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Helium inventory management and losses for LHC cryogenics: strategy and results for run 1

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Abstract

The Large Hadron Collider (LHC) cryogenic system requires an unprecedented helium inventory of 130 tons. If the operational availability for physics was clearly set first priority for run 1 (from first cool-down to long shut-down 1), specific measures were taken from the beginning towards the best rational use of helium during this period. Additional storage capacity was installed to match schedule constraints. Tools were developed to monitor the inventory. Operational achievements were analyzed and corrections applied. After recalling the strategy defined for managing the helium inventory and associated infrastructure, tools and methods developed, the achieved results and perspectives will be presented.

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Keywords: LHC; helium; inventory; storage; losses

1. Introduction

The LHC cryogenic system requires an unprecedented helium inventory of 130 tons, as described in the LHC design report [1]. The helium storage and inventory management strategy has evolved over time to match investments and operational constraints, with plans to further decouple the helium inventory from the market. Simultaneously and like all large scale cryogenic systems, helium losses had to be identified and reduced while

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bringing operational availability to a satisfactory level, as explained by Delikaris et al. (2013) [2]. Therefore, specific tools and methods were progressively developed, covering all major operation phases.

2. The LHC helium storage and inventory management

2.1. Description of the helium storage

Considering investment cost limitations and environmental impact concerns, it was decided at design stage to store only about half of the entire LHC helium inventory in a series of room temperature medium pressure vessels distributed at the 8 access points of the LHC, and interconnected via a helium ring line located along the 27 km long LHC tunnel. The complement of inventory was foreseen to be made when required for the cool-down of each independent sector, thus constraining the helium delivery logistics with the cool-down schedule. In addition, a external storage scenario was envisaged in case of complete thermal cycle of the LHC. This allowed initial cool-down and operation of the LHC for physics. At this occasion, it was demonstrated that the total helium inventory of the whole machine was significantly larger than expected by about one third, mostly due to a larger volume per unit of length in the cold masses. The helium inventory per major sub-system is illustrated in Fig. 1a.

On the basis of the initial experience when several months where required for logistics purposes, the foreseen external storage strategy for such a large proportion appeared not flexible enough for the operation and the global management of the LHC helium inventory. It was therefore decided to complement the initial gaseous storage system by six liquid helium storage tanks (see Fig. 1b), increasing the on-site storage capacity from about 40% to 100%, as described by Benda et al. (2012) [3]. This proved to be extremely useful since the end of 2011 as it allowed to secure the helium inventory for the annual Christmas break in less than 10 days, while the entire machine was kept cold at about 20 K, a regime much more tolerant to possible operation failures minimizing the risk of significant helium losses during these periods.

