WP09 in a nutshell – Cryogenics

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Technologies: Cryogenics systems for HL-LHC, Electronic, electrical equipment and instrumentation for accelerators

The foreseen increased luminosity will require new insertions at P1 and P5, each with an order of magnitude higher heat loads no longer compatible with present cryogenic lay-out and architecture. Specific cryogenic interfaces for these insertions as well as dedicated new helium refrigerators are required. At the same time, Interfaces with present LHC accelerator or detectors cryogenic systems will have to be assessed in order to maintain and possibly improve the helium management and the global availability.

HL-LHC High Luminosity LHC Project WP 09 - Cryogenics

WP 09 - Cryogenics - Q - Cryogenic system
  WP 9 - Cryogenics - Infrastructure - QSV warm storage
  WP 9 - Cryogenics - Infrastructure - QSD Cryogenic storage
  WP 9 - Cryogenics - Infrastructure - QSA Dryers
  WP 9 - Cryogenics - Infrastructure - Warm piping
  WP 9 - Cryogenics - Refrigeration - QSC Warm compressor station
  WP 9 - Cryogenics - Refrigeration - QSR/QUR Cold boxes
  WP 9 - Cryogenics - Cryogenic Distribution - QUI Interconnection boxes
  WP 9 - Cryogenics - Cryogenic Distribution - QRL/QXL Transfer lines
  WP 9 - Cryogenics - Controls & instrumentation

Fig. 1 - Cryogenic upgrade for HI-LHC project
Fig. 2 - Cold Box (left) and cryo distribution line (right) for Crab Cavities Test Stand at SPS

Fig. 3 - Cryogenic storage - Nitrogen tanks (left) and Helium tanks (right)

Fig. 4 - Example of cryogenic piping
Fig. 5 - Cold Boxes installed on the LHC Point 5 (left) and Point 4 (right)

Fig. 6 - Example of refrigerator

Fig. 7 - High Field Magnets layout
GENERAL PARAMETERS

The upgrade of the cryogenics for the HL-LHC will consist of the following.

- The design and installation of two new 1.9 K cryogenic plants at P1 and P5 for high luminosity insertions. This upgrade will be based on a new sectorization scheme aimed at separating the cooling of the magnets in these insertion regions from the arc magnets, and on a new cryogenic architecture based on electrical feedboxes located at ground level and vertical superconducting links.
- The design and installation of a new 4.2 K cryogenic plant at P4 for the Superconducting Radio Frequency (SRF) cryo-modules and other future possible cryogenic equipment (e-lens, RF harmonic system).
- Cryogenic design support for cryo-collimators and 11 T dipoles.

The luminosity upgrade programme (HL-LHC) requires modifications of the present LHC’s cryogenics as the beam bunch population will double and the luminosity in the detectors of the high luminosity insertions at P1 and P5 will be multiplied by a factor 5. Therefore the upgrade in the beam parameters will introduce new constraints to the cryogenic system.

- The collimation scheme must be upgraded by adding collimators to the continuous cryostat close to P2 and P7, and possibly also P1 and P5. The corresponding integration space must be created by developing shorter but stronger 11 T superconducting dipoles. As the new collimators will work at room temperature, cryogenic bypasses are required to guarantee the continuity of the cryogenic and electrical distribution.
- The increase of the level of radiation to the electronics could possibly require relocating power convertors and related current feedboxes to an access gallery at P7 and at ground level at P1 & P5. New superconducting links will be required to connect the displaced current feedboxes to the magnets.
- In order to better control the bunch longitudinal profile, reduce heating and improve the pile-up density, new cryo-modules of 800 MHz RF cavities could be added to the existing 400 MHz cryo-modules at P4 creating a high-harmonic RF system. Alternatively, discussions are underway to see if a better scheme would be the installation of a new 200 MHz SRF system, rather than the 800 MHz. From the cryogenic point of view the requests are similar, so we will consider below the 800 MHz system that is in an advanced phase of study.
- To improve the luminosity performance by addressing the geometric luminosity reduction factor and possibly allowing the levelling of the luminosity, cryo-modules of crab-cavities will be added at P1 & P5.
- Finally, the matching and final focusing of the beams will require completely new insertion cryo-assemblies at P1 & P5.

