DFM Engineering Detailed Design : Cryogenic flow scheme & Cool down

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Engineering Design Review of DFM 18.01.2022

Outline

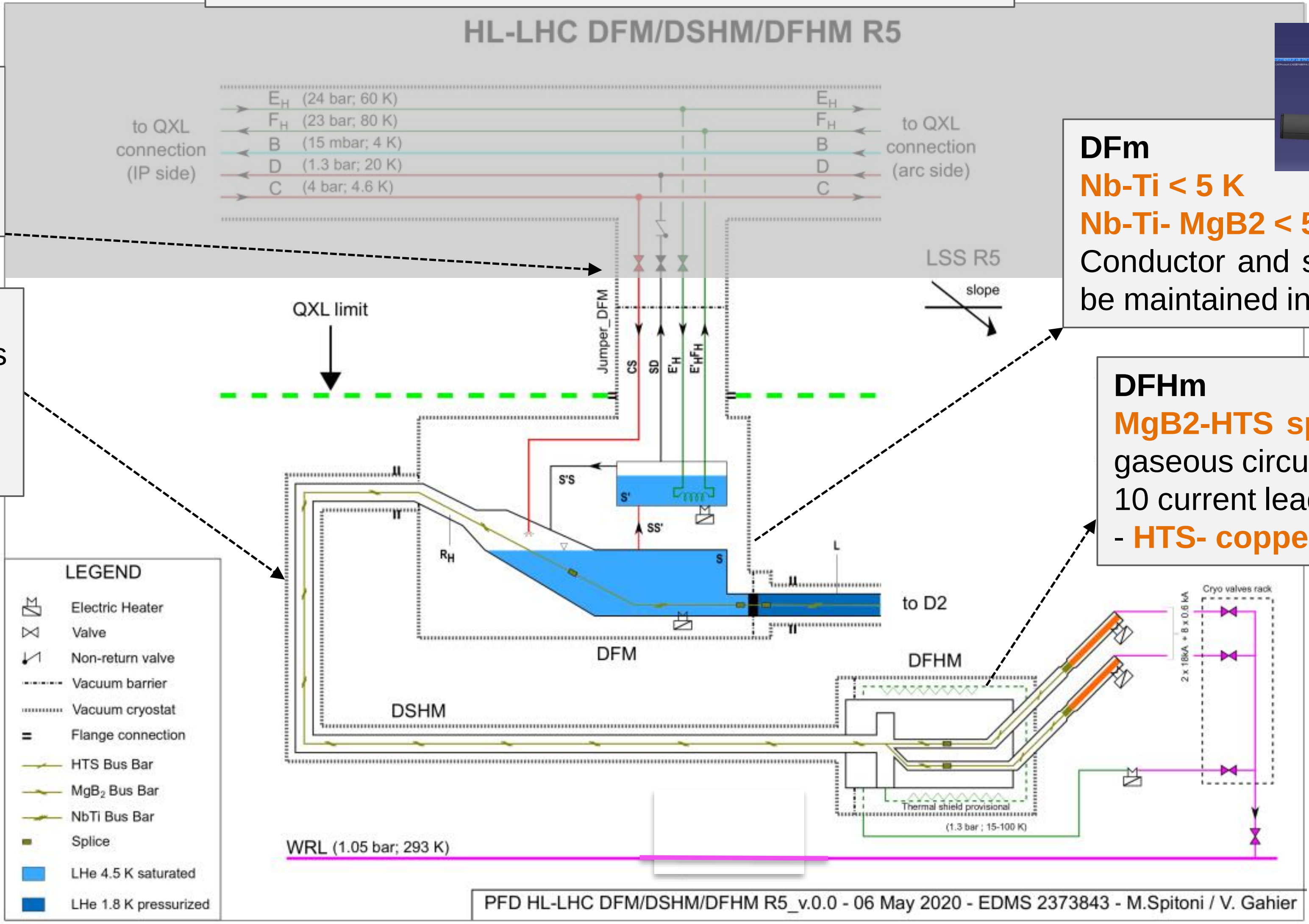
- PFD and interface
- Cryogenic safety : Pressure map
- Operating cases
  - Helium requirement
  - Controlled cool-down
- Cryo instrumentation

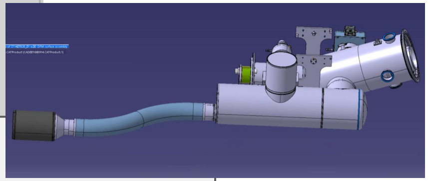
Zoom on Cold Powering for Matching Section cooling architecture

One cooling circuit from 4.5K to 300 K

One Service module feeding in particular supercritical helium to Cold Powering system.

