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


With very fruitful discussions and contributions from WP16 & WP9 teams

https://indico.cern.ch/event/891644/
Outline

• Project timeline
• Main functionalities and configuration of the cryogenic system
• Study phase and outcome
• Status and overview of the design
• Project status and next steps

More information about the project can be found in the project sharepoint website (subsite of WP16): https://espace.cern.ch/HiLumi/WP16/Cryogenics/SitePages/Home.aspx
**Project timeline**

- Schedule adapted to Nov. 2019 rescheduling of the HL-LHC IT String installation.
- Procurement to start 2\textsuperscript{nd} quarter 2020
- Baseline is to commission the cryogenic system before connecting the magnets.
- Fully compatible with HL-LHC IT String schedule.

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String approved TCC 06.02
Procurement start
Comm. of cryo system

- Schedule adapted to Nov. 2019 rescheduling of the HL-LHC IT String installation.
- Procurement to start 2\textsuperscript{nd} quarter 2020
- Baseline is to commission the cryogenic system before connecting the magnets.
- Fully compatible with HL-LHC IT String schedule.
Main functionalities and requirements

- Should be representative of the tunnel configuration (prototype)
- Controlled cool-down & warmup < 4 weeks each
- Magnet operation in HeII (1.9 K)
- Cold powering system (DFX, DSL, DFH): 6 g/s liquefaction at full current
- Pressure relief during quenches: up to 39 MJ released into the cold mass
- Back to 1.9 K after a quench in < 12 hours (target 1 quench/day at full current)
- Cooling of the beam screen at 60 K – 80 K canceled Oct 2018 review
- Ultimate heat load capacity for individual test of each pair of heat exchangers: 500 W for Q1-Q2a & Q2b-Q3 and 250 W for D1-CP. (values to be confirmed)

Main requirements for the SM18 cryogenic infrastructure

- Integrated in SM18 cryogenic infrastructure
- Liquid helium supply: up to 25 g/s @ 3.5 bar for ultimate heat load tests
- Low pressure pumping capacity: nominal powering < 4 g/s , ultimate up to 23 g/s (1 week)
- Thermal screen supply at 60 K
- Warm gas recovery from the current leads
- Compatibility with operation of the test benches in SM18.

### Operation mode Requirements

<table>
<thead>
<tr>
<th>Operation mode</th>
<th>Requirements</th>
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<tbody>
<tr>
<td>Standby</td>
<td>50 W (2 W / m recent news being updated)</td>
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<tr>
<td>Current ramping</td>
<td>290 W</td>
</tr>
<tr>
<td>Bayonet heat exchanger test</td>
<td>up to 500 W per each double bayonet</td>
</tr>
<tr>
<td>Cool down from 300 K to 4.5 K</td>
<td>&lt; 15 days (with conditions on ΔT)</td>
</tr>
<tr>
<td>Magnet filling and cool down from 4.5 K to 1.9 K</td>
<td>&lt; 40 hours</td>
</tr>
<tr>
<td>Quench recovery</td>
<td>&lt; 12 hours</td>
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<tr>
<td>Warm-up from 4.5 K to 300 K</td>
<td>&lt; 15 days</td>
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</tbody>
</table>
**Configuration of the cryogenic system**

**Existing equipment:**
- 6 kW cold box (up to 25 g/s liquefaction)
- Cold compressor
- Warm buffer and exhaust line
- Very Low Pressure pumping system (2 x 6 g/s @ 10 mbar)

**New equipment / modification / scope:**

**SQXL : cryogenic line “tunnel like”**
- Cryogenic line, service modules, return module
- String specific instrumentation (cold flowmeters)

**Proximity Cryogenics**
- String valve box
- Actively shielded VLP Pumping line.
- 30 kW heater
- Adaptation of Very Low Pressure Pumps interconnection
- Adaptation of warm buffer diffuser
- Cold compressor refurbishment

**Data acquisition and control**
(including for magnets & cold powering)
Functional studies and conceptual design

Simulations performed:

- Optimization of the 6 kW Linde refrigerator, low pressure pumping and infrastructure in the various operating modes.
- Modeling of cool-down, warm-up, nominal, etc.
- Pressure drops in pumping lines all operating modes
- Dynamic simulation of magnet quenches and quench recovery

Study of variants with possible boosting for liquid helium filling.
Taking into account (among other requirements):

- Integration in SM18 test program
- Specificities of Nb$_3$Sn magnets:
  - Ramping heat loads (up to 290 W)
  - Maximum temperature gradients

Main outcomes of the study phase

- A cold buffer is not necessary
- Due to ramping heat loads a cold compressor is necessary
- All requirements (power, cool-down & test rates, quenches, etc.) can be fulfilled with the proposed configuration.
Example of study (1): cool down from 300 K

Cool down time from 300 K to 4.5 K (based on lump model):
- Cold mass weight = 84.2 tons
- GHe mass flow = 100 g/s

Estimated time: 8.5 days (requirement 15 days)
Maximum calculated temperature difference between GHe flow and cold mass is 22.5 K
Example of study (2): simulation of quenches

