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ACCELERATOR FAULT TRACKING AT CERN

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Abstract

CERN's Accelerator Fault Tracking (AFT) system aims to facilitate answering questions like: "Why are we not doing physics when we should be?" and "What can we do to increase machine availability?"

People have tracked faults for many years, using numerous, diverse, distributed and un-related systems. As a result, and despite a lot of effort, it has been difficult to get a clear and consistent overview of what is going on, where the problems are, how long they last for, and what is the impact. This is particularly true for the LHC, where faults may induce long recovery times after being fixed.

The AFT project was launched in February 2014 as a collaboration between the Controls and Operations groups with stakeholders from the LHC Availability Working Group (AWG).

The AFT system has been used successfully in operation for LHC since 2015, yielding a lot of interest and generating a growing user community. In 2017 the scope has been extended to cover the entire Injector Complex.

This paper will describe the AFT system and the way it is used in terms of architecture, features, user communities, workflows and added value for the organisation.

INTRODUCTION

People at CERN have tracked faults for many years, using numerous diverse, distributed and un-related systems. As a result, and despite a lot of effort, it was difficult to get a clear and consistent overview of what is going on, where the problems are, how long they last for, and what is the impact. This is particularly true for the LHC, where faults may induce long recovery times after being fixed.

In February 2014, CERN's Beams Department launched the Accelerator Fault Tracking (AFT) project as collaboration between the Controls and Operations groups with key stakeholders from the LHC Availability Working Group (AWG).

The project was initially divided into 3 phases, with the 1st phase completed ahead of the LHC restart (post Long Shutdown 1: 2013-2014) and delivering the means to achieve consistent and coherent data capture for LHC, from an operational perspective. Phase 2 of the project was in progress during 2015-16 working on detailed fault classification and facilitating analysis for equipment groups. Phase 3 (still pending) foresees extended integration with other systems e.g. asset management tracking to be able to make predictive failure analysis and plan preventive maintenance operations.

Due to the success of AFT for LHC during 2015, in 2016 CERN's Machine Advisory Committee proposed that AFT be used for CERN's Injector Complex. As such, work started in late 2016 to prepare AFT for use in the Injector Complex for the start of operation in April 2017. Since then, work has been on-going to further refine the system to cater for additional injector-specific needs and adapt to emerging requirements.

AFT SYSTEM

The AFT system aims to facilitate answering questions like: "Why are we not doing physics when we should be?" and "What can we do to increase machine availability?" To support this, AFT needs to provide the means to consistently and coherently capture details of faults and other events impacting machine availability (e.g. beam-related effects) together with the tools to visualize, analyze and extract the data.

Architecture

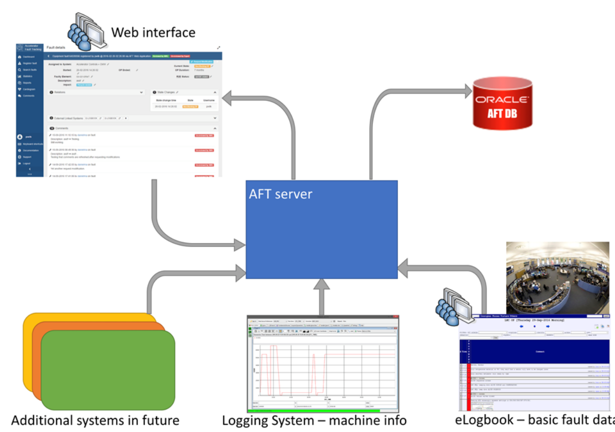

Figure 1: High-level AFT system architecture.

