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FUNCTIONAL SPECIFICATION

DFM CRYOSTAT

COLD POWERING WORK PACKAGE – WP6A

[HL-LHC EQCOD ACCORDING TO CONFIGURATION MANAGEMENT]

Abstract

The HL-LHC project requires a new cold powering system for the supply of the new matching section magnets on each side of ATLAS and CMS experiments. The D2 cold powering system contains a chain of three cryostats hydraulically and electrically connected in series and made of a 130 meters superconducting link with connection boxes, named DFM and DFHm at each ends.

This document presents the functional specifications of the DFM device.

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TRACEABILITY

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1 SCOPE

1.1 Description

The HL-LHC project [1] requires a new cold powering system for the supply of the new matching sections magnets on each side of ATLAS and CMS experiments. The D2 cold powering system contains a chain of three devices connected in series and composed of a superconducting link of about 130 m length (referred as DSHm or SCLink) with connection devices, named DFM at the magnet connection side and DFHm at the current leads connection side in the UR service gallery.

The DFM device connecting the superconducting link to the D2 magnets is composed of a saturated liquid helium vessel located in an insulation vacuum vessel.

The electrical connections between superconducting leads from the magnets and the SCLink sides 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 DFM.

1.2 Scope of the document

This document presents the functional specifications of the DFM device.

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 DFM DEVICE

3.1 Main functions

The DFM 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 DFM 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 SCLink 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 600mm;
  - The NbTi extensions are flexible and can be routed with a bending radius larger or equal to 125mm; they shall be routed in the DFM so that they can compensate a thermal contraction movement of the cable of about 30 mm;
- Only the NbTi cable extensions are accessible during the assembly of the DFM.
- 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.
- The NbTi cables shall be designed to allow their bended insertion in the DFM;
- The stabilization of the NbTi cables shall be done keeping into account the flexibility and routing needs during installation.

3.2.3 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.

3.2.4 Magnet side cables interfaces

As detailed in §3.3., the triplet and DFM 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 Figure 1. The length of the NbTi bus bars on the DFM side shall be suggested by the DFM design (up to 2m).

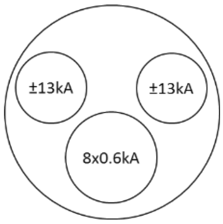

Figure1: Layout of the leads at the plug interface. Top is vertical.

3.3 Cryogenics requirements

3.3.1 General

The cryogenic baseline layout of the DFM device is presented in the general cryogenic layout [8] and [9]. The DFM 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 SCLink.

The DFM device shall:

- Ensure the temperature control of the superconductors in operation (conductors and splices):
  - NbTi < 5K: by immersion of leads and splices in liquid helium;
  - MgB2 to NbTi splices < 5 K.
- Ensure the controlled supply, by liquid vaporisation, of gaseous helium mass flow at 4.5K to the SCLink helium volume up to 3 g.s-1 (Nominal 2 g.s-1).
- From the liquid helium level to the SCLink helium volume, the gaseous flowing area shall be at least the free gaseous helium section of the SCLink, at best 1.5 times the section to avoid local pressure drop;
- In case of liquid helium supply stop, the DFM shall ensure an operational autonomy of at least ten minutes in nominal conditions (splices entirely immersed and gaseous mass flow production of 2 $g.s^{-1}$).

In addition, the DFM 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 are demonstrated acceptable (see §3.3.3);
- Transient modes and abnormal 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;
- Access to valves and instrumentation shall be granted for inspection and maintenance.

3.3.2 Interfaces with cryogenic lines

The DFM cryogenic design shall be compatible with the cryogenic layout [8], 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	DN12	Mix liquid-gas helium	1.3	2.5	[4.5;300]
Return gas helium for transient phases	SD	To line D	DN25	Gaseous helium	1.3	2.5	[4.5;300]
DFM helium volume	S	From line CS To DSHm	NA	Saturated liquid helium bath	1.3	2.5	[4.5;300]
Thermal shield return	E'_HF_{H2}	From D2 jumper	TBD	Gaseous helium	24	25	[60;300]
Inlet coil warm up	TBD	From E'_HF_H	DN4	Gaseous helium	24	25	[40;300]
Outlet coil warm up	TBD	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 20 W;
- The thermal design of the DFM 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.

