LHC CRYOGENICS – STRATEGY, UNAVAILABILITY ROOT CAUSES AND LIMITATIONS (RUN 2016)

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Abstract

Run2 (2016) is considered as very successful year. The cryogenic availability indicated by Cryo Maintain (CM) interlock reached the level of 98.6 %. Such a good result comes from multiple factors, where operation scenario is a strategic key point for the cryogenic production plants configuration. New operation scenario, with optimization on P18/P2 cryogenic plants, was validated and set as production configuration from 25th March 2016. Helium yearly consumption was on the level of 14% of total inventory.

Consolidations and repairs applied during YETS 2015 were effective and resulted directly in improvement of cryogenic stability and availability.

Beam screen (BS) heat load was handled without particular problems thanks to optimized feed-forward logic and also by fact that beam parameters were limited by other factors than cryogenics. However, in some cases related heat load deposition was ~50% higher than values assumed for the LHC design.

Last year operation period was affected with one major failure of a helium compressor. The system reconfiguration and applied strategy for the cryogenic spare parts allowed for continuous operation of the plant and replacement of defective part during dedicated technical stop.

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]. Each operation scenario is validated with several tests before admittance for operation with physics. Figure 1 presents three operation scenarios applied for Run1, Run2 (2015) and Run2 (2016).

The LHC Run1, with beam parameters lower than nominal, allowed for LHC operation with disabled cryoplants A at P6 and P8 (see Fig.1). The cooling power for both related sectors was provided by plant B. This configuration allowed for electrical power savings over 3 years of operation between 10% and 20% with relation to the installed power.

Run2 (2015) operation scenario was put in place in order to optimize for availability of rotating machines. Thanks to lower than assumed for design heat load at 1.9 K combined with built-in capacity margin on cold compressors, three 1.8 K pumping units could be stopped and kept as hot spares in case of failures.

Run2 (2016) operation scenario was put in production from 25th March after dedicated validation test. This operation scenario completes assumed approach to run one cold pumping unit over two sectors with 4 pumping units off.

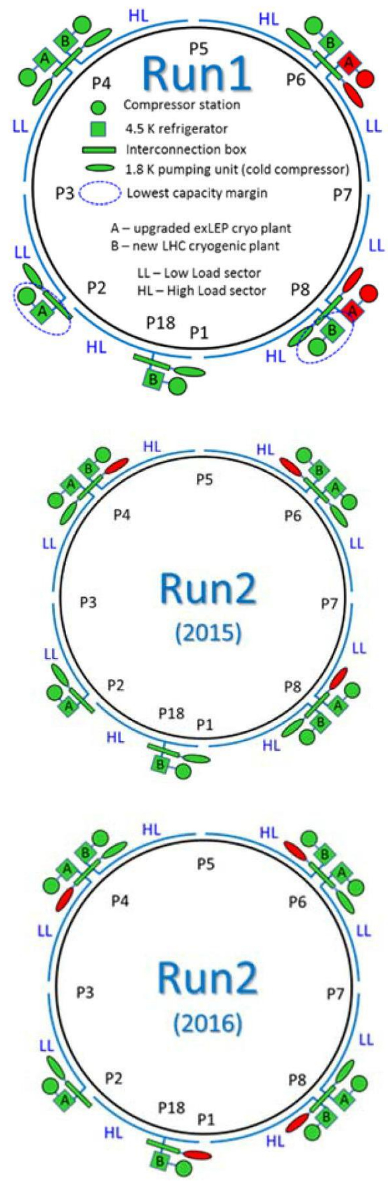

Figure 1: LHC cryogenic operation scenarios

GLOBAL CAPACITY OPTIMIZATION FOR SECTORS 2-3 AND 7-8

Sectors 2-3 and 7-8 are equipped with the same type of cryogenic plant upgraded from LEP. Experience of 2015 run shown that global capacity of these two plants shall be investigated and optimized (valid especially for sector 2-3 which is one of the most heat loaded sectors from electron cloud effect). In March 2016 two mentioned plants were tested and optimized reaching capacity limit for BS heat load compensation at the level of 10.3 kW and 9.3 kW for sectors 2-3 and 7-8 respectively (195 W/hc for s2-3 and 175 W/hc for s7-8). The limits are valid for steady state operation with reserved ~50-60 g/s of cold flow for 1.9 K refrigeration.