SC link (DSHm) ~ 117 m
15 cables cooled by gaseous helium
Cryostat at **1 W/m**
MgB2 < 17 K



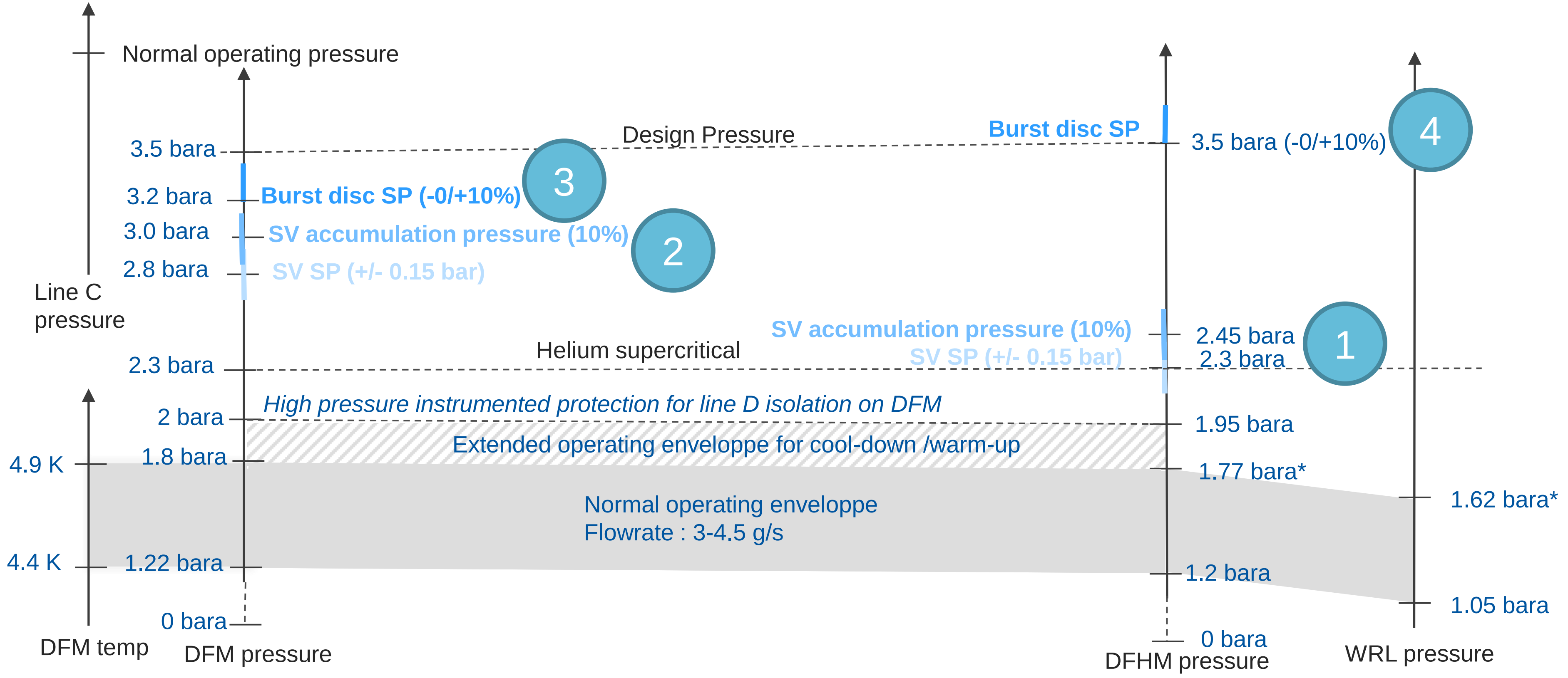


DFm
Nb-Ti < 5 K
Nb-Ti- MgB2 < 5K
Conductor and splices to be maintained in LHe

DFHm
MgB2-HTS splice < 17 K by forced gaseous circulation
10 current leads
- **HTS- copper transition < 50 K**

