FUNCTIONAL SPECIFICATION

INTERFACES DEFINITION

DFX DEVICE

COLD POWERING WORK PACKAGE – WP6A

[HL-LHC EQCOD ACCORDING TO CONFIGURATION MANAGEMENT]

Abstract

The HL-LHC project requires a cold powering system for the supply of the new inner triplet magnets on each side of ATLAS and CMS experiments. Each inner triplet's cold powering system includes a cryostat – DFX- electrically connected to the Superconducling Link, on the 4.2 K side, and to the magnet bus-bas, on the 1.9 K side.

This document presents the functional specifications, details the interfaces and define the delivery conditions of the DFX device.

Draft for information

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TRACEABILITY

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0.1	2018 06 05	1st issue
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1 SCOPE

1.1 Description

The HL-LHC project requires a new cold powering system for the supply of the new inner triplet magnets on each side of ATLAS and CMS experiments [1]. Each inner triplet cold powering system contains a cryostat – DFX- electrically connected to the Superconducling Link, on the 4.2 K side, and to the magnet bus-bas, on the 1.9 K side.

The DFX device connecting the superconducting link to the triplet magnets is composed of a saturated liquid helium vessel located in an insulated vacuum cryostat.

The electrical connections between superconducting leads from the magnets and the SC Link cables are immersed in liquid helium to ensure the required cooling. A controlled cooling of the cold powering system is ensured by a gaseous mass flow produced by vaporising liquid helium in the DFX.

1.2 Scope of the document

This document presents the functional specifications and the interfaces of the DFX series devices. It should be noted that the DFX prototype is a spare unit for the HL-LHC machine and shall therefore be designed according to the HL-LHC machine requirements. The prototype DFX is produced in the framework of the CERN-UK collaboration. For this reason, a specific mention is made in the paragraph: items supplied by CERN.

Mechanical interfaces are detailed in a specific document, see [20].

2 APPLICABLE DOCUMENTS / GENERAL REQUIREMENTS

According to the CERN safety rules GSI-M4 [2], "The manufacture […] by collaborating institutions, of all new cryogenic equipment shall comply with the applicable CERN Safety Rules [3], European directives and harmonised standards". In particular:

- The Pressure European Directive 2014-68-EU [4] and relevant European standards for electrical devices apply;
- The use of plastic and other non-metallic materials at CERN shall comply with the IS 41 [5] with respect to fire safety and radiation resistance;
- The ALARA principle shall apply at each steps of the design phase (As Low As Reasonably Achievable);
- HL-LHC Quality Assurance requirements.

3 FUNCTIONAL DESCRIPTION OF THE DFX DEVICE

3.1 Main functions

The DFX has the following main functions:

- Ensure the electrical performance of the SC Link Nb-Ti to MgB_2 cables electrical connection;
- Ensure the electrical connectivity between the SClink and the superconducting magnets cables;
- Ensure the immersion in liquid helium of the electrical MgB_2-NbTi and NbTi-NbTi splices and of the NbTi leads;
- Ensure the controlled supply of gaseous mass flow to the SC Link helium volume;
- Ensure maintenance-free operation over the life time of the machine, i.e. at least 20 years, and 500 thermal cycles between nominal and operation configurations. For integrated systems which cannot be maintenance-free like helium level gauges and burst disks, accessibility for easy replacement shall be possible.

3.2 Electrical requirements

3.2.1 General

The cold powering system of HL-LHC is detailed in [14].

The DFX shall be designed to:

- Ensure the electrical continuity between the magnet circuits and the SC Link cold powering circuits;
- Ensure the execution of the electrical connections during installation;
- Ensure the electrical integrity over the life time;

3.2.2 SC Link electrical interfaces

The SC Link electrical interfaces are listed below:

- The cable bundle is made of MgB_2 cables soldered to NbTi leads extensions;
- The MgB_2/NbTi splices are part of the SC Link. They are:
    - Contained in a rigid protecting structure of dimensions Ø200 mm x 700mm;
    - The NbTi extensions are flexible and can be routed with a bending radius larger or equal to 125mm; they shall be routed in the DFX so that they can compensate a thermal contraction movement of the cable of about 50 mm;
- Only the NbTi cable extensions are accessible during the assembly of the DFX.
- The NbTi cable extensions shall be routed and connected to the Nb-Ti bus bars coming out from the lambda plate;
- Cables and splices supports (in the DFX helium volume) shall be designed to withstand the Lorentz forces and kept in position within the helium vessel to ensure electrical integrity. CERN has decided to de-scope the cables and splices supports from the prototype collaboration. However, their mechanical interfaces to the helium reservoir shall comply with [20];
- The NbTi cables shall be designed to allow their bended insertion in the DFX;
- The stabilization of the NbTi cables shall be done keeping into account the flexibility and routing needs during installation.

