First experiences with the LHC BLM sanity checks

2010 JINST 5 C12044

(http://iopscience.iop.org/1748-0221/5/12/C12044)

PUBLISHED BY IOP PUBLISHING FOR SISSA

RECEIVED: *October 15, 2010*
ACCEPTED: *November 27, 2010*
PUBLISHED: *December 20, 2010*

TOPICAL WORKSHOP ON ELECTRONICS FOR PARTICLE PHYSICS 2010,
20–24 SEPTEMBER 2010,
AACHEN, GERMANY

2010 JINST 5 C12044

First experiences with the LHC BLM sanity checks

J. Emery,[1] B. Dehning, E. Effinger, A. Nordt, M.G. Sapinski and C. Zamantzas

CERN,
CH-1211 Genève 23, Switzerland

E-mail: Jonathan.emery@cern.ch

ABSTRACT: The reliability concerns have driven the design of the Large Hardron Collider (LHC) Beam Loss Monitoring (BLM) system from the early stage of the studies up to the present commissioning and the latest development of diagnostic tools. To protect the system against non-conformities, new ways of automatic checking have been developed and implemented. These checks are regularly and systematically executed by the LHC operation team to ensure that the system status is after each test "as good as new". The sanity checks are part of this strategy. They are testing the electrical part of the detectors (ionisation chamber or secondary emission detector), their cable connections to the front-end electronics, further connections to the back-end electronics and their ability to request a beam abort. During the installation and in the early commissioning phase, these checks have shown their ability to find also non-conformities caused by unexpected failure event scenarios. In every day operation, a non-conformity discovered by this check inhibits any further injections into the LHC until the check confirms the absence of non-conformities.

KEYWORDS: Control and monitor systems online; Beam-line instrumentation (beam position and profile monitors; beam-intensity monitors; bunch length monitors)

[1]Corresponding author.

doi:10.1088/1748-0221/5/12/C12044

Contents

1 LHC BLM overview

The Beam Loss Monitoring (BLM) system for the Large Hadron Collider (LHC) has been designed to protect the machine equipments against unintended energy deposition by losses especially on the superconducting magnets. When a partial loss of the proton beam around the ring exceeds a predetermined threshold, the system sends a beam abort request, which will result in a complete dump of both beams. In addition to the protective functionality, the system is used as measurement instrument for various studies and fine tuning of the accelerator.

1.1 Hardware

There are about 4000 monitors around the 27km of the LHC tunnel ring. The most wildly used detector type is the ionisation chamber, which is supplied by high voltage and produces a current proportional to the received particles with a high dynamic range (10e9).

The signal of 8 of these detectors is integrated and digitalized every 40μs by the Current to Frequency card (BLECF) [1] with a dynamic range of about 10e8 (10pA to 1mA). The resulting data are transmitted to the surface through a redundant optical link to the Threshold Comparators card (BLETC) [2]. This card produces longer integration windows up to 80s and continuously compares these values to predefined thresholds. Additionally, this card processes the maximum of these running sums every second for display and long term logging. In the case of losses above the thresholds, the card inhibits the beam permit signal, which is sent to the Combiner and Survey card (BLECS) and transmitted further to other systems to abort the beam. This last card also takes care of various checks sequences including the sanity checks.

The figure 1 gives a complete hardware overview from the ionisation chambers placed in the tunnel (left) to the external systems (right). Users of the produced information like databases

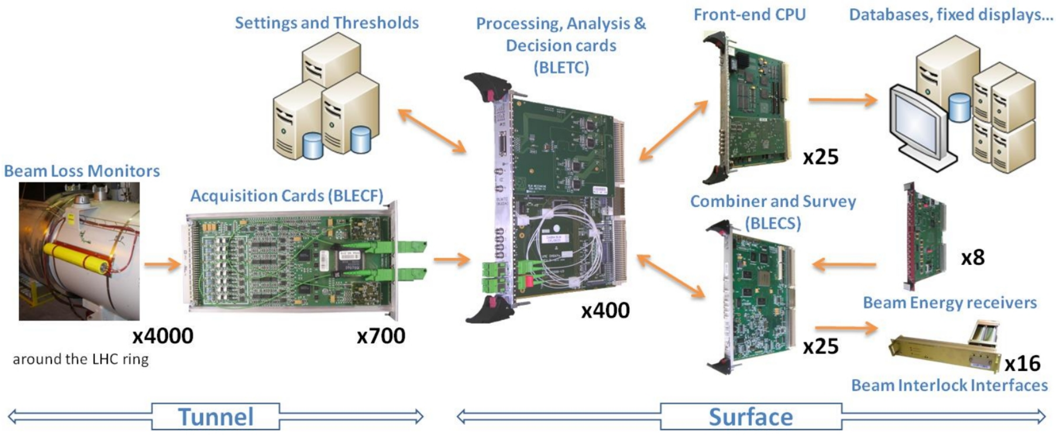

Figure 1. Overview of the LHC BLM hardware system.