Cryogenic safety

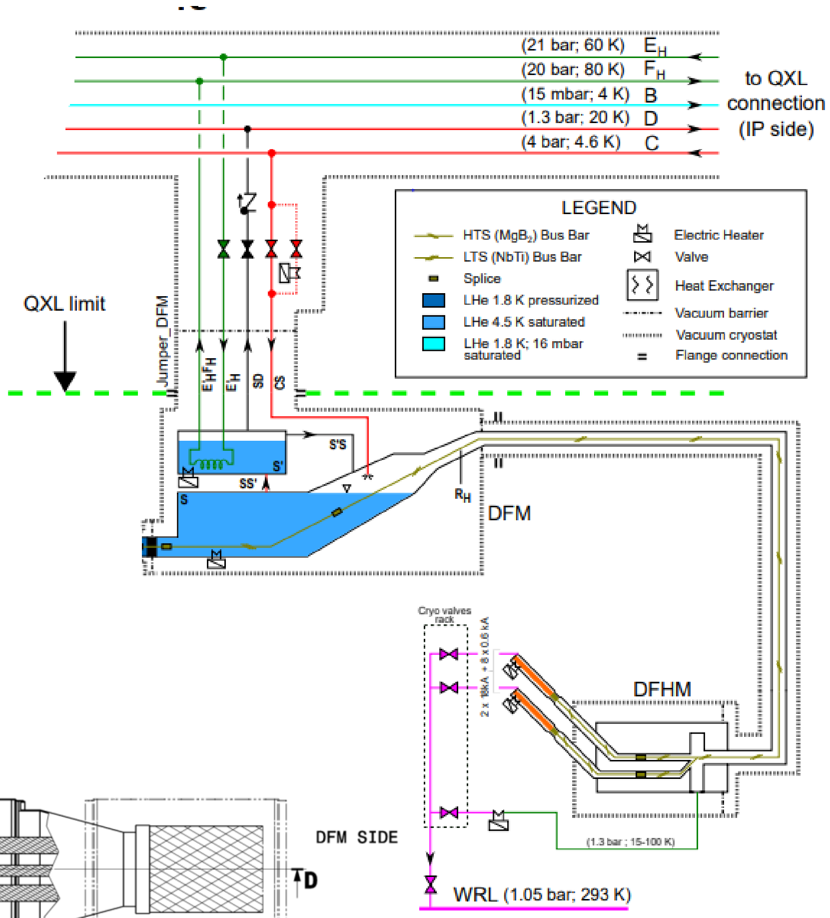
- All Cold powering systems are designed at 3.5 bara;
- Staggered safety protection system to ensure release of helium at safe location similarly to the Triplets system;
- In case of Power cut, the SC link will stay thermalized since the DFHM SV willl relieve first.