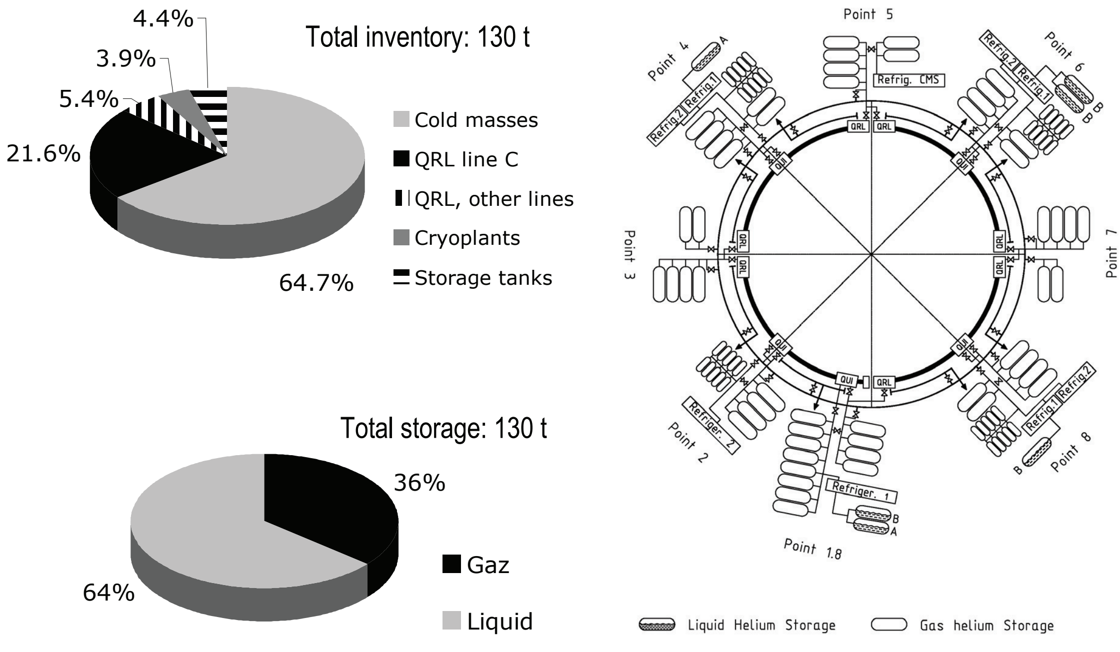

Fig. 1. Helium inventory: (a) per sub-system; (b) per storage type; (c) helium storage distribution for LHC.

2.2. Global helium management strategy

In addition to the overall LHC inventory of 130 t, a strategic storage of 15 t (about one sector) has been defined to guarantee the operation in the case of an urgent need or difficulties with deliveries from the market. The helium supply contracts (minimum 2) includes deliveries of helium via 4.5 t liquid helium containers, and a clause for temporary storage of part of the LHC inventory. The typical rates for the later would represent at least 3 months when emptying or re-filling the machine, giving a serious constraints for the schedule of the LHC. The complementary liquid helium storage allowed decoupling the needs of the machine schedule from the acceptable rates of the market, providing a real value for the associated cost. However and despite state-of-the-art heat losses, this storage would lose about 50% of their content within a year if no re-liquefaction was available, as foreseen now every 4 years for long shut-downs and overhaul maintenance campaigns.

During the next operation campaign, it is foreseen to refurbish two small-scale helium liquefiers (capacity equivalent to 20 l/h) in order to further minimize the required external temporary storage from 90 tons now to a maximum of 30 tons, and keeping about 125 tons at CERN.

This strategy illustrated in Fig. 2. would provide the most cost effective storage system with the minimum constraints on the accelerator schedule.

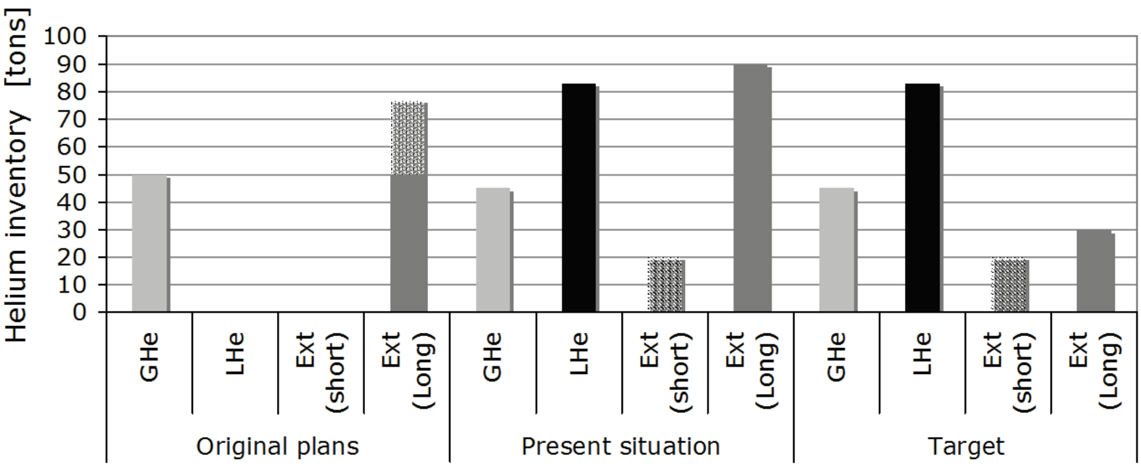

Fig. 2. Helium inventory management.

3. Helium losses

If helium loss was not the first priority for initial cool-down and early commissioning, it was always a concern due to the large costs involved and as it is one of the key parameter to set high quality requirements, in return allowing to achieve high operational availability. Therefore and in addition to availability and power consumption, the helium inventory was one of the key performance on-line indicators that were established for the operators. Besides, a methodology providing an evaluation of the helium losses was established combining a series of periodic estimates for categories of activities.

