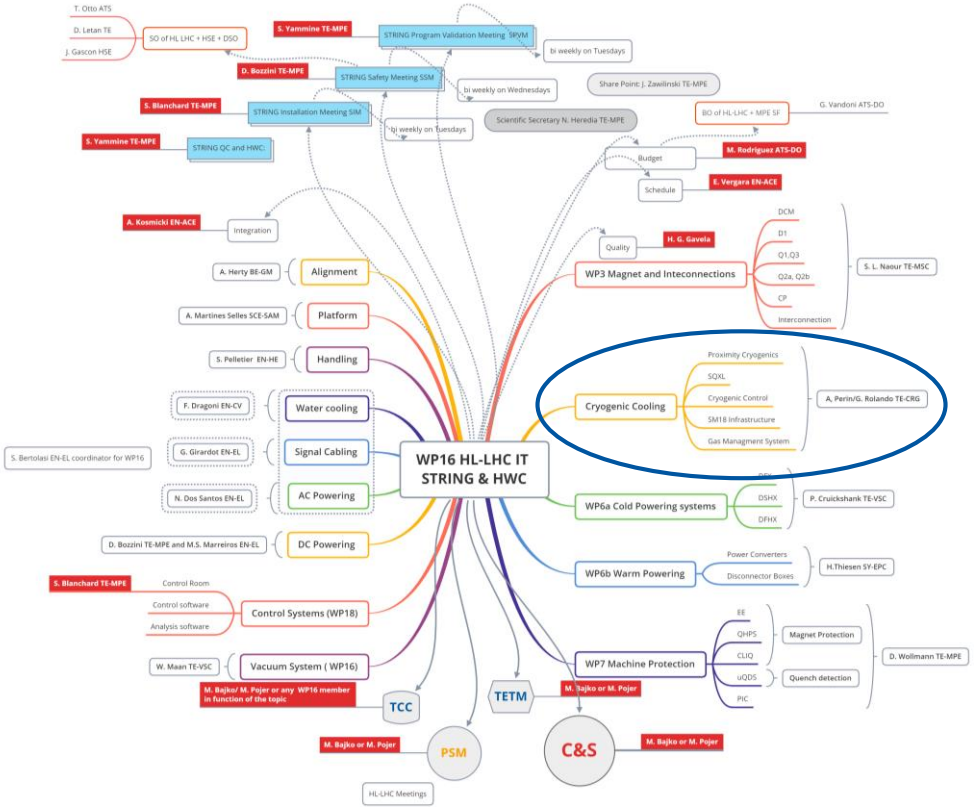
12th HL-LHC Collaboration meeting, Uppsala, 22.09.2022

