WHO OPERATES CRYOGENICS?

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Abstract
Cryogenics systems are strategic components of superconducting accelerators. To ensure the requested quality of this service the organization of the cryogenic operation must be well incorporated into the global operation policy. This paper aims to define the constraints of the cryogenic operation induced by the cryogenic system itself, and by the interference to other systems. The skills of the operation crew are reviewed and some typical operation activities presented. As the operation of such large systems requires a complex organization with maintenance and cryogenic expert teams, several operational structures will be exposed showing their respective advantages and drawbacks.

1. INTRODUCTION TO A LARGE CRYOGENIC SYSTEM: LHC MAIN RING CRYOGENICS

Eight large cryoplants (Fig. 1) will produce refrigeration for the LHC ring. Each plant normally supplies a whole LHC machine sector of about 3.3 km length via a separate cryogenic distribution line (QRL), with interconnections at every basic machine cell length of 107 meters within the arc.

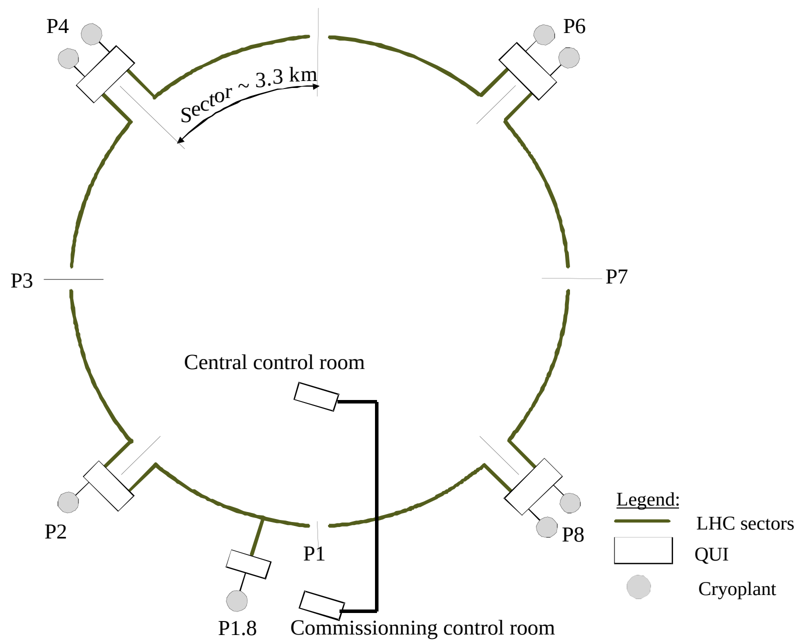

Fig. 1: LHC cryogenic system

The cryogenic system is separated in four distinct entities (Fig. 1). A typical entity is made of (Fig. 1) two cryoplants linked to the distributed cryogenic load located inside the LHC tunnel via a cryogenic interconnection box (QUI) located at a LHC access point (IP).

The 4.5K and 1.8K helium refrigerators constitute a cryoplant and are the main components of the production system. They are delivered and commissionned by industry and integrated by CERN into the cryogenic system of LHC. Figure 2 presents the different components of this system and their interconnections.

