CRYOGENICS EXPERIENCE WITH HIGH LUMINOSITY RUNNING & FEEDFORWARD CONTROLS

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Abstract

The first part of the presentation will summarize the overall cryogenic performance and availability for 2017 and the expected performance for 2018 taking into account the beam induced heat loads in the inner triplets magnets and the beam screen circuits. The second part will focus on the update of the expected cryogenic limitations as well as on the available cryogenic power studies and associated tuning in order to deliver the required cooling power with respect to the 2018 beams operational conditions. The feedforward controls and refrigeration capacity improvements on the inner triplets and beam screen circuits will be discussed.

INTRODUCTION

The cryogenic infrastructure built around LHC ring is composed of 8 cryogenic plants supplying 8 related LHC sectors. Thanks to different intersection piping, various operation scenarios can be set for operation depending on availability of the cryogenic equipment (e.g. because of failure reasons) or optimizing for energy consumption and availability [1, 2, 3].

OVERALL CRYOGENIC PERFORMANCE AND AVAILIBILITY

During year 2017, as shown in Fig. 1, the global LHC cryogenic availability was in the range 97.9 % and the overall CRYO availability (included utilities & user fault) is in the highest range never reached (96.2%). As an example, major power failure seen in 2016 (weasel issues) do not appear in 2017.

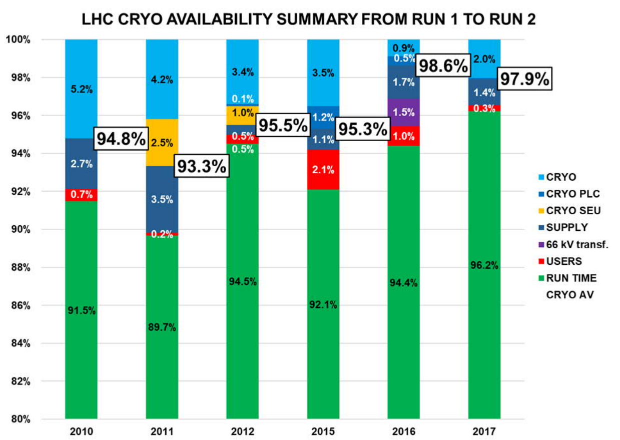

Figure 1: Cryogenic availability from Run1 to Run2

The three mains contributors from Cryo system generate 50% of the total 4.5 K Cryoplant downtime. Among these, two can be attributed to the aging effect of the components on LEP equipment (25 years old). Figure 2 shows a detail of major issues.

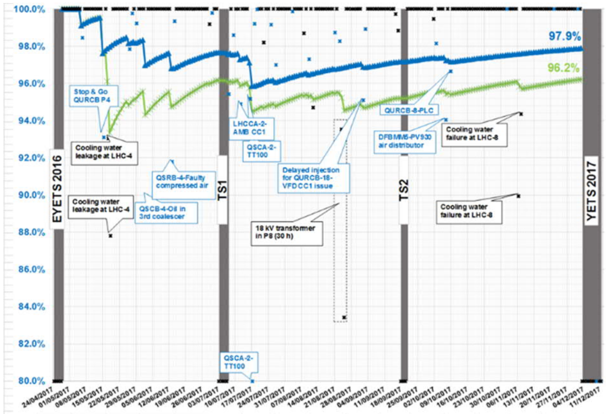

Figure 2: Cryo availability since 2017-04-28

Long term comparison

A long-term comparison of the Cryoplant breakdown (Fig. 3) shows slightly more 1.8K cryoplant stop in 2017. Main origins are filter clogging at P4 (2 times), internal signal perturbation (one time) & intervention on a hot spare unit to recover full functionality (one time).

