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ACCEPTANCE CRITERIA

PART B - LMQXFA COLD MASS AND CRYOASSEMBLY

Abstract

This document specifies the acceptance criteria for the LMQXFA cold mass and cryoassembly. If all the requirements specified in this document are met, then the U.S. HL-LHC AUP LMQXFA and LQXFA deliverables will be accepted by

Please note that the definition of threshold as it is being used by the American contribution is not the same as objective, according to the HL-LHC quality policy.

TRACEABILITY

Prepared by: R. Carcagno, (US LARP/AUP)	***Date:*** 2020-04-16
AUP Verified by: S. Feher	***Date:*** 2020-04-16
Verified by: V. Baglin, M. Bajko, A. Ballarino, I. Bejar Alonso, A. Devred, M. Martino, S. Claudet, P. Fessia, A. Infantino, S. Izquierdo, H. Mainaud-Durand, T. Otto, M. Pojer, H. Prin, D. Ramos, L. Tavian, R. Van Weelderen, D. Wollmann	***Date:*** 2020-05-22
AUP Approved by: G. Apollinari	***Date:*** 2020-04-16
Approved by: L. Bottura, O. Bruning, J.M. Jimenez, L. Rossi, E. Todesco	***Date:*** 2020-05-27
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Ref. Doc: LMQXFA Functional Requirement Specification (EDMS 1686197)	

Rev. No.	***Date***	***Description of Changes*** *(major changes only, minor changes in EDMS)*

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US HL-LHC Accelerator Upgrade Project

ACCEPTANCE CRITERIA PART B:
Cryo-Assemblies Fabrication

Prepared by: Ruben Carcagno, US HL-LHC AUP Deputy Project Manager, FNAL Sandor Feher, US HL-LHC AUP L2 Manager, FNAL
Reviewed by: Sandor Feher, US HL-LHC AUPL2 Manager, FNAL Ezio Todesco, HL-LHC WP3 Leader, CERN
Approved by: E. Todesco, HL-LHC WP3 Leader, CERN Luca Bottura, Magnet Group Leader, CERN Lucio Rossi, HL-LHC Project Manager, CERN Sandor Feher, US HL-LHC AUP L2 Manager, FNAL Ruben Carcagno, US HL-LHC AUP Deputy Project Manager, FNAL Giorgio Apollinari, US HL-LHC AUP Project Manager, FNAL

Revision History

Revision	Date	Section No.	Revision Description
v0	6/27/2018	All	Initial Release
V0.9	4/16/2020	5,8,10,13,14	Added LMQXFA-R-O-05 and LMQXFA-R-T-28; updated LMQXFA-R-T-20 Hi-pot table V.0.9 shows in red the changes between version 0.5 and V1.0
V1.0	5/26/2020		

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1. Cold Mass Assembly

Requirement LMQXFA-R-T-01: The LMQXFA assembly physical length (end cover to end cover, including tolerances) must be ≤ 10,100 mm. This dimension is at room temperature (296 K).

Verification Method: Mechanical measurements after fabrication of each cold mass assembly

Procedure summary: The surface of the Survey/Alignment target located on the front end of the cold mass (End Cover) is defining the end positions of the cold mass. Using Laser Tracker, we will determine the length requirement within 0.1 mm precision.

Reference: Cold Mass Assembly Traveler [1]

Requirement LMQXFA-R-T-02: The LHe stainless steel vessel outer diameter, including tolerances, must not exceed 632 mm. This dimension is at room temperature (296 K).

Verification Method: Mechanical measurements after fabrication of each cold mass assembly

Procedure summary: The outer surface of the Cold Mass is measured using Laser Tracker survey with 0.1 mm precision at four different locations along the cold mass. A circle is fitted at each four locations and determined the maximum deviation from the circle.

Reference: Cold Mass Assembly Traveler [1].

Requirement LMQXFA-R-T-03: The LMQXFA end cover must include piping listed in Table 1 for cryogenic and electrical connectivity purposes.

Table 1: LMQXFA interface piping, penetrations and other functions (dimensions are at room temperature)

Function	**Number**	**Inner diameter (mm)**
Cold Bore Connection	1	150
Helium Vessel Connection	2	100
Busbar Connection	1	50
Heat Exchanger Connection	2	100

Verification Method: Mechanical measurements after fabrication of each cold mass assembly

Procedure summary: Laser Tracker survey and comparison with piping locations specified in the Interface Specification [3]

Reference: Cold Mass Assembly Traveler [1], Interface Specification [3]

Requirement LMQXFA-R-T-04: The LMQXFA cold mass assembly must not have any obstructions or interferences that will prevent insertion along the entire LMQXFA length of (i) the CERN-supplied 74 mm OD (plus 2 mm for tolerance value) heat exchanger tubes and their supports through the MQXFA cooling channels, of (ii) the busbar cartridge used to connect in series the two magnets making the cold mass, and of (iii) the cold bore.

