A SYSTEMATIC MEASUREMENT ANALYZER FOR LHC OPERATIONAL DATA

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Abstract

The CERN Accelerator Logging Service stores data from hundreds of thousands of parameters and measurements, mostly from the Large Hadron Collider (LHC). The systematic measurement analyzer is a Java-based tool that is used to visualize and analyze various beam measurement data over multiple fills and time intervals during the operational cycle, such as ramp or squeeze. Statistical analysis and various manipulations of data are possible, including correlation with several machine parameters such as β^* and energy. Examples of analyses performed include checks of collimator positions, beam losses throughout the cycle and tune stability during the squeeze which is then used for feed-forward purposes.

INTRODUCTION

The CERN Large Hadron Collider (LHC) was designed and built to accelerate two counter-rotating beams to an energy of 7 TeV and deliver high energy collisions of protons or heavy ions in the four experiments, namely ATLAS, ALICE, CMS and LHCb [1]. Data from thousands of devices in the CERN accelerator infrastructure, amounting to around 1 million signals and 50 TB/year are stored by the CERN accelerator logging service (CALS) [2].

An overview of the software architecture is shown in Fig. 1. Two Oracle databases are used for storage. The Measurement database (MDB) is used to store raw data for a short period of time, which is then filtered and transferred to the Logging database (LDB) for indefinite storage of filtered data. The databases subscribe to specific properties of each device via the Java API for Parameter Control (JAPC) [3] or PVSS for the industrial SCADA systems.

A Java GUI called TIMBER is provided to visualize and extract the logged data. However, in order to assess the stability of the machine and perform analyses over several fills and machine modes, a tool called Systematic Measurement Analyzer was developed. This paper describes the implementation of the tool as well as some typical use case scenarios where it has proved to be useful.

LHC MACHINE CYCLE

The operation of the LHC follows well-established stages, which together form a machine cycle. A typical LHC machine cycle is shown in Fig. 2. At the injection stage (1), the LHC receives two beams from the Super Proton Synchrotron (SPS) at an energy of 450 GeV per beam. The beams arrive in bunch trains, which may consist of 1-144 bunches, depending on whether the machine is to be filled for beam tests or physics. When the filling procedure is completed, both beams are ramped up (2) until the desired energy is reached. At flat top (3), the machine operators initiate the beam squeeze procedure (4), in which corrector magnets are used to shrink the beam size at the experimental insertion points (IPs) to achieve the desired β^* (the β-function at the experimental IPs).

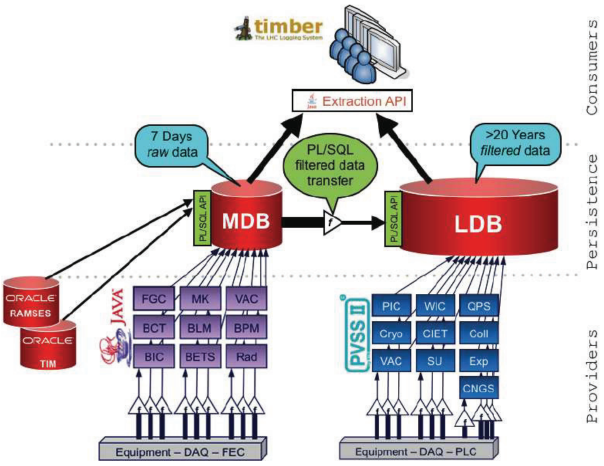

Figure 1: The CERN accelerator logging service architecture [2].

Up to this point, the beams are separated by several σ (r.m.s. beam size) in all IPs. Hence, the final step is to collapse the separation orbit bumps and bring the beams into collisions. The operational state known as stable beams (5) is declared, and the experiments begin taking data. The beams may be extracted or dumped (6) at any point during the fill due to operational requirements, equipment failures, beam instabilities or operator mistakes. When this happens, the machine is ramped down (7) to injection energy in preparation for the next fill. The data presented in Fig. 2 are taken from fill number 3131, in which a total of 1374 bunches were present in the machine, and 130 × 130μb^{-1} of luminosity was delivered to the ATLAS and CMS experiments in 3.5 hours of stable beams.