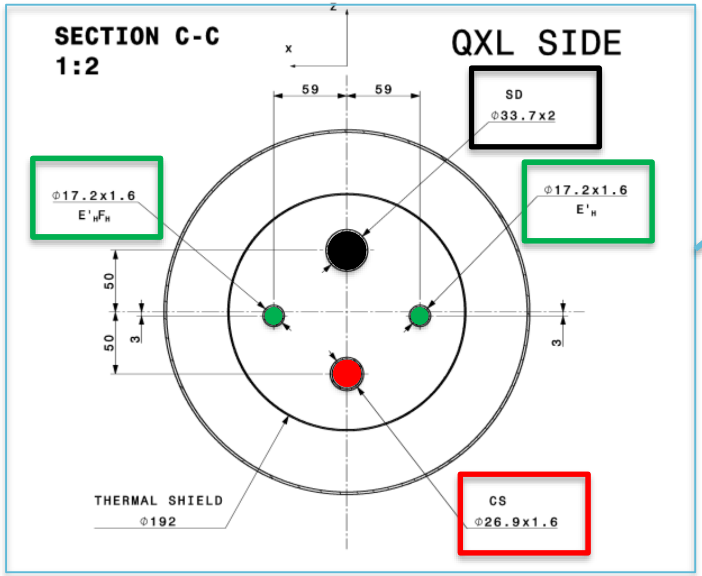


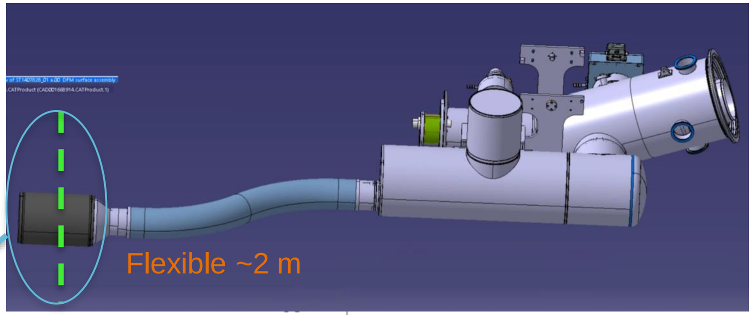
* Considering minimized pressure drop

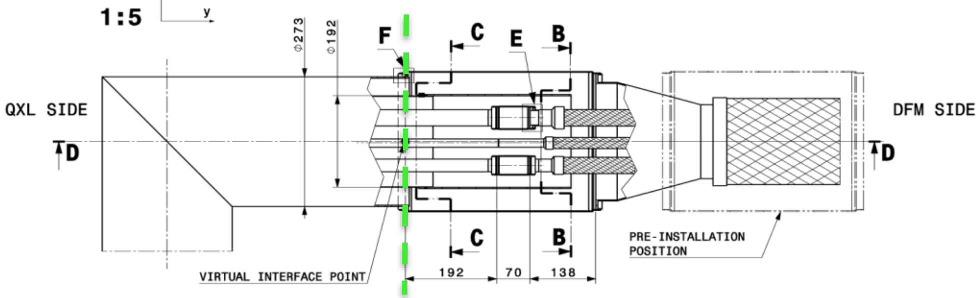
Cryogenic interface and functionality

- The cryogenic distribution circuit to the Matching section Cold Powering system (similar at Triplets) → DFM Jumper
  - **E'H** (60K, 19 bar) to **E'HFH** to feed the coil heater immersed in the liquid bath. Its functionality is to generate gaseous helium to the SC link, acts as a back-up of the immersed electrical heater (and vice-versa). Heat transfer mostly by film boiling.
  - **CS** line (4.6K to 5.3 K, 2.3 to 4 bar) feed the DFM in liquid helium
  - **SD** line relieves any overpressure from the DFM to the line D.









All hydraulic diameters were confirmed in EDMS 2364324

Diameters standardised with Triplet Cold Powering system

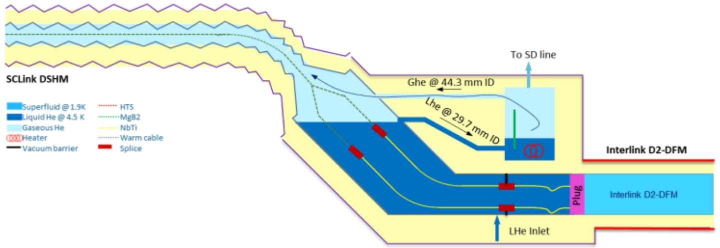
DFM concept

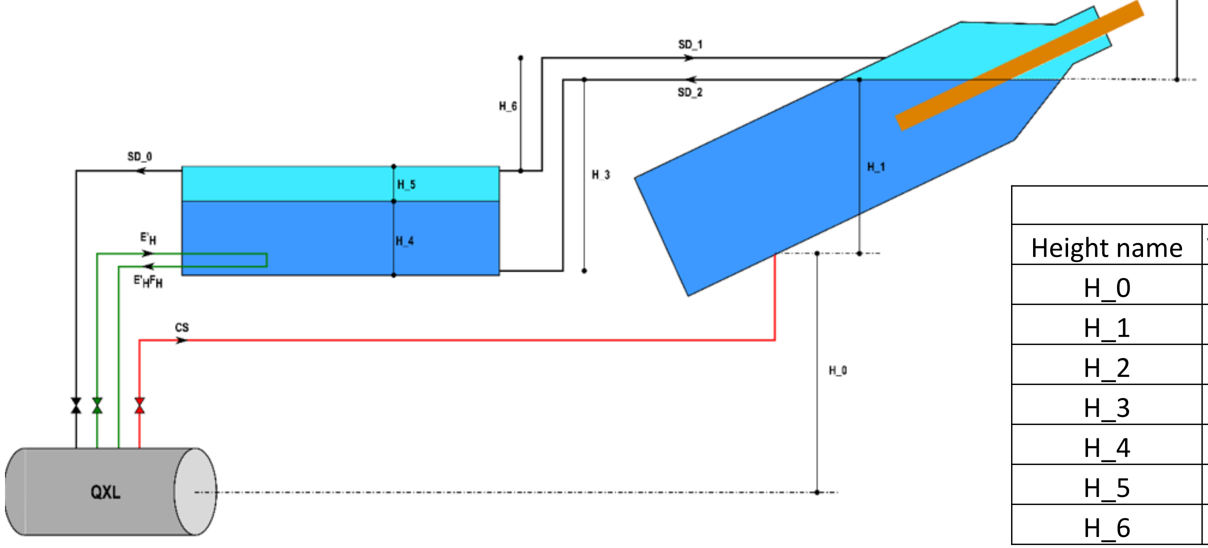
- Two helium vessels communicating by gravity :
  - One vessel where liquid helium is injecting and where the splices are kept immersed. Electrical heaters are present at the bottom for emptying.
  - One vessel where the gaseous helium is generated via heating system (coil or electrical heater)

- Similar concept retained and successfully proven on Demo 2.

- Static heat loads should be lower than 25 W.

$$\Delta P_{LHe} + \Delta P_{GHe} < \rho \cdot g \cdot H$$





Height table			
Height name	Value [m]	Phase [-]	ΔP [mbar]
H_0	1.5	0	17.51
H_1	0.27	0	3.17
H_2	10	2	5.07
H_3	0.39	0	4.60
H_4	0.15	0	1.76
H_5	0.1	1	0.22
H_6	0.33	1	0.71

