PRE-OPERATION, DURING OPERATION AND POST-OPERATIONAL VERIFICATION OF PROTECTION SYSTEMS

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Abstract

This paper will provide an overview of the software checks performed on the Beam Interlock System ensuring that the system is functioning to specification. Critical protection functions are implemented in hardware, at the same time software tools play an important role in guaranteeing the correct configuration and operation of the system during all phases of operation. This paper will describe tests carried out pre-, during- and post-operation, if protection system integrity is not sure, subsequent injections of beam into the LHC will be inhibited.

INTRODUCTION

In order to prevent damage in the Large Hadron Collider (LHC) due to uncontrolled beam losses or failures, a Machine Protection System has been implemented which detects potential dangerous situations and eventually extracts the circulating proton beam of the machine into a graphite absorber. The heart of this system is the Beam Interlock System (BIS) [1] which allows a fast and reliable transmission of beam dump requests to the LHC Beam Dumping System (LBDS).

The BIS has been designed as a highly dependable system, meaning that a failure of the BIS could lead to a sequence of events that result in a significant damage of the LHC. To prevent this and in order to verify the integrity of the BIS, a set of operational checks have been implemented.

MOTIVATION

To protect the LHC ring from beam damage the BIS relies on 17 Beam Interlock Controllers (BIC) installed in the underground areas spanning over more than 27 km. The BICs are linked using redundant optical fibres which define the Beam Permit Loops (BPL). These loops propagate beam dump requests, from more than 190 user systems connected to the BIS, to the LHC Beam Dumping System (LBDS). With such a complex distributed system, the need of having software operational tools for diagnostics is a must.

The aim of the operational tools is to verify the system´s operation from end-to-end and to inhibit next beam injection into the LHC in case of a problem detected.

The scope of the project covers all software modules implemented to provide to the operators and equipment experts the necessary tools to guarantee the safe operation and to ensure that the system is in an “as good as new” state.

The verification of the BIS is carried out in three stages: (1) pre-; (2) during- and (3) post- operational checks which are executed on demand by the LHC Sequencer [2] depending on the operational mode of the machine. The outcome of the checks leads to the actions represented in Table 1.

Table 1: Result of Operational Checks

Test	Passed	Failed
Pre-	Injection allowed	Injection inhibited
During-	Continue operation	Warning experts
Post-	Injection allowed	Injection inhibited

The operational tools described hereafter are implemented with the standard tools and infrastructure used in the CERN accelerator control system (i.e.: Java, Swing, Spring Framework, Controls Middleware CMW and the Controls Configuration Database CCDB).

PRE-OPERATIONAL CHECKS

Before injecting beam in the machine, it is required to ensure that all safety critical components of the BIS are correctly configured and ready for operation. The configuration of such relevant components is defined in an Oracle reference database (CCDB) and maintained by the system experts with a strict versioning and access control. A wrong configuration of a critical part of the BIS could have serious implications on safety (e.g.: in case of a user system input that should never be masked is connected to a maskable input); it could lead to miss a beam dump request from a user system and in the worst case could lead to important damage to the machine.

Pre-Operational Checks Implementation

The pre-operational checks have been implemented as a sequence in the middle tier of the LHC Sequencer, which is a high level software application in charge of orchestrating the execution of tasks in a controlled way, helping the operators to drive the LHC. The pre-operational tests are launched programmatically before the beam injection phase, guaranteeing the consistency in the configuration of the physical system against the reference database.

In case of encountering any inconsistency, a failure will be propagated to the BIS by disabling the software permit through the Software Interlock System (SIS) which will inhibit next beam injection (see Fig. 1). In addition, a new entry on the LHC logbook will be created for log tracking.

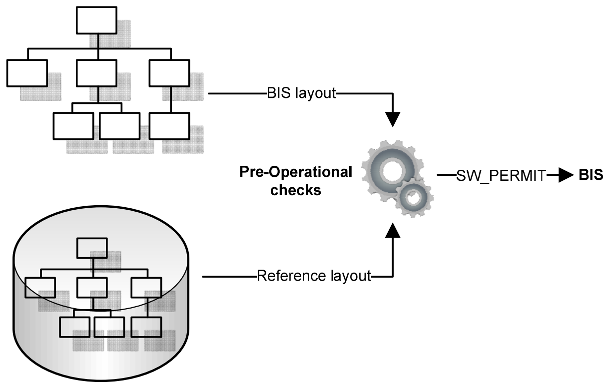

Figure 1: Pre-Operational checks workflow.

The sequence of checks implemented includes:

- Jumper configuration: it guarantees that no masked hardware inputs exist. It verifies that both redundant input channels from the user systems are enabled if required for operation.
- User system presence: it verifies the existence of the user system interfaces on those inputs defined as enabled in the database.
- User system ID: it prevents crossings between user system connections. It verifies that the unique identifier of the user system interface matches with the one defined in the database.

Besides, it is possible to perform on demand tests with each individual user system of the BIS. These tests consist in requesting the user system to force independently both redundant channels to the BIS to a false state to guarantee that the system is able to perform a beam dump request. Due to timing constraints this action cannot be performed on every user system before injection, however it is strongly recommended to be executed on a regular basis (e.g.: technical stops) to prevent possible blind failures of the user system interfaces.

DURING-OPERATION CHECKS

During beam operation, it is required to verify the integrity of the infrastructure and that several critical elements behave correctly and within tolerances. The online monitoring can have some impact on the dependability of the system, as despite critical protection functions are built into the hardware, the online verification can contribute to improve the availability of the system (e.g.: detection of a faulty redundant power supply that can be repaired during a technical stop in the shadow of beam operation).

In case of errors detected, the equipment experts will be informed but no other actions will be taken.

