CRYOGENICS SYSTEM: STRATEGY TO ACHIEVE NOMINAL PERFORMANCE AND RELIABLE OPERATION

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Abstract

During the LHC operation in 2010 and 2011, the cryogenic system has achieved an availability level fulfilling the overall requirement. To reach this level, the cryogenic system has profited like many other beam-dependent systems from the reduced beam parameters. Therefore, impacts of some failures occurred during the LHC operation were mitigated by using the overcapacity margin, the existing built-in redundancy in between adjacent sector cryogenic plants and the “cannibalization” of spares on two idle cryogenic plants. These two first years of operation were also crucial to identify the weaknesses of the present cryogenic maintenance plan and new issues like SEUs. After the LS1, nominal beam parameters are expected and the mitigated measures will be less effective or not applicable at all. Consequently, a consolidation plan to improve the MTBF and the MTTR of the LHC cryogenic system is under definition. Concerning shutdown periods, the present cryogenic sectorization imposes some restrictions in the type of interventions (e.g. cryo-magnet removal) which can be done without affecting the operating conditions of the adjacent sector. This creates additional constrains and possible extra down-time in the schedule of the shutdowns including the hardware commissioning.

This presentation focuses on the consolidation plan foreseen during the LS1 [1] to improve the performance of the LHC cryogenic system in terms of availability and sectorization [2].

INTRODUCTION

During the LS1, the main constraint will be the available resources to perform the identified consolidations. Consequently the proposed strategy is based on first to recover the nominal performance of the cryogenic system including the safety aspects for personnel, hardware and helium inventory; and secondly to improve the reliability and the availability of the system.

RECOVERY OF NOMINAL PERFORMANCE

Safety first

Some safety issues were identified during the first operation period and mitigation measures have been taken to allow safe LHC operation. During LS1, consolidations are needed to recover the required level of safety compatible with the LHC operation at nominal condition.

Concerning safety related to personnel, collectors have to be added on the safety valves protecting the inner triplet vacuum enclosure. In case of helium release in the vacuum enclosure, the discharge flow is collected and discharged after the evacuation door allowing personnel evacuation without crossing a cold helium jam. Some deflectors must also be added on DFB access-door safety valves to avoid direct helium jet in the tunnel transport area. Personnel access to equipment located behind the LHC machine (QRL, cable trays…) is presently difficult and risky both for personnel and hardware. Access platforms are consequently required. The sectorization of the helium ring line is also highly recommended to reduce the risks of oxygen deficiency hazard and helium inventory loss. Following the 2008 incident, the periodic monitoring of the tunnel ventilation conditions (temperature, pressure and air speed) is recommended.

Concerning safety related to equipment, the completion of the insulation vacuum enclosure protection must be performed on 3.5 sectors; this includes DN200 safety valves on the cryo-magnets as well as DN240 safety valves on the DFB access-doors. In addition, temporary safety devices must be replaced by final design safety valves. The protection of the beam vacuum pipes must also be consolidated by adding periodic rupture disks.

To complete the safety chapter, the quench lines at the odd points must be consolidated. Today, these lines are not conformed and are consigned with a risk of large helium losses in case of massive magnet quenches.

Table 1: Hardware consolidations for nominal performance recovery

Consolidations	Present limitations	
	Steady-state	Transient
DFBA Splices	X	
DFBA flexible hoses		X
DFBX current-lead controls	X	
Inner-triplet copper braids	X	X
Y lines	X	X
Leaks (in S3-4, S4-5, P8…)	X	X
Beam screen circuit (Q6R5)	X	
Instrumentation NC		X
Standalone magnet and DBF cooling limitation	X	X
Leaks in LN2 pre-coolers	X	X

Hardware consolidation

In the present configuration, some equipment needs consolidation in order to fulfil the nominal condition requirements. Table 1 gives the list of these required consolidations and points out the present limitations.

RELIABILITY AND AVAILABILITY IMPROVEMENT

Cryogenic failure/stop statistics

Figure 1 shows the statistics concerning failures and stops during 2010 and 2011.

As no SEU failures were present in 2010, we can notice an important reduction of short and medium stops in 2011 as well as a stable number of long stops. Concerning SEUs affecting the cryogenic systems, temporarily consolidations are deployed during the present Xmas stop. Less than 1/3 of short and long stops have direct cryogenic cause.

Concerning beam dumps induced by the cryogenic system, half of the short stops (including the SEUs) have generated beam dumps.

