CONFIGURATION AND VALIDATION OF THE LHC BEAM LOSS MONITORING SYSTEM

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Abstract

The LHC Beam Loss Monitoring (BLM) system is one of the most complex instrumentation systems deployed in the LHC. As well as protecting the machine, the system is also used as a means of diagnosing machine faults, and providing feedback of losses to the control room and several systems such as the Collimation, the Beam Dump and the Post-Mortem. The system has to transmit and process signals from over 4’000 monitors, and has approaching 3 million configurable parameters.

This paper describes the types of configuration data needed, the means used to store and deploy all the parameters in such a distributed system and how operators are able to alter the operating parameters of the system, particularly with regard to the loss threshold values. The various security mechanisms put in place, both at the hardware and software level, to avoid accidental or malicious modification of these BLM parameters are also shown for each case.

INTRODUCTION

The Large Hadron Collider (LHC) is the next circular accelerator being constructed at the European Organisation for Nuclear Research (CERN). It will provide head-on collisions of protons at a centre of mass energy of 14 TeV for high energy particle physics research. In order to reach the required magnetic field strengths, superconducting magnets cooled with superfluid helium will be used. The energy stored in the LHC can potentially damage many elements of the accelerator or could make its operation very inefficient.

The strategy for machine protection and quench prevention of the LHC is mainly based on the Beam Loss Monitoring (BLM) system. At each turn, there will be several thousands of data to record and process in order to decide if the beams should be permitted to continue circulating or their safe extraction is necessary to be triggered. The decision involves a proper analysis of the loss pattern in time and a comparison with predefined threshold levels that need to be chosen dynamically depending on the energy of the circulating beam. This complexity needs to be minimized by all means to maximize the reliability of the BLM system and allow a feasible implementation. The processing of the acquired data and the comparison with predefined threshold levels is needed to be performed in real-time and thus requires dedicated hardware to meet the demanding time and performance requirements.

To overcome such limitations, a great effort has been committed to provide a highly efficient, reliable and feasible implementation of the BLM system by employing various state of the art techniques in analogue and digital electronics, databases and computing, which include redundancies and optimizations across all of its levels of abstraction.

SYSTEM CONFIGURATION

The BLM system is making use of modern field programmable gate arrays (FPGAs), which include the resources needed to design complex processing and can be reprogrammed making them ideal for future upgrades or system specification changes. There is a common FPGA firmware that is deployed to all crates at the Front-End Computer’s (FEC) boot procedure or if required could be read from the flash memory on power on.

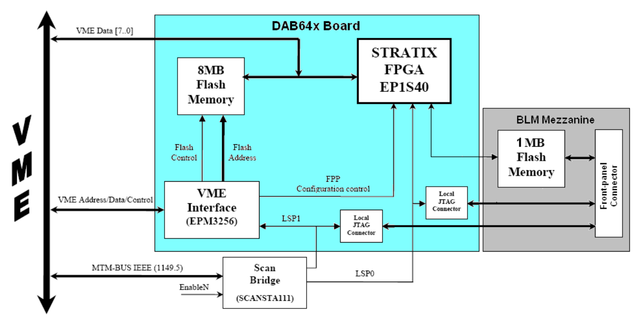

Figure 1: Block diagram of the FPGA firmware deployment and initialisation options.

More specifically, the FPGA configuration can be forced to be loaded either remotely via the FEC and the VME bus, locally via the JTAG connection that is provided in the front panel, or set to auto-configurable by utilising the on-board memory. Figure 1 shows a block diagram of the interconnections in the Threshold Comparator (BLETC) module.

The dataset of thresholds and settings for the complete BLM system during the deployment procedure is split to the relevant parameters for each module. In that way, they include only information which is unique for each monitor, crate or sector that the module will need to protect. Among those it includes the monitor names, their threshold values, the serial numbers for the BLETC and the two acquisition modules [1] which are connected to it, as well as the Connection and Masking matrices. Table 1 shows the complete list of the parameters stored on each processing module.

