DATA ANALYSIS AND SYSTEM SURVEY FRAMEWORK FOR THE LHC BEAM LOSS MONITORING SYSTEM

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Abstract

A data analysis framework has been developed to perform systematic queries and automatic analysis of the large amount of data produced by the LHC beam loss monitoring system. The framework is used to provide continuous system supervision and can give advance warning of any potential system failures. It is also used to facilitate LHC beam loss analysis for determining the critical beam-abort threshold values. This paper describes the functionality of the framework and the results achieved from the analysis.

INTRODUCTION

The Beam Loss Monitoring (BLM) system of the Large Hadron Collider (LHC) has been designed to provide damage protection for the machine equipment and to prevent quenches of the superconducting magnets [1]. There are about 4000 detectors constantly measuring the particle losses from the circulating beams and the system triggers the safe extraction of the beam if any of the detector signals exceeds the predefined beam-abort thresholds. In order to reliably provide high level protection to the LHC operation, the BLM system is designed to have cross-redundancy within the system and requires on-line surveillance [2] and off-line diagnostics. During the LHC Run1 period (2009 – 2013), many scripts were developed to make use of the data from the LHC logging database for off-line system diagnostics using a general data analysis framework [3]. This offline-analysis framework (OAF) has been developed by the CERN beam instrumentation group's software team as a general purpose data analysis tool. This paper will focus on the sets of scripts derived from the OAF for the BLM system diagnostics. It gives an overview of the operational checks for the BLM system during the LHC Run2 period and concludes with a summary of the system status and proposals for future developments.

ANALYSIS FRAMEWORK

The primary purposes of the checks are to detect the deterioration in equipment and potential errors in the settings of the system. These scripts, developed using the OAF framework, are run from a Linux server with status reports sent to equipment experts on a daily basis. In addition, the scripts can be triggered manually in order to quickly review the system status after a hardware intervention or changes of system setting parameters.

Although a migration of OAF from Python to Java was proposed in [3], the framework remains using Python as the coding language due to the rich number of data analysis packages provided by the Anaconda Platform [4]. The framework provides a Python module for data extraction from the LHC measurement and logging database, using the query Java API which was supplied by the CERN database team to enforce 'fair-use' policy. All the data that are extracted from the database are formatted as a time-indexed 'Dataframe', which is a high-performance, easy-to-use data structure defined by the Pandas library [5]. In order to visualize the analysis result, the matplotlib library is used to render the data plots with any tables generated by LaTex scripts.

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SYSTEM DIAGNOSTIC REPORTS

There are five software tasks that have been developed using the framework and are executed on a daily basis by the Linux server. Each of the tasks generates a summary report and sends a notification email with the report to equipment experts. This process ensures the equipment experts are aware of the system status and that the software tasks are successfully triggered, avoiding that errors go unnoticed due to software errors.

The content of each tasks and examples of the analysis results will be shown in this section.

Channel Connectivity Test

There are about 4000 beam loss detectors around the 27 km of the LHC ring. The cable integrity of these detectors are checked by adding a small harmonic modulation signal on the high voltage power supply of the detector and detecting the harmonic variation of the detector current signal from the measurement side [6]. The FPGA of the front-end electronics calculates the amplitude and phase of the harmonic variation of the detector signal and compares the results with predefined limits to survey the integrity of the components. The connectivity test is enforced before every LHC beam injection and at least once every 24 hours. The next injection will be blocked if any channel has failed the test.

There are three types of beam loss detector installed in the LHC ring. The main detector type is an Ionization Chamber (IC) while Little Ionization Chambers (LIC) and Secondary Emission Monitors (SEM), both with much less sensitivity comparing to the ICs (14 times and 70,000 times less sensitive repectively [7]), are installed in parallel to the ICs to extend the dynamic range of the beam loss measurement in high loss locations. Due to the smaller detector capacitance of the LIC and SEM, their response to the voltage modulation has smaller amplitude (noted as 'Gain' in Fig. 1). This feature has been used to discriminate between IC and LIC/SEM channels, and thus allows the identification of any wrongly connected detectors after new detector installation or replacement.

