LHC ACCELERATOR FAULT TRACKER – FIRST EXPERIENCE

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Abstract

Availability is one of the key performance indicators of LHC operation, being directly correlated with integrated luminosity production. An effective tool for availability tracking is a necessity to ensure a coherent capture of fault information and relevant dependencies on operational modes and beam parameters. At the beginning of LHC Run 2 in 2015, the Accelerator Fault Tracking (AFT) tool was deployed at CERN to track faults or events affecting LHC operation. Information derived from the AFT is crucial for the identification of areas to improve LHC availability, and hence LHC physics production. For the 2015 run, the AFT has been used by members of the CERN Availability Working Group, LHC Machine coordinators and equipment owners to identify the main contributors to downtime and to understand the evolution of LHC availability throughout the year. In this paper the 2015 experience with the AFT for availability tracking is summarised and an overview of the first results as well as an outlook to future developments is given.

LHC ACCELERATOR FAULT TRACKER

The need for consistent and reliable information on accelerator availability has been under scrutiny for several years at CERN, and an Availability Working Group (AWG) was established to discuss a strategy for improvement [1]. As an outcome of the activities of the AWG, an Accelerator Fault Tracking project (AFT) for the LHC was launched at CERN in February 2014 and is managed by the Controls Group [2]. The main goal of this project is to develop a tool capable of identifying:

- When machines are not in use when they should be.
- What the causes of unplanned downtime are
- Patterns, relations between systems, operational modes, etc.

The AFT tool was released at the beginning of the 2015 LHC Run, allowing for systematic and consistent LHC fault tracking throughout the year. The initial focus of the project is on the LHC, but the developed infrastructure is able to handle any CERN accelerator. Results presented in this paper are based on data stored in the AFT.

LHC FAULT REVIEW IN 2015

In 2015, a weekly fault review using the AFT data was carried out by the core members of the Availability Working Group (AWG) to ensure high-quality data for availability studies. The review process required about 5 h per week, involving two people. The focus of the analysis is on hardware systems as well as operational performance [1], therefore the scope of the fault review process extends to all possible causes of LHC downtime, not only considering hardware faults.

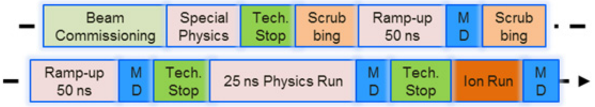

Figure 1: 2015 LHC Schedule.

The analysis presented in this paper focuses on the period from 6th April to 13th December 2015, i.e. starting from beam commissioning to the end of the LHC ion run (Fig. 1). In the reference period, 1375 causes for downtime were recorded and analysed. Where applicable, specific pre-defined attributes (e.g. 'access in the tunnel required for maintenance') were assigned to each downtime cause, to account for the effective LHC downtime and the resulting operational overheads.

In addition, the AFT allows defining relevant dependencies among different downtime causes. The most commonly observed dependency is the so-called 'parent/child relationship'. A primary downtime cause ('parent') is responsible for the occurrence of additional downtime ('child'). As an example, beam losses (parent) can lead to a magnet quench (child), which implies a quench recovery time for the cryogenic system (2nd-level child). In 2015, 90 relevant parent/child dependencies were identified and recorded.

A widely used overview of LHC Availability over a given time period, the so-called "Cardiogram of LHC Operation" (Fig. 2), can be produced via the AFT. The cardiogram provides information related to beam energy and intensity, the accelerator mode, time in collisions (i.e. 'stable beams') and system availability over time. This allows to easily correlate faults with operating conditions. Downtime associated to a given cause is indicated in red in the chart. This view was consistently used in 2015 to monitor LHC performance throughout the year.

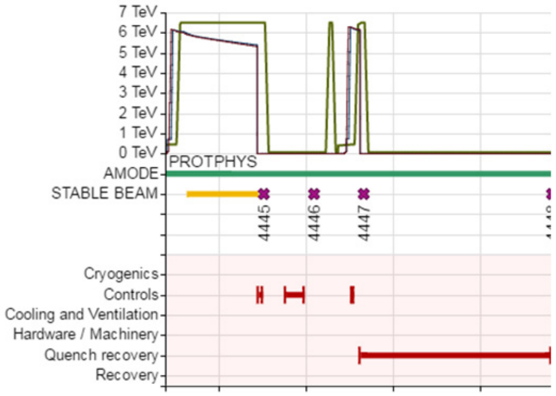

Figure 2: Example of the so-called "cardiogram" of LHC operation for the cryogenic system.

The data collected in the AFT for hardware systems has been validated and corroborated in collaboration with equipment experts at the end of the year. In 2016, thanks to the extended capabilities of the AFT tool, such validation will be carried out on a weekly basis and will be managed directly via the AFT.