Figure 1 shows the distributed nature of the AFT system. At the core is a Java server, based on Spring Boot, which provides the necessary business logic and the means to both write and read back data. Certain functionality is exposed via RMI for use in CERN's Electronic Logbook, which has been adapted to allow operators to enter basic fault data that is sent directly to AFT where it is persisted in a relational database. This is the primary means of initial fault data capture. The AFT server also exposes methods to read and write data via REST. For the time being, the REST API is only used by the AFT Web application, which allows any authenticated user to consult the fault data, related statistics and graphical displays of historical data. The AFT Web application also allows authorized system experts to complete the details of faults assigned to their systems, while AWG members are able to define relations between faults (e.g. parent and child or blocking). The Web application is written in TypeScript and developed using the AngularJS framework. Authentication and row-level

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authorisation is implemented using Spring Security and is fully data-driven. In order to easily understand the impact of faults on machine operation, additional data describing operational modes, beam intensities etc. are periodically extracted from CERN's Accelerator Logging Service [1] and combined with AFT data in various displays. Further integration of data from other systems (e.g. Post-mortem and Alarms) is foreseen for the future.

Features

AFT includes a number of core features:

Basic fault registration can be made from the ELogbook (Fig. 2) or the Web application (Fig. 3). The initial registration process is intended to be as lightweight as possible for the operators, only requiring essential data to be filled at this stage.

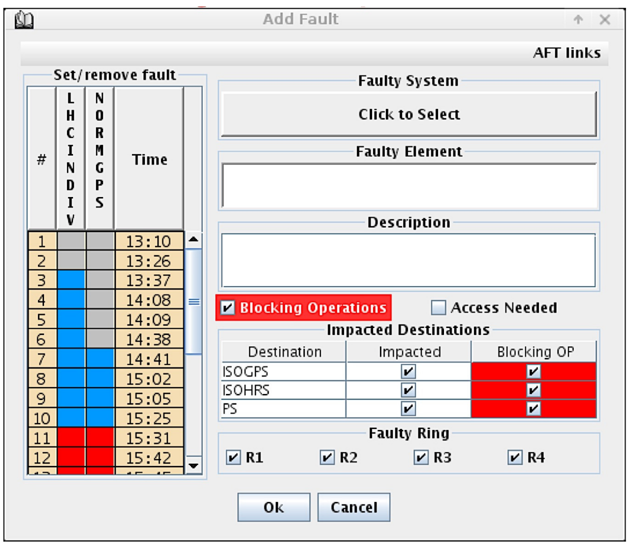

Figure 2: AFT fault registration screen in the ELogbook.

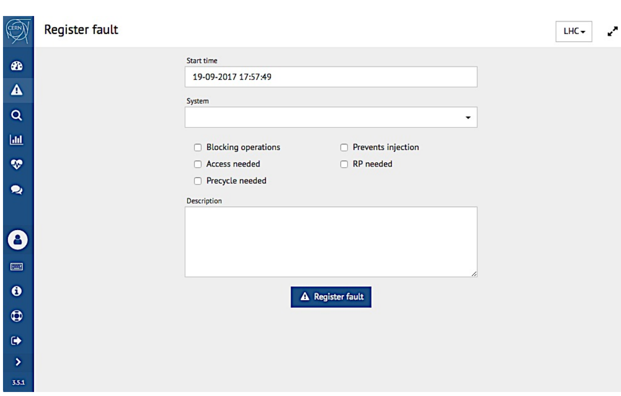

Figure 3: Fault registration in the AFT Web application.

Faults can be searched for within a time window or predefined interval (Fig. 4). Advanced filtering criteria are available with dynamic attributes corresponding to the selected accelerator or a filtered system.

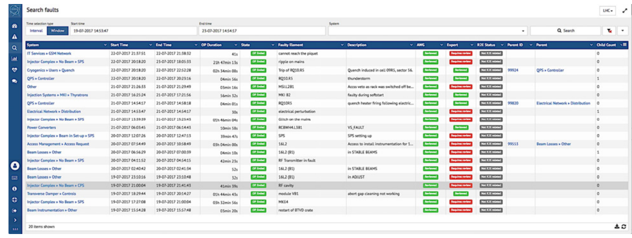

Figure 4: Fault search.

The details of any fault can be consulted and edited (Fig. 5), including managing relations between faults and linking to external systems. Fault edition is available only to users with appropriate roles.

