

HANDLING OF BLM ABORT THRESHOLDS IN THE LHC

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Abstract

The Beam Loss Monitoring system (BLM) for the LHC consists of about 3600 Ionization Chambers located around the ring. Its main purpose is to request a beam abort when the measured losses exceed a certain threshold. The BLM detectors integrate the measured signals in 12 different time intervals (running from 40 us to 83.8 s) enabling for a different set of abort thresholds depending on the duration of the beam loss. Furthermore, 32 energy levels running from 0 to 7 TeV account for the fact that the energy density of a particle shower increases with the energy of the primary particle, i.e. the beam energy. Thus, about $1.3E6$ thresholds must be handled and sent to the appropriate processing modules for the system to function. These thresholds are highly critical for the safety of the machine and depend to a large part on human judgment, which cannot be replaced by automatic test procedures. The BLM team has defined well established procedures to compute, set and check new BLM thresholds, in order to avoid and/or find non-conformities due to manipulation. These procedures, as well as the tools developed to automate this process are described in detail in this document.

INTRODUCTION

The BLM ICs are situated around the LHC ring in likely loss locations. The radiation tolerant acquisition cards [1], situated in the tunnel below the quadrupole magnets (in the arcs) or in side tunnels (next to the straight sections), integrate the signals detected by the ICs via a Current to Frequency Converter during time windows of $40\mu s$. The signals are digitized and sent to the surface installations via redundant optical links for further processing. The surface electronics [2] receives the data from the two optical links for decoding and processing. The system keeps a history of the signals received and it computes 12 running sums that correspond to signals integrated in 12 different integration windows. The different running sums are continuously compared to a set of predefined thresholds and a beam dump is requested via the Beam Interlock System (BIS) if any of the thresholds are exceeded. The surface electronics is also responsible for continuously sending both the recorded signals and the abort threshold to the Logging database, where they are stored for offline analysis.

The abort thresholds can be independently set for each BLM detector in the form of a 12×32 table that accounts for the 12 BLM running sums and the 32 LHC energy levels. In this document we describe the process of computation, deployment into the electronics and verification of the abort thresholds.

THRESHOLD CALCULATION

The main goal of the BLM system is to avoid quenches to the LHC Superconducting (SC) magnets and any damage induced by beam losses. The abort thresholds for a particular BLM depend on several factors, such as the type of equipment that the monitor is protecting and the position of the detector with respect to both the beam line and the protected device. Taking this into consideration, and in order to reduce the number of different sets of thresholds tables, the BLM monitors are sorted by families. The BLM Master thresholds $T(E_{beam}, \Delta t)$, which represent our best knowledge of the quench or damage levels for all the BLM families, can be described by:

$$T(E_{beam}, \Delta t) = Q_{BLM}(E_{beam}) \cdot N_P(E_{beam}, \Delta t) \quad (1)$$

where Q_{BLM} represents the signal observed by a BLM due to a single lost proton and N_P corresponds to the maximum number of protons allowed to be lost in the protected element. The energy dependence comes from the fact that the development of the hadronic showers depends on the energy of the primary particle, and from the reduction of the quench levels in SC magnets with increasing current. The time dependence comes from thermodynamical arguments and accounts for the energy that can be deposited in the different equipment within a certain time interval. Both Q_{BLM} and N_P strongly rely on Monte Carlo simulations and therefore include calculations uncertainties. These are corrected by performing measurements with dedicated beams or by analyzing data during the standard LHC operation.

The applied BLM thresholds, i.e. the values set in the electronics, are related to equation (1) by an extra coefficient ($t(E_{beam}, \Delta t) = MF \times T(E_{beam}, \Delta t)$). The Monitor Factor, MF , is enforced to be lower than one and can be independently chosen for each monitor. This adds the safety factor required to account for uncertainty in the calculated thresholds.