2015 LHC AVAILABILITY

Using data stored and validated in the AFT database, a thorough analysis of 2015 LHC availability has been possible. Fig. 3 shows the recorded "Number of Faults" (blue) and "Downtime" in h (red) by week. The number of faults ranged from about 20 to 60 faults per week, with an associated downtime of 20 to 100 h. A detailed overview of the system downtime distributions between Technical Stops is shown in Fig. 3.a, b, c, d. As a result, LHC availability in 2015 was on average 69 %. In the period between Technical Stop 1 (TS1, week 25) and Technical Stop 2 (TS2, week 36), the availability dropped to 64 %. The downtime was mainly driven by 1) the occurrence of an earth-fault on a sextupole corrector circuit and 2) the sensitivity to radiation effects (Single Event Upsets, SEUs) of some electronic boards used in the magnet protection system (QPS mBS boards) [3]. These boards were replaced during TS2, which solved the problem with SEUs. The sextupole corrector circuit was instead condemned and has not been in use for the rest of the run. The cryogenic system was still responsible for the longest downtime in this time period, as machine scrubbing (50 ns and 25 ns) had a direct impact on the generated heat loads to be managed by the cryogenic system [4]. A 69 % availability was then recovered after TS2 and 79 % availability was reached during the ion run. As expected, the period extending up to TS2 was used to address teething problems related to hardware interventions and changes to the machine performed during the Long-Shutdown.

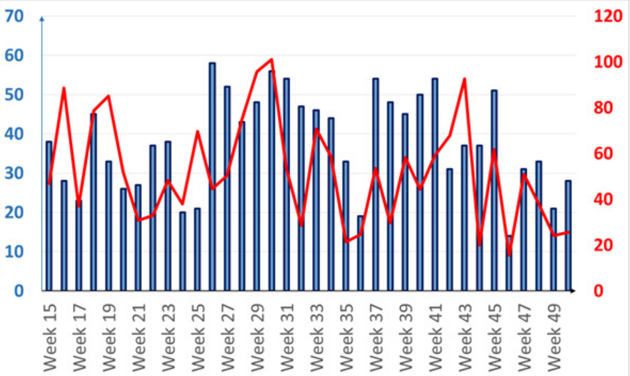

Figure 3: Number of Faults (blue) and Downtime (red) in h by week in 2015.

The downtime distributions shown in Fig.s 4.a, b, c, d account for all systems faults related to the five top contributors to downtime, even those occurring in the shadow of others, and are referred to as 'integrated' system downtime.

In the period leading up to TS1, the cryogenic system, the injector complex and the QPS were the biggest contributors to the downtime. In particular two long stops associated to the injectors had a direct impact on LHC operation: the replacement of a Linac2 HV cable and a SPS magnet replacement.

After TS2 all major hardware teething problems were solved, therefore the period between TS2 and TS3 (25 ns proton Run) is considered the reference period for the evaluation of LHC performance in view of future runs. Fig. 4.c highlights the main limitation of operation in this period coming from the performance of the cryogenic system, which is highly affected by the increasing heat loads when ramping-up the beam intensity [5].

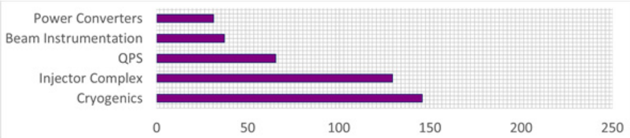

Figure 4.a: Integrated system downtime [h] before TS1 (top 5 contributors).

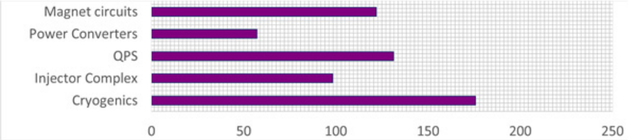

Figure 4.b: Integrated system downtime [h] between TS1 and TS2 (top 5 contributors).

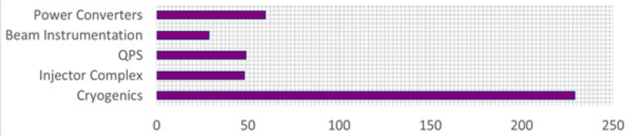

Figure 4.c: Integrated system downtime [h] between TS2 and TS3 (top 5 contributors).

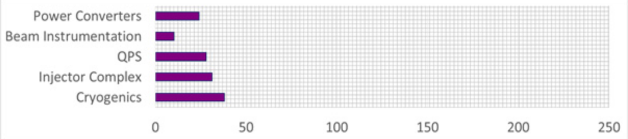

Figure 4.d: Integrated system downtime [h] after TS3 (top 5 contributors).