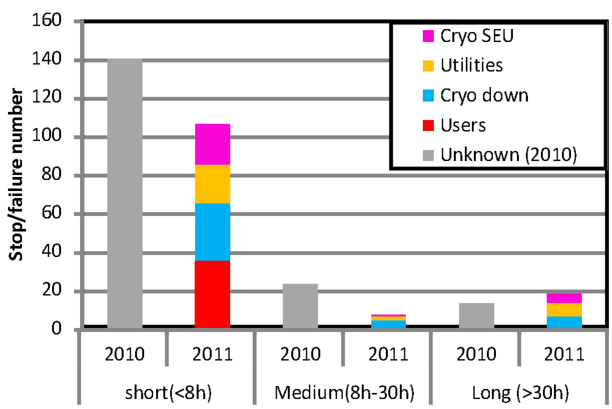


Figure 1: Cryogenic failures and stops.

Table 2 gives the 10 medium and long cryogenic failures which have occurred in 2011. Mitigation actions have already been taken for most of them except for two failures which are in accordance with the foreseen MTBF data.

In 2011, some cryogenic near-miss failures have also been recorded. Table 3 gives the list of these near-misses. Additional long stops have been avoided by sharing the cryogenic operation and refrigeration loads in-between sector cryogenic plants or by cannibalizing components on plants which are voluntarily stopped because of the reduced operation beam parameters. Some actions have been taken to solve the problems for the 2012 operation run. Some near-misses can still appear in 2012 but the 2011 mitigations will be still applicable. After the LS1, shared operation will be no longer possible and a new spare strategy for warm screw compressors must be approved and implemented to reduce the downtime of the cryogenic system in case of major compressor failures.

Table 2: 2011 medium and long stops

Point	Date	Equipment	Origin	Action / Decision	Treated for	
					2012	> LS1
P2	26 Apr	Cold compressor magnetic bearings	Old card type on pre-series	Cards upgraded after failure	Yes	Yes
P4	18 Aug	Cold compressor	Lost of instrumentation with diagnostic issue	TT replaced, new diagnostic and degraded restart procedures	Yes	Yes
P4	16 Nov	Cold compressor frequency drive	CC4 power card 1st error	Systematic HW exchange every 10 y	No	Yes
P4	20 Nov	Cold compressor frequency drive	CC4 power card 2nd error	Systematic preventive renewal	Yes	Yes
P4	28 Nov	Super-conducting link	Common vacuum of the DSLC with a DFBLC heater vacuum	Separation of vacua per type	Yes	Yes
P8	13 May	PLC (4.5 K plant)	PLC 1st crash	Considered as "normal" MTBF (1/y)	No	No
P8	25 May	PLC (4.5 K plant)	PLC 2nd crash	Crashed PLC CPU systematic replacement by now	Yes	Yes
P8	18 Jun	Screw compressor	Early bearing damage due to balancing piston depressurization	Consolidation done during Xmas'11 stop	Yes	Yes
P8	13 Aug	Cold compressor	Hard landing of CC4 rotor	New procedure to shorter the recovery time	Yes	Yes
P8	1 Nov	Oil valve positioner	Positioner failure	Considered as "normal" MTBF (1/y)	No	No

Table 3: 2011 near-miss failures

Point	Equipment	Origin	Action / Decision	Treated for	
				2012	> LS1
P2	Screw compressor	Compressor failure	**Shared operation** P18/P2	No, but*	Yes, if**
P2	Valve bellows	Big leak on a valve bellows (Ex-LEP)	**Cannibalization** of components on the P8 stopped plant Consolidation budget for LS1	No, but*	Yes
P2	Cold compressor electronics	Electronic card failure	**Cannibalization** of components on the P6 stopped plant Additional spare ordered	Yes	Yes
P4	Screw compressor	Compressor failure	**Shared operation** with adjacent plant	No, but*	Yes, if**
P4	Cold compressor electronics	Electronic card failure	**Cannibalization** of components on the P8 stopped plant Additional spare ordered	Yes	Yes
P8	Screw compressor	Compressor failure	**Shared operation** with adjacent plant	No, but*	Yes, if**

*: No, but 2011 mitigation measures still possible

**: Yes, if new spare strategy for compressors approved and implemented

Hardware consolidation for availability improvement

Table 4 lists the hardware consolidations to improve the availability of the cryogenic system. It is recommended to perform during LS1 all improvements related to steady-state operation