These channel and board specific parameters are stored in the normally unused space of the configuration memory

Table 1: Parameters Deployed on Each BLETC Module

Name	Data (x32bit)	Description
Thresholds	8192	Threshold values table (16 channels x 12 Running Sums x 32 Energy Levels)
Channel Connected	1	Channel definition: CONNECTED / DISCONNECTED from the BIS
ChannelMask	1	Channel definition: "MASKABLE"/"UNMASKABLE"
BLECF Serial A	1	Acquisition Card's Serial Number (for Channels 1-8)
BLECF Serial B	1	Acquisition Card's Serial Number (for Channels 9-16)
BLETC Serial	2	Threshold Comparator's Card Serial number
BLETC Firmware Version	1	Threshold Comparator's Firmware Version
Expert Monitor Names	128	Expert Monitor Names for the 16 channels.
Official Monitor Names	128	Official Monitor Names for the 16 channels.
DCUM	16	DCUM Numbers of each channel
Family Names	128	Threshold Family Name of each channel
Monitor Coefficients	16	Monitor Threshold Coefficient for each channel
Last LSA Modification	2	Timestamp: Last Modification of the MASTER table in LSA database
Last Flash Modification	2	Timestamp: Last Modification of the non volatile on-board memory
Flash Checksum	1	CRC value for/from the FEC to check the table integrity.
Total	8620	

taking advantage of the high reliability and the non volatile properties of the particular flash memory.

After the initialisation of the module an FPGA process fetches the data from the flash space and makes a local copy in its embedded memory. By design, the processing electronics provide the functionality to update remotely the stored parameters and if safety reasons require it, only local updates can be enforced by an on-board switch. The new settings are loaded from the memory on the FPGA either on request or at the next boot.

STORAGE OF SETTINGS

In order to collect and verify the vast amount of data necessary as well as to automatise the procedure and minimise the errors in future changes several databases have been employed. Those include the Manufacturing and Test Folders (MTF), the LHC Layout and the LHC Software Architecture (LSA) databases.

Initially the data are imported in MTF and are copied and linked together after scrutinous verification to the Layout. The latter provides hierarchical views of the system as well as information on the position in the tunnel and with respect to all other elements of the LHC (see [3]). The complete dataset can be one-way synchronised to LSA where it is split into tables to hold information for each monitor, crate or sector. All the final configuration parameters have been chosen to be stored in LSA, which is the settings management system at CERN. It has been built with high availability in mind and provides significant features like strong security, detailed history of changes, and roll-back to a previous state.

STAGE and FINAL Tables

The LSA database structure uses data staging – the BLM parameters exist in STAGE and FINAL tables. The STAGE tables allow BLM experts to load parameters available from the Layout database, to add the threshold values, and perform consistency checks before persisting the data to the FINAL tables. A dedicated database procedure is used to commit changes made in the STAGE tables to the FINAL tables. Many constraints (rules governing the data) have been implemented within the database to ensure data integrity.

MASTER and APPLIED Tables

The MASTER table content is produced by a database procedure, which combines the data of the various FINAL tables. The threshold values appearing in this table correspond to the absolute limits known from simulations and measurements to protect the different elements from damage.