or operational applications are connected to the front-end CPU (top-right). The beam interlock interfaces and the beam energy receiver are connected to the BLECS (bottom-right).

1.2 Reliability

The reliability concerns have driven the design and implementation of the LHC BLM system. The PhD thesis of G. Guaglio [3] has introduced the calculation of the failure rate of the main components. Based on this first results, failure scenarios have been identified and strategies to minimize them have been developed. The component reception procedures, installation and yearly maintenance, regular checks and continuous checks are the areas where various actions have been taken.

The focus of this paper is on the regular checks of the hardware, combined under the name sanity checks. The idea is to reduce as much as possible the probability of a failure event leading to an incident by detecting non conformities on the system before a problematic situation occurs. To achieve this goal, the system should be checked as often as possible without reducing significantly the availability (the system is unavailible when being checked). The regular check of the settings, called online check [4], which ensures the consistency between settings held inside the front-end and in the LHC Software Architecture (LSA) database will not be covered. To enforce the triggering of these procedures, hardware timers are implemented. If not triggered at least every 24h, the next injection in the LHC will be blocked through the beam permit lines connecting to the Beam Interlock System (BIS).

2 Sanity checks

As previously introduced, the sanity checks are the procedures which are regularly running to ensure that the hardware is in a defined state, i.e. "as good as new". In case of a detected non-conformity, the beam permit is not given back and no injections in the LHC can be performed. The internal beam permit check and the connectivity check [5] are the different parts of this procedure.

2010 JINST 5 C12044

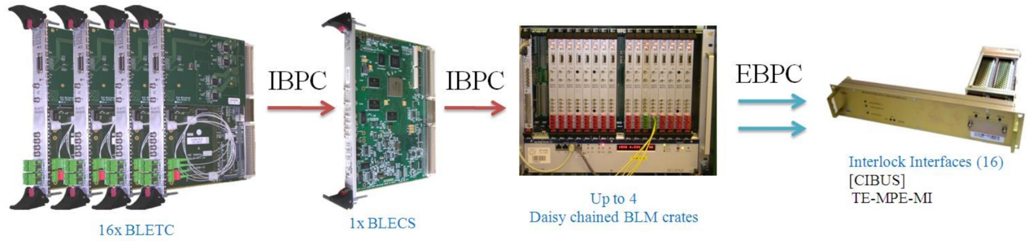

Figure 2. The Internal Beam Permit Check (IBPC) tests the beam permit links of the BLM system; the External Beam Permit Check (EBPC) tests the connections from the BLM to the interlock system.

2.1 Internal and external beam permit check

The Internal Beam Permit Check (IBPC) ensures that all Thresholds Comparators cards are able to request the beam dump by checking if the signal is correctly passed through the daisy chain interconnecting the cards. To perform this check, the processing has been introduced in the Field-Programmable Gate Array (FPGA) of the Combiner card. All the Threshold Comparators are requesting the beam dump one after each other and the FPGA checks that these signals are propagated to all the interconnected BLM crates (figure 2). The External Beam Permit Check (EBPC) tests the connection between the BLM system and the machine interlock interface; this function is under the responsibility of the Beam Interlock System (BIS).

2.2 Connectivity check

The primary purpose of this check is to ensure the integrity of the cabling of each beam loss detector. By adding a small harmonic modulation signal (0.06Hz, 30V) on the high voltage supply of the detector (1500V), it is possible to detect a small current on the measurement side. If anywhere in the signal chain a cable is missing, disconnected or discontinued for any reason, the measurement will not show any harmonic variation of the current.

The second goal is to survey the integrity of the components. The measured amplitude and phase of every channel (detector or spare) is compared to a predefined threshold measured for every channel. If one of them is outside the limits, the beam will not be permitted in the LHC.