Adaptability of the cold boxes capacity for the heat load transients was tested with rapid increase and decrease of the heat load delivered by electrical heaters (-/+5 kW for s7-8 and -/+6 kW for s2-3 without losses of CM signal). The corresponding curves are presented in Figures 2 and 3.

Considering real dynamic behaviour of the system with beam, value of 160 W/hc is assumed as guaranteed operation limit applicable for all cryogenic plants of the LHC for next operation year.

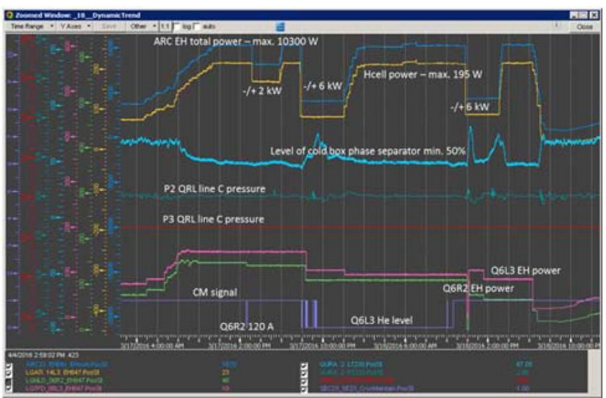

Figure 2: capacity optimization for s2-3.

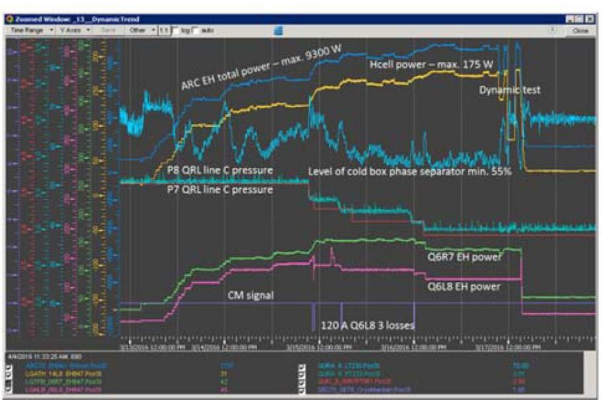

Figure 3: Capacity optimization for s7-8.

POST 2015 REPAIRS, MAIN FAILURES AND OPERATIONAL DIFFICULTIES

During YETS 2015 main cryogenic refrigerator supplying sector 8-1 (QSRB at P8) was repaired for two internal leaks. First leak concerned turbines circuits (mentioned in Evian 2015) and second one concerned Aluminium/Stainless steel transition which was repaired temporarily with special vacuum varnish (related spare part was ordered and is planned to be installed during EYETS). The performed repairs allowed for smooth operation of the cold box during whole 2016 year significantly reducing number of CM signal losses.

Main failures during 2016 concerned two warm compressors (P8 and P4) and two electrical motors for warm compressor station at P2. Additionally two PLCs controlling production plants had to be replaced because of failures.

Five RFL valves, controlling AL turbines operation were replaced. First prototypes of new technical solution to replace the RFL valves are planned to be installed for testing during EYETS.

CRYOGENIC AVAILABILITY

Similarly to LHC Run1, presented cryogenic availability is based on signal from cryo-maintain (CM) interlock and was equal to 98.6 % including only losses generated by cryogenics and to 94.4% including losses generated by users and supply. The analysed operation time window for 2016 started on 25th March and ended on 5th December (TSs were excluded for the analysis). The layout and main contributors for downtime are presented in Fig. 4. Comparison with results from Run1 is provided in Fig. 5.

