PROTECTING DETECTORS IN ALICE

Mateusz Lechman[1], Andre Augustinus[1], Peter Chochula[1], Antonio Di Mauro[1], Lennart Stig Jirden[1], Peter Rosinsky[1], Heinrich Schindler[1] Giacinto De Cataldo[1, 2], Ombretta Pinazza[1, 3], Alexander Kurepin[1, 4] , Alberto Moreno[5]
[1]CERN, Geneva, Switzerland
[2]INFN-Bari, Bari, Italy
[3]INFN-Bologna, Bologna, Italy
[4]RAS/INR, Moscow, Russia
[5]Universidad Politécnica de Madrid, Madrid, Spain

Abstract

ALICE (A Large Ion Collider Experiment) is one of the big LHC (Large Hadron Collider) experiments at CERN in Geneva. It is composed of many sophisticated and complex detectors mounted very compactly around the beam pipe. Each detector is a unique masterpiece of design, engineering and construction and any damage to it could stop the experiment for months or even for years. It is therefore essential that the detectors are protected from any danger and this is one very important role of the Detector Control System (DCS). One of the main dangers for the detectors is the particle beam itself. Since the detectors are designed to be extremely sensitive to particles they are also vulnerable to any excess of beam conditions provided by the LHC accelerator. The beam protection consists of a combination of hardware interlocks and control software and this paper will describe how this is implemented and handled in ALICE. Tools have also been developed to support operators and shift leaders in the decision making related to beam safety. The gained experiences and conclusions from the individual safety projects are also presented.

INTRODUCTION

The Large Hadron Collider (LHC) at CERN is the most powerful accelerator ever built. A top energy of 360 MJ will be stored when two counter-rotating proton beams, containing up to 2808 bunches of 1.1 x 10^{11} protons, will collide every 25 ns at a centre of mass energy of 14 TeV in each of the four experiments distributed along the 27 km accelerator ring.

Local beam losses at various levels may induce a quench of the super-conducting magnets or even a physical damage to machine components and experiments detectors. Such losses can be the consequence of various instabilities (beam failures) happening during beam injections or with circulating beams.

Depending on the nature and amount of beam loss, several kinds of damages can be produced: high voltage trips and accelerated ageing in gaseous detectors, single event upsets in front-end electronics or even permanent damage to semiconductor devices and electronics components.

In order to prevent such damages a complex protection system has been developed comprising numerous diagnostic systems and passive protection elements [1]. The ALICE experiment [2] is protected by a dedicated Beam Condition Monitor (BCM) system connected to the LHC Beam Interlock System (BIS) [3]. In addition safe states have been defined for all sub-detectors to establish the best conditions implying the smaller risk of damage in given beam operating modes.

BEAM CONDITION MONITOR

The Beam Condition Monitor system provides real-time monitoring of the radiation level in the ALICE experimental area. In order to protect the detectors against multi-turn beam failures it triggers a beam dump if the instantaneous radiation level crosses a certain threshold.

Used Components

The ALICE BCM design was based on the Beam Condition Monitor system of the LHCb experiment [4].

The beam background is measured using pCVD (polycrystalline Chemical Vapour Deposition) diamond sensors that are grouped in two stations located close to the beam pipe on both sides of the interaction point. The readings from these sensors are digitized by CFC (current-to-frequency converter) cards and then sent to a TELL1 board [5] via optical links. The TELL1 board calculates running sums (RS) over 1, 2 and 32 CFC data frames with corresponding integration times of 40 µs (RS1), 80 µs (RS2) and 1.28 ms (RS32), respectively. In addition “RS32 Sums” are calculated by summing up the RS32 values of 5 out of 8 sensors of one station discarding the two highest values and the lowest value.

Access to the registers of the TELL1 board is provided via an on-board credit card-sized PC (CCPC). The CCPC can communicate via DIM (Distributed Information Management System) with the SCADA software package PVSS. The DIM server is running on the CCPC and a DIM client is part of the PVSS project.

Interface to BIS

ALICE provides three flags (user permits) to the LHC Beam Interlock System via the TELL1 board:

- Beam permit - inhibiting/allowing the beam circulation (acting on both beams simultaneously),
- Injection permit for beam 1 – injected via the TI2 transfer line from SPS (Super Proton Synchrotron) to LHC,
- Injection permit for beam 2.

A beam dump is triggered by the TELL1 firmware via removal of the beam permit if values of monitored running sums exceed defined thresholds.

The injection permits are controlled by the central Detector Control System (DCS) [6] and they are set when ALICE is prepared for incoming beam.

Control Layer

A dedicated PVSS project is used to supervise and control the performance of the TELL1 board and auxiliary devices such as CAEN power supply and VME crate. The designed panels provide experts and DCS operators with all important information including status of BIS flags, the beam background level and reasons of beam aborts.

In case of emergency, the control and monitoring of the CCPC can be continued by the DCS operator (even without the PVSS layer and DIM) via emergency command line scripts, based on the SSH connection tool PLINK.

The values of the BCM thresholds are changed dynamically depending on the state of the most sensitive ALICE sub-detectors and a "beam mode" published by the CCC (CERN Control Centre). The more strict limits are activated before turning on the selected subsystems.

Post Mortem

The causes of emergency beam aborts have to be revealed to improve protection systems and operational procedures. In such cases, analysis of data registered shortly before the dump is essential.

The incoming data stream from the CFC cards is written into a circular buffer on the TELL1 board. This buffer is frozen when a Post Mortem (PM) signal is received via the LHC machine timing system.