This procedure takes place in the Combiner card FPGA. For this purpose the acquisitions data are written by the front-end CPU onto the memory of the FPGA. In the FPGA digital filtering is applied, as well as amplitude and phase recognition and finally threshold comparisons against the predefined reference database (LSA) settings.

The entire signal period of each channel is also saved into the volatile memory of the card. A dedicated application has been developed to download, save and analyze the information and display channel signals. It also generates warnings when signals are getting close to the accepted limit. In addition it is possible to display individual or groups of channels for observation.

2.3 Optimization of the connectivity check

Since the first presentation of this technique [5], optimisation has been applied to minimize the influence of the check to the system and improve the measurement repeatability.

2010 JINST 5 C12044

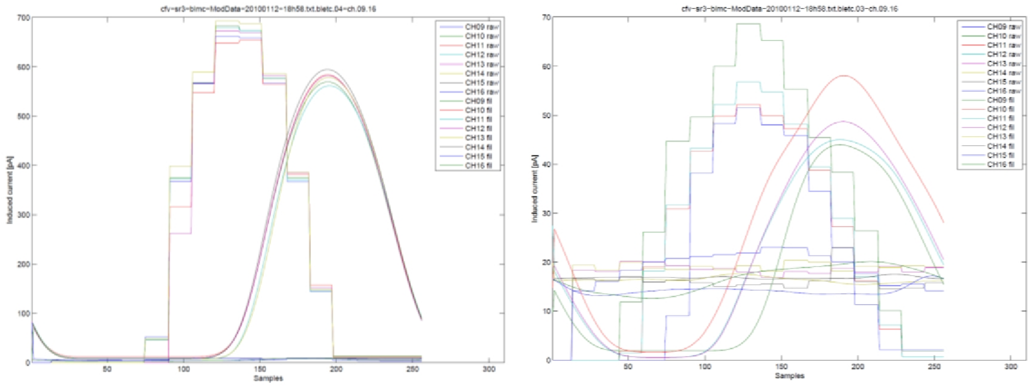

Figure 3. Volatile memory data for IC (left) and SEM (right). The raw data received from the CPU (stairs) are smoothed by a low pass filter (FIR) before amplitude and phase determination.

The harmonic amplitude excitation has been doubled to increase the signal to noise ratio on the secondary emission monitors (10 times smaller than the IC). To avoid a too long lasting negative induced current on the IC (the lower part of the sinus is now truncated) the frequency of the modulation has been doubled. Systematic measurements have shown very good reproducibility even with a truncated signal and an improved signal to noise ratio with the SEM.

The second part of the improvements concerns the digital processing. The parameters of the low pass filter were optimized to improve the smoothing of the "stairs" introduced by the signal quantification and the rejection of unwanted parasitical frequencies (figure 3). The base offset subtraction to the calculated peak to peak amplitude has been introduced to minimize the error introduced by the variation of this base offset.

2.4 Reproducibility of measurements

To measure the reproducibility of the connectivity check, 100 executions were performed in a row. Root and python scripts were used to extract the measured data from the databases to perform statistical calculation. Figure 4 shows the results for the IC (top) and the SEM (bottom) by two dimensional representations. The standard deviation over the 100 checks is plotted versus amplitude (left) and phase (right). As expected, the amplitude repeatability of the IC is better than for the SEM since the signal is about 10 times higher. The difference in amplitude can be explained by the differences in the equivalent circuit capacitance, 312pF (IC) and 22pF (SEM) [5]. Structures can be observed on the IC phase plot (right-top) which are due to sampling frequency (resulting by 1.4 [deg] of resolution).

3 Non-conformities

During the commissioning of the LHC BLM installation in 2009 and during the early stage of the operation, multiple types of non-conformities have been detected by the connectivity check. The table 1 highlights the occurrences of these events and the resulting signal deviation from the expected behaviour. Comparing these values with the reproducibility presented in 2.4, we can conclude that they can easily be detected by this technique.