Status of the cryogenics system of the HL-LHC IT String

A. Perin, on behalf of the WP16 cryogenics team

Indico: https://indico.cern.ch/event/1161569

Overview – Cryogenics for WP16



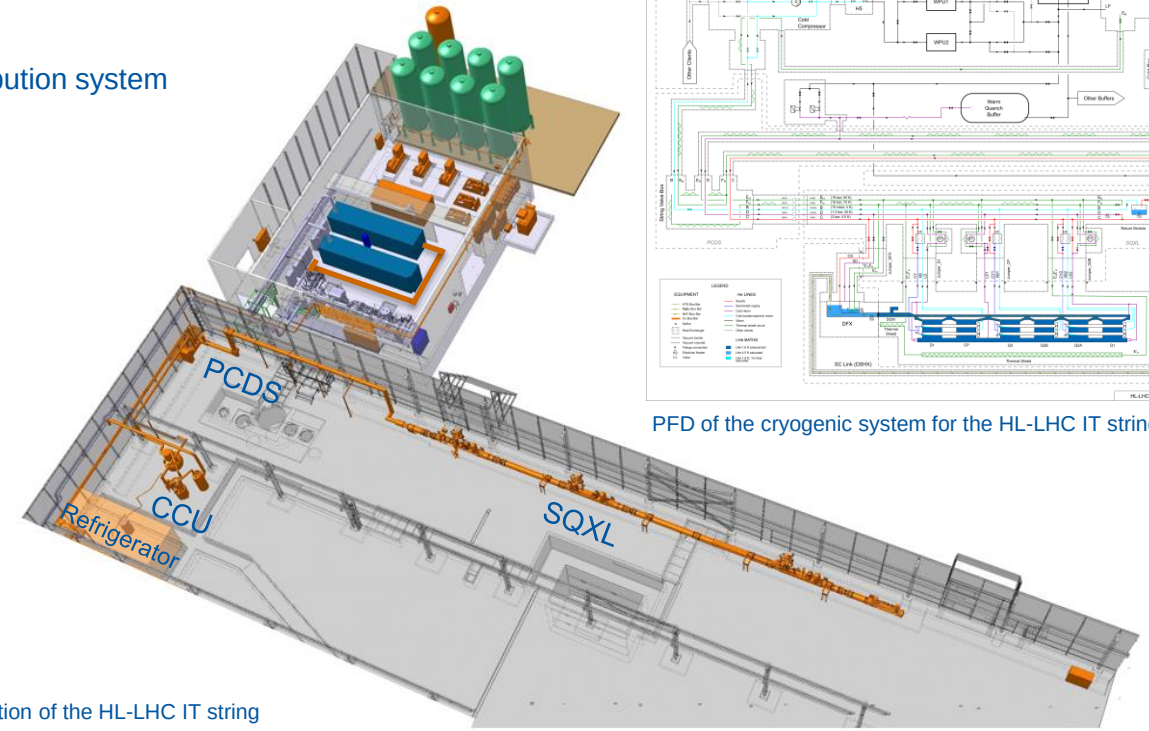
- All cryogenic process aspects
- Design, construction and installation of the String specific cryogenic infrastructure and cryogenic distribution system
- Cryogenics data acquisition and control system
- Commissioning and cryogenic validation program
- Operation of all cryogenic aspects

Layout of the cryogenic system

Specific to the IT String
PCDS: proximity cryogenic distribution system
SQXL: cryogenic distribution line
CCU: cold compressor unit
Quench relief line

Part of SM18 infrastructure
Warm quench buffer
Existing refrigerator
Warm pumping units
Main helium storage

+ electrical & control system

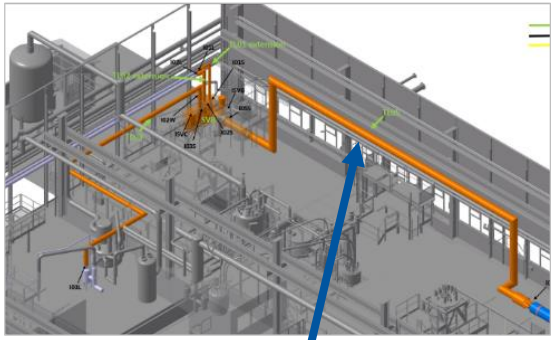


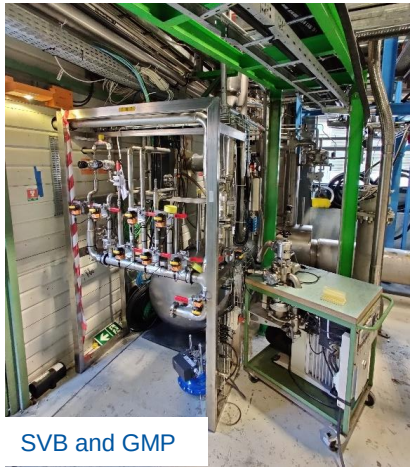
PFD of the cryogenic system for the HL-LHC IT string

In orange: cryogenic equipment for the operation of the HL-LHC IT string

Status of the proximity cryogenics

- Installation of the String Valve Box (SVB) and of the PCDS cryogenic transfer lines completed in September-October 2021
- Other components :
  - Gas Management Panel, completed
  - Main He guard, completed
- Pressure and leak tests of the PCDS, completed





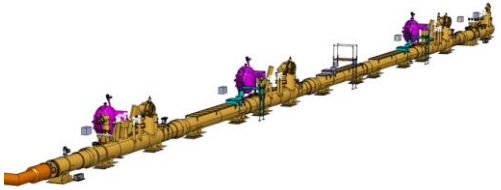
SVB and GMP

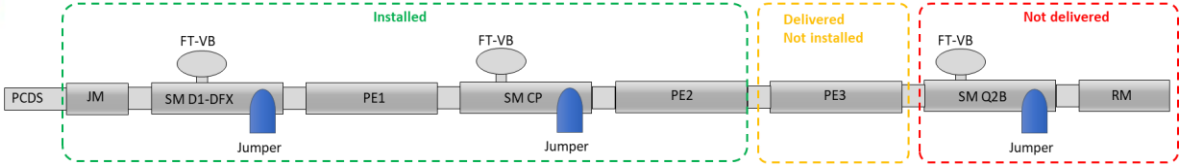
Main He guard

TL05

Status of the SQXL

- Junction module, jumpers DX-D1 & CP and pipe elements PE1 and PE2: installed
- Delivery of jumper Q2b and return module planned September 2022
- End of installation, including pressure & leak tests, by november 2022





Assembly of flowmeter boxes at CERN

SQXL being installed in SM18

Assembly of the return module at Kriosystem.