Verification Method: Inspection on each cold mass assembly using a test pipe.

Procedure summary: A test pipe will be inserted into the cooling channel. The test pipe will be manufactured with a precision of 0.1 mm. A test pipe will be inserted into the Cold bore tube prior and after it is installed into the cold mass to measure that the requirement is met. The test pipe will be manufactured with a precision of 0.1 mm

Reference: Cold Mass Assembly Traveler [1]

Requirement LMQXFA-R-T-05: The LMQXFA magnetic elements are two identical MQXFA magnets connected in series and with the same polarity. The MQXFA magnets must satisfy the MQXFA requirements specification and the LMQXFA interface specification.

Verification Method: MQXFA acceptance criteria part A. [5]

Requirement LMQXFA-R-T-06: The distance between the two nodal points of the MQXFA magnetic lengths is 4806 mm ± 5 mm at room temperature (296 K).

Verification Method: SSW magnetic measurements during cold testing.

Procedure summary: Using SSW the magnets are individually powered (through the trim leads) and the nodal points are determined.

Reference: SSW technique described in Cold Mass Assembly Traveler [1]

Requirement LMQXFA-R-O-01: The maximum deviation of each MQXFA magnet axis along the common magnetic axis must be within ±0.5 mm both in horizontal and in vertical direction. The deviation of each MQXFA field angle from the common magnetic field angle must be within ±2 mrad.

Verification Method: SSW wire magnetic measurements.

Procedure summary: SSW magnetic measurements during cold testing is used for both the magnetic axes and field angle determination. The magnets are powered independently at low current values through the trim leads.

Reference: SSW technique described in Cold Mass Assembly Traveler [1]

Requirement LMQXFA-R-O-02: The common magnetic axis of the two-magnet system should be determined with respect to cold mass fiducials with accuracy of ±0.2 mm to both nodal points. The common average MQXFA field angle with respect to cold mass fiducials should be measured with accuracy better than 0.5 mrad. The magnetic length and the nodal points of each of the two MQXFA magnets in the cold mass need to be known within ±1 mm accuracy relative to external fiducials.

Verification Method: SSW magnetic measurements and rotating coil measurements are used.

Procedure summary: SSW magnetic measurements during cold testing by powering the magnets in series for measuring the common magnetic axes relative to survey fiducials. For the magnetic length rotating coil measurement are done.

Reference: SSW technique described in Cold Mass Assembly Traveler [1]

Requirement LMQXFA-R-T-07: The LMQXFA is a pressure vessel that must be designed and documented in accordance with CERN and U.S. HL-LHC Accelerator Upgrade Project safety agreements.

Verification Method: CERN approval of agreed upon pressure vessel safety documentation for each cold mass assembly

Procedure summary: submit safety documentation demonstrating compliance with CERN safety requirements, including pressure testing at 25 bar. CERN verifies that submitted documentation complies with the US-CERN pressure vessel safety agreement.

Reference: Launch Safety Agreement and Other US-CERN safety agreements [7][8][9]

Requirement LMQXFA-R-T-08: The LMQXFA pressure vessel material for the cylindrical shell and end covers must be Austenitic Stainless-Steel Grade 316LN with Co content lower than 0.1%.

Verification Method: This material will be supplied by CERN according to the agreed list of materials in [6]. Therefore, as long as CERN is the supplier, this requirement is considered to be met.

Procedure summary: n/a.

Reference: List of Materials [6]

Requirement LMQXFA-R-T-09: The LMQXFA provides a 1.9 K helium vessel that must be designed for a Maximum Allowable Working Pressure (MAWP) of 20 bar differential with an applied test pressure of 25 bar differential.

Verification Method: CERN approval of pressure vessel design safety documentation

Procedure summary: design is first reviewed and approved by the standard FNAL safety process. Safety documentation is then submitted to CERN demonstrating compliance with CERN safety requirements.

CERN verifies that submitted documentation complies with the US-CERN pressure vessel safety agreements.

Reference: Launch Safety Agreement and other US-CERN safety agreements [7][8][9]

Requirement LMQXFA-R-T-10: The LMQXFA cold mass assembly must be capable of sustaining loads resulting from up to 20 bar of pressure differential without physical damage or performance degradation. The load conditions will be specified in [10].

Verification Method: pre-series test

Procedure summary: induce a 20-bar pressure differential load during the cold mass assembly prototype test and verify that there is no performance degradation; quench test and field harmonics will not change after the pressure test.