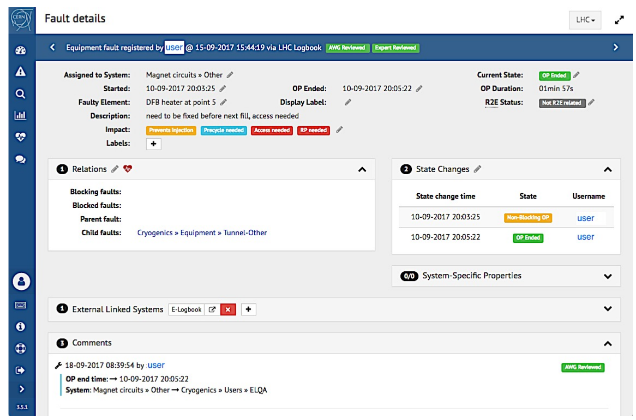

Figure 5: Fault details and edition.

The AFT system provides a wide range of generic and accelerator-specific fault and availability statistics for either all accelerator top-level systems, or at the level of a selected sub-system. For example, Figure 6 shows the statistical view of the number of faults per system versus the average and total durations.

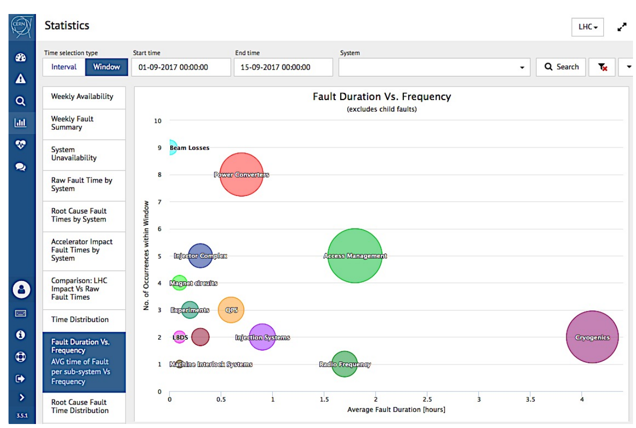

Figure 6: Fault duration versus frequency statistic.

The *Cardiogram* (Fig. 7) is a historical view of the accelerator activity together with corresponding faults, including start times, durations, impact on operations and inter-fault relations.

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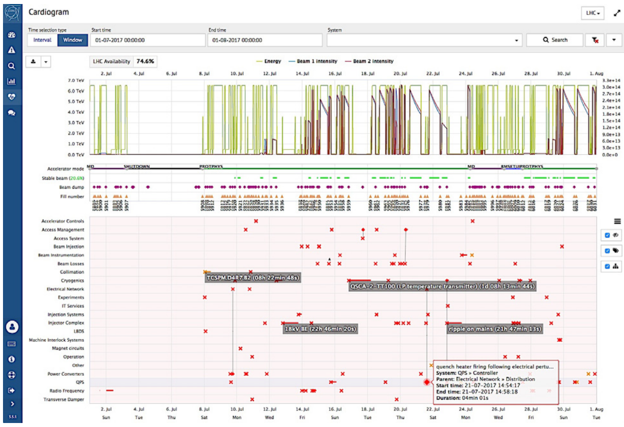

Figure 7: LHC Cardiogram.

In order to provide out-of-the-box common overviews of accelerator activity and to tailor AFT to the specific needs of individuals or groups, AFT provides generic dashboards by default, and the option for user-customisable dashboards in addition (Fig. 8). These dashboards typically show overviews of accelerator or sub-system activity and performance in fixed or dynamic time windows. Dashboards can easily be configured via copy-paste and drag-and-drop or extended over time to show additional attributes or statistics. User-created dashboards can optionally be shared with other users.