3.2.3 Electrical instrumentation: Voltage Taps

The number and layout of the Voltage taps distribution is presented in [17] and [18].

- Voltage taps shall be routed to a vacuum vessel-mounted instrumentation interfaces;
- Feedthrough in the helium vessels shall be made through adequately sized passages and wires routed through IFS-type feedthroughs; due to reliability constraints, no cold ceramic feedthroughs shall be adopted in the design;
- The MgB_2/NbTi splices will be pre-equipped with Voltage Taps mounted prior to tunnel installation; wire routing shall be done in the DFX during tunnel installation, see [18].
- NbTi/NbTi splices will carry V-taps on the cables; the wires soldering will be done during tunnel installation;
- The DFX shall carry at its vacuum vessel IFS-type feedthrough interfaces ensuring connectivity with the warm cables, see [20].

3.2.4 Electrical connection between conductors

The alignment between the superconducting cables from the magnets and the SC Link is ensured by the flexibility of the NbTi cables on the SC Link side. Cables passing through the lambda plate are stabilised and present a flexibility limited to the thermal contraction requirements between the plug and the splices.

The access to the NbTi/NbTi splices shall be granted during installation and maintenance.

3.2.5 Magnet side cables interfaces

As detailed in §3.3., the triplet and DFX helium vessels are hydraulically separated with a device referred as lambda plate, ensuring the electrical continuity between the two volumes. A layout proposal of the leads in the plug is presented Figure1 and [19]. The length of the NbTi bus bars on the DFX side shall be suggested by the DFX design (up to 3m).

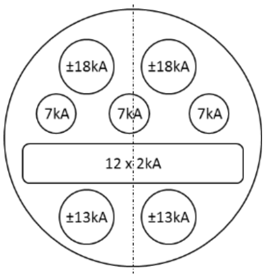

Figure1: Layout of the leads at the lambda plate interface. Top is vertical.

3.3 Cryogenics requirements

3.3.1 General

The cryogenic baseline layout of the DFX device is presented in the general cryogenic layout [8] and [9]. The DFX is a vacuum insulated saturated liquid helium bath. The helium volume is hydraulically separated from the magnet side and shared with the helium volume of the SC Link.

The DFX device shall:

- Ensure the temperature control of the superconductors (conductors and splices):
  - NbTi < 5K: by immersion of leads and splices in liquid helium;
  - MgB_2 to NbTi splices < 5 K.
- Ensure the controlled supply, by liquid vaporisation, of gaseous helium mass flow at 4.5K to the SC Link helium volume up to 10 $g.s^{-1}$ (Nominal 5 $g.s^{-1}$) [15];
- From the liquid helium level to the SC Link helium volume, the gaseous flowing area shall be at least the free gaseous helium section of the SC Link, at best 1.5 times the section to avoid local pressure drop;
- In case of liquid helium supply stop, the DFX shall ensure an operational autonomy of at least ten minutes in nominal conditions (splices entirely immersed and gaseous mass flow production of 5 $g.s^{-1}$);

In addition, the DFX design shall follow, where applicable, the standard practice at CERN for cryogenics applications:

- Helium volumes at 4.5K may not be shielded if heat loads remain acceptable (see §3.3.3);
- Transient modes and off-nominal cases shall be considered in the design, and as a minimum include cool down and warm up phases;
- For saturated LHe volumes, a constant increasing slope between coldest point (lambda plate) and Liquid/Gas interface must be ensured;
- The instrumentation used in active control loops shall be doubled for operational redundancy:
  - LHe level gauges: doubled up to the control system for continuity of operation with the possibility to replace a LHe gauge at cold (without liquid) or at warm within a minimal intervention time so as to comply with the ALARA principle;
  - Temperature sensors: possibility to connect one redundant sensor on measuring card. Such temperature sensors shall be replaceable at warm during long shut downs;
- Accessibility to valves and instrumentation for inspection and easy maintenance.