Operating modes and helium flow requirement

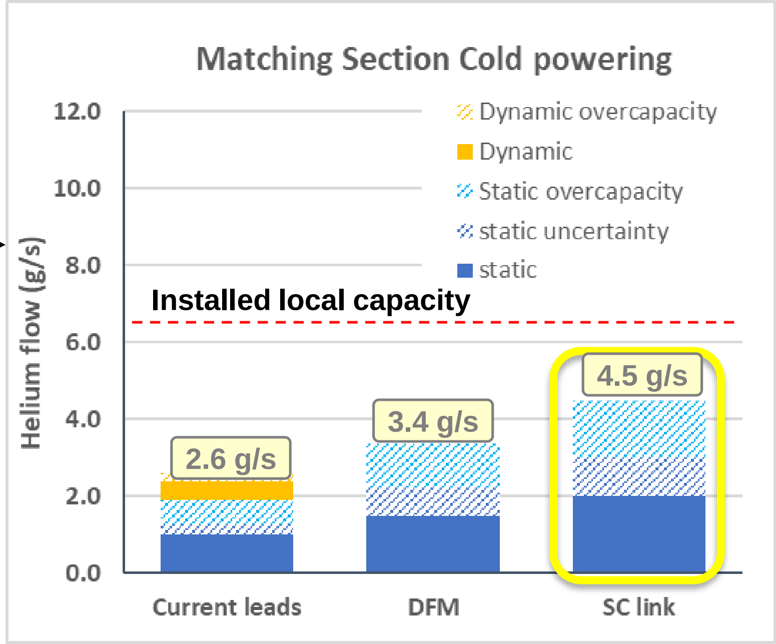
- Helium flow for the **DFM system is governed by the SC link requirement** (117 m at 1 W/m) leading to the **same required helium flow when the system is powered or not**.
- For the Cold Powering for the Triplets, the helium flow is determined by the current leads requirements.
- After **recommendations of the heat load review panel** (refer to EDMS 2588891) , the helium installed local capacity for Matching section Cold Powering to **6.5 g/s**.

Cool down
- Circuit **Purging ; Flushing**
- **Cool down** from 300 K to 4.5 K
- Re cool down after unplanned stop

Planned Operation
- **Standby** no current during normal operation
- **Nominal full current** (ultimate and nominal)
- Standby mode during **Technical Stop**

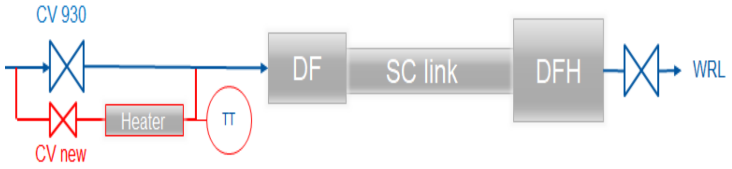
Unplanned Operation
- Power cut (with blocked outlet)
- Quench / electrical short circuit…
- Degraded performance (SC link; current lead…)