Reference: Cold Mass Assembly Traveler [1], Pre-series Test Plan [11]

Requirement LMQXFA-R-T-11: The LMQXFA cold mass will have two main superconducting leads on each side going through the busbar line connection. An additional pair of resistive leads (trim) are required to have current unbalance up to 35 A between the two magnets during operation. The additional leads exit the cold mass through the helium vessel connection. Four additional resistive leads (CLIQ, two per magnet) are required for protection system. These four additional leads exit the cold mass through the helium vessel connection.

Verification Method: engineering check

Procedure summary: lead engineer verifies compliance with approved interface documentation and approves drawings for fabrication. For each cold mass assembly and prior to assembling end covers, visually inspect bus for proper installation including solder joints and insulation.

Reference: Final Design Report [14]**,** Bus Bar Traveler [2], Interface Documentation [3]

Requirement LMQXFA-R-T-12: The 18 kA busbars will be made with the same Nb-Ti cable used for the connections of the magnet.

Verification Method: engineering check

Procedure summary: lead engineer verifies that approved materials are used on each cold mass assembly

Reference: Bus Bar Traveler [2]

Requirement LMQXFA-R-T-13: The busbars must include expansion loops, to be contained within the end cover section and able to accommodate up to 30 mm of axial movement due to differential thermal expansion/contraction. The maximum force allowed for a 30 mm displacement is 500 N, to be confirmed after manufacturing of the first cold mass.

Verification Method: engineering check and visual inspection

Procedure summary: lead engineer verifies that design satisfies requirement and approves drawings for fabrication. Visually inspects each cold mass assembly for compliance.

Reference: Final Design Report[14], Bus bar Traveler [2], Interface Documentation [3]

Requirement LMQXFA-R-O-03: The busbars will include maximum four internal splices. Each splice resistance target value must be less than 1.0 nΩ at 1.9 K. A target value at room temperature will also be specified after the completion of the prototype program. An acceptance threshold will be defined after the completion of the short model program.

Verification Method: measurements during cold testing of each cold mass assembly

Procedure summary: measure splice resistance at 1.9K and verify values under 1.0 nΩ

Reference: Pre-series Test Plan [11]

Requirement LMQXFA-R-T-14: Splices are to be soldered with CERN approved materials [12]

Verification Method: engineering check for each splice in cold mass assembly

Procedure summary: for each cold mass assembly, lead engineer verifies that approved materials and procedures have been used in all splices. After verification, lead engineer signs compliance in Traveler.

Reference: Bus Bar Traveler [2], Cold Mass Assembly Traveler [1]

Requirement LMQXFA-R-T-15: The 35 A leads and the CLIQ leads are copper resistive leads. The cross-section of the 35 A leads and the CLIQ lead has a 10 mm^2 cross-section.

Verification Method: engineering check and visual inspection

Procedure summary: lead engineer verifies that design satisfies requirement and approves drawings for fabrication. Visually inspects each cold mass assembly and signs cold mass assembly Traveler for compliance.

Reference: Final Design Report [14], Cold Mass Assembly Traveler [1]

Requirement LMQXFA-R-T-16: In each cold mass, four temperature sensors will be installed. These sensors are the short type thermometer assembly (36 mm x 12 mm x 10 mm) typically used by CERN and specified in [13]

Note: Thermometer assemblies will be calibrated and supplied by CERN

Verification Method: measurements, visual inspection

Procedure summary: for each cold mass assembly and after installation of these CERN-provided sensors, a 4-wire resistance measurement of each sensor is conducted and recorded to verify the identity and operability of the device. The lead engineer inspects the measurements and visually inspects each device for appropriate placement and strain relief and verifies that these sensors are installed according to instructions. After verification, the lead engineer signs cold mass assembly Traveler for compliance.

Reference: Cold Mass Assembly Traveler [1]

Requirement LMQXFA-R-T-17: The LMQXFA cold mass assembly includes a minimum of 32 voltage taps. The Quench Detection voltage taps should follow MQXFA redundancy requirement.

Verification Method: engineering check, measurements

Procedure summary: the lead engineer verifies that the design satisfies this requirement and approves drawings for fabrication. For each cold mass assembly, measurements of continuity and resistance are recorded. The lead engineer inspects these measurements and visually inspects the voltage taps to verify compliance. After verification, the lead engineer signs the cold mass assembly Traveler.

Reference: Final Design Report [14], Cold Mass Assembly Traveler [1]

Requirement LMQXFA-R-T-18: Instrumentation wires type, preliminary quantity and function are given in Table 2.