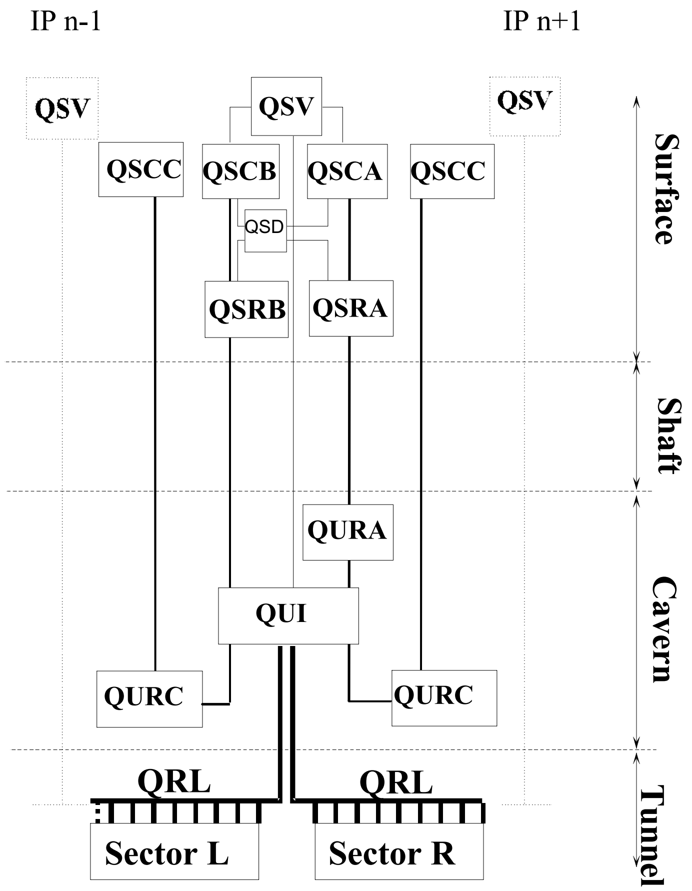

Fig. 2: Typical LHC cryogenic system at one interaction point

The following sets of components constitute a refrigerator and are considered as autonomous cryogenic units: {QSCA, QSRA, QURA} and {QSCB,QSRB}for the 4.5K refrigerator A and B; {QSCC,QURC} for the 1.8K refrigerator; {QUI, QSD, QSV} are the interconnection boxes, the liquid nitrogen storage and the gaseous helium storage connected to the cryoplants.

There is a right (R) and a left (L) hand sector around each refrigeration system,. A sector is composed of different sections namely a regular arc, dispersion suppressors (DS) and long straight sections (LSS) (Fig. 3). The load, per sector, is the QRL, the superconducting magnets, two electrical feed boxes (DFB) controlling the cooling of the magnet current leads, superconducting cavities (at IP4 only) and other cryogenic equipment installed in the long straight sections located near the access points.

The cryogenic equipment installed in the tunnel is fed with helium from the QRL via so-called service modules. About 70% of the cryogenic element are the 107 meters long regular machine cells consisting each of 8 superconducting magnets and their associated QRL and service module. They are 23 such cells and four smaller cells per sector.

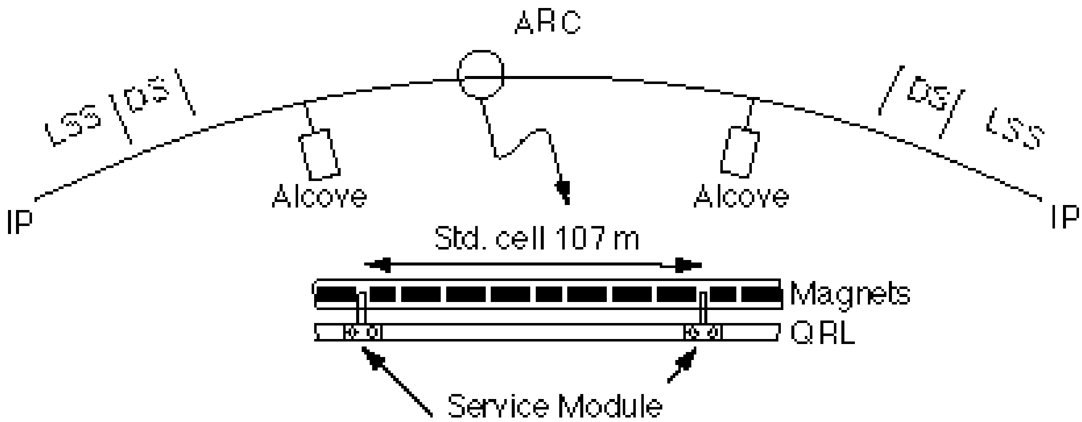

Fig. 3: LHC sector

2. HOW CRYOGENICS INTERACTS WITH OTHER SYSTEMS

2.1 Dependence on utilities (Water, Power, Air, Control)

These utilities are vital for the cryogenic system. They are developed and maintained by dedicated technical groups and a technical control team monitors them. The knowledge of the cryogenic operator about the interface and the nature of the dependence on these systems is fundamental to develop recovery procedures.