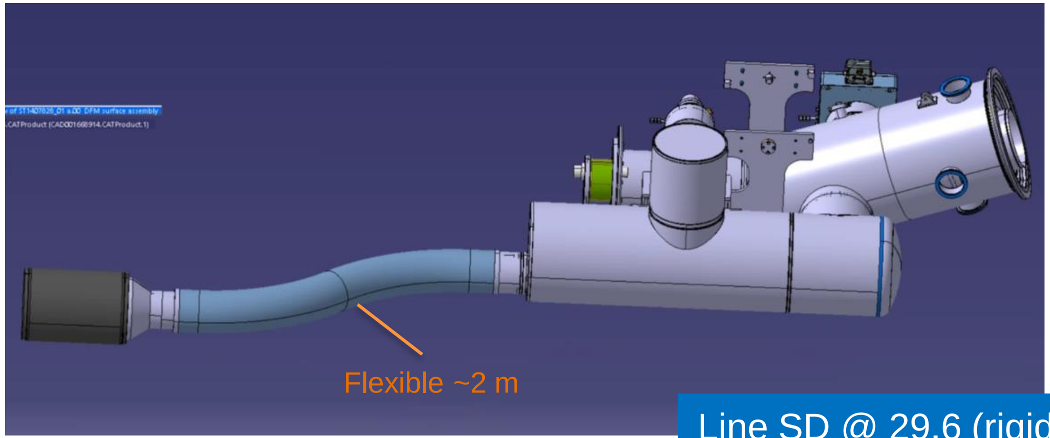
Warm up
- **Warm up** to 300 K

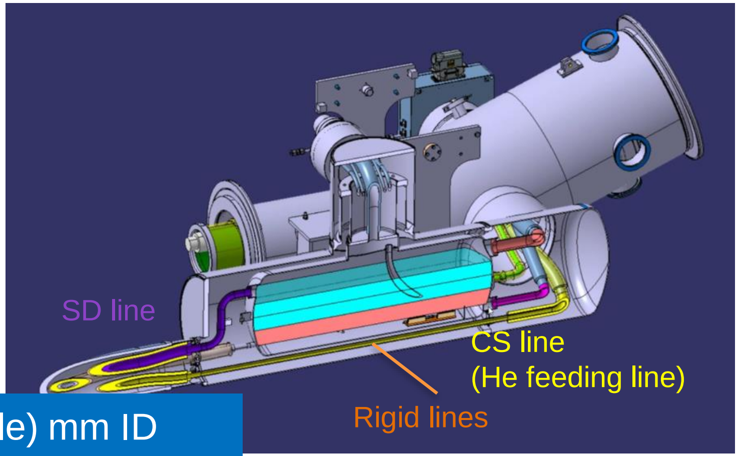


Controlled Cool-down / Warm-up

- MgB2 conductor is sensitive to strain, and excessive stress would lead to degradation of its critical current : Requirement of a controlled cooldown for the SC link.
- A serie of meetings were held to define the optimum solution according to WP6A contraints : a heater installed in parallel of the nominal feeding line. Solution validated by an approved ECR. (Refer to https://indico.cern.ch/category/13546/)
- The constraints are :
  - 30K maximum DT on the SC link
  - Controlled cooldown down to 80 K
  - 3 to 4 g/s cooldown /warm-up flow rate through the link
- Current hydraulic design and safety aspects were also considered for the controlled cool-down / warm-up design



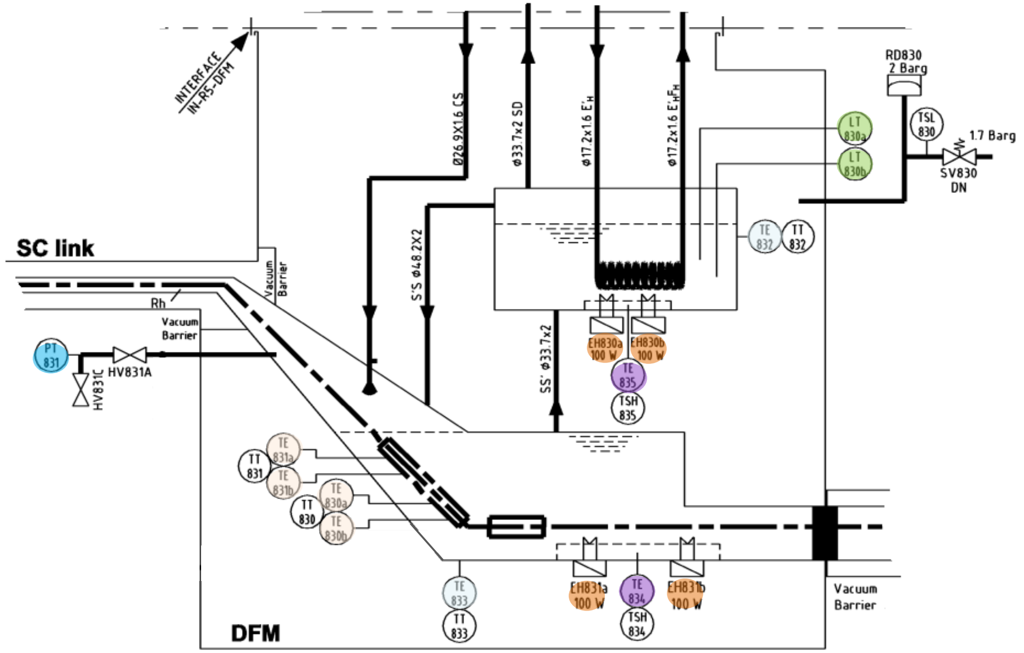




Line SD @ 29.6 (rigid) / 34.2(flexible) mm ID
Line CS @ 23.7 (rigid) / 25.5 (flexible) mm ID

Hydraulic diameter are sufficient for DFM cool-down

DFM Instrumentation requirement



Extract of PID lhclsqrg0042-v0 – DPT removed

Instrument	Number	Comment
Thermometer	2+2S	Temperature measurement on the MgB2-Nb-Ti splices. Short block - Cernox 3 points. No HV potential.
Thermometer	2	Temperature measurement for cool-down / warm-up – Long block – Cernox 3 points
Thermometer	2	PT-100 to be installed on a copper block for heater protection
Level gauge	1+1S	Superconducting gauge for liquid/gas level control
Pressure transducer	1	To monitor DFM pressure
Electrical heater	2+2S	• Two 100 W electrical heaters in liquid helium for mass flow production; • Two 100W electrical heaters at the lowest immersed position for liquid vaporisation during WU. Electrical heaters to be installed on a copper plate to increase global heat exchange area.

- On contrary of DFX, no Differential Pressure measurement due to the reduced height in the main helium bath. This DPT was forecast to follow the liquid filling phase. Instead, temperature probes can be installed in the vessel vacuum.

