

THE LHC CRYOGENIC OPERATION AVAILABILITY RESULTS FROM THE FIRST PHYSICS RUN OF THREE YEARS

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Abstract

The LHC (Large Hadron Collider) accelerator consists in eight cryogenically independent sectors, each 3.3 km long with a cold mass of 4'500 t cooled at 1.9 K. Each helium cryogenic plant combines an 18 kW at 4.5 K refrigerator and a 2.4 kW at 1.8 K refrigeration unit. Since early operation for physics in November 2009, the availability has been above 90% for more than 260 days per year, ending at 94.8% in 2012 and corresponding to an equivalent availability of more than 99% per independent sector. The operation and support methodology as well as the achieved performance results are presented. Emphasis is given on implementing operational return for short, medium and long term consolidations. Perspective for restart after the first long shutdown of the LHC works will be described.

INTRODUCTION

The LHC accelerator (26.7 km circumference) is equipped with high field superconducting magnets, totalizing a cold mass of 36'000 t, operated at 1.9 K [1, 2]. The cryogenic system consists in eight 18 kW at 4.5 K helium refrigerators each of them respectively combined with eight 2.4 kW at 1.8 K refrigeration units.

Form the operational point of view this implementation leads to eight cryogenically independent sectors (see Fig. 1), each of them connected to a pair of refrigerators, one providing the cooling capacity at 4.5 K, the other one to further cool it down to 1.9 K (see Fig. 2). Process control and operational procedures are similar for each sector and its pair of refrigerators thus optimising the operation by a unique team, however, requirements for beams concerns the overall availability of the accelerator. It imposes to work on all downtime causes of the eight sectors and pairs of refrigerators with the same priority.

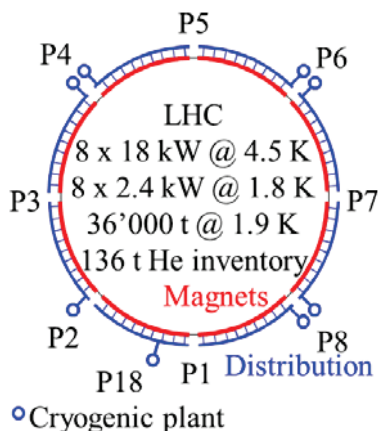


Figure 1: Layout of the LHC cryogenic system

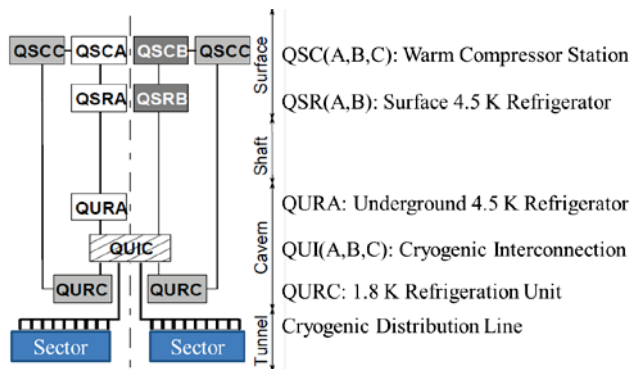


Figure 2: Typical LHC cryogenic Point

The key numbers of the main equipment of the LHC cryogenic system are summarized in Table 1.

Table 1: Inventory of main components

Helium screw compressors	64
Cold compressors	28
Expansion turbines	74
I/O signals	60'000
PLC	120
PID control loops	4'000

CRYOGENIC OPERATION AND SUPPORT ORGANISATION

After completion of the installation phase, the cryogenics group structure evolved from a project oriented to an operation and support structure. Due to the team size, the cryogenics operation teams for the accelerator or physics detectors and test facilities remain independent.

Three support teams for mechanics, electricity-instrumentation- controls and metrology-instrumentation have been established thus allowing keeping the know-how and providing support in their respective domains. Besides, a dedicated methodology team takes care of schedule and maintenance methods, tools and logistics, including cryogen distribution. All technical support, methodology and logistics teams are common to the respective operation teams for accelerators or physics detectors and test cryogenic facilities.

Cryogenic operation is based on several layers of monitoring and technical support: shift work 24h/7days in the CERN Control Center, two layers of sequential operation stand-by teams for field intervention in case of long duration, one layer of maintenance stand-by duty, one layer of instrumentation, electricity and controls stand-by duty service. Specific coordination is ensured

via two dedicated recurrent forums. The first one is specifically checking cryogenic performance aspects where each cause of downtime is reported and analysed. Its treatment protocol is evaluated and possible improvement or consolidation reviewed. The second one focuses at the preventive and corrective maintenance request for intervention and associated procedures.