Table 2: LMQXFA Instrumentation wiring

LMQXFA Wiring	Qty	Type
Voltage Taps	41	26 AWG polyimide coated wire
Temperature Sensor Leads for Tunnel operation	16	30 AWG polyimide coated wire
Temperature Sensor leads for Test stand operation	4	4x36 AWG polyimide + Tefzel quad twist single strand wire
Warm Up Heater Leads	8	18 AWG polyimide coated wire
Quench Heater Leads	32	18 AWG polyimide coated wire

Note: Instrumentation wiring specification supplied by CERN

Verification Method: QC testing

Procedure summary: use vendors qualified by CERN, QC to verify compliance with specifications. After verification, the lead engineer signs the cold mass assembly Traveler.

Reference: List of Materials [6]

Requirement LMQXFA-R-T-19: The LMQXFA instrumentation wiring must exit the cold mass assembly through the helium vessel connection. Instrumentation of each magnet will exit the cold mass on opposite sides.

Verification Method: engineering check, visual inspection

Procedure summary: the lead engineer verifies that the design satisfies this requirement and approves drawings for fabrication. For each cold mass assembly, the lead engineer visually inspects that instrumentation wiring has been installed according to approved procedures. After verification, the lead engineer signs the cold mass assembly Traveler.

Reference: Final Design Report [14], Cold Mass Assembly Traveler [1], Interface Specification [3]

Requirement LMQXFA-R-T-20: The LMQXFA cold mass assembly voltage limits must meet or exceed the MQXFA voltage limit requirements specified in [1]:

Table 3: Required hi-pot test voltages and leakage current [15]

Circuit Element	**Expected Vmax [V]**	**V hi-pot**	**I hi-pot [µA]*****	**Minimum time duration [s]**
Coil to Ground at RT before helium exposure *	n.a.	3.68 kV	10	30
Coil to Quench Heater at RT before helium exposure *	n.a.	3.68 kV	10	30
Coil to Ground at cold **	670	1.84 kV	10	30
Coil to Quench Heater at cold **	900	2.3 kV	10	30
Coil to Ground at RT after helium exposure *	n.a.	368 V	10	30
Coil to Quench Heater at RT after helium exposure *	n.a.	460 V	10	30
Coil to Ground at 100±20K and 1.2±0.2 bar	n.a.	425 V	10	30
Coil to Quench Heater at 100±20K and 1.2±0.2 bar	n.a.	425 V	10	30

* Room Temperature conditions refer to air at 20±3 °C and relative humidity lower than 60%

** Cold conditions refer to nominal cryogenic conditions (superfluid helium)

*** Maximum leakage current does not include leakage of the test station.

Verification Method: hi-pot measurements for the magnets inside the cold mass.

Procedure summary: Conduct hi-pot measurements for the conditions specified in Table 3 and verify that leakage current is below the specified limit. Room temperature measurements are in air or bagged in dry N_2.

Reference: MQXFA Functional Requirements Specification[4], Electrical Design Criteria for HL-LHC Inner Triplet Magnets [15], Magnet Assembly Traveler [16], Magnet test Plan [17], Magnet test traveler [18]

Requirement LMQXFA-R-T-21: The LMQXFA cold mass assembly will have 12 mirrors positioned in groups of 4, in the mid-point and towards the cold mass ends, at 45°, 135°, 225° and 315°, to be used for the monitoring of the position of the cold mass inside the cryostat.

Verification Method: Mechanical measurements after fabrication of each cold mass assembly

Procedure summary: Laser Tracker survey and comparison with piping locations specified in the Interface Specification [3]

Reference: Cold Mass Assembly Traveler [1]

Requirement LMQXFA-R-T-22: The LMQXFA quench performance requirements must meet or exceed the MQXFA magnet quench performance requirements[5]. This means:

(a) After a thermal cycle to room temperature, the cold mass should attain the nominal operating current with no more than 3 quenches per magnet (**MQXFA-R-T-17)**

(b) The cold mass must not quench while ramping down at 150 A/s from the nominal operating current (**MQXFA-R-T-18)**

Verification Method: testing for each magnet

Procedure summary: for each cold mass assembly and after training is completed, perform a thermal cycle and verify that the cold mass assembly is capable of reaching nominal operating current with no more than 3 quenches per magnet. Beyond 3 quenches per magnet, a discussion with CERN is required for cold mass assembly acceptance. Verify that the cold mass assembly does not quench while ramping down at 150 A/s from the nominal operating current.