Status of the String infrastructure

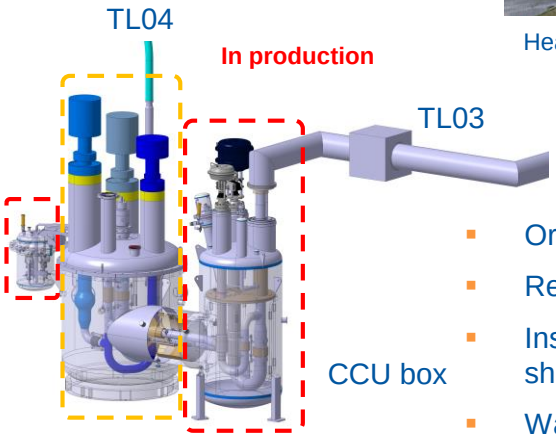
- Manufacturing and installation of the heater unit completed
- Warm Quench Buffer (WQB) connected to SH18 infrastructure and compressor station during shutdown in January 2022
- Thermometers for WQB wall temperature monitoring, installed

Heater unit outside SM18

Installation of thermometers on top of WQB

WQB connected to SM18 cryo infrastructure

CCU box being refurbished



- Order for new CC drive unit placed with Linde (delivery end of 2022)
- Refurbishment and extension of the Cold Compressor box, ongoing
- Installation of the Cold Compressor unit planned during the SM18 shutdown (1st quarter 2023)
- Warm piping and quench line extension, to be completed by mid-2023

Status of the electrical & control systems

ELECTRICITY

- Electrical cabinet for PCDS, CCU and heater unit, installed.
  CCU part to be finalized
- Electrical cabinets and fieldboxes for the SQXL, completed and installed
- Manufacturing of the crates for IT magnets instrumentation, in progress
- PCDS, heaters unit and WQB cabling, completed
- Cabling for SQXL and magnets dependent on SQXL installation and cabling campaign

All electrical cryo cabinets installed in SM18

24V rack

PCDS, CCU and heater unit cabinet

CONTROL

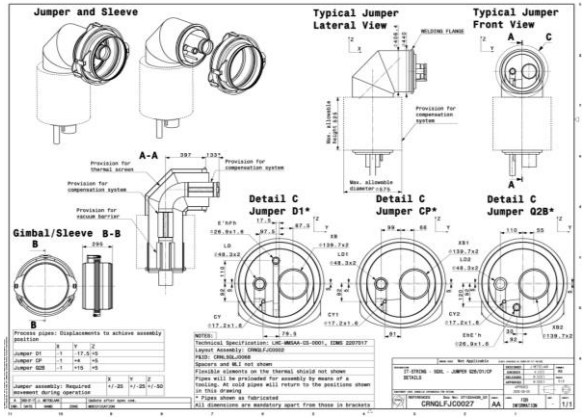
- PLC skeleton including all instrumentation, completed
- Synoptic of cryo infrastructure, in progress
- Front End Computer (FEC) installation, completed
- Control logic and interlocks, in progress

Interfaces

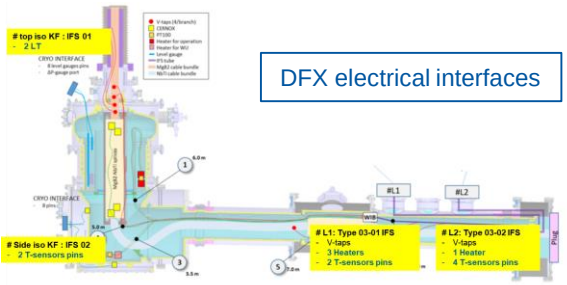
Interface	with	Status	Notes
Mechanical	WP3 - IT magnets	*	CRNQLFJC0027 CRNQLFJC0028
	WP6a - DFX		CRNQLFJC0028
	WP6a - DFHX		EDMS 2341133
	TE-VSC		At SQXL flanges
Electrical	WP3 - IT magnets		
	WP6a - DFX		Indico 1163418
	WP6a - DFHX		Indico 1163418
	TE-VSC		