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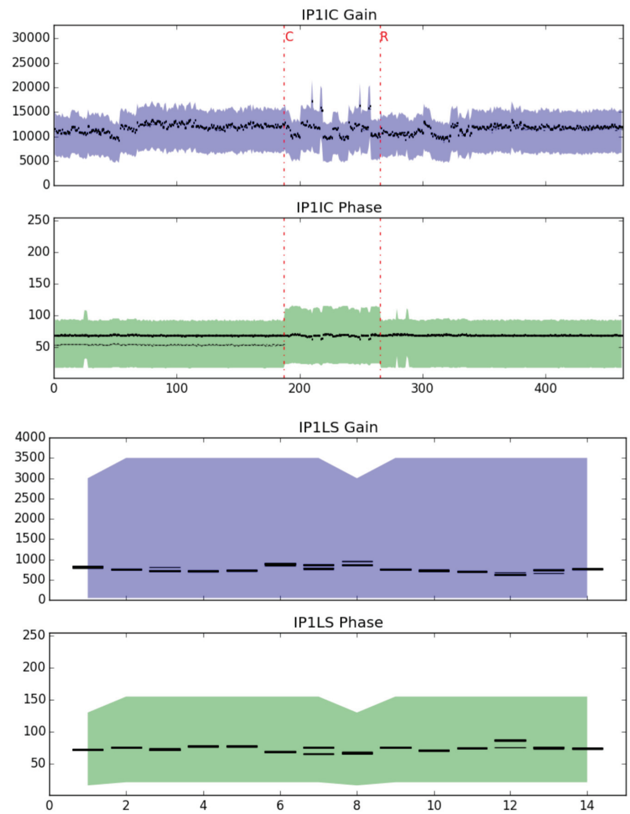

Figure 1: The connectivity test results of all BLMs in Point 1 of the LHC. The measured data points are in black while the shaded regions show the predefined limits for each channel.

The script extracts the connectivity results of all channels for the previous 24 hours and produces a list of failed channels for the equipment experts to review. Figure 1 shows the results of all BLM channels from Point 1 of the LHC. If any of the results are outside the limits set, the test will fail. The script will also issue a warning if the calculated results are within a 10% margin of the limits.

In addition to the connectivity test, a constant input current of 10 pA is injected by a digital-to-analogue converter (DAC) with the output monitored for every channel. This serves as a continuous connectivity survey. Radiation dose induced negative leakage currents may reduce this constant current, therefore the circuit is designed to actively compensate by increasing the input current [2]. The script will compare the measured output value over days and report any channel which sees a sudden increase. Such cases may indicate a degradation of the system integrity due to radiation which cannot otherwise be detected.

Power Supply Status

Both the high voltage and low voltage power supply status of the BLM detectors and front-end modules are constantly monitored. The status flags are transmitted and logged in the LHC measurement and logging database. If any of the voltage levels is out of their operational tolerances during beam operation, safe beam extraction will be triggered. During periods without beam such a power failure could remain unnoticed due to the large number of flags to be checked. A dedicated script is therefore employed to regularly check all important flags and produce 'waterfall' plots for all BLM crates. Figure 2 shows one of these plots for high voltage power supply status of the three VME crates at Point 1 of the LHC. The red and green colour bands indicate the time and card slot number where the HV_OK variable turns to false state. In this case it was due to a power reset of the front-end electronics. The purple line shows when a connectivity test was triggered. In the past modulating the high voltage during a connectivity test could trigger an error of the HV supply, however this problem has been solved for Run2.

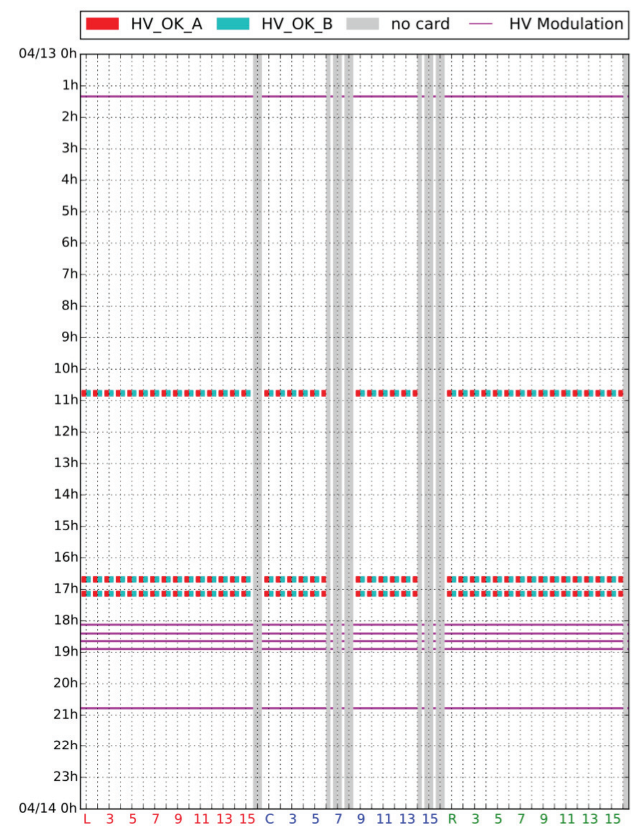

Figure 2: HV Power supply status of three BLM VME crates at Point 1 of the LHC. The x axis is the VME slot number of the acquisition card and the y axis is the time of the day.

