BEAM LOSS MONITORING FOR RUN 2 OF THE LHC

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Abstract

The Beam Loss Monitoring (BLM) system of the LHC consists of over 3600 ionization chambers. The main task of the system is to prevent the superconducting magnets from quenching and protect the machine components from damage, as a result of critical beam losses. The BLM system therefore requests a beam abort when the measured dose in the chambers exceeds a threshold value. During Long Shutdown 1 (LS1) a series of modifications were made to the system. Based on the experience from Run 1 and from improved simulation models, all the threshold settings were revised, and modified where required. This was done to improve the machine safety at 7 TeV, and to reduce beam abort requests when neither a magnet quench nor damage to machine components is expected. In addition to the updates of the threshold values, about 800 monitors were relocated. This improves the response to unforeseen beam losses in the millisecond time scale due to micron size dust particles present in the vacuum chamber. This contribution will discuss all the changes made to the BLM system, with the reasoning behind them.

BEAM LOSS MONITORING SYSTEM

Energy deposition from beam losses can cause a quench of the superconducting LHC magnets or even lead to damage. The main protection against this is provided by the Beam Loss Monitoring (BLM) system. The BLM system consists of almost 4000 detectors spread around the LHC ring. The main detector type is an Ionization Chamber (IC), which are 50 cm long with an active volume of 1.5 l, filled with N_2 at 100 mbar overpressure. The detectors are parallel plate chambers with 61 circular aluminium electrodes of diameter of 7.5 cm, separated by a drift gap of 0.5 cm [1].

To cover the full dynamic range in locations with high losses, the ICs are installed in parallel to other less sensitive monitor types: Secondary Emission Monitors (SEM) or Little Ionization Chambers (LIC). Both are based on the same geometry as the ICs, but consist of only of three electrodes. The LICs have the same properties as the ICs but due to the reduced volume are 60 times less sensitive, while the SEMs operate in a 10^{-7} mbar vacuum and are 70,000 times less sensitive than the ICs.

For the start of Run 2, only the ICs are connected to the Beam Interlock System (BIS) [2] and able to give beam abort requests. The two other detector types are installed for monitoring purposes only.

NEW INSTALLATIONS

Relocation of Monitors

The operation of the LHC during Run 1 was affected by losses on the millisecond time scale. These losses are suspected to be provoked by dust particles falling into the beams, so-called Unidentified Falling Objects (UFOs) [3-4]. UFO events are seen as the most likely loss scenario in the LHC arcs during Run 2. Based on measurements performed with secondary particles generated by the beam wire scanner, it is calculated that the resulting signal of a UFO event at 7 TeV will be about 3 times higher than at 3.5 TeV [5].

To improve the response and the protection of the magnets against UFO losses, 816 ionization chambers were relocated from the quadrupole magnets (MQ) onto the intersection of the bending magnets (MB) in the arcs and dispersion suppressors (DS) of the LHC. Figure 1 shows how the existing BLMs were relocated. Figure 2 shows a monitor at the new location on top of a dipole-dipole interconnection. In this new location, the detectors monitor the losses from both beams.

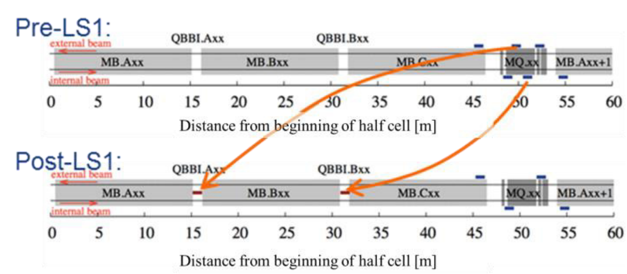

Figure 1: Relocation of beam loss monitors in the LHC arcs.

New Installations and Replacement of SEMs with LICs

SEMs are installed in parallel with the ICs to extend the dynamic range of the system towards higher dose rates to avoid saturation of the detector or electronics [6]. During Run 1 it was seen that in the events which surpassed the dynamic range of the ICs, the signal from the SEMs was still dominated by noise and no proper measurements could be made. Thus the SEMs were replaced with LICs in several locations. To further increase the dynamic range of the LICs, they are installed with RC filters connected. These filters reduce the peak amplitude for short losses, stretching the length of the signal by a factor depending on the values of the RC circuit.