3.3.2 Interfaces with cryogenic lines

The DFX cryogenic design shall be compatible with the cryogenic layout [8] and the mechanical interfaces defined in [20], in particular:

- Connect through a “jumper” interface to the QXL cryogenic distribution line;
- Integrate and route the cryogenic lines detailed in Table2.

Table 2: Cryogenic parameters and equipment design pressures

Description	Ref:	Inlet outlet	DN [mm]	Fluid	Nominal pressure [bara]	Design pressure [bara]	Temperature range [K]
Inlet Liquid helium	CS	From line C	DN20	Mix liquid-gas helium	1.3	2.5	[4.5;300]
Return gas helium for transient phases	SD	To line D	DN40	Gaseous helium	1.3	2.5	[4.5;300]
DFX helium volume	S	From line CS To DSHx	NA	Saturated liquid helium bath	1.3	2.5	[4.5;300]
Outlet thermal shield	$E'_{H}F_{H2}$	From D1 side To DFX jumper	TBD	Gaseous helium	24	25	[60;300]
Inlet coil warm up		From $E'_{H}F_{H}$	DN4	Gaseous helium	24	25	[40;300]
Outlet coil warm up		To jumper	DN4	Gaseous helium	24	25	[40;300]

3.3.3 Heat loads

The following apply:

- The total static heat loads to the 4.5K volume shall not exceed 30 W;
- The thermal design of the DFX shall ensure that the temperature at any location of the vacuum vessel shall remain above the dew point temperature; as an indication, a minimum dew point temperature for the normal humidity conditions in the LHC tunnel is 12 degrees Celsius.

The total dynamic heat loads dissipated by all splices contained in the DFX at nominal current are lower than 3 W [16].

It is suggested to cover surfaces of temperature below 100 K and facing the 300 K walls with 30 layers of Multi-Layer Insulation (MLI), and surfaces with temperatures below 20 K and facing surfaces of temperature above 50 K with 10 layers of MLI (specific requirements for wet surfaces detailed in 3.3.5).

3.3.4 Design and test pressure

The design pressures of the three independent circuits are defined in Table 2:

- Helium volume: design pressure 2.5 bara;
- Heat exchanger circuit : design pressure 25 bara;
- Thermal shield line from magnet side: design pressure 25 bara.

Circuits shall be pressure tested to pressures defined by the Pressure European Directive (PED) and according to EN 13458-2 section 6.5 procedure as defined in [21].

3.3.5 Levels, dimensions and volumes

The DFX design shall ensure the following levels, dimensions and volumes for the control and production of the required mass flow during transient and nominal phases, see figure 2a:

- The nominal liquid level presents a vertical tolerance of ± 75 mm;
- The distance between the SCLink helium volume gas inlet and the nominal liquid range shall be greater than 110 mm;
- To comply with the ten minutes autonomy mentioned in 3.3.1., a minimum volume of 25 litres shall separate the nominal liquid range from to the heater device;

The DFX design shall ensure the following levels, dimensions and volumes for the respect of the MgB_2-NbTi splices immersion, see figure 2b:

- The vertical upper position of the splices at cold is 30mm higher than the initial one;
- To comply with the ten minutes autonomy mentioned in 3.3.1., a minimum volume of 6 litres shall be foreseen above the highest position of the splices.

The DFX design shall ensure the following levels, dimensions and volumes for the integrity of the safety relief devices, see figure 2c:

- A minimum of 300 mm vertical stratified gas shall separate the safety relief devices at 300K and the pipe inlet into the reservoir. The design effective distance shall be proven without risk of condensation by calculations;