Table 4: Hardware consolidations for availability improvement

Consolidations	**Improvement**	
	Steady-state	**Transient**
Maintenance and major overhauling	X	X
SEU consolidation	X	
Stand-alone magnet level capillaries	X	
DFBAO & DFBMJ instabilities	X	X
Line B mixing chamber in QUI		X
Quench valve controls for fast cool-down improvement		X
New CV241 QURC IHI Linde		X
Ex-LEP Cryo-valve consolidation	X	
Cryoplant configuration for cool-down (bypass)		X
Dryers for ATLAS (MR) and CMS	X	

Spares and redundancies for availability improvement

Proposals for spares and redundancies for improving the availability of the cryogenic system are given in Table 5.

Table 5: Spares, redundancies and upgrades for availability improvement

Proposals	**Status**
Spare strategy (hot vs stored)	
Warm compressors (LHC and its detectors)	S
Electrical motors (LHC and its detectors)	N
Special electronic equipment (PLC, VFD…)	N
Turbines, Cold compressors	Done
Redundancy	
Better sharing of HP-MP-BP flows	N
2 cryoplants with one 1.8 K refrigeration unit	Done
24 V electrical supply redundancy	N

S: under Study, N: Not planned

Spare strategy for warm compressor requires long procurement process and consequently needs urgent approval.

Concerning the LHC detectors, ATLAS and CMS, there is presently no available spare; however, some extra-capacity is present in the ATLAS boosters. During the Xmas'11 stop, a hot spare is being installed for ATLAS HP compression stage. In May'12, 2 new stored spares will be delivered for CMS (1 booster plus 1 HP stage already ordered). During the LS1, a hot-spare booster will be installed for ATLAS (already ordered) as well as 2 hot-spare skids for CMS (0.6 MCHF).

Concerning the 4.5 K refrigerators of the LHC machine, the warm compressor stations at Points 4, 6 and 8 have enough extra-capacity to guarantee the required nominal volumetric flow in the case of major failure of the biggest HP and/or booster machine partially compensated by the use of LN2 precooling to save HP flow (LN2 consumption compensated by electrical power saving but logistics to be reliable). To improve the capacity sharing between the compressor stations, the plant LP, MP, HP by-passes have to be reviewed. At Point 2, a volumetric flow of about 2000 m^3/h will be missing (even with LN2 precooling) for the HP stage. At Point 18, volumetric flows of 1500 m^3/h and 1050 m^3/h will be respectively missing for the HP and the booster compression stages. Consequently, to guarantee nominal operation with minor MTTR (~1 day), hot spares is recommended at Point 18 (2 hot spares) and at Point 2 (1 hot spare). To complete the spare strategy, stored spares is recommended for the Points 4, 6 and 8. However, Stal spares are not available any longer on the market (repair and major overhauling still possible) and space for the hot spare at P2 is not available.

Figure 2 shows the present warm compressor station for the 5 Points. Figure 3 shows the proposed consolidation with the following hypotheses:

- 2 new hot spares (h) at Point 18 (~1 MCHF)
- 1 new hot spare (h) at Point 2 (~ 0.5 MCHF)
- 4 new compressor skids at Point 2 to recover 6 Stal motor-compressors as stored spares and to free the space for the hot spare installation. (~2 MCHF)
- 1 new compressor skid at point 4 to recover 2 Stal motor-compressors as stored spares. (~0.5 MCHF)
- Add stored spares for the new compressors and for the missing Aerzen type (red type) (~0.9 MCHF).

The proposed configuration is compatible with a storage availability better than 90 %. For a storage availability higher that 97 %, a new compressor skid and a new compressor spare will be required (~0.8 MCHF).

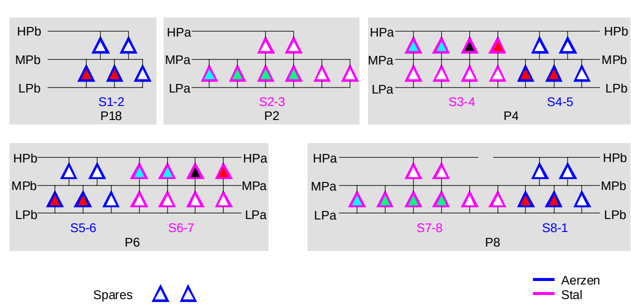


Figure 2: Present configuration of compressor stations of the LHC 4.5 K refrigerators