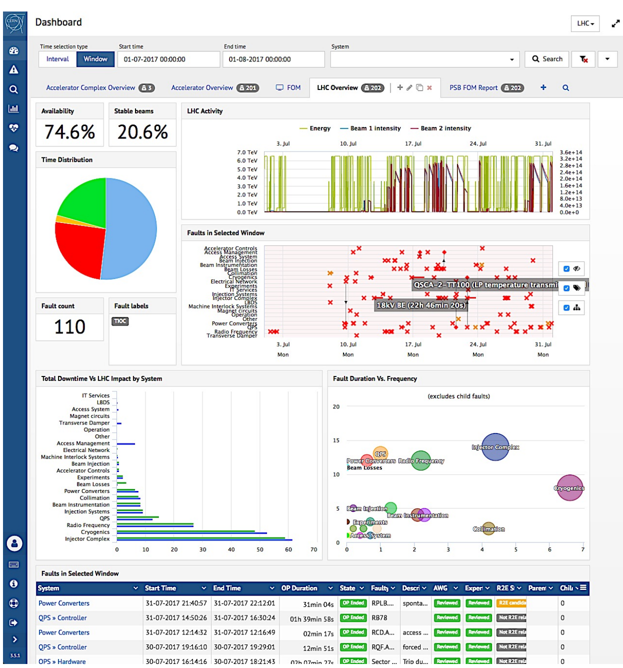

Figure 8: Default “LHC Overview” dashboard.

Users & Workflows

Any authenticated CERN user can consult the AFT system. Approximately 200 individuals use AFT.

There are 3 main categories of users:

1. Accelerator Operators – responsible for registering faults when they occur, including basic information such as start time, state (blocking operation or not), suspected system and elements in fault, impacted beam destinations, and a basic description of the problem.
2. System Experts – responsible for a given system in AFT (e.g. Vacuum, Cryogenics, Controls, etc.) and ensuring corresponding faults details are correct and complete. System experts can edit a fault description, the details of the element(s) in fault, and refine the assignment of the fault to a particular sub-system for which varying levels of granularity can be configured. After the above, system experts can flag faults as having been “expert reviewed”. System experts are notified of newly registered faults either immediately post-fault registration or on a periodic basis, according to the expert’s preferences.
3. AWG members and accelerator operation supervisors – responsible for reviewing all faults registered for a given accelerator and ensuring that fault details are correct and complete, including registering links between related faults – such as parent-child relations between root causes and subsequent induced faults [2]. AWG members can change any detail of a fault. They are also able to accept or reject any aspect of a structured “fault modification request” which can be submitted by any authenticated user. An example is when a System Expert wishes that a fault assigned to the system under their responsibility be re-assigned to a different system. To ensure an efficient and transparent re-assignment processes, the request and subsequent approval or rejection action will trigger the sending of notifications to the responsible persons of both the old and new systems.

ORGANISATIONAL VALUE

The AFT system is still relatively new, however it has already brought added value to CERN on various fronts.

Thanks to the clear assignment of roles and corresponding workflows and notifications – all relevant parties are informed when a fault is registered to a given system and quickly come to an agreement on the captured data – updating and completing when necessary. Combined with the possibility to define relationships between faults, and the way this is then used to display availability statistics, there is no more contention when it comes to reporting on availability and which systems were responsible for downtime. Figure 9 shows the AFT statistics chart displaying both the raw downtime by system during August 2017, and for the same period – the downtime by system in terms of impact on LHC availability. For the later case, downtime of child faults is attributed to the systems of corresponding parent faults, while downtime in the shadow of an on-going parallel fault is removed.

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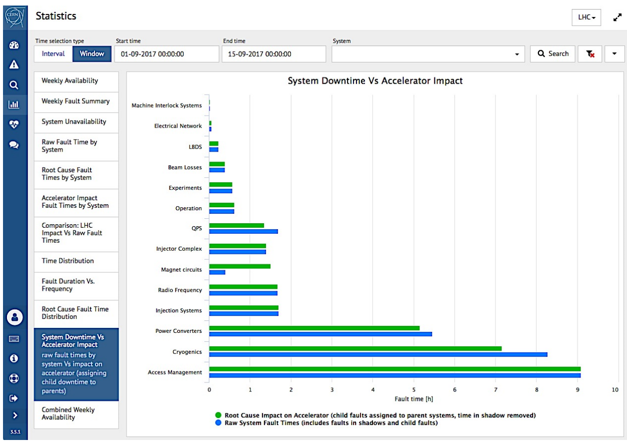

Figure 9: Raw downtime Vs. LHC impact August 2017.