3.1. Step 1: on-line helium inventory evaluation

With the cool-down of the first LHC sector in 2007, we were surprised by the large quantity of helium that had been required, and could not attribute it to permanent losses. In parallel with an evaluation campaign for unitary helium inventory of the major contributors (magnets, cryogenic distribution line, refrigerators), it was decided to have an on-line value of the helium inventory for each sub-system based on estimated volumes and calculated density using available pressure and temperature transmitters. For density values and to minimize the impact on the control system, a simple fit was used above 20 K, such as 48xP/T. Bellow 20 K, tabulated values for densities for all pressure and temperature ranges were loaded in the control system. An accuracy better than +/- 1% was obtained.

$$Mass\_total = \sum Density(P,T) \times Volume. \quad (1)$$

Combining the sum of the eight independent sectors, a “total LHC helium inventory” variable was created, displayed with trend curve in the control rooms, and archived for analysis and correlations. This allowed all members of the operation team to feel concerned by this parameter from which an indicator was derived: daily losses quoted in kg per day.

Without much stimulation, this indicator was checked spontaneously by team members and actions were taken to identify and treat major initial leaks or practices that induced helium losses, such as operation to close to safety valve settings. As a matter of fact, it favored smooth transients and well mastered operations, contributing to the learning phase of the team.

At a global level, it became clear that the losses had different rates and origins depending on the type of operation performed, and specific categories where defined: Christmas breaks (few weeks break at the end of the year with potentially helium transfer to the storage, and minimum maintenance activities), technical stops (about three periods of one week without beams, for interventions on technical systems), and beam operation. Each category was analyzed and treated specifically.

As a net gain, global losses during beam operation were reduced from about 200 kg/day to a best value over 2 consecutive weeks of about 100 kg/day.

3.2. Step 2: evaluation per LHC site

For the helium management purpose, the LHC cryogenic system could be considered as 5 independent sites, with periodic helium transfer. By comparing with an identical approach the net results in losses per day of the various sites, it has been possible to identify a ranking, illustrating where efforts where necessary and what should be the target at that time. The evaluation of the helium inventory was refined to reach an accuracy of 1%, and monthly reports were provided for each site, with an accounting-like method aiming at identifying all discrete changes. In other words, the helium inventory was treated like the operation availability, with all changes reported and analysed. This allowed identifying common modes of losses, and therefore treating them.

Besides and as a natural effect, all local operation teams did their best not to be the worst case!

The losses were further reduced, with a best value over 2 consecutive weeks of about 50 kg/day.

3.3. Step 3: measurement per building

Reaching the limits of self commitment to identify the helium leaks to atmosphere and correct them, it became clear that knowing where to look for would help: knowing that a leak exists on an installation allows to focus identification and to find the leak in a reasonable time. Having in mind a method based on a helium detector located below the roof of a building at Tore Supra in the 80ies, we investigated together with our cooling and ventilation colleagues the possibility to introduce a leak detector in the ventilation circuit of our buildings. The development of the method started with a proof of principle, followed by a sensitivity analysis and determination of a protocol for highest sensitivity and reproducibility. The main steps consisted of:

- Configuration of the ventilation to induce only fresh air into the building, giving the lowest residual value, better than 10^{-5} mbar.l/s;
- Configuration of the ventilation to have only 50% of fresh air, therefore recycling partly the potential helium content from a leak, with measured values of few 10^{-5} mbar.l/s within one hour;
- Injection of a pre-defined helium flow in the center of the building giving a new increase of the signal within an hour.

The ratio between the two responses was used to quantify the helium leak rate within a given building. All sixteen surface buildings were measured: 11 were about 1 kg/day, 2 could not be measured, 2 were about 3 to 4 kg/day and 1 was about 7-8 kg/day. With such a clear signature, the three worst cases were actively scrutinized and leaks were found on a low pressure leaky weld, loose fitting or damaged flow meter on a gas analyzer.

Such measurement campaigns are now performed periodically.

The losses were further reduced, with a best value over 2 consecutive weeks of about 25 kg/day.

3.4. Step 4: Plans for measurements in the LHC tunnel

Plans to adapt the method to the ventilation of each LHC sector have been studied, and a prototype is schedule for this autumn once nominal ventilation conditions will be restored after the long shut-down period. Periodic inspections did not identify leaks on cold circuits (no ice nor condensation observed), but many warm pipes and connections (mostly for the 1200 current leads around the LHC) should be checked more systematically than with manual on-site leak detection.

We are confident that this will at least provide an independent and reproducible evaluation of the eight sectors, allowing to quickly identifying possible deviations after interventions.