The system downtime distribution after TS3 (the period including the ion preparation run and the ion run) is shown in Fig. 4.d. Excellent availability (almost 80 %) was achieved in this period. In fact, thanks to the reduced heat loads during ion operation, the performance of the cryogenic system was comparable with that of the other systems leading to very high overall availability.

ANALYSIS OF 25 NS RUN

A detailed analysis of the availability during the 25 ns run has been carried out, as this is considered the most reproducible period of operation and is taken as a reference for extrapolation to future runs.

During the 25 ns run (Fig. 5), a total of 455 h was spent in stable beams, amounting to 32.7 % of the total time. The downtime amounted instead to 426 h (30.6 %).

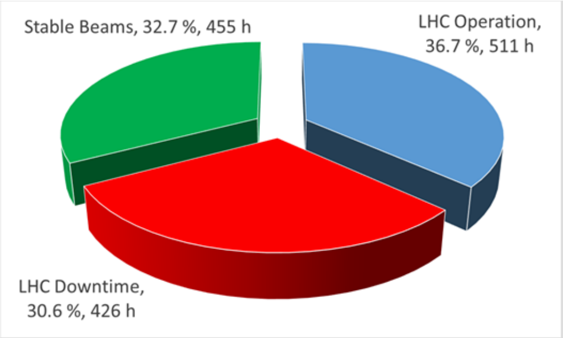

Figure 5: Breakdown of LHC Operation.

A total of 70 fills reached stable beams, out of which 22 were dumped by operators (End-Of-Fill, EOF) and 48 (68.6 %) were prematurely dumped due to failures. The resulting average turnaround time is 7.3 h and the average downtime per fill to stable beams was 6 h.

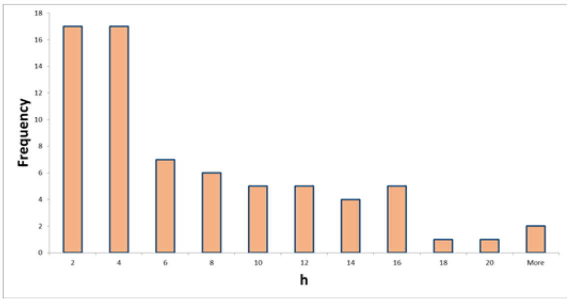

Figure 6: Distribution of stable beams duration during the 25 ns Run.

The distribution of the time spent in stable beams is illustrated in Fig. 6. The average duration of stable beams (both EOF and terminated by failures) was 6.3 h. Many fills were dumped prematurely (average 5 h), but some very long fills, lasting up to 20 h, are also present (average for EOF 9.5 h). Long fills were justified by the remarkably long luminosity lifetimes (~30 h, see [6]).

Fig. 4.c allows identifying the cryogenic system as the main LHC downtime cause. Nevertheless, this view considers child faults as part of the system directly affected by the fault occurrence (e.g. downtime due to quench recoveries is still attributed to the cryogenic system, even if a quench is not a primary cryogenic system fault). Taking into account only the downtime directly impacting on LHC operation, a re-assignment of the downtime due to child faults to the respective parents was carried out. For some faults, the time lost due to a necessary magnet pre-cycle to 6.5 TeV was also considered (in orange). Furthermore, an additional quantity, the so-called 'lost-physics' time, is assigned to all systems responsible for dumps while in stable beams. In each of such cases, additional 3 h (i.e. the difference between the average duration of a fill terminated by EOF and the average fill duration) are added to the system causing the dump. The result of this analysis is presented in Fig. 7. This view is extremely valuable, as it allows directly comparing the impact on availability of hardware systems and beam-related failures. As an example, unavailability due to beam losses is comparable to that of magnet circuits and QPS.

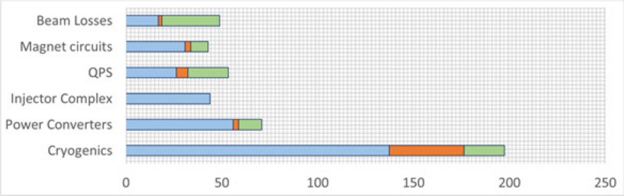

Figure 7: System impact [h] on LHC availability, accounting for system downtime (light blue), required magnet pre-cycles (orange) and 'lost physics' (green).

CONCLUSIONS

The AFT tool has proven to be a very powerful tool for availability and performance analyses. As shown for the 2015 LHC Run, the data analysis allows highlighting main contributors to downtime and performance limitations, correlating these with machine operating conditions and directly comparing impact on availability of hardware systems and beam-related failures. The AFT tool is still under development to include more features and ease the fault review process and data corroboration. Discussions are currently on-going to possibly extend the AFT to the CERN injector complex in the future.

ACKNOWLEDGEMENTS

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