3.3.5 Levels, dimensions and volumes

The DFM 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 ± 50 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 12 litres shall separate the nominal liquid range from to the heater device;

The DFM 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 3 litres shall be foreseen above the highest position of the splices.

The DFM 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;

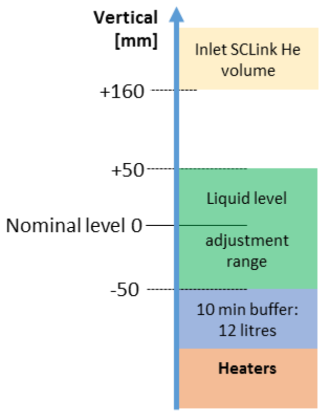

Figure 2a: levels and volumes for production and control of required mass flow

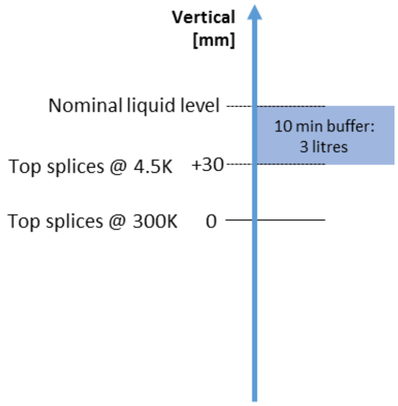

Figure 2b: levels and volumes for the immersion of splices

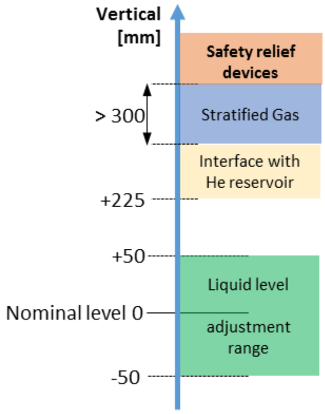

Figure 2c: levels and volumes for location of safety relief devices

3.3.6 Transients and nominal operating conditions

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

- Cool down transient

The DFM 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 DFM 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 DFM interfaces;
  - The rigid protection around the MgB_2-NbTi splices is fixed to the helium flange interface of the SC Link;
- Magnet side :
  - Lip type weld allowing 5 cutting-welding operations;
- Cryogenic jumper:
  - Fixed interface to QXL distribution module;

The DFM 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 various HL-LHC workpackages.

- 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;
  - 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 of diameter defined by the risk analysis.
- 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 DFM 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 TE-CRG to ensure the helium liquid level in the DFM helium bath, the splices and cables temperatures based on the measurement of temperatures and liquid levels.

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

- Cryogenic valves: the DFM 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 DFM 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]. 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. See 3.3.1 for replacement requirements.
Pressure transducer	Interface at 300K, accessible for inspection and replacement.
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 in agreement with CRG.

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 DFM insulation vacuum layout is defined in [13].

All surfaces exposed to insulation vacuum shall respect the specifications defined in [11].

The connection between insulation vacuum components is performed via ISO K flanges with standard clamps and elastomer seals.

The DFM shall present on both sides, a flexible element on the vacuum jacket designed to accept 10 mm axial stroke and +/-5 mm lateral stroke.

Note: at the jumper connection, the vacuum barrier is on the cryogenic lines side.

3.4.2 Interfaces with SCLink

At the interface with the SCLink, the DFM design shall include:

- A leak tight vacuum barrier;
- Pumping and instrumentation ports for the SCLink insulation vacuum volume;
- An interface for the pressure relief plate (supplied by CERN) for the SCLink insulation vacuum and DFM volumes of minimum diameter Ø100mm;
- The SCLink vacuum jacket flange dimension shall be detailed later on.

3.4.3 Interfaces with magnet side

The DFM design shall include a connection to the ISO-K type flange of the magnet interface. A D2-DFM superfluid link connects the DFM to the D2.

3.5 Integration and installation

The DFM is to be installed at four different locations in the machine; left and right of interaction points 1 and 5. The DFM is located about 45m away from the shaft where the SCLink enters the LHC tunnel. The DFM box shall comply with:

- Reserved area for transport;

- Reserved area for D2, QXL and beam;
- Reserved area for services;
- Reserved area for survey purposes;
- Provide access to perform splices and all required maintenance for DFM and QXL equipment.