AFT statistical and historical views and reports are used as inputs to daily, weekly, quarterly and annual status meetings and performance workshops. Not only does AFT save experts significant time to prepare reports, but it also ensures consistency across reports and between reporters. Since deploying AFT for CERN's injector complex – weekly meetings reporting on performance of the entire complex use the same type of AFT-generated reports for all accelerators concerned.

The AWG also produce periodic reports on availability, highlighting repeating and notable causes of downtime [3,4,5,6]. In turn such reports can be used to objectively consider areas to be targeted for consolidation and improvements such as the LHC Ventilation Doors following the LHC run in 2016. The report content is based fully on analysis of AFT data.

More and more equipment groups are increasingly tracking the faults related to their equipment with greater levels of detail. Once again – this is to facilitate the work of the system experts to understand the performance of their systems over time and target corresponding improvements.

Looking further ahead, a greater value can come from the AFT system by modelling system reliability based on the captured availability data. The idea is to predict potential failures ahead of time and schedule preventive maintenance and adapt operational procedures and schedules to try to maximise availability. This is extremely important given that availability has been cited as a defining factor in the success of the Hi-Luminosity LHC project [7,8] and is surely a key factor for things like the Future Circular Colliders (FCC) studies. For such models and predictions to become a reality, it is necessary to gather additional data over the coming years, and to further develop AFT – integrating with CERN's Layout [9] and CMMS systems (Infor EAM) [10] to be able to link faults to assets, including corresponding manufacturing data, intervention reports etc.

CONCLUSION

The Accelerator Fault Tracking system has been in use at CERN for the LHC since 2015. The system is extendable – as shown by the recent inclusion of CERN's Injector Complex. The AFT system has proven to be extremely useful, giving a basis for a common understanding of what problems exist and what is the corresponding impact on machine operation, performance and availability. Further work is foreseen in order to deliver additional time-saving data analysis and reporting features. It is also planned to integrate with other data management systems (e.g. Layout and CMMS – asset management) in order to have a means from which to start to analyse faults and availability taking into account geographical location, manufacturing and maintenance processes. Eventually it should be possible with the appropriate features and a significant data set – to be able to start to predict failures and target repairs and consolidation work before critical faults actually occur – thus maximising machine availability for physics.

REFERENCES

[1] C. Roderick *et al.*, "The CERN Accelerator Logging Service - 10 Years in Operation: A Look at the Past, Present, and Future", ICALEPCS'13, San Francisco, CA, USA, 2013, TUPPC028.

[2] A. Apollonio *et al.*, "LHC Accelerator Fault Tracker - First Experience", IPAC'16, Busan, Korea, 2016, TUPMB040.

[3] B. Todd, L. Ponce, A. Apollonio, "LHC Availability 2016: Restart to Technical Stop 1", CERN-ACCNOTE-2016-0047, 2016

[4] B. Todd, L. Ponce, A. Apollonio, "LHC Availability 2016: Technical Stop 1 to Technical Stop 2", CERNACC-NOTE-2016-0066, 2016

[5] B. Todd, L. Ponce, A. Apollonio, "LHC Availability 2016: Technical Stop 2 to Technical Stop 3", CERNACC-NOTE-2016-0065, 2016

[6] B. Todd, L. Ponce, A. Apollonio, "LHC Availability 2016: Proton Physics", CERN-ACC-NOTE-2016-0067, 2016

[7] A. Apollonio *et al.*, "Roadmap towards High Accelerator Availability for the CERN HL-LHC Era", IPAC'15, Richmond, VA, USA, TUPTY053.

[8] A. Apollonio *et al.*, "Lessons Learnt from the 2016 LHC Run and Prospects for HL-LHC Availability", IPAC'17, Copenhagen, Denmark, 2017, TUPVA006.

[9] P. Le Roux *et al.*, "The LHC Functional Layout Database as Foundation of the Controls System", ICALEPCS'07, Knoxville, Tennessee, USA, RPPA03.

[10] S. Mallón Amérigo *et al.*, "CERN's Global Equipment Data Repository", ICALEPCS'09, Kobe, Japan, 2009, TUB004.