In order to improve assessment on reliability data for the LHC accelerator cryogenic system, CERN has started to collect and implement data since 2009 in its Computer Aided Maintenance Management System (CAMMS) [3] with in parallel a global criticality analysis for the LHC cryogenic processes & components. Table 2 summarizes the main data of the LHC cryogenic system.

Table 2: Inventory of main CAMMS parameters

CAMMS data	LHC Cryogenic System
Referenced equipment	21'000
Referenced spare parts	4'200
Stored references	3'100
Individual materials	62'000
Maintenance tasks	320

OPERATION AND MONITORING STRATEGY

When defining the LHC operation strategy and the availability criteria, it was not desired to consider each temperature sensor or liquid helium level as an interlock to the magnet powering and therefore the beam permit. To be consistent with the modularity of the magnet powering capabilities, on each powering subsector was attributed a pair of cryogenic signals: a Cryo-Maintain (CM) signal corresponding to any condition that would require a slow discharge of the concerned magnets and a Cryo-Start (CS) with more stringent conditions to enable the powering with enough margin in order not to perturb the process during the transient and reach the CM threshold.

According to the European industrial standards for availability (EN 15341), the first step was to define a digital condition that can be true or false which best illustrate the ability to provide the expected service. A global CM signal was defined as the combination of all required conditions for the eight sectors (32 powering sub-sectors with independent CM). This allowed the definition of an availability figure per unit of time. On daily basis, an on-line availability result is displayed on the cryogenics control system.

The systematic analysis and reporting of unavailability blocks was performed with the aim to identify the root cause by type of origin such as “utilities, cryogenics, cryogenics following Single Event Upset (SEU, energetic neutrons), and users (magnet quenches or assimilated)”. This allowed defining improvement programs for operational procedures, tuning of settings or hardware to be modified. Over the last 3 years, the number of short stops (CM loss for less than 8 hours) was reduced from 140 to 81 per year, illustrating as well the progress made.

Besides the systematic analysis of all failures, the long stops (CM loss for more than 8 hours) associated to production failures were handled separately, as this was considered as first priority for improving the overall availability. Fig. 3 illustrates the progress made for the 4.5 K refrigerators availability and what should be continued for the 1.8 K refrigeration units.

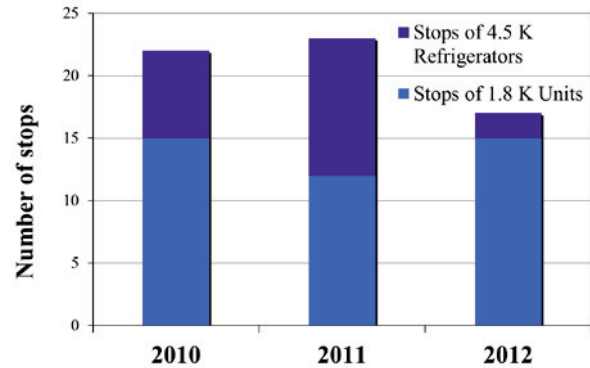


Figure 3: Summary of the cryogenic system long stops

RESULTS

Availability Results

During the first LHC beams, a global cryogenics availability of 90% was achieved without the possibility to quickly treat the origin of the identified faults. Mitigation programs were put in place whenever possible for important consolidations to be applied during technical stops of the accelerator (5 times 5 days during the yearly beam operation period) or end of the year stops (4 to 10 weeks). The main treated issues were the elimination of two air leaks in sub-atmospheric circuits, the replacement of all the cooling valves (1258) for current leads [4] as well as the treatment of the electronic cards (1200) for specific temperature sensors that were particularly affected by SEU.

An additional contribution to the improvement of availability, as a performance, was the high level requirement for implementing adequate operation settings for an energy efficiency-savings program. An adequate training for the operation team was implemented, including the evaluation of all settings improving the energetic efficiency and allowing the optimisation of the nominal cryogenic conditions recovery after failures leading to improved availability. The implementation of the energy efficiency-savings program resulted in a direct gain for CERN of 3 MCHF per year.

As shown in Fig. 4, summarizing the availability results (based on 265 days per year for beams, tuning or physics), a clear progress is observed during the last year (2012), due to the progress with operation of the cryogenic system, but as well linked to the reduction of utilities induced failures. Specifically for the electrical network glitches, the adequate settings of the tolerance thresholds for helium compressors and cooling water stations represented half of the gain. Clearly worth the efforts!