Reference: Cold Mass Assembly Traveler [1], Pre-series Test Plan [11]

LMQXFA-R-O-05: **After a thermal cycle to room temperature, LMQXFA cold mass should attain the nominal operating current with no more than 2 quenches.**

(NOTE: This objective requirement might be reconsidered and changed to threshold after additional testing experience is obtained on the first two pre-series cold masses).

Verification Method: power test all production cold masses

Procedure Summary: After magnet training is completed, perform a thermal cycle and verify that the cold mass reaches nominal operating current with no more than 2 quenches.

Requirement LMQXFA-R-T-23: After installation and routing of heat exchanger tubes, instrumentation wiring, and superconducting busbars there must be a free LMQXFA cross section area of 150 cm^2 in the helium volume.

Verification Method: engineering check, visual inspection

Procedure summary: lead engineer checks compliance of fabrication drawings with approved interface specifications and approves drawings for fabrication. Visual inspection during each cold mass assembly to verify that this requirement is met.

Reference: Final Design Report[14], Cold Mass Assembly Traveler [1]

Requirement LMQXFA-R-T-24: All LMQXFA components should withstand a maximum radiation dose of 35 MGy or shall be approved by CERN for use in a specific location.

Verification Method: Material properties and CERN approval of materials

Procedure summary: Design uses materials capable of surviving a radiation dose of 35 MGy, or CERN formally approves materials to be used in the cold mass fabrication.

Reference: Final Design Report [12], List of Materials [6]

Requirement LMQXFA-R-O-04: LMQXFA reliability requirements are the same as the MQXFA reliability requirements (specified in [4]).

Verification Method: See [5]

Procedure summary: See [5]

Reference: See [5]

LMQXFA-R-T-28: **LMQXFA cold mass shall be capable of continuous steady-state operation at nominal current in pressurized static superfluid helium (HeII) bat at 1.3 bar and at a temperature of 1.9K.**

Verification Method: Power test of all production cold masses

Procedure Summary: Operation of production cold masses at nominal current at 1.9 K for 300 minutes

Requirement LMQXFA-R-T-25: The LMQXFA cold mass assembly must meet the detailed interface specifications with the following systems: (1) MQXFA magnets; (2) The CERN supplied QQXF_SC Cryostats; (3) the CERN supplied piping; (4) CERN supplied Cryogenic System; (5) the CERN supplied power system; (6) the CERN supplied quench protection system, and (7) the CERN supplied instrumentation system. These interfaces are specified in Interface Control Document [3].

Verification Method: engineering check

Procedure summary: lead engineer checks compliance of fabrication drawings with approved interface specifications and approved drawings for fabrication.

Reference: Final Design Report [14]

Requirement LMQXFA-R-T-26: **The LMQXFA cold mass assembly must comply with CERN's Launch Safety Agreement (LSA) for IR Magnets (WP3) [7][8][9].**

Verification Method: CERN approval of safety documentation

Procedure summary: Safety documentation is submitted to CERN for approval, and CERN verifies compliance with the LSA and any other safety agreements.

Reference: Launch Safety Agreement and other agreements [7][8][9]

Requirement LMQXFA-R-T-27: **CERN provided parts for LMQXFA assemblies are specified in [20]. These parts for the prototype and series (including spares) will be supplied by CERN.**

Verification Method: See section "Acceptance of CERN supplied Parts"

Procedure summary: n/a

Reference: Parts Exchange [20]

2. CRYO-ASSEMBLY

Requirement LQXFA/B-R-T-01: The QQXF_SC vacuum vessel physical length (end flange to end flange) must be ≤ 9,500 mm (the actual length shell be specified to make sure that the length plus the tolerance value is less than 9,500 mm). This dimension is at room temperature (296 K).

Verification Method: Mechanical measurements after fabrication of each cryo-assembly

Procedure summary: The surface of the Cryostat flange using Laser Tracker, we will determine the length requirement within 0.1 mm precision. After verification, the lead engineer signs the cryo-assembly Traveler.

Reference: LQXFA/B cryo-assembly Traveler [19]

Requirement LQXFA/B- R-T-02: Any support structure attached to the vacuum vessel must be within the "stay clear" envelope sown in Figure 4. **The dimensions are taken at room temperature (296 K).**

Verification Method: Mechanical measurements after fabrication of each cryo-assembly

Procedure summary: Cryostat extremities are measured using Laser Tracker. We will determine any cryostat parts perpendicular distance with 0.1 mm precision relative to the straight lines of the "Stay clear" area. After verification, the lead engineer signs the cryo-assembly Traveler.