THRESHOLD DEPLOYMENT PROCEDURE

The settings of the BLM system, in particular the correct calculation and deployment of the abort thresholds into the electronic modules, may have an important impact on the operation of the LHC. Therefore, a specific procedure must be followed when a threshold change is required. The action flowchart, see Figure 1, is triggered by a threshold change request coming from a representative of one of the LHC systems (Operation, Collimation, Injection, Dump, Machine Protection, ...). The first step of the procedure

consist in recovering the program used to compute the previous set of thresholds from the official software repository and to check that those results are reproducible. Immediately after this the threshold computation program is modified in order to achieve the requested changes. Such modifications are documented in an Engineering Change Request (ECR) and sent back to the representatives of the LHC systems for approval. Once approved, the new release of the threshold computation program, together with the new threshold table files, are sent to the software repository and the BLM team proceeds to push the new threshold tables to the electronics.

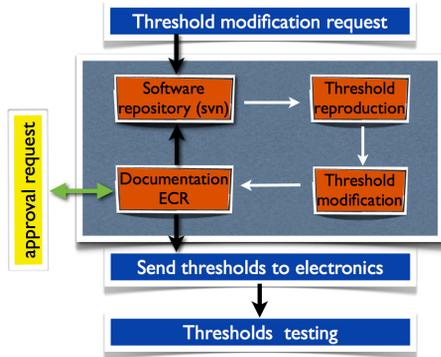


Figure 1: Block diagram of the threshold deployment procedure.

The process of sending new threshold tables to the Threshold Comparator module is sub-divided in three steps. The so called Master Refresh consists of generating the tables that will be stored in the LSA (LHC Software Architecture) database, which is where the LHC configuration parameters are stored. This action is performed through the on-line threshold expert application which requires the electronic signature of two members of the BLM team. In the two subsequent steps, the threshold tables are accordingly adapted to a readable format for the BLM crates and sent to the hardware. The two processes are carried out using independent on-line applications that request the electronic signature of a BLM expert. The procedure finishes with a set of tests to verify that all changes have been performed according to expectations.

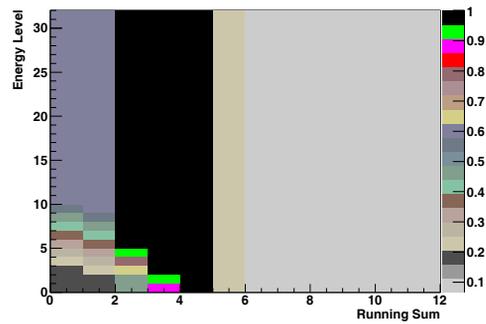
THRESHOLD TESTING

A set of checks have been defined in order to minimize the possibility of introducing wrong parameters into the system. In this section we discuss the different tests, grouping them in three categories, namely: tests performed during the manipulation process, tests performed immediately after a threshold modification and future tests.

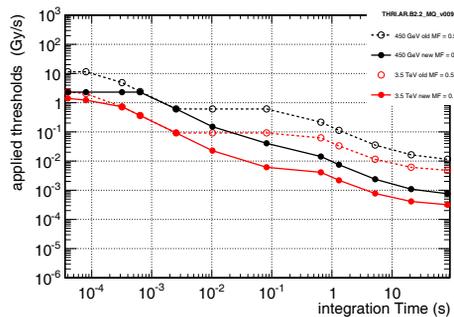
Tests During Manipulation

Grouped into this category are the processes of reproducing a set of existing thresholds, calculating a new set

of thresholds and sending thresholds to the hardware. The testing procedure in the first two cases is equivalent and involves the comparison of all 12×32 abort thresholds under study with a reference table. The reference table corresponds to a set of operational thresholds that have already been checked and are assumed to be correct. Figure 2 (a) illustrates the output of such a test. The x axis represents the BLM integration time window index while the y axis corresponds to the LHC energy levels. The ratio of threshold under study with respect to the reference is shown in a color scale, which is a fast way of detecting undesired modifications in a particular integration window or energy level. An explicit comparison of the abort thresholds and reference thresholds at 450 GeV and 3.5 TeV (injection and current collision energy) is also presented as an output of this test, as shown in Figure 2 (b).



(a) Ratio of new thresholds with respect to reference per (running sum, energy)



(b) Applied thresholds under study (new) and reference thresholds (old) versus integration time.