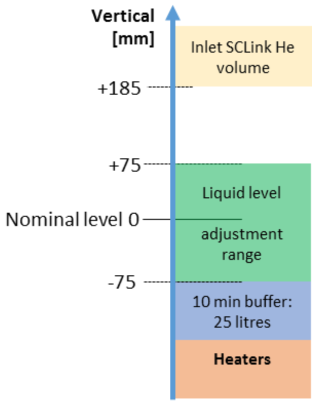

Figure 2a: levels and volumes for production and control of required mass flow

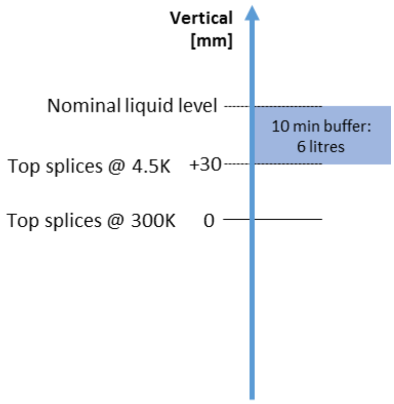

Figure 2b: levels and volumes for the immersion of splices

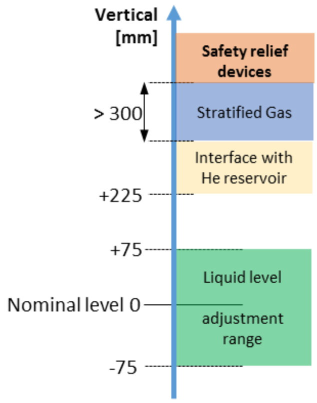

Figure 2c: levels and volumes for location of safety relief devices

3.3.6 Transients and nominal operating conditions

The DFX shall de designed to comply with the following operating conditions:

- Cool down transient

The DFX shall be cooled down separately from the SC Link by injecting cold gaseous helium through line CS. The SD line is used as return line.

- Nominal operation

During nominal operation, a mix of liquid and gaseous helium is flushed through line CS at 4.5 K and 1.3 bara. The inlet mass flow is regulated to ensure the nominal liquid level. Line SD is closed.

- Warm up transient

During warm up, after all liquid helium is vaporised, the system warms up due to static heat loads only.

3.3.7 Interfaces with helium volumes

The DFX design shall ensure the following welded connections between helium vessels:

- SC Link side :
    - Lip type weld allowing 5 cutting-welding operations;
    - The inner and outer corrugated pipes of the SC Link are mechanically independent and shall therefore be individually fixed to the DFX interfaces;
    - The rigid protection around the MgB_2-NbTi splices is fixed to the helium flange interface of the SC Link;
    - Mechanical interfaces detailed in [20].
- Magnet side :
    - Lip type weld allowing 5 cutting-welding operations;
    - Mechanical interfaces detailed in [20].

- Cryogenic jumper:
  - Fixed interface to QXL distribution module;
  - DFX cryogenic lines welded to interfaces as presented in [20].

The DFX helium vessel design shall consider mechanical flexibilities and induced loads.

3.3.8 Cryogenic safety

As defined in the CERN safety rules [2], a risk analysis shall be led and submitted to CERN for approval. It shall identify the Most Critical Incident, indicate mitigation actions and report on the design of safety pressure relief devices.

The exhaust of the safety relief pressure devices shall be released in the LHC tunnel to a location and orientation to be agreed with CERN.

- Helium volume safety devices;
  - The flowing area from the reservoir to the relief devices shall be designed according to ISO 21013-3.
  - The volume must be protected by a burst disc sized to the Most Critical Scenario and a relief valve sized to contain the static heat loads. The relief valve shall be equipped with a thermoswitch (note: the devices are supplied by CERN);
  - The burst disc and relief valve shall operate at ambient temperature, the vertical distance between the relief devices and the interface with the helium reservoir shall be as defined in 3.3.5.
- Insulation vacuum volume safety devices;
  - The protection shall contain a relief plate (supplied by CERN) of diameter defined by the risk analysis. Mechanical interfaces are defined in [20].
- Surfaces presenting surfaces below 10K shall be equipped with a minimum of 10 layers of MLI to limit heat transfer to fluid in case of insulation vacuum deterioration.
- The design shall ensure that safety relief devices may never face icing or condensation likely to influence their performance.
- The design shall demonstrate that any components may obstruct the relief device flowing areas if high flows occurs.

3.3.9 Thermo-mechanical design considerations

The DFX shall:

- Be mechanically connected:
  - To the SC Link helium and vacuum jackets;
  - With flexible elements to the magnet sides;
- Cope with the thermal contraction of NbTi cables ;
- Assure a fixed interface for the NbTi/NbTi splices in the helium vessel structure;
- The tensile load to the lambda plate shall not exceed 100 N per lead.