Reference: LQXFA/B cryo-assembly Traveler [19]

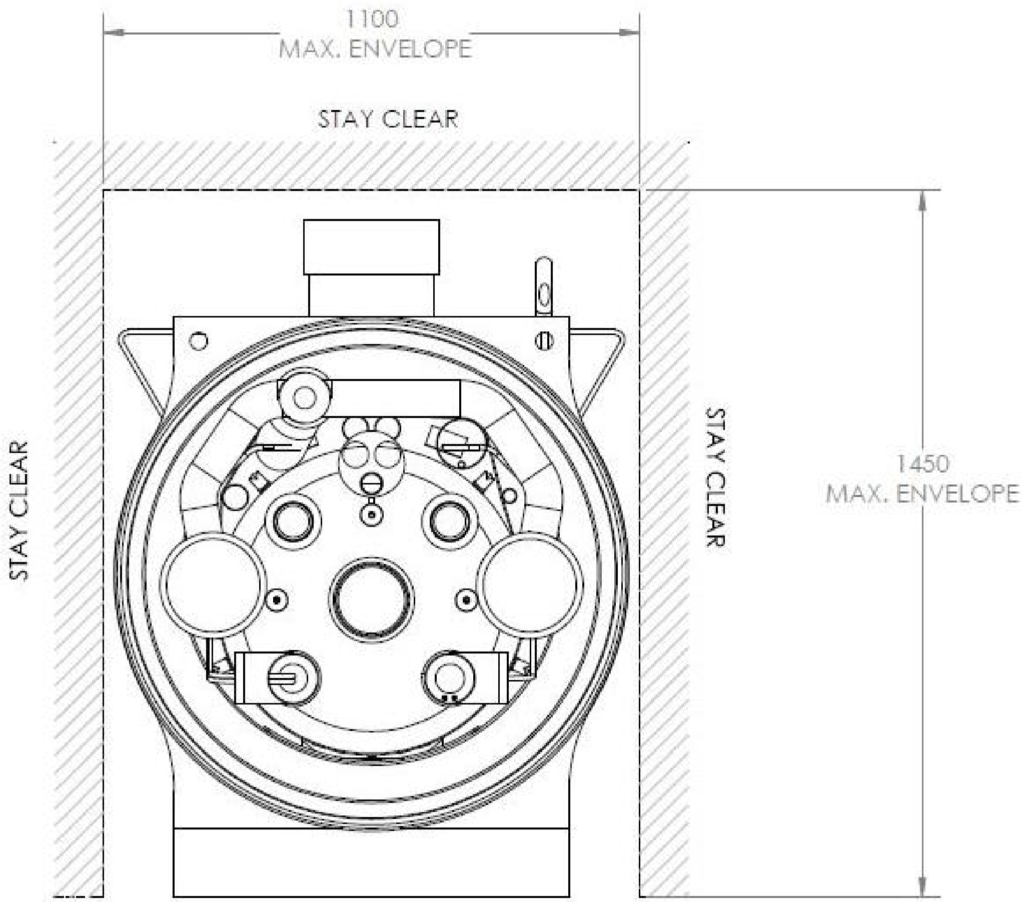

Figure 1: The "stay clear" is shown that has to be respected by the cryostat design.

Requirement LQXFA/B- R-T-03: The total weight of the whole cryostat assembly including the cold mass must be ≤ 22 500 kg.

Verification Method: Weight measurement.

Procedure summary: the weight of the cryo-assembly is measured.

Reference: LQXFA/B cryo-assembly Traveler [19]

Requirement LQXFA/B- R-T-04: The LQXFA/B/E/F cryostat assembly contains one LMQXFA cold mass. The LMQXFA cold mass must satisfy the LMQXFA requirements specifications and the QQXF_SC cryostat interface specifications.

Verification Method: see LMQXFA and MQXFA acceptance criteria

Procedure summary: see LMQXFA and MQXFA acceptance criteria

Reference: see LMQXFA and MQXFA acceptance criteria

Requirement LQXFA/B- R-T-05: LMQXFA positioning inside the QQXF_SC cryostat is described in the LMQXFA and QQXF_SC interface document [3].

Verification Method: Mechanical measurements after fabrication of each cryo-assembly

Procedure summary: Cold mass position is measured using alignment targets on the cold mass relative to cryostat flange using Laser Tracker. The results are compared with the interface specifications. After verification, the lead engineer signs the cryo-assembly Traveler.

Reference: LQXFA/B cryo-assembly Traveler [19]

Requirement LQXFA/B- R-T-06: LMQXFA alignment requirement must be met after the LQXFA/B cryo-assembly is completed.