2.2 Interaction with other components of the accelerator

Despite of its status of 'service' the cryogenic system will interact strongly with other components of the LHC. These interactions are not just a binary information exchange but reciprocal physical influences (Fig. 4).

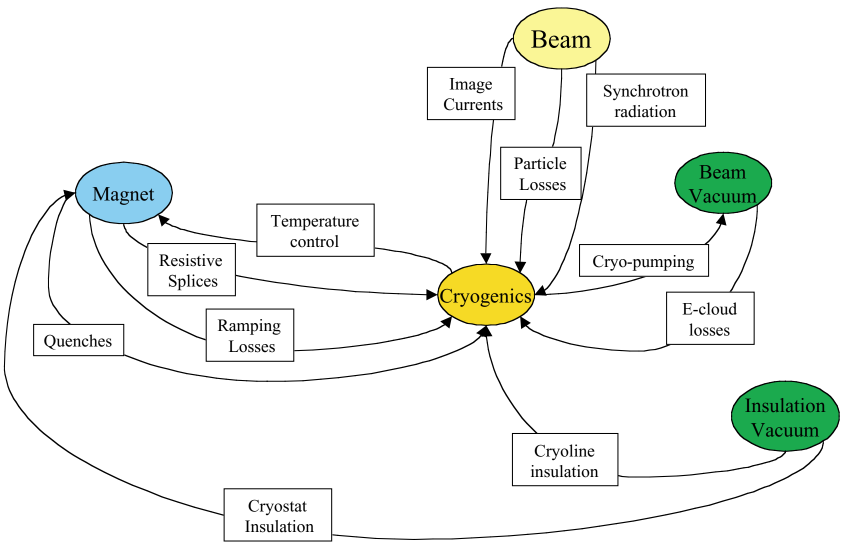

Fig. 4: Interactions with other accelerator components

2.2.1 Vacuum system

Variations of the temperature level in the QRL or in the magnets will induce outgasing in the vacuum system either in the insulation jacket or in the beam pipe depending where the variation is located. The vacuum degradation in the insulation jacket may lead to a large increase of the thermal losses overloading the capacity of the cryogenic system, limit the maximum beam energy and in extreme cases induce a quench. Degradation of the beam vacuum will shorten the beam lifetime and increase the beam losses.

2.2.2 Magnets

The field quality in superconducting magnets depends on the stability of the temperature control in the cold mass. If the temperature drifts out of the superconducting limit 10 mK above the working point, quenches will be induced leading to a beam dump.

2.2.3 Beam

In the previous paragraphs we have seen that the cryogenic system may affect the beam through the vacuum and the magnet. Reciprocally the beams will also have large impact on the cryogenic system. The beam losses in a cold mass may locally overheat the magnet inducing quenches. In normal operation the beam heat load will vary by a factor of 10 within an inner triplet which will impose the use of feed forward loops to avoid step functions in the cryogenic system

3. WHAT MEANS CRYOGENIC OPERATION?

To introduce the different skills developed by the cryogenic operation team, this chapter will review several aspects of typical cryogenic operation tasks.

3.1 Operation without beam

3.1.1 Cool down

This operation will follow the annual technical shutdown. Before start of the cooldown the operation team must complete a checkout of the cryogenic system in collaboration with the maintenance team. This checkout will review the applied maintenance procedure and verify weather each component (mechanical, electrical, control,…) is in operation mode.

Once the checkout completed the production system may start. Then the cooling capacity of the cryoplants can be checked as well as the cryogenic distribution line to avoid the warm up of a entire sector in case of problems.