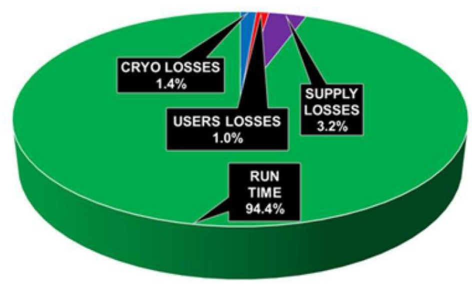

Figure 4: Cryogenic availability for 2016 run basing on CM indicator.

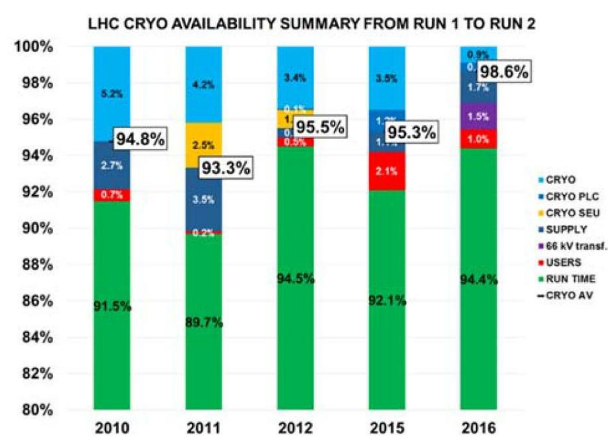

Figure 5: Cryogenic availability for Run1 and Run2.

Downtime analysis

The total time of unavailability for Run 2016 was 79h25min caused by 19 losses of CM signal.
About 60% of the down time was caused by two main contributors: production plants PLC failures and 1.8 K production plant process failures.

Figure 6 presents a layout of all contributors to the cryogenic down time in 2016.

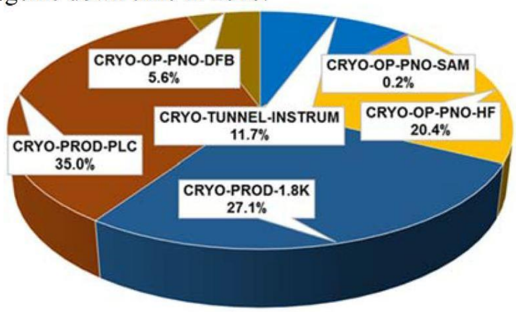

Figure 6: Cryogenic down time – contributors

The most frequent losses are attributed to DFBs liquid helium level perturbations caused by non-optimized process. However the number of CM losses was significantly reduced w.r.t. 2015 Run mainly by fact of QSRB P8 repairs and optimization of control system on related DFBs. The global view of number of CM losses is presented in Fig. 7.

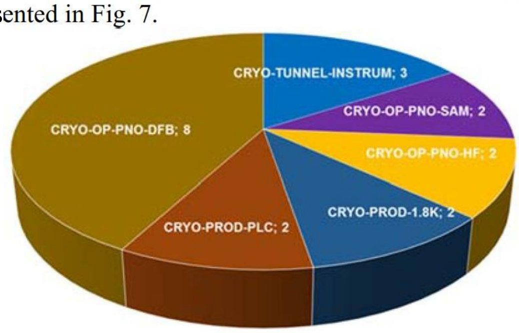

Figure 7: Number of CM losses – contributors.

The cryogenic team focuses to analyse origin and minimize both, most time consuming and most frequent losses.

Production plants availability

As shown in Fig. 6, the main contributors to the unavailability are the failures causing stops of the cryogenic production plants (4.5 K main refrigerators and 1.8 K pumping units). Such failures are very unlike because of long time constant for recovery of operation conditions. Thanks to collaboration between the cryogenic group and BE-ICS new improvements to the control system could be introduced over las years. Optimization in operation scenario which allows for stop of 4 over 8 cold pumping units resulted in statistical low down of the number of failures. Figures 8 and 9 show evolution of failures of 4.5 K refrigerators and 1.8 K pumping units respectively. Such operation scenario should be kept as long as it could compensate effectively for heat load coming from the tunnel equipment.