- **Requirement LMQXFA-R-T-06: The distance between the two nodal points of the MQXFA magnetic lengths is 4806 mm ± 5 mm at nominal operating temperature (1.9 K).**
- see **Requirement LMQXFA-R-T-06** verification process in the cold mass section.
- **Requirement LMQXFA-R-O-01: The maximum deviation of each MQXFA magnet axis along the common magnetic axis must be within ±0.5 mm both in horizontal and in vertical direction. The deviation of each MQXFA field angle from the common magnetic field angle must be within ±2 mrad.**
- see **Requirement LMQXFA-R-O-01** verification process in the Cold mass section.

Requirement LQXFA/B- R-T-07: Reference frame for Survey data and magnetic measurements data described in [21] must be used.

Verification Method: engineering check

Procedure summary: make sure that the survey date is reported in the reference frame described in [21]. After verification, the lead engineer signs the cryo-assembly Traveler.

Reference: LQXFA/B cryo-assembly Traveler [19]

Requirement LQXFA/B- R-T-08: The QQXF_SC cryostat must be designed and documented in accordance with CERN and U.S. HL-LHC Accelerator Upgrade Project safety agreements [7][8][9].

Verification Method: engineering check

Procedure summary: Do the relevant calculation to assure that the safety requirements are met.

Reference: LQXFA/B cryo-assembly Final Design Report [14]

Requirement LQXFA/B- R-T-09: The QQXF_SC cryostat vacuum vessel must be designed for a Maximum Allowable Working Pressure (MAWP) of 1 bar outside pressure and 0.5 bar inside pressure differential.

Verification Method: Pressure test.

Procedure summary: Apply the required pressure combination to prove that the vacuum vessel can withstand the pressure difference. After verification, the lead engineer signs the cryo-assembly Traveler.

Reference: Cryo-assembly Traveler [19]

Requirement LQXFA/B-R-T-10: The LQXFA/B cryostat assembly must be capable of sustaining loads resulting from pressure differential values (described in [10]) in the LHe containment vessel (cold mass and associated pipes) and pressure differential values (described in [10]) in the vacuum vessel without physical damage or performance degradation.

Verification Method: Horizontal test of LQXFA/B at FNAL.

Procedure summary: Cold testing the pre-series cryo-assembly under realistic quench pressures. The horizontal test stand was designed to perform the relevant test pressures that are expected to be seen in the tunnel operation.

Reference: Final Design Report [14].

Requirement LQXFA/B- R-T-11: The LHe containment vessel (Cold Mass and associated pipes) and all other pressurized pipes need to be leak tight under their operating pressure. The leak check must measure that the leak rate is lower than 10^{-9} torr-liter/sec.

Verification Method: Leak check.

Procedure summary: Follow leak detector leak check procedure. Leak detector procedure calls for the following leak criteria:

- Cold mass to insulation vacuum $< 1 \cdot 10^{-10}$ Pa.m3/s
- Cold mass to beam vacuum cold bores $< 1 \cdot 10^{-11}$ Pa.m3/s

- Cold mass to heat exchanger <1 · 10^{-6} Pa.m3/s

After verification, the lead engineer signs the cryo-assembly Traveler.
Reference: Cryo-assembly Traveler [19], Production Test Report

Requirement LQXFA/B- R-T-12: Instrumentation wiring and electrical busses during the assembly process must be handled carefully not to introduce any performance degradation.
Verification Method: engineering check, wiring continuity check.
Procedure summary: Electrical continuity procedure following wiring diagram checks. After verification, the lead engineer signs the cryo-assembly Traveler.
Reference: Cryo-assembly Traveler [19]

Requirement LQXFA/B- R-T-13: The LQXFA/B cryostat assembly voltage limits must meet or exceed the LMQXFA voltage limit requirements.
Verification Method: see **Requirement LMQXFA-R-T-20**
Procedure summary: see **Requirement LMQXFA-R-T-20**
Reference: see Requirement LMQXFA-R-T-20

Requirement LQXFA/B- R-T-14: The LQXFA/B quench performance must meet the LMQXFA cold mass quench performance requirements.
See **Requirement LMQXFA-R-T-22** verification process in the Cold mass section

Requirement LQXFA/B- R-O-01: LQXFA/B reliability requirements are the same as the LMQXFA reliability requirements.
See **Requirement LMQXFA-R-O-04** verification process in the Cold mass section

Requirement LQXFA/B- R-T-15: The LQXFA/B cryostat assembly must meet the detailed interface specifications with the following systems: (1) LMQXFA cold masses; (2) the CERN supplied Cryogenic System; (3) the CERN supplied power system; (4) the CERN supplied quench protection system, and (5) the CERN supplied instrumentation system. These interfaces are specified in Interface Control Document [3].
Verification Method: engineering check
Procedure summary: lead engineer checks compliance of fabrication drawings with approved interface specifications and approved drawings for fabrication.
Reference: Final Design Report [14]