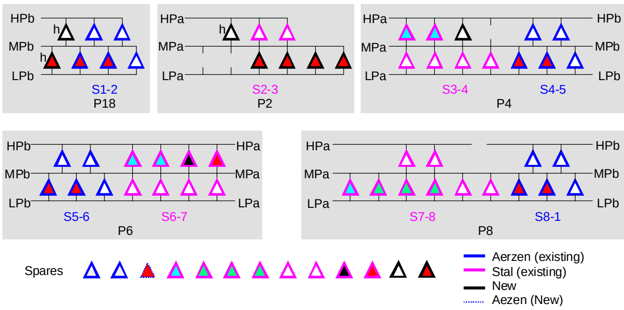


Figure 3: Proposed configuration of compressor stations of the LHC 4.5 K refrigerators

Concerning the LHC 1.8 K refrigeration units, the sum of the expected nominal 1.9 K refrigeration on two adjacent sectors is below the installed capacity of a single unit. Consequently, except for P2 (sector 2-3) where no back-up unit is existing, the present configuration offers already some redundancy. Figure 4 shows the present and the proposed configuration compatible with a MTTR of about 1 day with the following hypotheses:

- 1 new Keaser hot spare (h) at Point 2 (~ 0.5 MCHF)
- 1 new Mycom stored spare (~0.5 MCHF).

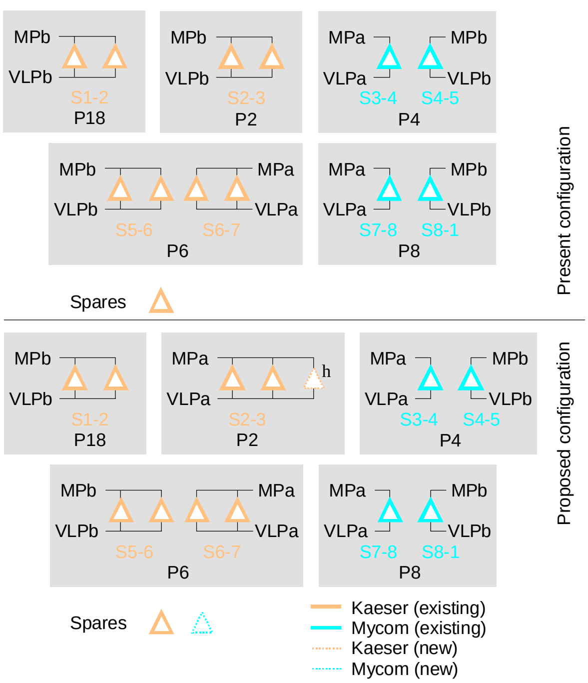


Figure 4: Present and proposed configuration of compressor stations of the LHC 1.8 K refrigeration units

In total, for LHC and its detectors, depending on the required storage availability (90 or 97 %), 7 to 8 MCHF are required to complete the present approved configuration scheme. This includes ~1.5 MCHF of non-competitive tendering, ~0.6 MCHF on Team budget (CMS) as well as new storage area (~100 m^2) for stored spares. This consolidation will require as well contribution from EN-EL and EN-ICE.

Upgrade for availability improvement

Proposals for upgrades for improving the availability of the cryogenic system are given in Table 6.

Table 6: Upgrades for availability improvement

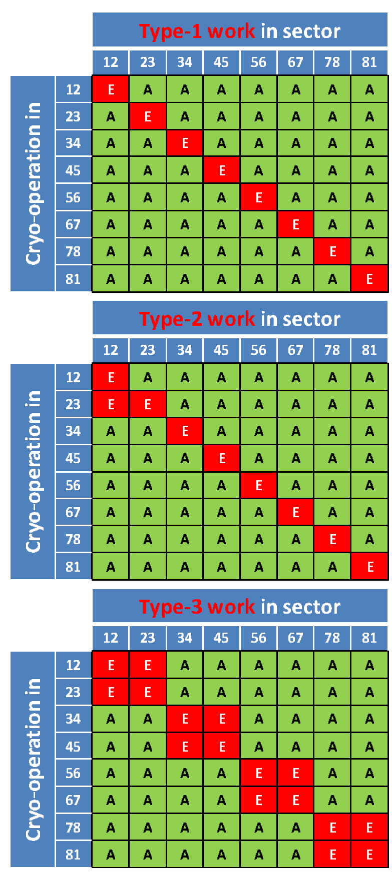
Upgrade proposals	Status
Sectorization for HWC flexibility improvement	S
LN2 for parallel cool-down	S
Robustness to power glitches	N
Interlock chain redundancy	N
ATLAS cryo-distribution	A