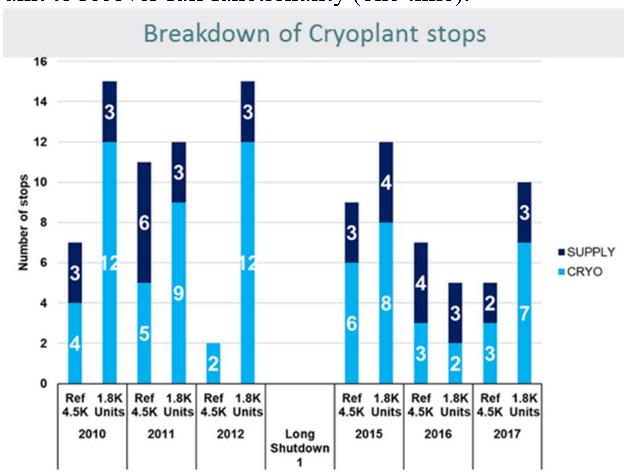

Figure 3: breakdown of cryoplants stops

As partial summary, year 2017 appears to be a good year from Cryo availability point of view but aging effect starts on former LEP cryoplant and we will have to challenge this issue in the coming years. See Table 1.

During year 2017, some incidents occurred on our equipment's. Every incident should have an impact on the global cryo availability. Thanks to our strategy, the optimization of the running equipment's to minimize the number of rotating machine in use helped a lot. None of the below reported incidents had an impact on the 2017 operation (equipment on cold stand-by mode).

- P6: Moto-compressor damaged by major fault on 3.3 kV electrical cell; Potential Stop from 0.1 to 3 days depending on the equipment.
- P8: Stop of Cold compressor unit during SVC compensator switch, 3 times in 2007; Potential Stop from 2 to 6 hours depending on the equipment.
- P6: Repetitive problem of turbine (flange leak); Potential poor supercritical helium quality generating DFB level oscillation and associated CM losses.

Table 1: Overall breakdown

	Cryo losses	Users losses	Supply losses	Total Losses
Quantity	27	9	3	39
Duration	107:20	15:26	69:28	192:14

To summarize, the run 2 availability for CRYO is in the range 97.9% to be compared with an availability of 98.6% in 2016, with a global yearly duration longer than 5000 hours as shown in Table 2.

Table 2: Run 2 Cryo Availability summary

Year	2016	2017
Due Operation duration [h]	5824	5100
Cryo losses	1.40%	2.1%
Total Cryo Downtime [h]	79	107
Cryo Availability for 8 sectors	98.60%	97.9%
Delayed injections [h]	12	0
Cryo Availability counting delays	98.40%	97.9%

Helium inventory

Concerning helium consumption, 2017 shows a significant reduction of Helium losses around LHC with operational losses in the range of 5.4 t (Fig. 4: Helium consumption from Run1 to Run 2). As usual, helium used during YETS is in the range 6.3 T. It should be noted a specific Helium consumption during purges of sector S12 about 0.6 T.

REFRIGERATION CAPACITY SUMMARY MEASURED IN 2017 AND EXPECTED FOR 2018

The maximum dynamic refrigeration capacity on beam screens is estimated at 160 W per half-cell. Four sectors were tested in their design configuration.

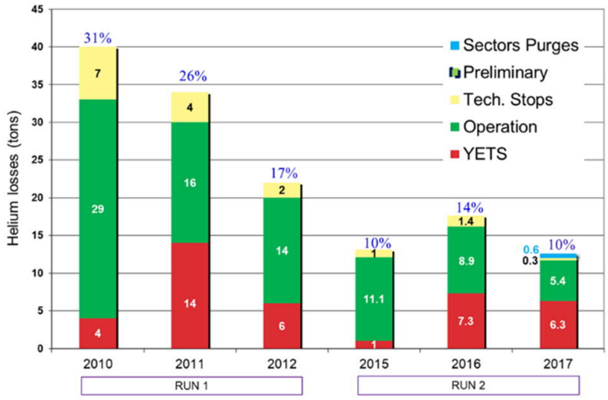

Figure 4: Helium consumption from Run1 to Run 2

Thanks to the system reconfiguration, by using one 1.8 K cryoplant per cryo/island, it was possible to spare about ~3 kW (equivalent to 20 W/hc) of cooling capacity to be added to the BS cooling power [4].