SOFTWARE ARCHITECTURE AND UI

The systematic measurement analyzer is written in Java, which is the standard for LHC operational applications run-

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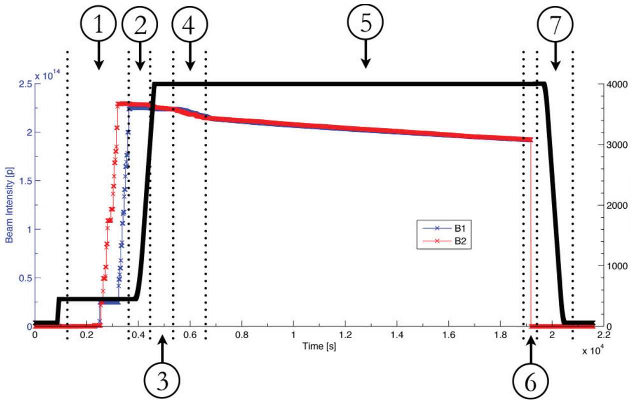

Figure 2: The LHC machine cycle, illustrated by the beam energy and beam intensities taken from fill number 3131 (t[0] = 05.10.2012 01:00:00). There are seven stages: 1) injection; 2) ramp; 3) flat top; 4) squeeze; 5) stable beams; 6) beam dump; 7) ramp down.

ning in the CERN Control Center. It was initially developed to optimize the squeeze and for feed-forward purposes [4]. A flowchart of the steps needed to extract and analyze the data is shown in Fig. 3. The user can input a set of predicates to filter which fills are to be used for the data extraction. These include the beam mode, beam energy, and fill duration. The latter is useful for instance if one needs to look at stable beams fills of sufficient length to make conclusions from the data [5]. The fills are selected based on a time window or by fill number.

The next step is to select the logging variables, which can be in numeric or vectornumeric format, in which case an index needs to be provided. The selection can be done via regular expressions, and simple operations (addition, subtraction, multiplication and division) can be applied on two or more variables. A list of pre-defined, frequently used variable names is available with human-readable names. The default abscissa for the subsequent charts is time, but one logging variable can also be plotted as a function of another. The data are extracted for the selected fills from the LDB via a Java API provided by CALS.

Plots can be generated for a specific interval, such as during the ramp or for the whole fill. It is possible to post-process the data, for example to synchronize all data sets to the start or end point of a beam mode, or perform scaling operations. Histograms can be made for a set of pre-defined analyses, such as the intensity transmission in ramp or squeeze, or the beam mode duration for one or both beams. The third category of plots provides an overview of the reproducibility of the data for a particular variable from one fill to another.

A screenshot of the user interface showing the main components is shown in Fig. 4. The predicate and fill selection panels are on the left hand side. The time spent in each machine mode can be viewed for each fill individually. The central part is used to display the plots, while the plotting operations can be accessed from the bottom panel. These

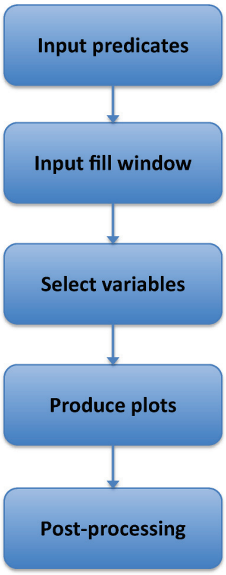

Figure 3: Analyzer usage flowchart to extract and visualize the data.

including adding a new chart or a new line to an existing chart. Post-processing and dataset synchronization with a given machine mode can be performed from here. The data can be exported from the chart to a text file for additional analyses.

USE CASES

Collimation System Performance in Stable Beams

The LHC collimation system [6] protects the machine agains damage due to beam losses. Almost 100 collimators, each having two jaws form a four-stage hierarchy to intercept, scatter and absorb highly energetic halo particles. Beam losses at specific locations in the LHC are measured by 3600 Beam Loss Monitors (BLMs). The cleaning inefficiency of the collimation system can be defined as the leakage of primary particles from the collimation hierarchy to the dispersion suppressor (DS) in insertion region (IR) 7, where the betatron collimation system is installed. It can be derived from the ratio of the BLM signal at one of the superconducting magnets in the start of the IR7 DS to the losses at the primary collimator, which is closest to the beam and normally has the highest losses. Figure 5 shows the ratio of the two signals over several fills during stable beams in 2015.