3.3.10 Control

A dedicated control loop system will be designed by CERN to ensure the helium liquid level in the DFX helium bath, the splices and cables temperatures based on the measurement of temperatures and liquid levels.

The DFX design shall integrate the instrumentation interfaces and reservations, the routing of the wires as well as the feedthroughs and the access for connection and inspection.

3.3.11 Hardware and instrumentation

The DFX device requirements for the cryogenic hardware are defined as follow:

- Cryogenic valves: the DFX design shall not include cryogenic valves;
- Liquid helium monitoring :
  - The liquid level associated to the gas flow production shall be monitored by two superconducting level gauges ;
    - One long gauge used during transient phases covering the vertical height of the reservoir;
    - One short gauge measuring precisely the allowable adjustment range over the liquid level nominal range;
  - The liquid helium volume containing the MgB_2-NbTi splices shall be monitored by a ΔP gauge;
- Helium vaporisation heater: the liquid vaporisation shall be performed by:
  - A heat exchanger made of DN4 copper tube, about 1 m long (1mm thick) immersed in liquid helium and circulating about 1 g/s gaseous helium from line E to F (about 60 K);
  - Two 100 W electrical heaters immersed in liquid helium;
  - The DFX shall present two 100W electrical heaters at the lowest position of the reservoir for vaporising liquid during warm up.

The cryogenic instrumentation layout is presented in [17] and [18], the DFX design shall present the required mechanical and feedthroughs interfaces, see [20]. The instrumentation sensors, wires, hardware are supplied by CERN as defined in §4. Table 3 presents the requirements on cryogenic sensors and cabling.

Table 3: Requirements on cryogenic sensors and cabling.

Item	Specification
Temperature sensors	The temperature distribution shall be monitored with PT100 type sensors for temperature above 50 K and Cernox type for temperatures below 50 K. Mechanical interfaces for the Cernox sensors are defined in [20].
Level gauges	CERN usually use ¼" diameter rigid probe. Other probes may be used after discussion and agreement with CERN. See 3.3.1 for replacement requirements.
Pressure transducer	Interface at 300K, accessible for inspection and replacement, position to be agreed with CERN.
Wire routing	The routing of wires shall be designed to cope with thermal contractions, turbulent flow during transients and pressure relief valves opening.
Pin layout	Defined by CERN.

Note: electrical insulation of wires shall comply with the IS41 [5]. Wires are defined in [18].

3.4 Insulation Vacuum

3.4.1 General insulation vacuum specifications

The DFX insulation vacuum is independent from the insulation vacuums of the triplet cryostats, the cryogenic lines and the SCLink. Separations are performed by vacuum barriers as detailed in [13].

The DFX design shall present interfaces for connecting the pumping system, to monitor and to protect the insulation volumes of the DFX and the one of the SCLink.

The connection between insulation vacuum components shall be performed using ISO K flanges with standard clamps and elastomer seals where possible. For non-standard dimensions, the tightness is performed with elastomer (Viton) O-rings of diameter 7mm to be compressed by design between 25 % and 30 %.

3.4.2 Insulation vacuum of the DFX

The DFX outer envelope shall present:

- An interface for the pumping equipment as defined in [20], the turbo pump must be installed horizontally;
- An interface for the gauges assembly as defined in [20];
- An interface for the relief plate DN200 as defined in [20].

3.4.3 Interfaces with the Cryogenic Jumper

At the interface with the cryogenic lines, the vacuum barrier is located on the cryogenic lines side.

3.4.4 Insulation vacuum of the SC Link

At the interface with the SC Link, the DFX design shall include:

- A leak tight vacuum barrier;
- An interface for the pumping equipment as defined in [20], the turbo pump must be installed horizontally;
- An interface for the gauges assembly as defined in [20];
- An interface for the relief plate DN100 as defined in [20].

3.4.5 Interfaces with magnet side

The DFX design shall interface with the magnet vacuum jacket as defined in [20].

Note: no vacuum (nor helium) sleeves can be slided toward the magnet side.