3.5. Achieved results

During the two years and a half of cool-down and powering tests prior to physics end of 2009, about 40 tons (31% of total inventory) were lost per year for leak tests, purge and commissioning. Clearly preserving helium had less priority than achieving operating results! However, the discrepancy between the foreseen total inventory and real time estimates forced us to prepare the on-line monitoring described above. We understood as well that trying to minimize the helium losses by better operation practices was a way to collectively learn how to best operate the LHC cryogenic system, allowing to reach better availability. Just after the operational availability for beams, the helium losses became our 2nd indicator analyzed weekly or after specific actions. While the availability was kept constant or increased, the helium losses were significantly reduced to 26% and eventually 17% of total inventory, as illustrated in Fig. 3.

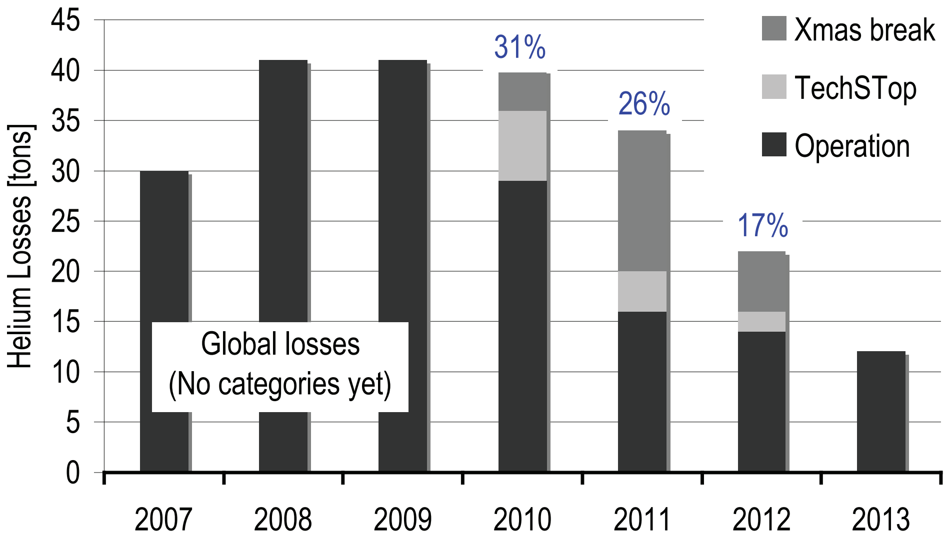

Fig. 3. Results obtained for the helium losses.

3.6. Other results during the long shut-down No1

After all maintenance, repair and consolidation works had been completed, thorough leak detection campaigns were organized on all sub-system prior to restart, in order to reach the best possible results compatible with the restart schedule.

Furthermore, methods and actions requiring coordination outside the cryogenic team were considered towards the reduction of the helium losses for the end of the magnet interconnection consolidation campaign. Actions were taken on two fronts:

• During the helium leak test campaigns at the end of the long shut-down No 1 of the LHC: instead of filling circuits to some 3 to 10 bar for higher sensitivity, circuits were pumped to get a low residual leak signal while the welds were equipped with dedicated clamshell-like tools to be evacuated from air before being connected to a helium leak detector. Re-filling the circuits up to 1 bar with helium was enough to properly validate the leak-rate of the welds done in-situ.

This work was initiated together with the colleagues from the vacuum group and proved to be extremely efficient, both for the leak detection and the quantity of helium used which were kept lower by at least a factor 5 with respect to initial installation phase. More than 10 tons were saved with this method.

• With volumes of more than 300 m^3, purging each sector of the LHC to fill it with clean helium could require more than one ton of helium, and was needed two to three times per sector before the initial cool-down of the LHC. The sequence of tasks between the end of the consolidation works to the cool-down (mechanical pressure tests, leak tests, flushing of circuits, high-voltage electrical tests) was optimized to minimize the number or required purge to be made. This was not possible for all cases, but between one and two tons of helium was saved thanks to this type of optimized organization.

4. Conclusion

Starting with the initial configuration aiming at minimizing investment costs and environmental impact, it has been required and possible to provide complementary infrastructure aiming at improving the operational flexibility. Ideas for further minimizing the interactions with the helium market could lead to the installation of small-scale re-liquefiers to cover the liquid helium storage losses during the future long shut-downs of about a year long.

Efforts within the cryogenic teams and via coordination with other groups at CERN allowed minimizing the helium losses during the leak test campaigns and preparation phase towards restart of the LHC. Once in nominal operating conditions, the method described in this paper will be used to rapidly evaluate and restore minimum helium losses. Based on tools and experience, the symbolic threshold of 10% of the total inventory per year has been set as a tentative goal.

The approach presented is site independent and could be applied to other large scale systems willing to consider helium management with a high degree of performance.

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