Acquisition Card Temperature

A script is also used to produce a daily overview for the card temperature of all BLM acquisition cards. Since the start of LHC Run2 all BLM crates in surface buildings are housed in temperature controlled racks. A large variation of card temperature thus indicates a failure of the cooling or ventilation system.

Figure 3 shows the temperature of acquisition card no. 9 in one VME crate of all surface buildings of the LHC. This card is located at the top centre of the rack, which is where the temperature is highest. The set-point temperature of the

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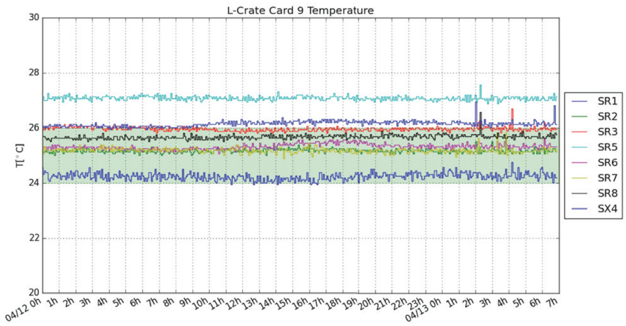

Figure 3: Temperature of one acquisition card in one crate of every Point in the LHC surface buildings.

crate depends on the regulation of the cooling circuit and is considered acceptable anywhere between 24 to 26 °C.

Optical Link Check

The BLM system requires long distance data transmission between the front-end electronics in the tunnel and data processing module on the surface and uses a radiation tolerant Gigabit Optical Link (GOL) [2]. Redundancy is provided by using two parallel optical links to ensure the continuation of the beam operation by avoiding unnecessary beam abort due to a data transmission error on one of the links. Several checking processes are implemented in the electronics to ensure the data completeness and correctness, rigorously checking for any such transmission errors. The script extracts the transmission errors from the database every day with the detailed reports generated helping equipment experts to take corrective action before transmission errors start to affect system availability.

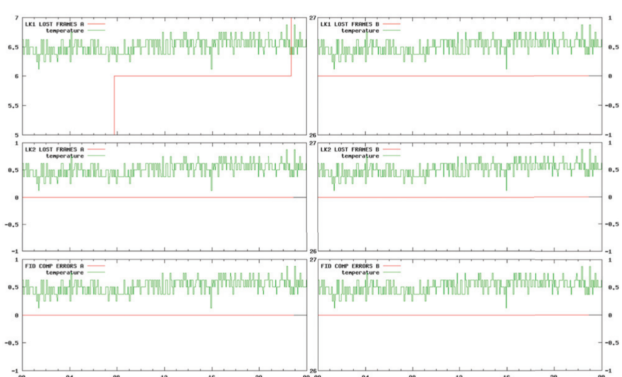

Figure 4: Example of an optical link report, where one of the two optical links has lost a frame (red line in top left plot). The green line shows the card temperature of the day, as a correlation between excessively high card temperatures and transmission errors has been observed.

BLM Threshold Changes

During beam operation, each BLM channel continuously integrates the detector signal in 12 different time intervals and compares them to a set of predefined abort thresholds. Safe beam extraction is triggered if any of the integrated signals exceeds the threshold for that particular integration time. Each BLM channel has its own abort thresholds which is both time interval and beam energy dependent. Reference [7] explains in detail how these beam abort thresholds are derived. In total, there are over 1 million threshold values for the BLM system. Since the abort thresholds are critical for machine protection, dedicated tools have been developed to make any changes to the thresholds. A dedicated script, using the analysis framework, monitors any threshold changes by comparing all BLM thresholds before and after the change. Any changes of the abort threshold values detected are documented in a report for comparison to the changes that should have been implemented. This daily report can also alert the expert of any unintentional setting changes.

CONCLUSION AND OUTLOOK

All the scripts presented in this article are based on the modules provided by the offline analysis framework (OAF). This framework provides a method for easy, automated data retrieval and analysis unified email reporting for the daily tasks. The scripts have shown reliable results and are easy to manage through configuration files.

Several future developments for the BLM system analysis are planned. For example, in addition to highlighting the threshold changes, the expert and family names of the BLM detectors can be added in addition to find any potential mistakes in the threshold settings. The framework has also been used to calculate beam loss over threshold ratios during the beam operation. The results may provide a chance to identify threshold setting bottle-necks in the LHC and facilitate threshold adjustments to further improve the machine availability.

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[4] Anaconda Platform, `http://www.continuum.io`

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