### 39 MJ quench

<table>
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<tr>
<th>State after quench</th>
<th>Pressure [bar]</th>
<th>Temp. [K]</th>
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<tbody>
<tr>
<td>Cryostat helium</td>
<td>16.1</td>
<td>27.8</td>
</tr>
<tr>
<td>Line D helium</td>
<td>12.6</td>
<td>18.7</td>
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<tr>
<td>Warm buffer</td>
<td>11</td>
<td>295</td>
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</table>

#### Time to nominal conditions for different quench energies

<table>
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<th>Quench energy</th>
<th>Init. Temp.</th>
<th>Re-cool down time</th>
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<tr>
<td>39 MJ</td>
<td>28 K</td>
<td>10 h</td>
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<tr>
<td>22 MJ</td>
<td>19 K</td>
<td>8 h</td>
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<tr>
<td>6.25 MJ</td>
<td>6 K</td>
<td>7.5 h</td>
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#### Calculated cold mass temperatures and re-cooling time

![Graphs and tables showing simulation results](image-url)
Status and design of the Cryogenic system

Detailed design started in June 2019
Currently finalizing the technical specifications, integration and interface drawings.
Naming, PID, valve sizing: 90% complete (about 500 items in PBS).
Design & procurement of main components: split into Proximity & SQXL

Cryo process and instrumentation diagram of the HL-LHC IT String
Status for the proximity cryogenics

- Re-using as far as possible existing equipment.
- Detailed integration validated.
- Cold compressor unit to be refurbished.

- **Status**: technical specification for main components (orange components below) planned for March 2020
Status for the SQXL

• Design and dimensions in synergy with the HL-LHC QXL (WP9).
• All interfaces to magnets & powering as for HL-LHC.
• Will provide all functionalities as the tunnel version.
• Additional flow measurements (cold flowmeters) for quench analysis.
• Status: technical specification planned for April 2020
## Project timeline & cost

- Schedule adapted to Nov. 2019 rescheduling of the HL-LHC IT String installation.
- Baseline documentation ready for approval, baseline EVM done.
- Procurement to start 2\textsuperscript{nd} quarter 2020
- Baseline is to commission the cryogenic system before connecting the magnets.
- Fully compatible with String schedule.
- Cost : 2.5 MCHF

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- Fully compatible with String schedule.
- Cost : 2.5 MCHF
Conclusions

• A configuration of the cryogenic system has been defined that fulfills all the cryogenic requirements for the HL-LHC IT String and for the operation of SM18. All main components have been defined and sized.

• Detailed thermohydraulic studies and simulations have been performed to determine the behaviour of the HL-LHC IT String and of the cryogenic infrastructure. Main outcome: no need of a cold quench buffer but a cold compressor is necessary.

• Work ongoing for the preparation of the technical specifications for the main components: procurement planned to start in the second quarter of 2020.

• The project schedule is fully compliant with the requirements of the HL-LHC IT String test program.
Operating modes

The provisional list of operation modes for the HLString:

- **Cooldown**
  - CD: Cool down from 300 K to 4.5 K (with substeps)
  - MF: Magnet filling with liquid
  - CD 6: Cool down from 4.5 K to 1.8 K

- **Test campaign**
  - ST: Standby no current
  - CR: Current ramping
  - NF: Nominal full current
  - HL: Maximum heat load test
  - MQ: Magnet quench
  - QR: Quench recovery

- **Warmup**
  - ME: Magnet emptying
  - WU: Warm up from 5 K to 300 K
Cool down from 4.5 K to 1.8 K (CD6)

- Cool down from 4.5 K to 2 K at maximum WPU pumping speed (@18 g/s)
- Below 2 K, WPU pumping speed is progressively reduced to achieve 1.8 K
- Cool down from 4.5 K to 1.8 K requires 2.4 h
- Mass flow required for re-filling of cryostat from 4.5 K to 2 K is 6.6 g/s
- The overall mass flow (pumping + re-fill) does not exceed the liquefaction capacity (25 g/s) of the cold box
## Major upcoming milestones (in the next 18 months)

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<td>Safety: complete safety file (exclude visitors during operation?)</td>
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<tr>
<td>Quality: complete interface documents</td>
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<td>Infrastructure: <strong>place order for the cryogenic infrastructure</strong></td>
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- Installation of cryo system March-May 2021
- HWC July 2021
- Ready for connection December 2021 with 1st magnet

### Installation: of metallic structure
TE-CRG Project Organization

Project coordination
A. Perin

Global specs. and project management
A. Perin, O. Pirotte
G. Rolando
O. Duran Lucas

SOXIL & magnets
TE-CRG-ME / WP9
M. Sisti
J. Metselaar
+ FSU for design

Proximity cryogenics & calculations
TE-CRG-ME
G. Rolando
O. Duran Lucas
J. Mouleyre
+ FSU for design

Controls
TE-CRG-CE
M. Pezzetti
A. Tovar

Instrumentation
TE-CRG-CI
J. Casas

Prep. of operation
TE-CRG-ML
N. Guillotin
J.-P. Lamboy

TCC HL-LHC IT String Cryo, A. Perin, TE-CRG, 27.02.2020, INDICO 891644