3.6 Maintainability

The operations of maintenance and repairs to be considered in the design of the DFM 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 and manufacturing

All materials used in the DFM device shall:

- Be delivered with a material certificate compliant with the application;
- Cobalt content for stainless steel shall be below 0.1%;
- Helium pressure vessels materials shall comply with the CERN material specification N°510-Ed.5 [6]. Any change to this specification shall be agreed by CERN;
- Vacuum vessels shall be made of stainless steel of grade EN1.4306, EN1.4307, EN1.4404 or EN1.4435;
- Bellows shall be made of stainless steel of grade EN1.4404 or EN1.4435;
- All stainless steel part of the DFX shall be made of stainless steel of grade EN1.4404 or EN1.4435.
- The materials used in the DFM shall comply with an integrated dose over the HL-LHC operation as defined in [7].
- All polymer materials shall comply with the CERN IS41 [5].

Manufacturing processes and design shall minimise the risk of leaks between helium and vacuum volumes.

Each weld ensuring a leak tightness function must be inspected by visual (ISO17637) and radiographic (ISO5817) means according to standards and by qualified personnel (ISO 9712 Level2).

All leak tight welds shall conform to ISO 5817, quality level B. Final weld beads shall not be modified by grinding or machining. All welding repair shall be documented in a non-conformity report.

3.8 Quality Assurance documentation

In addition to specifications defined in paragraph 2, CERN requires to receive and approve the documentation presented in table4 according to standards where applicable:

Table 4: Documentation

Phase	Requirements
Design	- Specification drawings according to ISO-GPS; - Design and calculation reports according to applicable standards; - Safety file as defined in [2];
Procurement	- Technical specifications with certification requirements;
Manufacturing	- Manufacturing drawings to ISO-GPS standards; - Manufacturing and Inspection plan; - Welding book - Welder certifications (ISO9606-1) - Weld qualification (ISO 15614-1) - Welds visual and radiographic inspection reports (ISO 17637, ISO 17636-1) - NDT operator certification (ISO 9712 NDT level2) - Cleaning procedure and reports - Pressure test procedure and reports - Leak test procedure, report, personnel certification (ISO 9712); - Dimensional control reports;
Assembly & qualification	- Assembly and maintenance procedures; - CE certification;
Archiving	- Archiving of all documentation in MTF, CERN database;

Note: all certifications and qualifications shall be according to a harmonised standard to the Pressure European Directive 2014/68/EU.

4 REFERENCES

[1] L.Rossi et al. "High-Luminosity Large Hadron Collider (HL-LHC): Technical Design Report V. 0.1", EDMS 1833445.
[2] CERN HSE department "GSI-M-4 – Cryogenic equipment", EDMS 1327191.
[3] CERN HSE department "CERN Safety rules", https://hse.cern/content/safety-rules
[4] European Parliament "Pressure European Directive 2014/68/EU", https://eur-lex.europa.eu/homepage.html , direct link PED2014/68/EU
[5] CERN HSE department "Safety Instruction : The Use of Plastic and other Non-Metallic Materials at CERN with respect to Fire Safety and Radiation Resistance", EDMS 335806
[6] GS-IS & EN-MME CERN groups "Material Specification, Welded and seamless stainless steel tubes", EDMS 1380627
[7] R.Garcia, presentation at HL-MCF meeting, https://indico.cern.ch/category/8387/
[8] D.Berkowitz "Process flow diagram of HL-LHC D2 R5", EDMS1750118
[9] D.Berkowitz "Preliminary naming, operational parameters and flow diagrams of the cryogenic distribution lines for HL-LHC", EDMS1573115.
[10] Ch.Balle "Installation guide for LHC cryogenic thermometers", EDMS 110748
[11] A.Vidal et al. "Specification for mechanical assemblies or sub-assemblies exposed to insulation vacuum" EDMS 1584250.
[12]
[13] Y. Leclercq, J. Fleiter, Y.Yang "Insulation Vacuum Proposal for the Cold Powering Chain of Cryostats", EDMS2048016
[14] A. Ballarino "Cold powering: Updated baseline and results from Demo1 construction", 8th HL-LHC collaboration meeting. Indico event 742082.

[16] J.Fleiter "NbTi bus bars in DFX Lhe bath", DFX weekly meeting, Indico773560