The values for their overall cooling capacity for BS is presented in Table 3. It is proposed to validate the sector S12 during the YETS2017/2018 to complete measurements for High load sectors

Table 3: Half Cell refrigeration capacity

Sector	Capacity [W/HalfCell]
S12	?
S23	195
S34	125
S45	?
S56	?
S67	?
S78	175
S81	230

During year 2017 tests were conducted, to measure the maximum amount of energy that can be extracted on the inner triplet cold masses before saturation of the exchanger, to estimate the maximum dynamic losses acceptable. AS shown in Fig. 5, measured value are 270 W +/- 10% for ITL1 & ITR1 & 255 W for ITL5 +/-10%; it was not possible to measure ITR5 for instrumentation issue. This test was revalidated during the “no levelling” run in 2017. The equivalent luminosity was in the range $2.0*10^{34}$ cm-2 s-1 stable beam with Inner triplet cold masses maintained at a temperature lower than 2.0 K.

CONTROLS AND REFRIGERATION CAPACITY IMPROVMENTS

Configuration in 2017

During year 2017, individual Feed Forward control system has been deployed in sector S81 for full-size validation. Until Beginning October 2017: all FF loop were

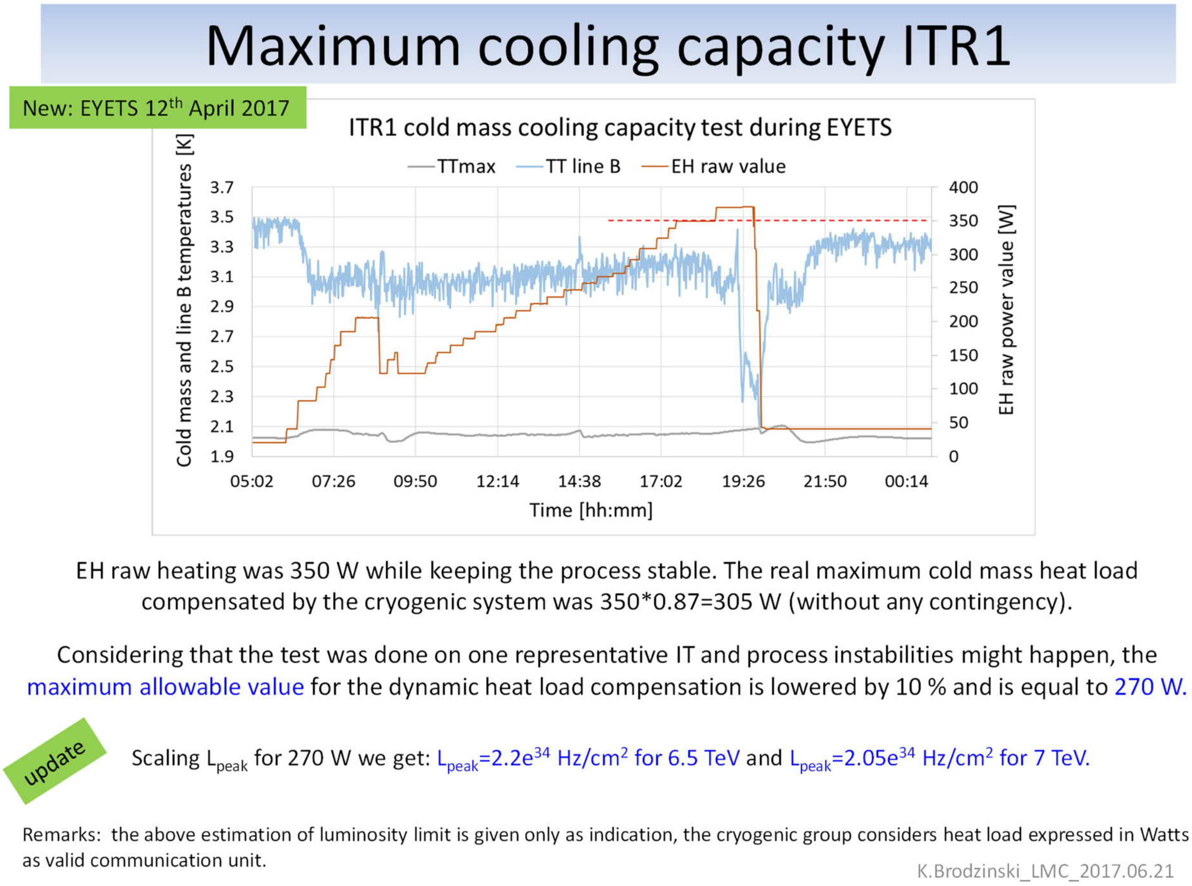

Figure 5: High load inner triplet ITR1 cooling capacity

equally tuned, then from October individual FF loop has been setup progressively.