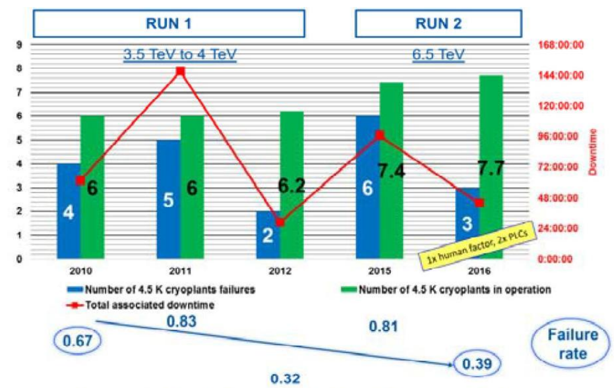

Figure 8: Statistics of 4.5 K refrigerator failures.

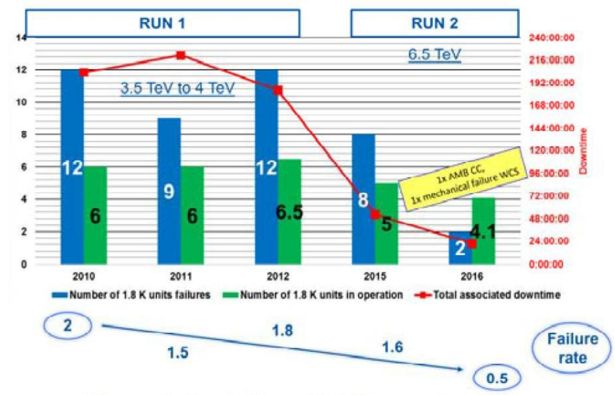

Figure 9: Statistics of 1.8 K pumping units.

Helium losses

Thanks to collective effort in the cryogenic team during Run1, LS1 and Run2 the helium loses were significantly reduced reaching level of 14% of total inventory for 2016 run. The increase of the YETS losses in 2016 relates to the fact that the machine was emptied from helium and some helium was lost during the transients and warm storage on the surface (while in 2015 YETS the helium stayed in the magnets). Additionally, significant contribution (~2.3 t) to the losses comes also from two incidents classified as an operational issues during YETS. Figure 10 presents evolution of the helium losses for Run1 and Run2.

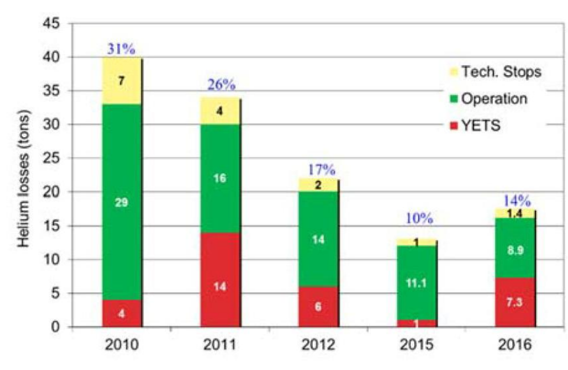

Figure 10: Helium losses evolution.

BEAM SCREEN HEAT LOAD VS COOLING CAPACITY

The handling of BS heat load during operation year of 2016 was fully under control. The distribution of the heat load in 2016 was similar to one form 2015 with four high loaded sectors and four low loaded sectors. In the first phase of operation, just after restart on the beginning of the year, the maximun loaded sector (s1-2) raised with the heat load to nearly 160 W/hc. Then cleaning effect allowed for decrease of the load and operate second half of the year at the level of 90-120 W/hc for high loaded sectors and at 40-60 W/hc for low loaded sectors. The overview on the heat load disstribution over the sectors in 2016 is presented in Fig. 11.