Completed | On track, not finalized | In work | Blocking point

SQXL – IT magnets interface



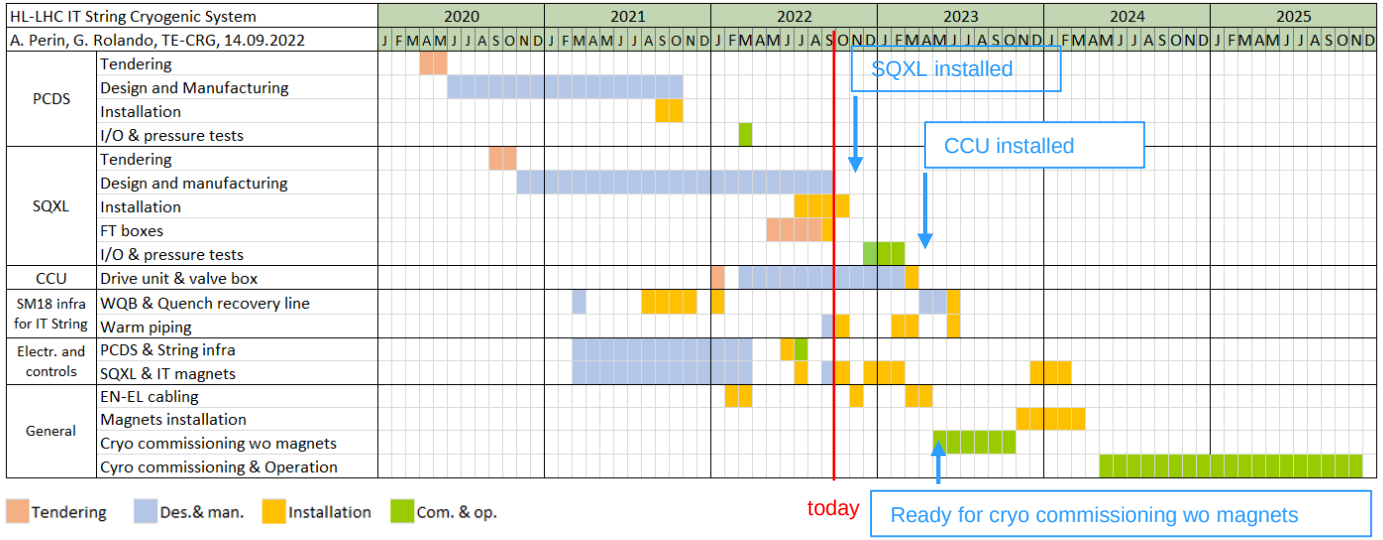
DFX electrical interfaces



* SQXL – IT magnets interconnection is performed by WP3. Detailed flanges and procedure in work, to be jointly defined by WP3 and TE-CRG

Schedule

- PCDS: installed & tested, String infrastructure: to be completed in 2023
- Manufacturing and installation of SQXL: schedule shift of ~10 months . End of installation in October
- Cold compressor drive unit and box: installation planned during SM18 shutdown of March 2023
- Cold commissioning of the cryogenic system without magnets from May 2023



Equipment	Subcomponents	Total progress
SQXL	SQXL	80%
	Flowmeters	62%
	Electricity	80%
PCDS	Gas management pannel and He Guard	100%
	Transfer lines & SVB	94%
	Electricity	100%
String infra	Cold compressor drive unit & box	44%
	Heaters unit	95%
	Quench recovery system	55%
	Electricity	76%

Commissioning without magnets

Reference document: EDMS 2620402

Commissioning of the cryogenic system without magnets from May 2023

Objectives of the commissioning of the IT String cryogenic system without magnets:

- Validate the mechanical and thermal design of the cryogenic system
- Verify the operation and calibration of the instrumentation at Room Temperature & cold conditions
- Validate the cold compressor performance
- Tune the control loops to reduce commissioning time with magnets

Commissioning with magnets & operation

Commissioning before powering

- Validate the mechanical and thermal design of IT magnets and Cold powering system
- Verify the operation and calibration of the instrumentation at Room Temperature & cold conditions
- Tune magnet and Cold powering control loops