Conclusions

- The cooling circuit feeds in series the three different components of the Cold Powering System from 4.5 K to 300K. Helium flow is defined by the SC link requirement.

- Cryogenic interfaces for are defined and hydraulic diameters are confirmed.

- DFM concept is based on two helium vessels communicating by gravity : this concept was successfully proven on Demo 2.

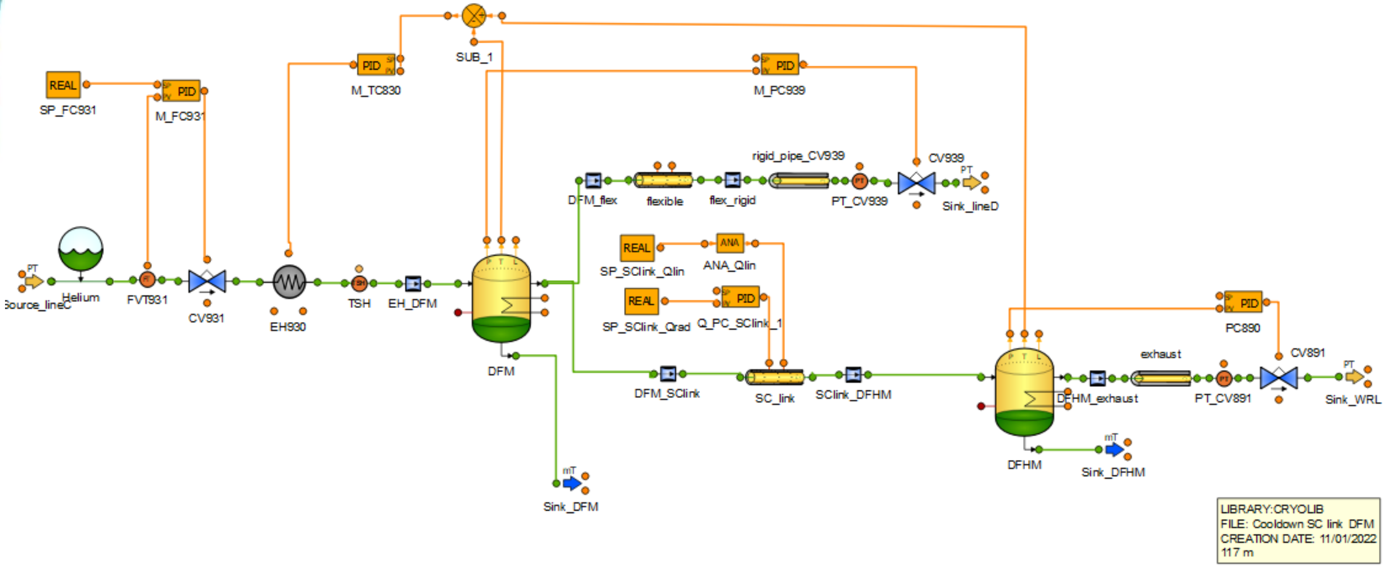
- The controlled cooldown and warm-up requirement is considered in the cryogenic design.

- DFM cryogenic instrumentation was reviewed. DPT to follow liquid filling on the main helium bath is removed due to the reduced height to be measured.

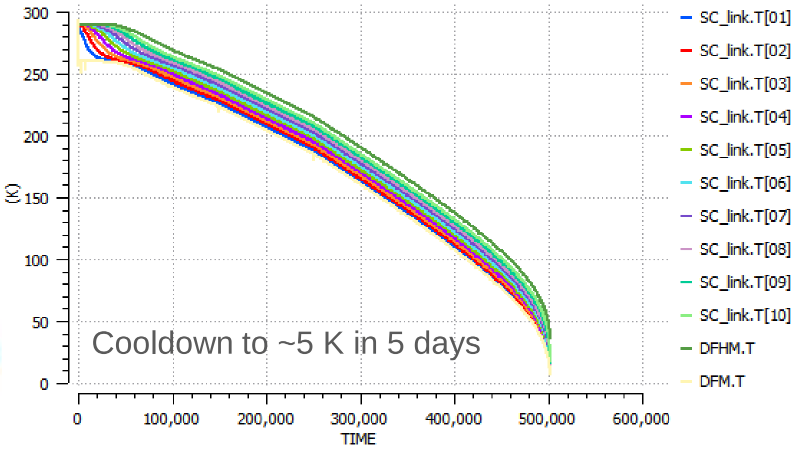
Spare slides

Dynamic simulation of controlled cool-down (Bonus)