The DFX shall present on the magnet side, a flexible element on the vacuum jacket designed to accept ±20 mm axial stroke and a minimum of +/-5 mm lateral stroke.

Note: the flexibility between the DFX and the magnet interface may require higher lateral offset to ensure the slope requirement expressed in 3.3.1.

3.4.6 Vacuum and leak tightness requirements

The nominal insulation vacuum level in operation is 1.10^{-5} mbar as defined in [13].

Leak tightness requirement are expressed in 3.7.4. Cleaning requirements are expressed in 3.7.5.

3.5 Integration and installation

The DFX is to be installed at four different locations in the machine; left and right of interaction points 1 and 5 in the LHC tunnel. The DFX device is physically located between 86m and 93m from the IP and interfaces on one side with the triplets chain of cryostats and on the other side with the SCLink (DSHx).

The DFX is mechanically independent from the beam tube and shall be permanently fixed to the tunnel infrastructure.

3.5.1 Tunnel environment

A dedicated 3D integration model has been developed by WP15 for the DFX environment. A detailed report presenting the DFX integration areas is available in §3 of [12]. Differences between the various DFX locations are detailed as well as the slope of the tunnel to be carefully taken into consideration for the cryogenic requirement for LHe saturated bath expressed in §3.3 of this specification. The DFX shall be adjusted in height accordingly.

The DFX design and supports shall respect the available volume for the DFX integration detailed in [12]. The area is shared between the beam line, the transport area, the cable trays, the QXL and other ancillaries as presented in [12].

3.5.2 Accessibility during installation and maintenance

The components present in the DFX area are detailed in [12]. A preliminary order of installation and the associated constraints is presented, in particular:

- The beam line is installed after the DFX and the installation reservation shall be reserved;
- The survey equipment (HLS and WPS) are installed after the DFX allowing the use of the reservations for installation. For important maintenance, only the WPS equipment can be removed.
- The transport reservation can eventually be used during installation or maintenance;
- The reservation for cable trays and service will be installed before the DFX and can therefore not be used for installation nor maintenance;

The DFX design shall allow its transport within the LHC tunnel. In order to position at installation, the DFX shall present survey targets on its outer envelope visible from the transport area defined in [12].

The DFX design shall optimise the maintenance operation in view of ALARA.

3.5.3 Access limitations in the tunnel

For the purpose of this specification, the interventions in the LHC tunnel are defined as follow:

- Unscheduled interventions for inspections and light work during Technical Stops (e.g. for electrical checks on patch panel);
- Planned interventions for routine maintenance requiring warm up during YETS (e.g. replacement of burst disks);
- Unscheduled medium repair work interventions requiring warm up during YETS (e.g. NbTi/NbTi repair);
- Unscheduled heavy repair work interventions requiring warm up during EYETS or unscheduled extended machine stop (e.g. MgB2/NbTi repair, plug replacement);

3.5.4 Mechanical interfaces

The mechanical interface between the magnets cryostats and the DFX is defined in [20].

The interface between the DFX and the SCLink is located in a horizontal plane 1.8 m +/- 10 cm above the beam and located below the entry pit. Mechanical interfaces are detailed in drawings, see [20].

The interface between the DFX jumper and the QXL interface is defined in [20].

3.6 Maintainability

The operations of maintenance and repairs to be considered in the design of the DFX are defined as follow. The design shall consider the ALARA principle for these operations.

3.6.1 Unscheduled Inspections

Access for inspection of patch panels, vacuum equipment, close cryogenic valves and safety relief devices shall be granted.

3.6.2 Planned maintenance

Replacement of safety relief devices, vacuum equipment shall be considered in the design keeping into account the ALARA principle.

3.6.3 Unscheduled medium repair

Replacement of plug, heater, instrumentation devices as well as repair of NbTi-NbTi splices shall be considered in the design of the DFX and the operation optimised toward the ALARA principle.

3.6.4 Unscheduled heavy repair

Repair of the MgB_2-NbTi splices in the tunnel may be considered in the design of the DFX.

3.7 Materials, manufacturing and inspections

Technical specifications are defined in the DFX prototype Technical Specification [21].

4 ITEMS SUPPLIED BY CERN

Items supplied by CERN are defined in the DFX prototype Technical Specification [21].

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