In addition to these replacements, new monitors were installed in the locations which were seen to have been missing monitors during Run 1, e.g. additional monitors for ion losses, or where new equipment was added such as the new collimators or Roman Pots installed during LS1. A total of 50 new monitors were installed.

Figure 2: A relocated BLM on the transition between two dipole magnets.

Changes to the Injection Regions

For the injection regions a set of RC filters were added to the monitors to avoid saturation from the short losses observed during the injection process. In certain locations where the ICs would still be expected to saturate even with filters, they were replaced by LICs to obtain a factor 10 increase in the dynamic range.

Some of the filtered ICs were connected to special "blindable" crates. The "blindable" option allows the selected BLMs to be blocked from giving a beam interlock request during the injection process. After the injection the monitors return to normal operation. This was done as a result of issues observed with losses coming from upstream in the transfer lines, which could lead to a dump of the circulating beam in the LHC. The need for this "blindable" option is being studied in conjunction with the stability of the injection process during the first part of Run 2 [7].

BEAM ABORT THRESHOLDS

The main goals of the BLM system are to avoid quenching the superconducting magnets and to prevent damage from beam losses [8]. This is done by requesting a beam abort when the losses cross a predefined threshold. The thresholds are optimised such that the protection functionality does not reduce the LHC machine availability.

The signal observed for a beam loss provoking a magnet quench can be calculated as follows:

$$BLM_{signal}(E,t) = \frac{BLM_{response}(E,t) \times QuenchLevel(E,t)}{EnergyDeposit(E,t)}, \quad (1)$$

where $BLM_{response}$ is the dose in the BLM per lost proton, *QuenchLevel* is the energy required to quench a magnet and *EnergyDeposit* is energy deposited in the magnet per lost proton. The input values arebased on FLUKA [9]and QP3 [10] simulations which were fine-tuned through quench test measurements [11-12].

BLM_{signal} can be used to set levels for protecting with the BLMs. These values are called Master Threshold values (MT) and are calculated as:

$$MT(E,t) = N \times BLM_{signal}(E,t) \times f_{corr}, \quad (2)$$

where N is a safety factor that ensures the threshold levels are below the quench level. Currently the value is set to 3. f_{corr} accounts for corrections that are applied to adjust for effects from electronics, filters, injection losses etc., and for adjustments based on dedicated tests and experience from operation.

The final thresholds, the Applied Thresholds (AT), are obtained by multiplying the master thresholds with a factor that is specific to each monitor, the Monitor Factor (MF):

$$AT = MT \times MF. \quad (3)$$

The monitor factor can be a value between 0 and 1 and allows fast adjustments of the threshold values during operation.

The BLM system integrates the signals produced by beam losses in 12 different time intervals (running sums, RS), spanning from 40 μs to 83.8 s. Furthermore, the system takes into account 29 energy steps from 0 to 7 TeV.

The thresholds are grouped in families based on the element they are protecting and the position of the monitor with respect to the protected element. All the monitors in each family have identical master thresholds.

THRESHOLDS FOR RUN 2

During LS1, all the threshold values that were used in Run 1 were re-evaluated. Improvements in FLUKA and QP3 simulations and experience from Run 1 showed that new underlying models for threshold calculations were needed. Due to this, most of the thresholds for Run 2 are completely new.

Since the losses from Beam1 and Beam2 were found to be identical, the division based on beam was removed. In addition, the number of SEM and LIC families is initially reduced to one, each with threshold limits set to the maximum of the electronics limit. These settings might change during Run 2 based on operational experience.

Based on the observations of the UFO losses during Run 1, quench tests and new simulation models, it was seen that the relocated monitors could all have the same threshold settings and be placed in a single threshold family. Since a UFO loss is now the most probable loss scenario in the LHC arcs, all the quadrupole BLM families in the arcs and dispersion suppressor region were also modified to protect against UFO losses.