S: under Study, N: Not planned, A: Approved

The upgrade proposal of the sectorization in between sectors is developed hereafter. Sectorization in between sectors was already implemented during the design of the LHC cryogenic system. The level of sectorization depends of the type of works to be performed:

- Type 1 work: Opening of M lines (e.g. interconnect splice repair), of continuous cryostat cold masses (e.g. diode repair), of RF cavity cold masses, of beam pipe and W enclosure (e.g. DN200 safety valve consolidation).
- Type 2 work: Opening of QRL headers (C, D E & F), of C' lines and beam screen circuits, of standalone magnet cold masses (e.g. Q6 level capillary).
- Type 3 work: Opening of sub-atmospheric circuits (B, X, Y lines) (e.g line Y line repair or magnet removal).

Figure 5 shows the sectorization matrixes of the different types of work.



Type-1 work in sector

Cryo-operation in	12	23	34	45	56	67	78	81
12	E	A	A	A	A	A	A	A
23	A	E	A	A	A	A	A	A
34	A	A	E	A	A	A	A	A
45	A	A	A	E	A	A	A	A
56	A	A	A	A	E	A	A	A
67	A	A	A	A	A	E	A	A
78	A	A	A	A	A	A	E	A
81	A	A	A	A	A	A	A	E

Type-2 work in sector

Cryo-operation in	12	23	34	45	56	67	78	81
12	E	A	A	A	A	A	A	A
23	E	E	A	A	A	A	A	A
34	A	A	E	A	A	A	A	A
45	A	A	A	E	A	A	A	A
56	A	A	A	A	E	A	A	A
67	A	A	A	A	A	E	A	A
78	A	A	A	A	A	A	E	A
81	A	A	A	A	A	A	A	E

Type-3 work in sector

Cryo-operation in	12	23	34	45	56	67	78	81
12	E	E	A	A	A	A	A	A
23	E	E	A	A	A	A	A	A
34	A	A	E	E	A	A	A	A
45	A	A	E	E	A	A	A	A
56	A	A	A	A	E	E	A	A
67	A	A	A	A	E	E	A	A
78	A	A	A	A	A	A	E	E
81	A	A	A	A	A	A	E	E

Figure 5: present sectorization matrixes depending of work types (E: Excluded, A: Allowed)

The sectorisation is already ultimate for type 1 work, has a singularity in S12 for type-2 work (not possible to perform type-2 work in S12 in parallel with cryogenic operation in S23) and does not allow to perform type-3 work in a sector in parallel with cryogenic operation in the adjacent sector.

Adding 7 valves (DN250) on the header B in the interconnection boxes will allow to improve the sectorization for type-3 work at the same level that the present type-2 work. This upgrade will cost about 150 kCHF per valve, i.e. about 1 MCHF for the complete upgrade. To be noticed that today, no solution is existing to perform type-2 and type-3 works 3 in S12 in parallel with cryo operation in S23.

CONCLUSION

Consolidation for nominal performance recovery of cryogenics is about on tracks

Concerning the improvement of the cryogenic availability, some measures are already taken to reach in 2012 an overall cryo-availability increase from 90 % to 95 %. Direct cryo-downs (including SEU) represent 50 % of the total stops; consequently, improvement of user and utility stabilities is also important. Some long cryo-stops were avoided in 2011 thanks to cannibalization and operation sharing of non-used cryo-plants; it will be no more possible for nominal operation after LS1 and a strategy of warm compressor spares is proposed with an additional budget estimated to ~7-8 MCHF. In addition, manpower need must be consolidated.

Concerning the improvement of sectorization in-between sectors, the level of sectorization is already ultimate for type-1 work (e.g. splice/diode repair) and optimized on 7 sectors for type-2 work (e.g. intervention on standalone magnet cold masses and on beam screens). The sectorization could be improved on 7 sectors for type-3 work (e.g. Magnet removal); the corresponding cost estimate is about 1 MCHF for the interconnection box upgrade.

REFERENCES

[1] O. Pirotte *et al*, “Review of the consolidation works scheduled for the LHC cryogenic installations during a long shutdown” Chamonix 2011 LHC Performance Workshop

[2] G. Ferlin, “Decoupling of adjacent cryogenic sectors”, LHC Performance Workshop - Chamonix 2010