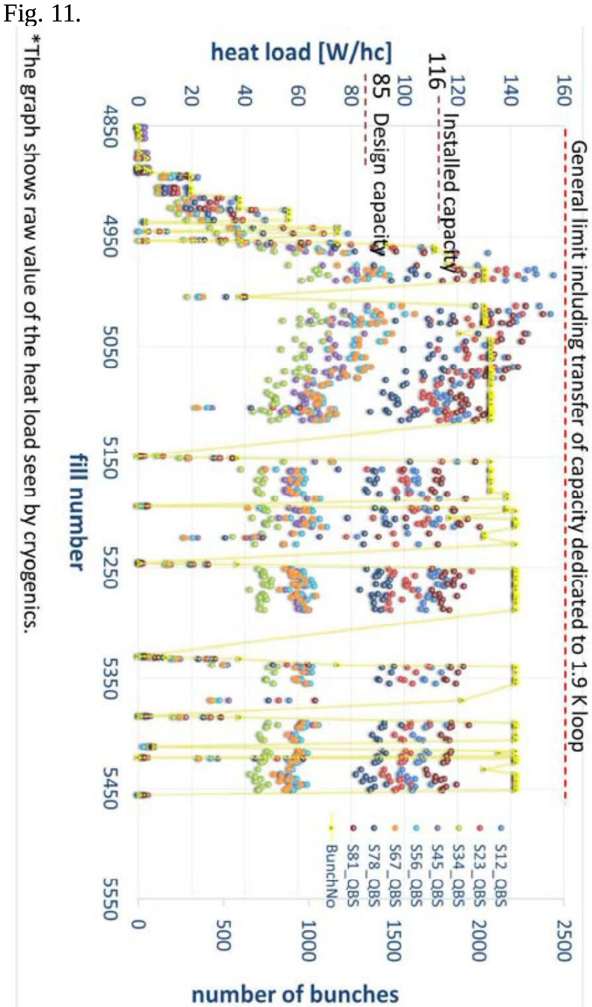

Figure 11: BS heat loads seen by cryogenics.

It is important to mention that stable operational of the BS cooling loops during 2016 was a result of multiple parameters. The main improvement applied on local control system was fead-forward logic, which could be tuned and adapted for smooth operation. The second improvement was mentioned in above section optimization of global capacity of the cryogenic plants suplying sectors 2-3 and 7-8. However, stable operation was achieved also due to the fact that beam injection scheme was limited to 72 bunches/train and injections with 144 or 288 bunches/train did not took place in 2016.

Fact of non homogenious distribution of the heat load over the sectors is still not understood. Complete warm up of sector 1-2 can give more information on the phenomenon.

EYETS PREPARATION AND MAIN ACTIVITIES

All LHC LSSs and arcs will be emptied from liquid helium and conditioned at about 30 K except of sector 1-2 which will be completely warmed up and conditioned for 31L2 dipole replacement.

During extended year end technical stop (EYETS) the following main activities will be performed on the cryogenic system:

- P8 cold box repairs – replacement of AL/SS transition
- P4 and P6 exLEP plants – installation of additional coalescers for oil separation
- PLCs upgrade – up to ~50% of all PLCs
- Replacement of charcoal in 14 adsorbers
- Installation of RFL prototype valves controlling the turbines operation parameters
- Other planned updates of software, maintenance and repairs standard activities.

CONCLUSIONS

The LHC Run2 (2016) is considered as a very successful year for cryogenics with availability at 98.6 % including only losses generated by cryogenics and to 94.4% including losses generated by users and supply. New applied configuration with 4 cold pumping units stopped was a good choice as operation scenario. Declared failures could be mitigated by reconfiguration of the system or by repairs using available spare components. Feed forward logic was optimized and successfully operated during the run. The global cryogenic capacity on sectors 2-3 and 7-8 were aligned with all other cryogenic plants at guaranteed operational values of 160 W/hc. Warm up of s1-2 will give additional information to study BS heat load generation. Cryogenic group proposes that Run2 (2017) is operated with the same scenario as 2016. The next operational challenge will be adaptation of the cryogenic capacity to cope with beam injection scheme of 144 and 288 bunches/train.

ACKNOWLEDGMENT

Many thanks to all members of the cryogenic operation and support teams for their engagement and professional approach in 2016 Run.

REFERENCES

[1] O. Bruning et al., “LHC Design Report,” Geneva, 2004.
[2] K. Brodzinski et al. “LHC cryogenics – Run2 (2015) summary and perspectives”, LHC Beam Operation Workshop – Evian 2015.