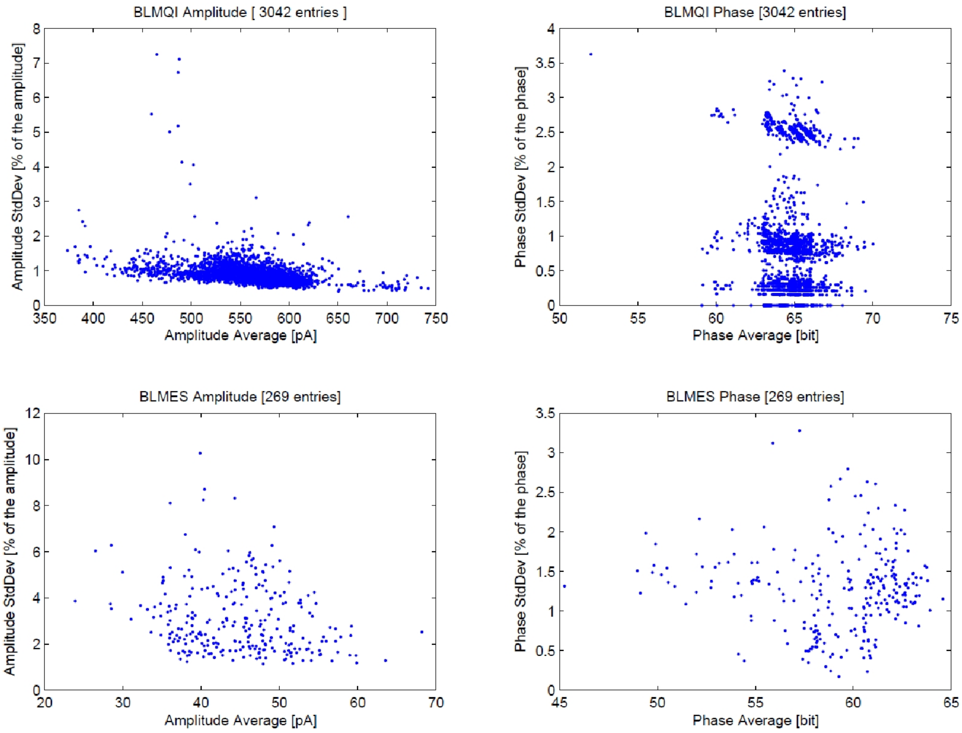

Figure 4. Connectivity check measurements for the IC (top) and SEM (Bottom).

Table 1. Non-conformities detected with the connectivity check since spring 2009.

Type of non-conformity	Occurrence	Modified parameter	Deviation from the expected behavior	IC parameters sensitivity
Chamber filter badly soldered or disconnected	27	Phase and amplitude	9%-33%	3% and 2%
Tunnel card (BLECF) non-conform behavior on one or more channel	4	Phase	10%-30%	3%
Monitor not supplied with high voltage	4	Phase and amplitude	Large	3% and 2%
Connection of monitor on the wrong channel	3	Phase and amplitude	Large	3% and 2%
High voltage distribution box	1	Phase and amplitude	Large	3% and 2%

The most frequent non-conformities are related to the chamber high voltage input filter. The soldering on the ground pin was not done as expected. Environmental condition stresses this weak point which then fails randomly. Figure 5 shows an example of this non-conformity. Following this, all the 459 spares in stock were opened for inspection and about 10% showed various soldering non-conformities. By knowing the parallel capacitor value (470nF) and the measurement repeatability (1-3%), the measure sensitivity for this particular component has been estimated to be around 10% of its initial value (i.e. 50nF).