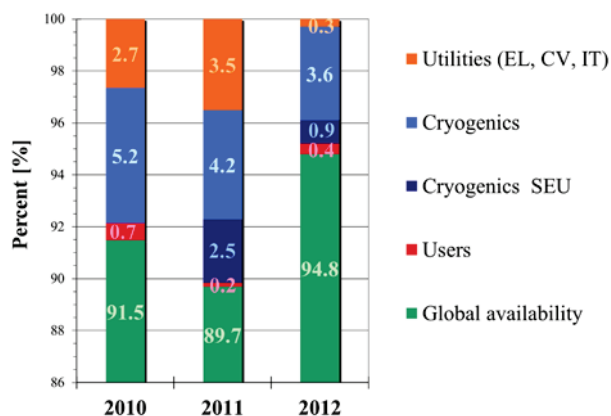


Figure 4: Availability results

Helium Inventory Management

The overall LHC inventory represents 136 t of helium. In order to cope with urgent situations during operation, an additional quantity of 15 t is permanently maintained in situ as strategic storage. For 2010 and 2011 respectively, the overall losses remained high (30% and 25% of the inventory), due to increased losses during the first end-of-the-year technical stop with helium stored in the recently commissioned liquid helium tanks but with the operational part significantly reduced in 2011. During 2012, due to the combination of a massive campaign for localising all detectable leaks and the reduced operational losses, the overall figure improved dramatically, reducing the losses by nearly a factor 2 down to 16% of the inventory as shown in Fig. 5.

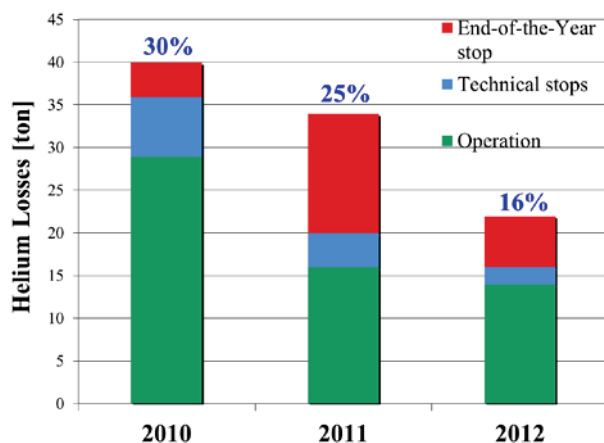


Figure 5 : Evolution of helium losses

CONSOLIDATIONS AND RESTART AFTER THE FIRST LONG SHUTDOWN

Thanks to the early consolidation work, as described in the Results section, already performed while ramping up the LHC luminosity, no major changes are foreseen during the first Long Shutdown (LS1) of the LHC. The full preventive maintenance plan is scheduled, including

the major overhauling of the helium compressors stations at manufacture’s premises.

Critical spares for rotating machinery have been ordered and are now on stock. Based on criticality analysis, specific electronic units (frequency drives, magnetic bearing controllers, heating control electronic cards) are in the process of upgrade in order to cope with the Radiation to Equipment (R2E) updated measurements. Interventions on identified leaks in several insulation vacuum sections are scheduled to be repaired for the refrigeration production plants as well as for the distribution line and magnets in the tunnel.

With the magnet interconnections to be consolidated, including the interface with the current leads and the electronics displacement for higher tolerance to high energetic neutrons (SEU, R2E project), a complete re-commissioning effort will be required prior to cool-down.

CONCLUSION

After a delicate start-up due to the extraordinary complexity of the LHC cryogenic system, we could immediately achieve a reference baseline with 90% of overall availability for beams over a typical year. The efforts performed by operation and support teams allowed dividing by 2 the downtime in 2012, giving a global availability of 94.8%. This corresponds to better than 99.3% availability for each the eight cryogenically independent sectors. Besides the correct design and its implementation, it illustrates that the methods and organisation in place are appropriate.

The assimilated operational experience in combination with the scheduled consolidation work, are key factors towards future availability at close-to-nominal beam energy and intensity. A similar systematic approach shall be kept after the restart of the LHC accelerator at nominal conditions with new higher heat loads corresponding to increased beam parameters.

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REFERENCES

- [1] LHC Design Report, CERN-2004-003, June 2014, Vol. 1, Chapter 11, page 309-337
- [2] Ph. Lebrun, “Cryogenics for the Large Hadron Collider”, IEEE Transactions on Applied Superconductivity, Vol. 10, No1, March 2000
- [3] G. Perinic et al., “First Assessment of Reliability Data for the LH Accelerator and Detector Cryogenic System Components”, CEC/ICMC 2011, June 2011
- [4] K. Brodzinski et al., “The LHC Cryogenic Operation for First Collisions and Physics Run”, ICEC23/ICMC, July 2010