Requirement LQXFA/B- R-T-16: The LQXFA/B/E/F cryostat assembly must comply with CERN's Launch Safety Agreement (LSA) for IR Magnets (WP3) Error! Reference source not found.**.**
Verification Method: CERN approval of agreed upon pressure vessel safety documentation for each cold mass assembly
Procedure summary: submit safety documentation demonstrating compliance with CERN safety requirements. CERN verifies that submitted documentation complies with the US-CERN safety agreement.
Reference: Launch Safety Agreement and Other US-CERN safety agreements [7][8][9]

Requirement LQXFA/B- R-T-17: CERN provides all the parts for QQXF_SC cryostat. The cryostat kit for the prototype and 10 production units will be supplied and shipped to Fermilab by CERN at no cost to US HL-LHC AUP. The list of the components of the kit can be found in [20].
Verification Method: engineering check
Procedure summary: Parts Inspections at receipt of the cryostat kit. After inspection, the lead engineer signs the shipping document.

Reference: Parts Exchange document [20].

Requirement LQXFA/B- R-T-18: Cryostat assembly tooling will be designed, procured and shipped to Fermilab by CERN or a vendor selected by CERN at no cost to US HL-LHC AUP. The tooling that will be used for cryostat assemblies at CERN and Fermilab will be identical with minor differences that are site and cryostat specific (if any).

Verification Method: engineering check

Procedure summary: Vendor will install the tooling on the Fermilab site. The first Cryo-assembly fabrication will be supervised by CERN personnel. The tooling will be commissioned at the same time.

Reference: Cryo-assembly Traveler [19]

Requirement LQXFA/B- R-T-19: Cryostat assembly procedures including every QC and QA steps will be developed by CERN. The first prototype cryostat assembly work will be directed by CERN personnel to assure proper transfer of the procedures to Fermilab. At Fermilab an engineer will be assigned to be in charge for the cryostat assembly work.

Verification Method: Engineering check

Procedure summary: Detailed planning of the work with CERN personnel. After the pre-series cryostat assembly is complete, the lead engineer signs the Pre-series Cryo-assembly traveler.

Reference: Cryo-assembly Traveler [19].

Requirement LQXFA/B- R-T-20: AUP is responsible for shipping the Cryo-assemblies to CERN without any performance degradation.

Verification Method: See Part C

Procedure summary: See Part C

Reference: See Part C [22]

3. References

[1] HL-LHC LMQXFA Cold Mass Assembly Traveler (vector:464525) [EDMS 2375006]
[2] HL-LHC LMQXFA Bus Bar Traveler (vector:464507) [EDMS 2375002]
[3] Interface Control Document WBS 302.4.02 – 302.4.03, US-HiLumi-doc-210, [EDMS 1868475]
[4] MQXFA Functional Requirements Specifications, [EDMS 1535430]
[5] MQXFA Acceptance Criteria Part A, [EDMS 2031083]
[6] Cold Mass List of Material, [EDMS 1868473]
[7] CERN Launch Safety Agreement for IR Magnets (WP3), [EDMS 1550065]
[8] Conformity approach for Pressure Equipment for the High Luminosity LHC Project, [EDMS 1698982]
[9] Exceptional Approach to Conformity Assessment of Pressure Vessels in WP3, [EDMS 1753780]
[10] Load conditions for the triplet cold masses in different operational scenario, [EDMS 1868420]
[11] Pre-series Test Plan, US-HiLumi-doc-2462
[12] Soldering material and procedure defined by [EDMS 2324588]
[13] LHC-QIT-ES-0001 rev 1.1, "LHC Cryogenic Thermometers" [EDMS 107381]
[14] Q1/Q2 Cryostat Assembly and Horizontal Test Final Design Report [US-HiLumi-doc-2882]
[15] Electrical Design Criteria for HL-LHC Inner Triplet Magnets [EDMS 1963398]
[16] Magnet Assembly Traveler [SU-1008-8070]
[17] Magnet Test Plan [US-HiLumi-doc-728]
[18] Magnet test traveler [BNL-MDC No. LARP-330]
[19] LQXFA/B cryo-assembly Traveler [TBD]
[20] Parts exchange between US HL-LHC AUP and CERN HL-LHC WP3 [US-HiLumi-doc-844]

[21] L. Bottura, D. Missiaen, "Definitions of Survey and Magnetic Data for the Inner Triplet Systems at IR1, 2, 5 and 8" [EDMS 367802]
[22] S HL-LHC AUP - LQXFA - Acceptance Criteria Part C [US-HiLumi-doc-1145]