IT String test program

- SM18 cryo infrastructure limitations: lower liquefaction and low-pressure pumping capacity in SM18 wrt to IP1 and IP5. No beam screen circuit
- Assessment of bayonet heat extraction capacity (max. < 500 W), heat loads during current ramping
- Thermo-hydraulic analysis of quenches
- Assessment of heat conduction in magnet cryostat & heat removal capacity of adjacent cooling loops
- Characterization of the subcooling heat exchanger
- (In work) Pressure waves analysis with cold pressure sensors: work ongoing with CRG instrumentation team & MSC

Conclusions

- **Mechanical activities:**
  - Proximity cryogenics: manufacturing complete, installation well advanced
  - Delays in manufacturing and installation of SQXL and cold compressor unit, compatible with global project schedule
  - Main components of the infrastructure to be completed by March 2023
  - Jumper connection final details and procedures to be finalized
- **Electricity and control system**
  - Electrical system and cabling completed for PCDS, quench recovery system, heater unit and cold compressor (minor modifications needed)
  - Electrical system and local cabling for SQXL after mechanical installation and EN-EL cabling campaign (November 2022)
- **Next main milestones**
  - End of SQXL installation in November 2022 and pressure test by end of 2022
  - Cold commissioning of the cryogenic system without magnets in May 2023

Operation modes & requirements

Operation mode	Requirements
Cool down 293 K - 4.5 K	Max duration: 15 days Max. temperature gradient over the string of magnets: 30 K
Magnet filling & cool down 4.5 K - 1.9 K	Max. duration: 40 hours
Steady state	Static heat load to cold masses at 1.9 K: 140 W
Current ramping	Additional dynamic heat load to cold masses 1.9 K: 350 W
Bayonet HX test	Extract up to 500 W per each double bayonet HX
Quench	Limit the pressure increase in the magnet cryostat Recover the helium expelled from the magnet cryostat
Quench recovery	Recover nominal operating conditions in max.12 hours
Warm up 4.5 K – 293 K	Max. duration: 15 days Max. temperature gradient over the string of magnets: 30 K

Additional requirements:

- Supply up to 10 g/s of LHe to the Cold Powering
- Supply up to 26 g/s of LHe for the bayonet HX test
- Provide up to 26 g/s of low-pressure pumping capacity @ 1.9 K for bayonet HX test
- Provide thermal shield circuit at 50 – 75 K
- Recover warm GHe from current leads outlet
- Not interfere with other SM18 test benches

Commissioning without magnets

Reference document: EDMS 2620402

#	Tested component	Test type	Test duration	Test priority	Test description	Notes
1	PCDS	RT	2w	Mandatory	Pressure and leak tests	Validate the mechanical integrity
2	SQXL	RT	2w	Mandatory	Pressure and leak tests	Validate the mechanical integrity
3	PCDS & SQXL	RT	1w	Mandatory	Purge	Clean the cryogenic circuits to avoid icir and clogging at cold
4	Instrumentation	RT	2w PCDS 2w SQXL 2w Other eq.	Mandatory	Synchronization test	Verify instrumentation and acquisition channels
5	Control system/ Cold box	4.5 K	2w	High	Cool down test	Validate the cold box control loops wrt the cool down procedure required for t IT String. Validate the thermo-mechanical design
6	Instrumentation	4.5 K	1d	High	Instrumentation test at cold	Verify instrumentation operation and calibration at cold (TTs, LTs)
7	Control system/ SQXL	4.5 K	1w	High	Tuning of line D temperature regulation control loop	Validate the control loop for the regulation of the temperature in line D
8	PCDS and SQXL	4.5 K	1w	Medium	Heat load test	Validate the thermal design Assess the heat load
9	Control system/ Cold box	4.5 K	1w	High	Tuning cold box control loops	Validate the control loops of the cold bo against variations in the LHe supply demand (to simulate current ramping)
10	Control system/ Quench recovery system	tbc	1w	High	Verify the control loop regulating the opening of CV035 based on the pressure in line D Verify the opening time of CV035	Validate the control loops of the quench recovery system. If the test is performed at cold, addition information about the quench recovery system could be obtained (heat load on the quench recovery line, cold test of th WQB thermometers)
11	Cold compressor	1.9 K	4w	High	Cold compressor characterization	Assess the performance of the cold compressor: pressure ratio vs mass flow rotation speed, stall limit, endurance te
12	Control system/ Cold compressor	1.9 K	3w	High	Tuning of cold compressor control loops	Validate the control loops of the cold compressor for the various operation modes (cool down, start, steady state, current ramping with pre-loading, stop)
13	Flowmeters	4.5 K	1w	Low	Cold test	Validate the thermo-mechanical design the flowmeter box Verify the flowmeter calibration
14	Control system/ Heater unit	4.5 K	1w	High	Tuning of the heater unit control loops	Validate the control loops of the heater unit for quench recovery and warm up