Figure 2: Comparison of BLM abort threshold with respect to a reference table

A second level test is performed during the master refresh process. The on-line threshold expert application benefits from the data staging functionality of the LSA database. The BLM parameters are initially stored in stage tables, that allow BLM experts to add thresholds and perform tests of consistency, before conversion to final tables. The Master tables are then produced by combining the data from the different final tables. Note that the final stage comparisons is an on line equivalent of the previously outlined test when the reference tables are adequately chosen.

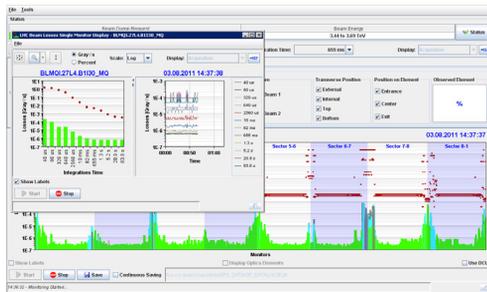


Figure 3: View of the BLM fixed Display

In the application, the threshold tables are either directly read from the LSA database or exported from the BLM software repository. Hence, this step in the test procedure ensures that the submission of the BLM thresholds to the software repository is properly executed.

Tests After Threshold Modification in the System

The BLM fixed display application, see Figure 3, provides monitoring of the real time losses and abort thresholds for all monitors around the LHC ring. It therefore provides with an “in-situ” validation that the deployed set of thresholds have been modified according to expectations. The dependence of the abort thresholds with integration times, however, can only be visually checked for each monitor independently. Therefore, this test is only feasible when the number of monitors affected by the change is small. Furthermore, the fixed display only shows the abort thresholds at the current LHC energy level.

Figure 4 shows the abort thresholds at collision energy before (a) and after (b) a large threshold modification campaign that took place before the beginning of the 2011 run. This is a visual comparison but allows the checking of abort thresholds for a large number of monitors at the same time. The test is typically performed exclusively for monitors that are scheduled to be changed. The very last test consists of using the LSA database functionality to request the number and type of modification that have been implemented since a reference date. This check complements the ones described above and ensures that unscheduled modifications are not performed by accident.

Future Tests

Despite the large number of checks defined by the BLM team there is still room for improvement in the testing procedure, since a significant fraction of the existing checks rely on visual verification. The current efforts on threshold testing is therefore being focused on automation.

The Management of Critical Settings (MCS) check is an on request test that the operators execute after the settings of any of the related LHC equipment has been modified or manipulated and is automatically required every 24 hours if not done. During this test the Front End Computers read all

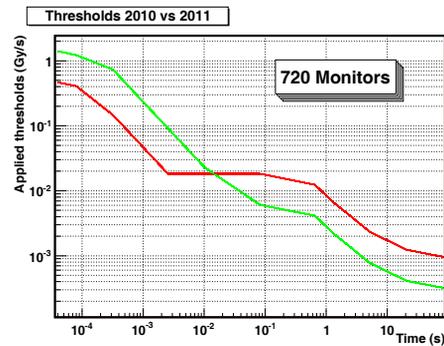


Figure 4: Applied thresholds before (red) and after (green) modification. The thresholds correspond to 720 monitors protecting main quadrupoles in the arcs.

the currently used parameters, in our case the BLM abort thresholds, by increasing the LHC energy levels. The foreseen test will request the BLM abort threshold recorded during two consecutive MCS checks allowing for comparison and detection of threshold changes in any of the BLM monitors.

Signals that are observed to be over the abort threshold but did not produce any damage on the equipment or quench of a SC magnet may be used to tune the BLM abort thresholds. A continuous comparison of the observed signals in all 12 integration with the corresponding abort thresholds is also foreseen. The last schedule test is based on the comparison of abort thresholds with respect to neighboring monitors rather than reference values. This will show locations around the LHC ring where large differences in neighboring BLMs could become a limiting factor from the operational point of view.

CONCLUSION

About $1.3 \cdot 10^6$ abort thresholds extremely critical for the safety of the machine need to be computed, tested and sent to the hardware. A specific procedure is followed when a new set of thresholds need to be implemented into the system. The BLM effort is currently concentrated in the automation of the exiting test and the implementation of techniques that allow for tuning of the abort thresholds by using data collected during the LHC operation.

REFERENCES

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