Collimator LVDT - Magnet Current Correlation

Linear Variable Differential Transformers (LVDTs) provide an independent read-out of the LHC collimator jaw positions. During Run 1, the LVDT readings at some collimators were found to be susceptible to electromagnetic interference from nearby magnets [7]. The plot in Fig. 6 shows the correlation of the difference in the collimator

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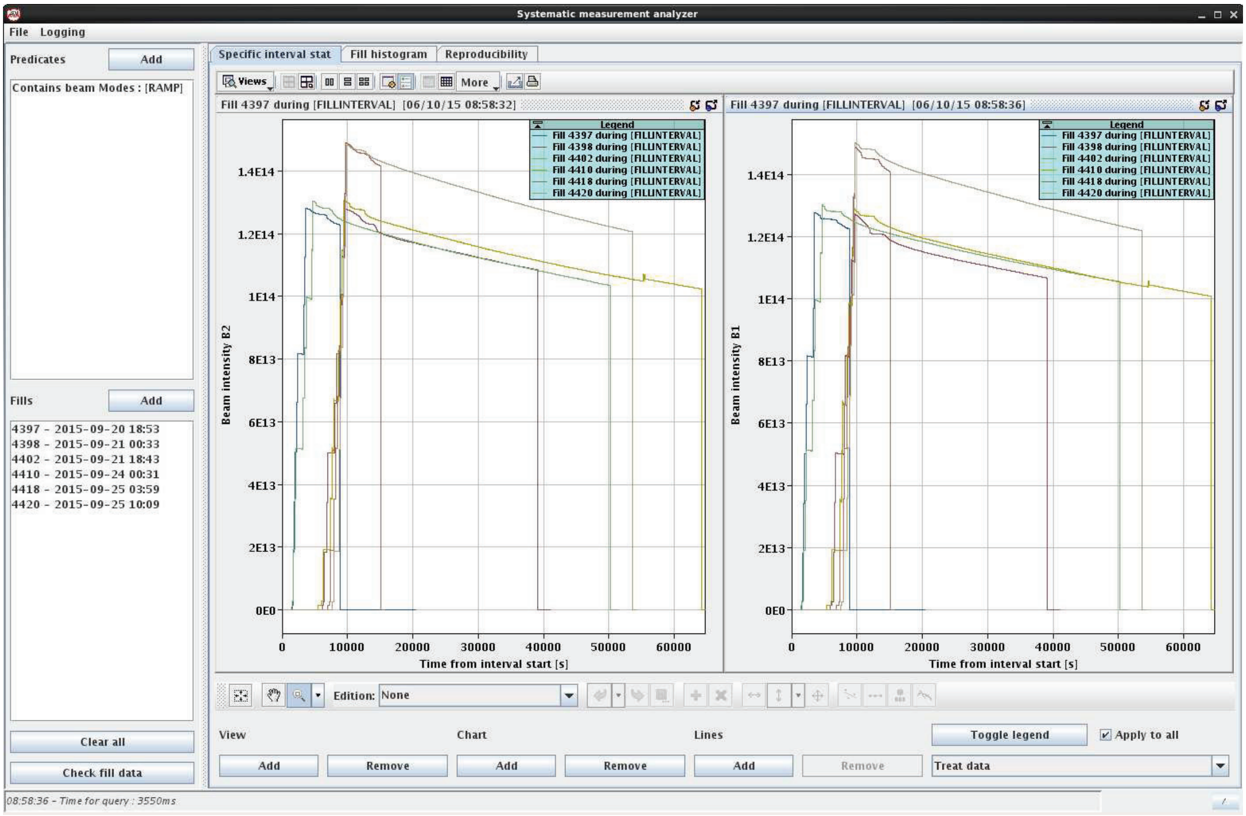

Contains beam Modes : [RAMP]

4397 - 2015-09-20 18:53
4398 - 2015-09-21 00:33
4402 - 2015-09-21 18:43
4410 - 2015-09-24 00:31
4418 - 2015-09-25 03:59
4420 - 2015-09-25 10:09

Edition: None

☑ Apply to all

Treat data

08:58:36 - Time for query : 3550ms

Figure 4: Screenshot of the analyzer user interface, showing the beam intensity evolution in several fills in B1 and B2.

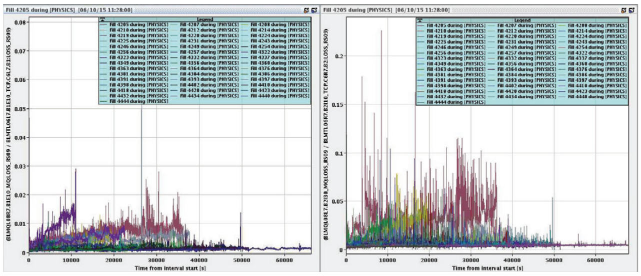

Figure 5: Collimation cleaning inefficiency in stable beams.

gap measured by the gap LVDT and calculated from the left and right motor positions, as a function of the magnet current during several LHC pre-cycles. An offset of 200 μm is reached at maximum current. This led to several of the worst-affected LVDTs to be replaced by a new design (I2PS [8]), which is not affected by this interference.