2010 JINST 5 C12044

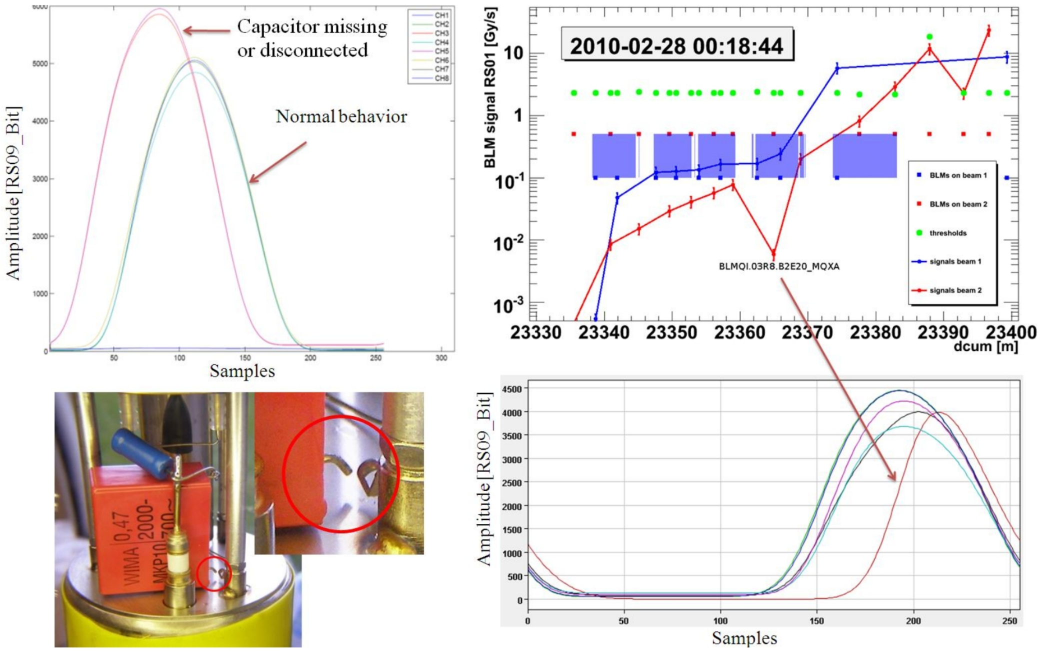

Figure 5. Modulated signal (left-top) with a non-conformity on the HV input filter shown on the detector (left-bottom). Detector sensitivity loss due to non-conformity of the tunnel card discovered by measurements with beam (right-top) and confirmed by the connectivity check (right-bottom).

A second interesting case has been identified during a beam test. A detector was identified to have lost sensitivity. Figure 5 (right-top) shows the beam loss signal for different detectors versus their physical position. The detector with a smaller signal than expected is identified with its name. Below, the modulation of this detector shows a clear difference with the others (10% phase difference). This was due to non-conformity on the tunnel board analog circuit. Such changes can accurately be measured and monitored by the connectivity check.

4 Summary

The sanity checks are parts of the global strategy of high reliability of the LHC BLM system. They are checking regularly the hardware and searching for non-conformities on the detector cabling and its internal parts. The link to the beam interlock system to inhibit the next injection in case of non-conformity and the integration of their executions into the LHC sequencer has been completed during the shutdown 2009-2010. It ensures the regularity of their executions mandatory for the luminosity increase toward the nominal operation of the LHC. After few months of operating them on a daily basis, the stability of the procedures and the reproducibility of the measurements have been confirmed. The accuracy of the connectivity check results obtained by the optimization of the parameters and the signal processing has enabled the detection of unexpected variation of components values. It extended the use of this check to the detection of non-conformity on the high voltage filter of individual ionization chambers as well as specific decrease of the sensitivity of the current to frequency card. In addition to these unexpected features, the detection of disconnected

2010 JINST 5 C12044

detector has been confirmed by real case in the LHC tunnel. The fast execution time of about 6 minutes has allowed these checks to become a convenient way of regularly checking the conformity of the cabling as well as multiple hardware parts of the LHC BLM system.

References

[1] E. Effinger et al., *The LHC beam loss monitoring system's data acquisition card*, talk given at the 12th *Workshop on Electronics for LHC and future Experiments (LECC06)*, September 25–29, Valencia, Spain (2006), online at http://cdsweb.cern.ch/record/1027422/files/p108.pdf.

[2] C. Zamantzas et al., *An FPGA based implementation for real-time processing of the LHC beam loss monitoring system's data*, *IEEE Nucl. Sci. Symp. Conf. Rec.* **2** (2006) 950.

[3] G. Guaglio, *Reliability of the beam loss monitor system for the Large Hadron Collider at CERN*, Ph.D. Thesis, University Clermont-Ferrand II-Blaise Pascal, Clermont-Ferrand, France (2005).

[4] C. Zamantzas et al., *Configuration and validation of the LHC beam loss monitoring system*, in the proceedings of the 9th *European Workshop on Beam Diagnostics and Instrumentation for Particle Accelerators (DIPAC09)*, May 25–27, Basel, Switzerland (2009), online at http://dipac09.web.psi.ch/Proceedings/papers/tupb31.pdf.

[5] J. Emery et al., *LHC BLM single channel connectivity test using the standard installation*, in the proceedings of the 9th *European Workshop on Beam Diagnostics and Instrumentation for Particle Accelerators (DIPAC09)*, May 25–27, Basel, Switzerland (2009), online at http://dipac09.web.psi.ch/Proceedings/papers/tupd26.pdf.

2010 JINST 5 C12044