The cooldown of LHC cryogenic components will last 11 days. During this time the operation team will closely observe the temperature trends, evaluate and correct deviations, identify malfunctions and abnormal heat losses. The operation team will also have to manage the logistics for LN2 and LHe supply delivered to the site by several lorries per day.

3.1.2 Quench recovery

Quenches are considered as normal events in a superconducting machine (1 per week at HERA during the first years of operation). Depending on the extension of a quench (from 1 to 4 cells) the recovery time will last between 3 to 10 hours. It is foreseen to have an automatic quench recovery procedure as it was the case for the LEP quadrupoles. But the operators may reduce the recovery time and the impact of such events by acting on the power capacity of the refrigerators or by giving priorities adapted to the request of the beam operation team.

In addition the cryogenics operators must closely cooperate with the beam operation team to reduce the number of quenches.

3.1.3 Recovery after utilities or cryogenic failures

These events are common in cryogenic operation (four times per cryoplant and year for LEP2). In order to improve the recovery time and the operation efficiency the cryogenic operator will have to:

- Identify the failure
- Cooperate with the utility operation to take the actions reducing the downtime to the minimum (for utility failure)
- Solve the problem by the intervention of the operator himself or requesting the intervention of the cryogenic maintenance team for major cryogenic failures
- Restart the cryogenic system as fast as possible. The cryogenic system acts as a downtime amplifier and the expected downtime for LHC will be 6 hours + 3* (time of the stop duration).
- Report all actions and important issues to prevent new occurrence of identical trouble.

In case of a main (400 kV) power cut, the eight cryoplants will be stopped. One expects that, even with a fully automatic control system, one operator per cryoplant is needed to guaranty a rapid restart. During LEP operation it was noted than after a long period of running at a stable working point such a brutal event has often consequences on minor components of a cryoplant which may impose a restart under degraded conditions.

3.2 Operation with beam

While the accelerator is working with beam, the cryogenic operation team will monitor and optimize the cooling capacity to:

- Improve the stability of the physical cold mass parameters, as a very tight temperature margin (+/–5 mK) has to be guaranteed
- Tune all control parameter to reject any perturbations.
- Check if the temperatures remain within the operational margin to detect and correct malfunctions.
- Reduce the power consumption. (5.5 MW per sector of electrical consumption at nominal)

4. WHO IS IN CHARGE OF THE CRYOGENIC OPERATION?

According to the tasks described in Chapter 4 we can summarize the skills of the operators as follow:

- Understand the cryogenic environment (utilities, control, etc.)
- Understand the interaction with other systems
- Understand the cryogenic system behavior
- Be able to monitor and correct the system with beam operation
- Work out the beam operation period
- Be able to deal with the cryogenic hardware
- Be able to cooperate with the maintenance team

It appears clearly that the creation of a cryogenic operation structure is mandatory.

4.1 The cryogenic operation structure

Figure 5 presents a possible structure for the cryogenic operation:

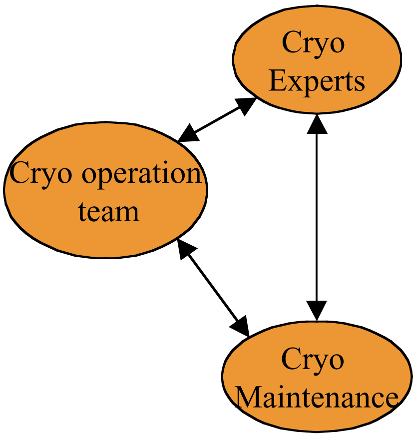

Fig. 5: Cryogenics operation structure

The cryogenic operation team will be in charge of monitoring and optimizing the cryogenic system and the operational procedures for interventions and recovery. It will be the first line intervention on failure. Finally it will coordinate the maintenance and upgrade work with the accelerator operation needs.

The cryogenic expert team is constituted of specialists for the different aspects of the cryogenic system (refrigerators, compressors, process, controls, mechanics, …). This team will support the operation team for optimization and will develop upgrades for continuous improvement of the system. The task of this team is essential for the first years of operation.