Beam-based Optimization of the Squeeze

The betatron squeeze is a critical operational phase of the LHC due to the reduced aperture margins in the superconducting triplets at top energy. In order to reduce the beam losses and therefore improve the intensity transmission during the squeeze, a fill-to-fill analysis was made to determine the reproducibility of the main beam parameters such as the tune and orbit [9]. The very good reproducibility allowed the possibility to apply feed-forward corrections, hence minimizing the trims made by the real-time feedback systems for the tune and orbit during the squeeze [4]. This has the effect of reducing the possibility for the beams to be lost in case of trips of the real-time feedback systems.

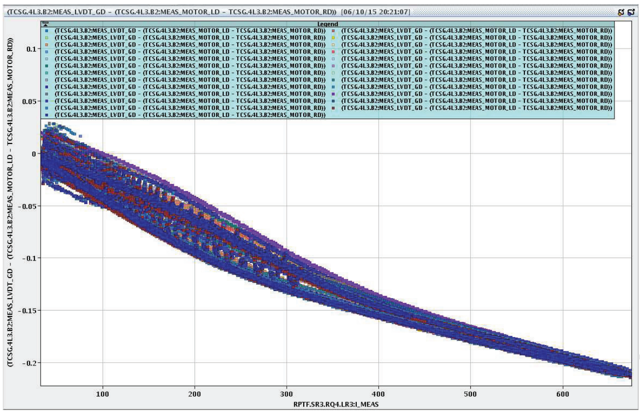

Figure 6: Correlation of the collimator jaw gap motor-LVDT offset and the current in a nearby magnet.

Beam Mode Duration Statistics

The systematic measurement analyzer can produce bar charts to visualize the time spent in any or all of the 18 LHC

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machine modes in each fill. This is useful to determine the operational efficiency and turnaround time of the LHC from one physics fill to the next. The plot in Fig. 7 is for all fills in September 2015.

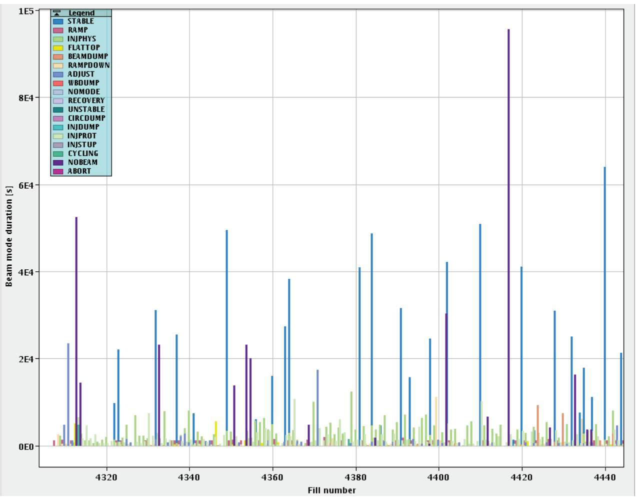

Figure 7: Beam mode duration statistics.

Luminosity-intensity Correlation in Stable Beams

Another example of the functionality of the tool is shown in Fig. 8, in which the ATLAS instantaneous luminosity is plotted as a function of the B1 intensity during stable beams. Although the luminosity and intensity decay depend on a number of factors, such as emittance blow-up and losses at collimators respectively [10], this type of analysis is still useful to obtain a quick overview of the situation over several fills online.

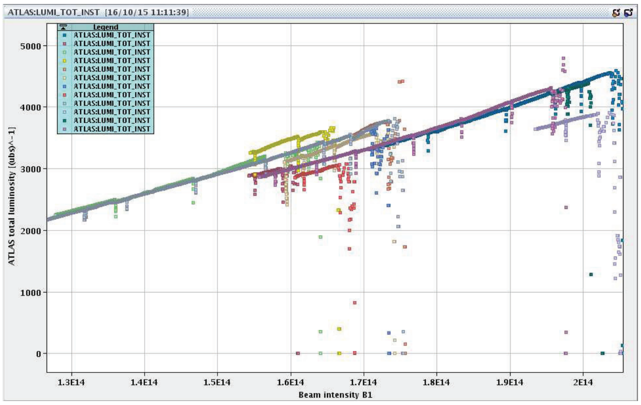

Figure 8: ATLAS instantaneous luminosity as a function of B1 intensity during several fills.

CONCLUSION AND OUTLOOK

This paper documents a tool which is useful for performing fill-to-fill analyses need to monitor the performance and behaviour of the LHC and its equipment. It has been successfully in several case studies which have been presented. Further enhancements of the tool include curve fitting, which could be used for example to calculate the beam lifetime evolution during stable beams.

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