Commissioning with magnets & operation

Commissioning before powering

#	Tested component	Test type	Test duration	Test priority	Test description	Notes
1	Cold mass	RT	2w	Mandatory	Pressure and leak test	Validate the magnets mechanical integrity
2	Cold mass	RT	1w	Mandatory	Purge of the whole system	Clean the cryogenic circuits to avoid icing and clogging at cold
3	Instrumentation	RT	2w Cold pow. 2w Cold mass	Mandatory	Synchronization test	Verify instrumentation and acquisition channels
4	Cold mass	1.9 K	1w	High	Static heat load test	Assess the static heat load
5	Control system/ Cold mass	1.9 K	1w	High	Tuning of pre-loading control loop	Validate the control loops for the pre-loading of the cryogenic system for current ramping
6	Cold mass	1.9 K	1w	High	Dynamic heat load test	Assess the dynamic heat load
7	Control system/ Return module	1.9 K	1d	Medium	Tuning of the return module control loop	Validate the control loop that stabilizes the mass flow processed by the cold compressor in case of variations in the heat load of the cold mass by generating a mass flow in the return module
8	Control system/ Cold mass	1.9 K	3d	High	Tuning of the control loop regulating the supply of LHe to the bayonet HXs	Determine a priori regulation parameters for the controller before installation in the QXL. Validate the model developed by B. Bradu
9	Control system/ Bayonet HX	1.9 K	1d	High	Overflow test	Tune the bayonet HX control loop. Asses the time to recover operating conditions in case of overflow
10	DFHX	4.5 K	2w	Mandatory	Coherence test	Check the instrumentation chain of each Current Lead
11	DFX	4.5 K	3-4w	High	Static heat load test	Validate the thermal design
12	DSHX & DFHX	4.5 K		High	Static heat load test	Validate the thermal design
13	Current leads	4.5 K		High	Mass flow regulation test in static conditions	Validate the current leads design in static conditions
14	Control system/ DFX	4.5 K		High	Tuning of DFX control loop against thermal disturbances	Assess the effect of disturbances of the order of 0.2-0.3 K of the LHe supply temperature on the level regulation in the DFX
15	Control system/ DFX	4.5 K		High	Tuning of the electrical and coil heaters control loops	Validate the control loops for the mass flow generation with both the electrical and coil heaters

IT String test program

#	Tested component	Test type (Warm / Cold)	Test duration	Test priority	Test description	Notes
1	Bayonet HXs	1.9 K	1w	High	Maximum heat load test	Assess the maximum heat removal capacity of the bayonet HXs
2	Magnet cryostat	1.9 K	1w	Medium	Heat conduction test	Assess the heat removal capacity of the adjacent cooling loops wrt to heat loads applied at each magnet pair Assess the heat conduction along the He bath and the effect of restrictions at interconnections
3	Control system/ Quench recovery system/ Cold mass	1.9 K	NA	High	Quench	Assess the quench dynamic of the IT String (mass flow, pressure evolution, etc…) at different quench energies
4	Control system/ Quench recovery system	1.9 K	3d	Low	QRV set pressure test	Assess the effect on the quench dynamic of small changes in the set pressure of the QRVs
5	Current leads	4.5 K	3w	High	Mass flow regulation test in static conditions	Validate the current leads design in static conditions
6	Cold powering system	4.5 K		High	Warm up test from nominal conditions	Assess the warm-up time of the system starting from nominal conditions (4.5 K and 3.5 bar in line C)
7	Cold powering system	20 K		High	Warm up test from cold stand-by conditions	Assess the warm-up time of the system starting from cold stand-by conditions (20 K and 3.5 bar in line C)
8	DSHX	4.5 K		High	Pressure drop test	Assess the pressure drop along the DSHX at different mass flow rates

Reference document: EDMS 2620402