Heat loads to the cryogenic system have various origins and uncertainties. As done for the LHC two categories of heat loads are considered: static heat loads ($Q_{\text{static}}$) to be compensated just to reach the desired temperature level, and dynamic heat loads ($Q_{\text{dynamic}}$) due to energising or circulating beams. These heat loads are primarily considered without contingency to avoid piling-up margins. However, the cooling capacity to be installed has to include margins that vary for the static and dynamic heat loads to properly allow the nominal beam scenario. This margin vanishes for the ultimate beam scenario. For new equipment, the thermal performance of supporting systems, radiative insulation and thermal shields is considered identical to that of existing LHC equipment.

The beam screens of the new inner triplets at P1 and P5 (See WP12) will be protected by tungsten shielding that will be able to absorb about half of the energy deposited by collision debris escaping the high luminosity detectors. For simplicity at this stage, beam screen loads were considered to be between 4.6 K and 20 K as for the current LHC. However, the large dynamic power to be extracted could force consideration of the next possible
temperature range compatible with beam vacuum requirements, i.e. the range 40 K to 60 K. Despite this thick W-shielding, the 1.9 K load, i.e. the energy that collision debris deposited onto the magnet coil and cold mass, increases by four times with respect to the nominal LHC case. The W-shielding, in any case, reduces the overall refrigeration cost and increases the lifetime of the inner-triplet coils.

NEW CRYOGENICS FOR POINT 4

The proposed cryogenic architecture of the upgraded P4 insertion can be seen in Fig. 8 and it is consisting of:

- a warm compressor station (WCS) located in a noise-insulated surface building and connected to a helium buffer storage;
- a lower cold box (LCB) located in the UX45 cavern and connected to a cryogenic distribution valve box (DVB), also located in the UX45 cavern;
- main cryogenic distribution lines connecting the cryo-modules to the distribution valve box;
- auxiliary cryogenic distribution lines interconnecting the new infrastructure with the existing QRL service modules (SM) and allowing redundancy cooling with adjacent-sector cryogenic plants;
- a warm-helium recovery line network.

This is considered as the present baseline, with the evaluation of an alternative scenario for the refrigeration part. The alternative scenario would consist of an upgrade of one of the existing refrigerator of P4 to fulfil the required cooling capacity of existing SRF modules with sufficient margin, while keeping the baseline new distribution scenario. As a complement, a new mobile refrigerator with a cooling capacity allowing RF tests of a single cryo-module during long shut-downs is under investigation, as all other cryogenic sub-systems would be stopped for maintenance and major overhauling.

The activities related to cryogenics at P4 will take place during LS2 (2019-2020).

NEW CRYOGENICS AT POINT 1 AND POINT 5

The proposed cryogenic architecture of the P1 and P5 can be seen in the Fig. 9 and it is consisting of:

- a warm compressor station (WCS) located in a noise-insulated surface building and connected to a helium buffer storage;
an upper cold box (UCB) located in a ground-level building;
a quench buffer (QV) located at ground level;
one or two cold compressor boxes (CCB) in an underground cavern;
two main cryogenic distribution lines (one per half-insertion);
two interconnection valve boxes with existing QRL cryogenic line allowing redundancy with the cryogenic plants of adjacent sectors.

At P1 and P5 the superconducting magnets of the ATLAS and CMS detectors are cooled by dedicated cryogenic plants. A possible redundancy with detector cryogenic plants could be interesting in the event of a major breakdown of the detector cryogenic plants.

The cooling capacity of 3 kW at 1.8 K is higher than the 2.4 kW installed capacity of an LHC sector, which corresponds to the present state-of-the-art for the cold compressor size. Consequently:

- larger cold compressors have to be studied and developed;
- or parallel cold compressor trains have to be implemented (one 1.5 kW train per half insertion);
- or duplication of the first stage of cold compression to keep the machine within the available size.

The tendering of the cryo-equipment required for P1 and P5 will not take place before 2021. This equipment will be installed during the Long-Shutdown 3 (2024-mid2026).

The main challenges of the overall cryogenic upgrade for the HL-LHC project, can be summarized as follows:

- Cooling circuits for large heat deposition.
- Cooling of HTS SC links and current feedboxes.
- Cooling and pressure relief of crab cavities.
- Validation tests on SC link, crab cavities, magnets, beam screens, etc.
- Quench containment and recovery.
- Larger 1.8 K refrigeration capacities beyond the present state-of-the-art.
- Large capacity (1500 W/3000 W) sub-cooling heat exchangers.
- Larger turndown capacity factor (up to 10) on the 1.8 K refrigeration cycle.