handle this 20 bar pressure difference. The lambda plug must minimize super-fluid helium flow from the 1.9 K region to the 4.5 K region. This eliminates a large heat flow into the 1.9 K region. There will be a small heat flow to the 1.9 K region along the conductors in the lambda plug.

The lambda plug and bus duct must carry the current for the low-beta interaction region quadrupoles and correction magnets at the quadrupole end of DFBX. A second bus duct and lambda plug must carry dipole busses at the dipole end of the DFBX. Fig.5 shows DFBX

Two approaches to making a vacuum tight lambda plug current feed through have been explored. One approach is to bond the conductor into a solid Vespel (plastic) plug. The plug has a machined ridge to allow it to seal against a finely machined stainless steel surface. This approach has been successfully tested by CERN for some of their lower current magnets lambda plugs [2]. LBNL did not use this approach because of radial space limitations in the bus duct assembly.

LBNL successfully tested lambda plugs fabricated from the conductors, NEMA-G10-CR, and Stycasr filled epoxy. The lambda plug diameter is about 88 mm. It carries four 7.5-kA cables, fourteen 600-A solid buses, and ten 120-A solid buses. In preliminary tests, the LBNL lambda plug was thermal cycled from 300 K to 77 K fifty times. At the end of the fifty thermal cycles, the lambda plug assembly was found to be vacuum tight at 77 K against helium at 1.4 bar. Fig. 5 shows the leads, bus ducts and helium tank in a partly assembled DFBX box C or G.

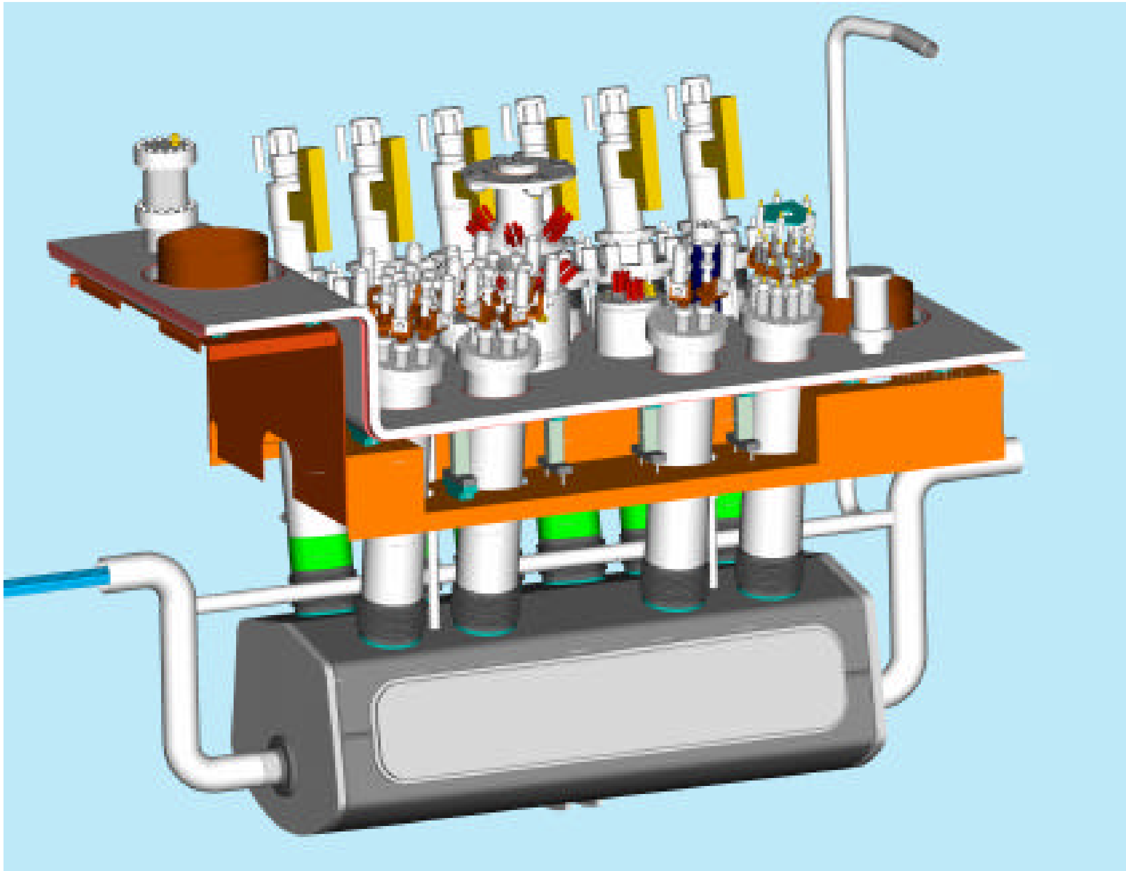

Fig 5. The DFBX box before the helium distribution piping and the shields have been installed. The lead chimneys for the HTS leads and the gas cooled leads are shown for DFBX boxes C or G. The liquid helium tank is at the bottom of the figure. The lambda plugs are located where the bus ducts connect to the lower part of the DFBX helium tank. The six combined HTS and gas-cooled leads are located at the rear of the box shown. The pure gas-cooled leads are in the chimneys to the front. Instrumentation lead ports are located in the middle of the DFBX top plate between the 7.5 kA leads and the correction magnet leads.

V. CONCLUDING COMMENTS

The DFBX boxes provide the current to the low beta quadrupoles and a dipole on either side of them. Power to the correction magnets passes through the DFBX. The DFBX also acts as a conduit for the instrumentation wires that go to these magnets.

The DFBX boxes also act as the cryogenic distribution center for the superconducting magnets on either side of them. The DFBX boxes provide 1.9 K cooling to the magnets and to the LHC beam tube. The DFBX provides cooling to the 65 K shields of the magnets on either side of them. The DFBX distributes 20 K helium from the CERN cryogenic system to the top of the 7.5-kA HTS leads and provides the cooling gas needed for the gas-cooled leads that are attached to the HTS leads. Helium at 4.5 K is provided to the helium tank that carries the magnet current busses and cools the lower end of the current leads (both HTS and gas-cooled leads). The DFBX boxes are complex because the current-lead chimneys, LHC beam pipe and cryogenic piping all share the same physical space within the DFBX vacuum vessel. Since the DFBX must fit between the low beta quadrupoles and the dipole that is part of the LHC beam spreading system, its length is limited. As a result, the lead chimneys must straddle the LHC beam pipe and the piping that distributes cryogens from the CERN cryogenic distribution system to the superconducting magnets

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