- Cooldown modelling performed with Ecosim



Modelled Temperature profile along the link during CD

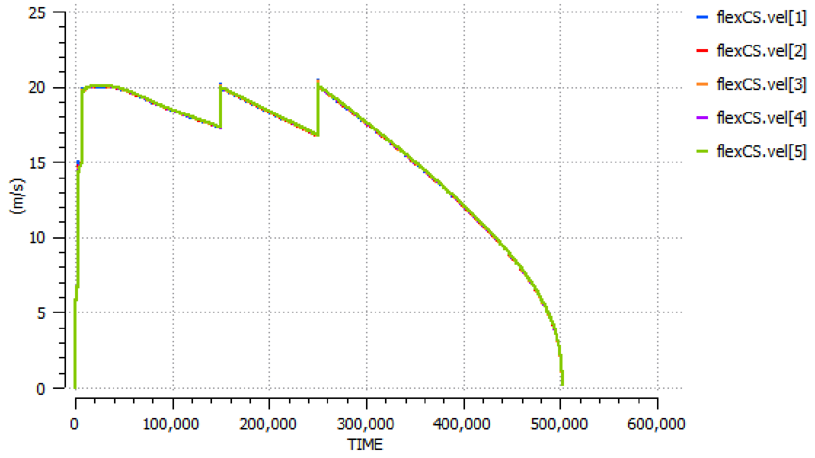


- P init : 1.3 bara
- T init : 290 K
- T env = 300 K
- SC link Metal : Copper
- DFM/DFHM metal : SS
- Pressure controlled at DFHM by PC890 at 1.3 bar
- Pressure controlled at DFM by PC839 at 1.7 bar
- DT controlled at 30 K on the SC link
- CD flow increased progressively from 1 to 4 g/s to avoid overpressure at warm conditions

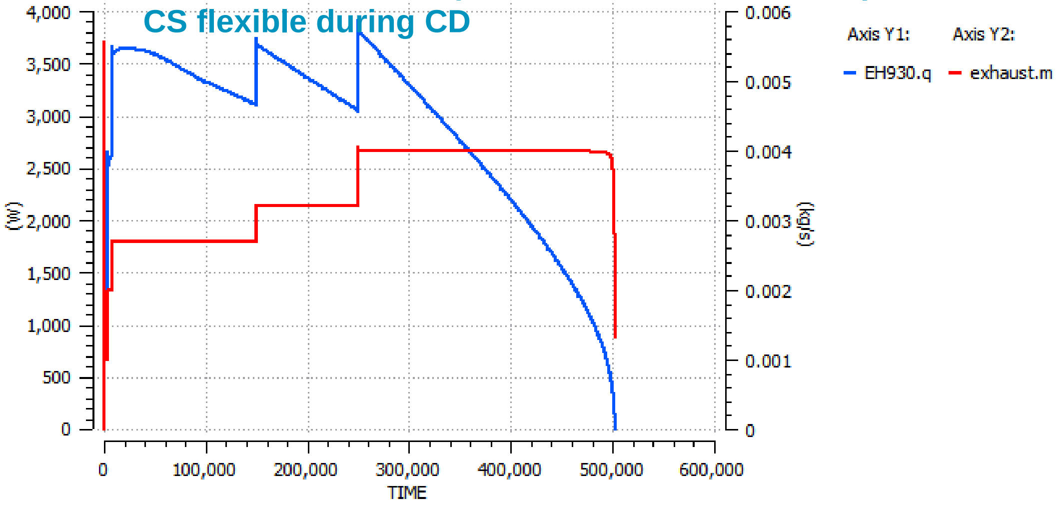
	Mass of metal (kg)	Hydraulic parameters
DFM	215	NA
SC Link	2250 (19 kg/m)	Length : 117 m Dh : 10 mm Friction factor: 0.1
DFHM	500	NA

Controlled Cool-down / Warm-up (Bonus)

Modelled velocity profile in CS flexible during CD



Modelled heater duty and CD mass flow aret profile in CS flexible during CD



Impact on hydraulic design

- Velocity in flexible to be limited to 20 m/s to avoid failure due to Flow Induced Vibrations. This threshold may be increased if limited operation in time.(flow to be limited from 2.7 to 4 g/s according to the temperature)

Impact on integration

Service module lenght is increased of 1 meter with the addition of :

- Cool-down / Warm up heater : cartridge type – 5 kW.
- A control valve

Advantages of the chosen solution :

- Possibility to benefit from the controlled CD of the magnets due to the reduced Kv of new supply valve
- No impact during normal operation
- Heater impact (potential high temperature) is a known and managed issue (e.g. 600 kW installed in the QUI) → Installation of DO to command the heater, Thermal switch installed at the outlet.

Helium flow requirement and thermal design DFHM

DFHM : Ultimate current

- Gaseous helium feeding DFHM from SC link available at 16 K
- DFHM designed for:
  - Design : 4.5 g/s
- Total Heat load < 30 W
- No condensation on external surface and feedthrough
- Thermal shield not required