The 3 figures (6, 7 & 8) based on comparison of 14 beam screen loops (15L1 to 27L1) during three “almost identical” fills shows respectively No FF applied, then common FF for entire sector, No e-cloud consideration applied and finally individual half-cell FF with e-cloud consideration applied.

To summarize, the individual Feed Forward control mode is efficient mainly with inhomogeneous sectors (up to 30 W/half-cell saved) because this system fits perfectly with every individual loop. Consequently, every loop is optimised whatever its thermal load level. Unfortunately, high load sectors are more homogeneous and the gain to expect from this updated regulation scheme will be less profitable.

Configuration in 2018

Taking into account measurements performed in 2017, the configuration applied for 2018 will be with an individual parametrization for all advanced regulations loops. Of course this new parametrization will be tuned during first high load runs of 2018. At least two or free similar fill will be necessary to tune and validate theses parameters for every new high load filing scheme as it was practiced in previous runs.

CONCLUSIONS

The LHC Run2 (2017) is considered as a very successful year for cryogenics with availability at 97.9% including only losses generated by cryogenics and to 96.2% including losses generated by users and supply.

New individual parametrization of Feed Forward loops has been deployed and will help after tuning to recover some cooling power margins for beam induced thermal load.

The cryogenic limitations for beam screen cope with 160 W/half-cell and simultaneously 270 W/triplet for the cold masses at 1.9 K. High load sector S12 will be validated for such level before run 2018.

ACKNOWLEDGMENT

Many thanks to all members of the cryogenic operation and support teams for their engagement and professional approach in 2017 run.

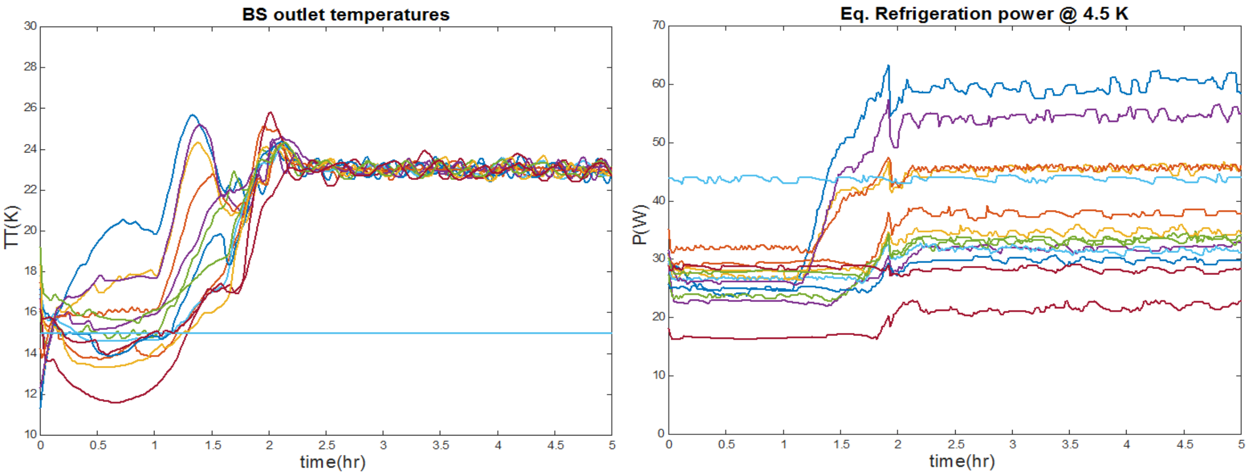

Figure 6: Fill 6240 (1916 bunches in 8b4e): No FF applied (control applied before LS1)