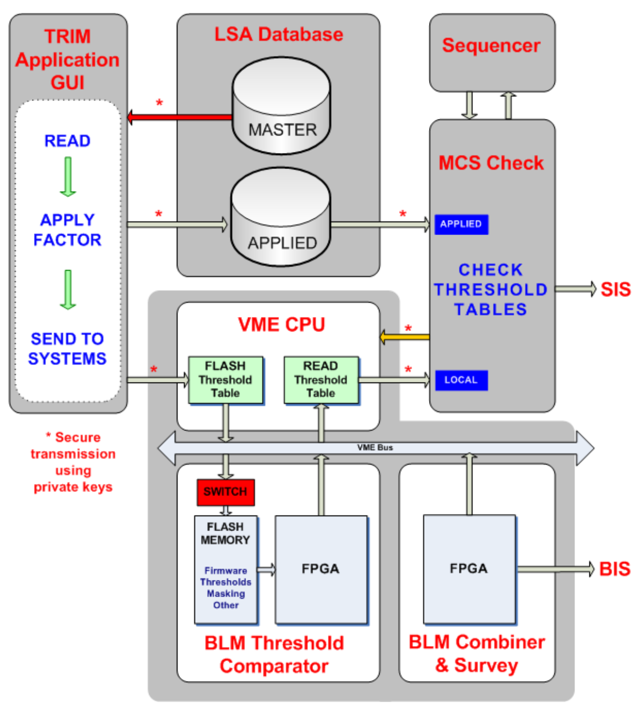

Figure 2: Block diagram of the data flow for the parameters configuration and verification.

A further process triggered by the operators reads the MASTER table, applies unique per monitor threshold coefficients (always < 1) and saves the new table as the APPLIED table. The latter is the table that the FEC sends to the FPGA, if allowed by a role based access system and the on-board switch in the processing electronics. In that way, operators and domain experts can readjust by scaling down the individual threshold values of each monitor, if this is found necessary, without impairing the protection characteristics of the system.

SYSTEM VALIDATION

The overall reliability of a system is augmented by checking as often as possible whether its functionality and performance has remained unchanged. For this reason, several checks have been integrated in the BLM system that either loop continuously or, for those tests that need to alter inputs or outputs of the system, are performed on request when the operation of the accelerator permits. The ‘on-request’ checks are initiated by the LHC Sequencer before each fill and are dictated to run at regular intervals by the Combiner and Survey (BLECS) module which can disallow a new beam to be injected in the machine.

Continuous Checks

The acquisition chain is tested using a 10pA test signal that is measured directly in the tunnel card. A status flag is raised if there is no response because of the injected signal within 100 seconds. This status flag is caught by the BLETC.

A continuous check of the connectivity and the error-free transmission between the acquisition and the processing modules is based on the double optical line, the embedded information in the packets and two error detection techniques [2], i.e. CRC32 and 8b/10b encoding.

Similarly, the Beam Energy reception is continuously checked and in the case of errors or disconnections the system defaults to the strictest threshold values, i.e. those for the highest energy.

The correct card assignment is performed by checking the embedded serial numbers arriving with every packet against those stored in the database. This function indirectly also checks continuously the correct channel assignment.

A continuous integrity check of the on-board memory that holds the threshold and settings tables is performed by the FEC, currently once per minute, that is able to discover corruption of the parameters.

On Request Checks

The Management of Critical Settings (MCS) Online Check is performed additionally after every update of the crates. The initiated test allows the FEC to read all the currently used parameters by incrementing the energy levels and recording the used threshold values. It subsequently transmits them to the MCS Online Check for comparison. Both the FEC and the Software Interlock System (SIS) receive the PASS/FAIL result.

With the purpose of discovering disconnected or failed channels a modulation of the high voltage supply of the detectors is initiated. (see [4])

The correct operation of the acquisition electronics is tested by enabling a signal of 100 pA to be injected on each input. The BLECS is able to detect the change by using the 1.3 second integrated values recorded.

The ability of the BLETC to generate a beam dump request signal for each of the ‘maskable’ and ‘un-maskable’ outputs, and its correct reception by the BLECS is tested by utilising dedicated backplane lines on each crate to issue commands.

Similarly, the correct beam dump requests transmission between the BLECS and the Beam Interlock system (BIS) is tested. In this case the request is transmitted over the ethernet connection available in the FEC.

CONCLUSIONS

In consequence, by performing its requested tasks the BLM system is able to have a constant and very detailed view on the state of the whole machine. This is supported by the back-end infrastructure of the databases, processes and applications to set up and verify its operation as well as to provide failsafe modifications in the future.

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