Figure 3 shows a comparison of the Run 1 and Run 2 thresholds for one of the BLM monitors on the main quadrupoles in the arc. In general the new thresholds are at the same level or higher than the old ones.

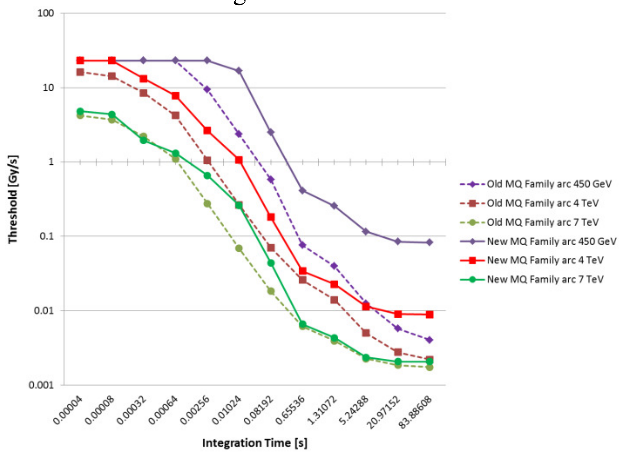

Figure 3: Comparison of Run 1 and Run 2 thresholds for BLM monitors on the main quadrupoles in the arc. The new thresholds are marked with a continuous line.

From the comparison with the old thresholds it can be seen that the new thresholds are very similar to the old ones, even though they are based on very different models. This is due to the fact that the old thresholds were corrected with data during Run 1 using the results of various tests and operational experience. This similarity can be seen as a first level of validation of the new thresholds, which will be further improved during Run 2 with the adjustments based on operational data at higher beam energies.

NEW BEAM ABORT THRESHOLD CALCULATION TOOLS

During Run 1 the thresholds were produced by a set of C++ scripts executed interactively in ROOT. To change the thresholds, the scripts were modified and the output then uploaded into the LHC Software Architecture (LSA) database [13-14] using a Java API interface. This type of modification required detailed bookkeeping of the changes and was clearly a potential source of human error. To reduce the possibility for mistakes, a new tool to calculate the thresholds at the database level was designed and introduced during LS1 [15].

With the new tool, new models and calculation methods can be introduced into the database via specific templates or in a table format. For instance the QP3 output can be written-in directly in a table format to be used as quench level values in Equation 1. The user then selects the set of parameters and methods via the interface, adds corrections and launches the calculations.

Comparison of the calculated thresholds against the previously calculated values or against other families can also be done. In addition, the calculator can retrieve the monitor factor parameters from the database to allow a comparison to the applied values. This can also be done for the historic valuesof all families. Figure 4 shows an example of a comparison of applied threshold values for the threshold families of Fig. 3.

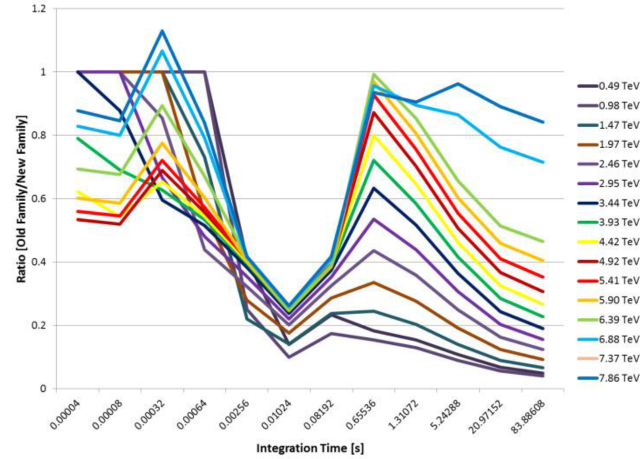

Figure 4: Comparison of the difference between old and new threshold settings. From the plot it is easy to see in which running sums and for which energy level the main changes have been applied.

CONCLUSIONS

The BLM system of the LHC has been updated during LS1 to improve the protection of the elements for the increased operation energy of Run 2. New monitors were installed and existing monitors relocated to better respond to the losses foreseen at this unprecedented energy. All the threshold values that were used during Run 1 were also reviewed and modified where required.

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