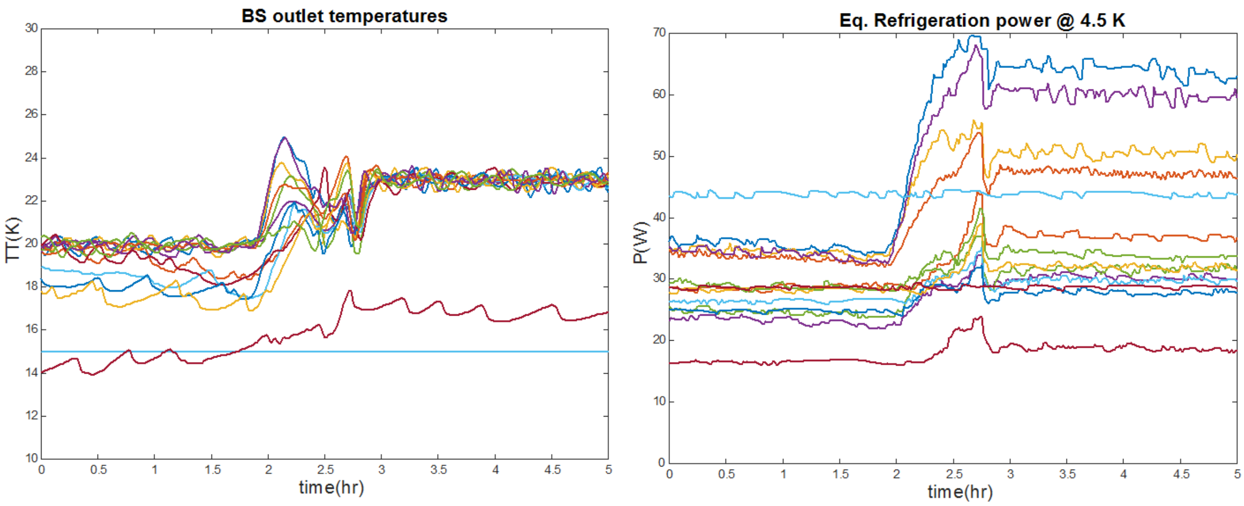

Figure 7: Fill 6245 (1916 bunches in 8b4e): Common FF for entire sector (control applied in 2017)

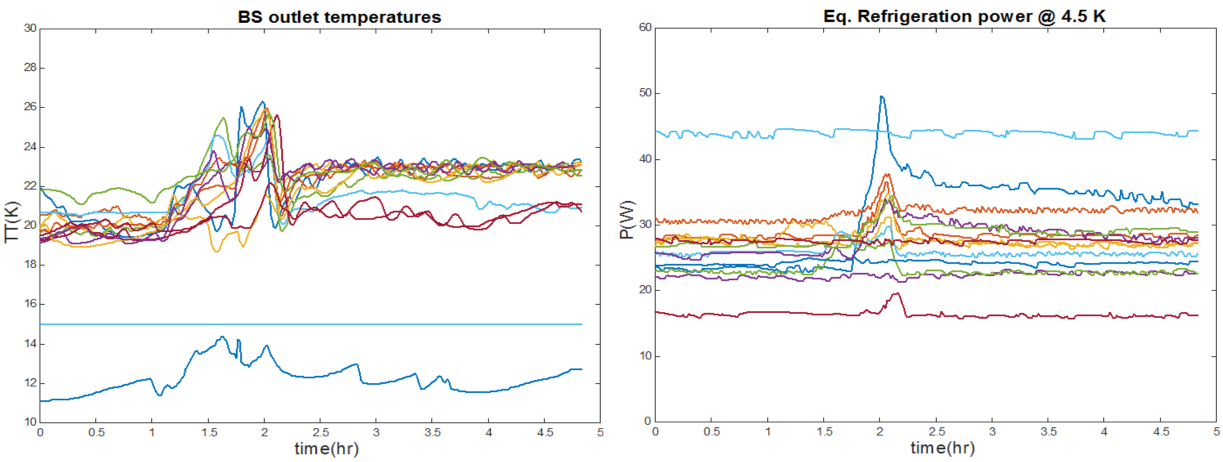

Figure 8: Fill 6276 (1868 bunches in 8b4e): Individual half-cell FF (control tested in 2017 and deployed for 2018)

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