The cryogenics maintenance & support teams constitute the second line intervention in case of major failures. They will have to manage all maintenance work with the feedback of the operation team. Moreover these teams will have to implement modifications proposed by the expert team mainly at the beginning of the operation or for later upgrades.

5. INTEGRATION SCENARII

There are several possibilities to integrate the cryogenic operation team in the global operation policy. We consider that the cryogenic expert team and the cryogenic maintenance team shall exist in all cases. Possible solutions with their advantages and drawbacks are presented below.

5.1 Independent cryogenic operation team

The intuitive solution is to create a cryogenic operation team independent of the existing teams for accelerator operation and technical monitoring in charge of the utilities survey.

In this case the cryogenic expertise may be partly incorporated in the operation team. This team will be very efficient in developing better cryogenic operation procedures and will be able to optimize the operation in a shorter time.

The day to day organization will be easier and dedicated to cryogenics and will permit the integration of the operation of other cryogenic systems of the laboratory.

The treatment of the interaction of cryogenics with other components will, however, require a close collaboration with the accelerator operation team which may imply a certain geographical proximity of the teams.

Shift operation will probably be needed for the startup of a machine such as LHC. This will imply a large crew which has to be found in accordance with the human resource policy of the laboratory.

5.2 Integration in the accelerator operation team

In this case the operation of the cryogenic system will be done by the accelerator operation crew.

The advantage is a better coupling between the cryogenic and accelerator operation. All interaction between the cryogenic system and others are mastered by the team. This team can easily develop strategies to limit their impact on the machine behavior.

In addition, cryogenic operation and accelerator operation are sharing human resources.

As the background of the two teams is rather different, an acculturation of the accelerator team to cryogenic problems is needed. For this reason the team will request a stronger expert support during recovery and degraded operation and will mainly depends of the cryogenic expert to establish the procedure, to optimize the cryogenic system and to interact with the maintenance team.

The cryogenic operation is often scheduled out of the normal accelerator operation.

5.3 Integration in a technical monitoring team

In this case the team in charge of monitoring utilities also performs the cryogenic operation.

The first benefit of such a solution will be the good coupling with other technical services, which will imply a better coordination for intervention on utilities reducing the recovery time for such events. The operators' skills and background are quite similar and the training to operate cryogenic systems will be straightforward. In addition, this team will be in direct contact with the accelerator which will be an asset to its motivation and the resources will be shared.

However, as the operators will have many systems to monitor, less attention will be given to the cryogenic system and some degradation may not be recognized. In this case a strong cryogenic expert support will be needed to optimize the cryogenic system. To handle the interaction with other systems, the cooperation will have to include the accelerator team and the cryogenics experts.

5.4 Outsourcing to industry

To face the shortage in human resources, cryogenic operation may be partly or totality outsourced. The problem is to decide what is strategic in the cryogenic operation and cannot be outsourced.

If the operation team is outsourced, the cryogenics will be disconnected from the other operation teams which will imply a strong cryogenics expert support, and an operation interface team which coordinates the activities. With the time the operation expertise may be lost and a strong dependence on the external subcontractor will be created.

Outsourcing should not mean hiring missing staff but procuring a service and the quality estimators of this service are very difficult to establish. Outsourcing of the maintenance is probably easier to follow, as the work can be well defined and controlled by means of a maintenance plan.

6. CONCLUSION

The integration of the cryogenic operation team into the global operational policy must be addressed with caution, and be adapted to the nature of this operation, the human resources and the financial constraints.

The operational structure may change during the lifetime of the accelerator, starting with a strong and dedicated cryogenic operation team and later-on joining other operation teams.

As Cryogenic Operation is a strategic component of a superconducting accelerator such as LHC, the outsourcing of the cryogenic operation is a managerial and political decision which has to be weighted.

7. ACKNOWLEDGEMENTS

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