Implementation in DIAMON

The during- operation checks have been implemented as monitoring agents in the DIAMON [3] framework, which is a monitoring tool in charge of diagnosing problems in the controls infrastructure. This solution was chosen as it is a standard and flexible tool used in the controls group that provides embedded services such as access to the logging system or role-based access control to restrict the access to the agents. The checks are structured into two parts: (1) related to the infrastructure and (2) related to the critical hardware itself. With regard to the infrastructure the agents check:

- Frontend VME hardware (redundant power supply status, fan speed, fan temperature, …).
- VME Operating system parameters (memory and CPU load, disk space, system resources, user processes running …).

With respect to the critical hardware, the agent monitors:

- pulse per second reception and timing alignment problems from the LHC Machine General Timing (GMT).
- spurious glitches in the reception of critical fail-safe signals (i.e.: high radiation levels can cause glitches on the link. See Fig. 2).
- matrix clock frequency within predefined tolerances.
- redundancy of power supplies for user interfaces with the user systems.
- consistency of non-critical serial channels used for monitoring.

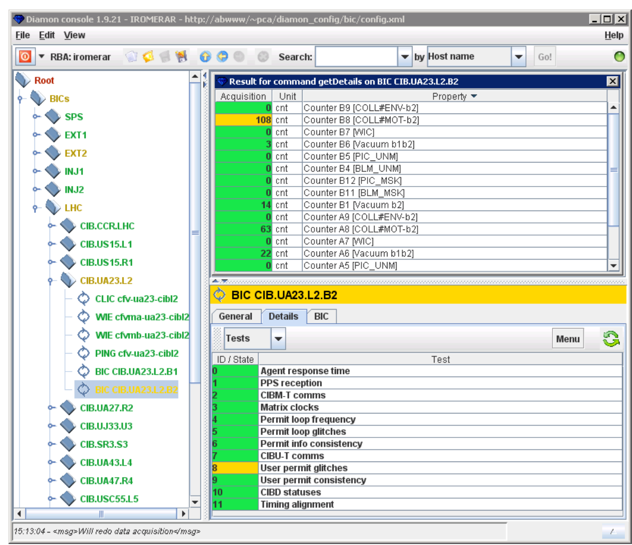

Figure 2: BIC agent in DIAMON console.

POST-OPERATIONAL CHECKS

After a beam dump, it is required to identify that the BIS was not the source of the beam abort and that all safety critical components of the system worked as expected. If the protection system integrity is compromised, beam operation must be inhibited until the problem is solved.

The post- operational checks were designed to fulfil the following requirements:

- be triggered after the reception of a PM event

- collect buffers from every BIC in the LHC and Injection Lines (INJ) as well as from LBDS system to reconstruct the sequence of events
- receive configuration data from reference database
- perform system checks and compare measured data against references
- inhibit beam operation via a software channel to the BIS if any relevant problem is found during the analysis
- display a summary of the checks performed, providing clear information of problems identified
- provide analysis of archived dumps

Furthermore, the post- operational checks of the BIS have to provide clear information about who was the first protection system provoking the beam dump.

Implementation in the Post-Mortem Framework

The Internal Post Operational Checks (IPOC) have been implemented as an analysis package in the PM framework [4], which is the system in charge of identifying the cause of the beam abort by performing individual system checks on the different equipment systems. These checks are immediately launched after an emergency dump. In such cases a PM event will be distributed all around the machine via the GMT and the PM buffers of the BICs are frozen, covering a time window around the event. The data PM buffers are pushed to the LHC PM server through a dedicated client library for analysis.

The IPOC module covers the following aspects of the BIS (e.g.: Fig. 3 shows the IPOC module being part of the PM framework):

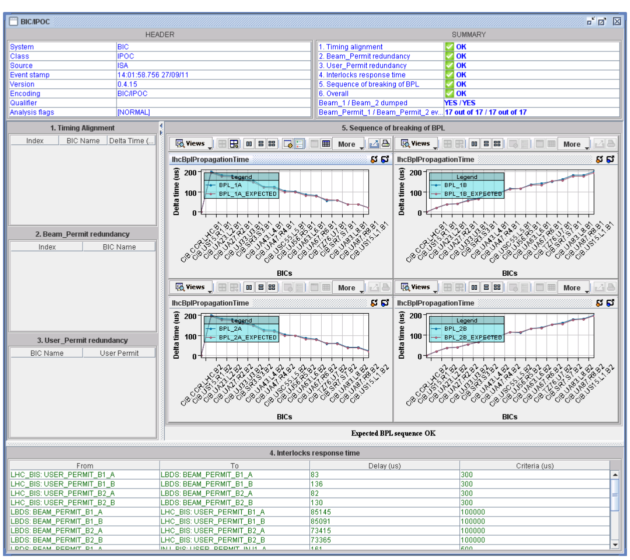

Figure 3: BIS-IPOC console.

- all records in the PM buffers of all BICs are time-stamped with the same timing references. This is vital for correlation of data.
- redundancy in the communication channels from the user systems up to reception of dump requests to LBDS is working.
- optical propagation delays in the Beam Permit Loops are as expected when comparing to the references.
- propagation of interlock signals between BIS and LBDS are correct and within tolerance.

CONCLUSIONS AND FUTURE PLANS

Operational verification tools must guarantee the correct configuration and integrity of the critical components of the BIS during all phases of beam operation. They have been intensively used during more than two years of LHC operation and partially deployed on the injector complex. It is demonstrated that the use of such tools plays an important role on prevention and diagnosis of problems and allowed gaining confidence in the reliability of the BIS.

In the near future it is foreseen to consolidate and improve the existing tools and to extend the scope of these checks to the BIS of the Super Proton Synchrotron (SPS) and related extraction areas.

REFERENCES

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