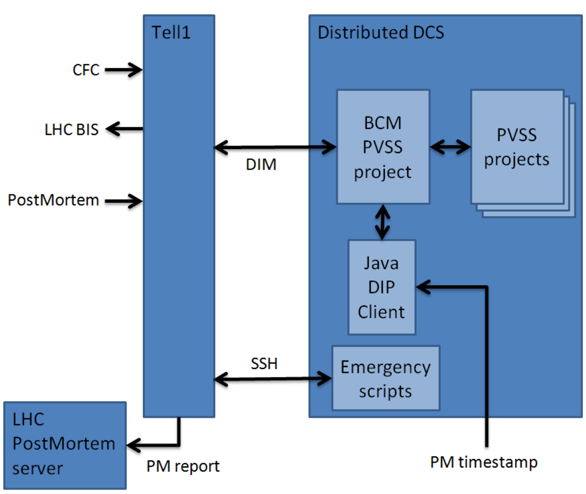

Figure 1: Beam Condition Monitor - the control layer.

The content of the circular memory buffer is marked using the published timestamp of the latest PM event and then sent to the LHC central PM server, from where it can be further analyzed.

The timestamp is distributed over Data Interchange Protocol (DIP) in nanoseconds. Since the PVSS DIM client does not support such accurate time resolution, a specialized client was implemented in Java for retrieving it.

The main communication flow in the BCM system is presented in Fig. 1.

OPERATING THE DETECTORS

ALICE consists of many subsystems integrated via a distributed PVSS project. The DCS shifter operates through a central User Interface (UI), which is connected to all sub-detectors and to the common systems like electricity, environment monitoring etc. The User Interface collects all the system states and alerts, and is able to send commands to change the status of the detectors.

The UI panels are designed with the goal of simplifying the actions and minimize the time and risk of mistakes. The most frequent procedures have been coded into scripts and panels, and the operator is asked to activate an existing procedure when needed, instead of interacting with the single detectors following their different and dynamic requirements

The SAFE and SUPERSAFE States

Certain LHC operations require detectors to be in a compatible, so called SAFE condition. During the LHC Injection, TI2 setup or beam adjust, the sensitive detectors typically lower their voltages to protect the electronics against excessive charge deposits.

During certain operations (such as testing of new LHC filling schema etc.) the detectors put even more restrictions on their settings. This condition is called SUPERSAFE.

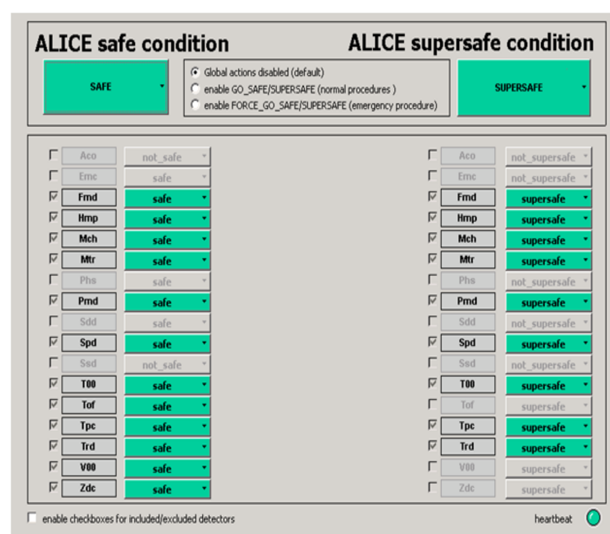

Figure 2: The SAFE/SUPERSAFE panel.

Each detector declares if it meets the SAFE and SUPERSAFE conditions. The central system collects this information and sends to the subsystems the GO_SAFE or GO_SUPERSAFE command through a PVSS datapoint to obtain the required level of safety. If a detector is in a SUPERSAFE condition, it can be brought back to SAFE using the RESTORE_SAFE action. The commands are available to the DCS operator from the SAFE/SUPERSAFE panel presented in Fig. 2.

The shifter can also send global commands (GO_SAFE, GO_SUPERSAFE and RESTORE_SAFE) that trigger relevant actions on side of all the detectors. When all the detectors are SAFE (or SUPERSAFE), the global state of ALICE is declared as SAFE (or SUPERSAFE).

An exclusion matrix is introduced to temporarily ignore individual detectors from the calculation of the global state. This matrix can only be changed under the supervision of the shift leader and the detector expert. The exclusion/inclusion from/to the safety matrix is also set via the SAFE/SUPERSAFE panel.

The GO_READY Matrix

When the beam condition requiring the SAFE/SUPERSAFE state is not present anymore, the detectors are sent, on request of the shift leader, to the READY state via the GO_READY command to start the data taking.

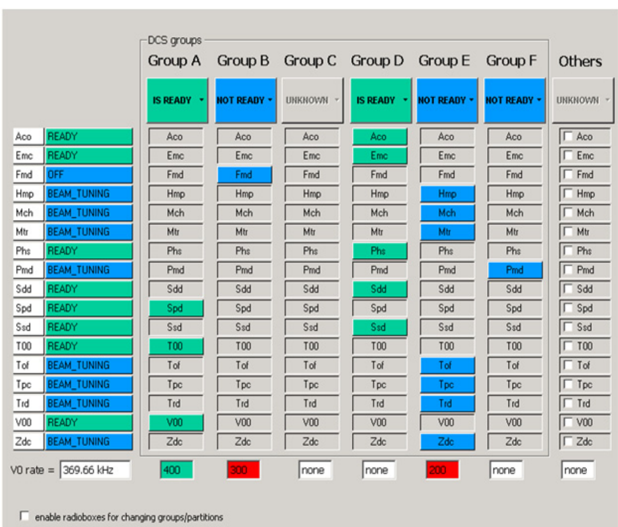

Figure 3: The GO_READY panel.

Different detectors will switch on the HV in different phases of the beam operation (the so-called luminometers right after injection, the gaseous detectors only at stable beams).

In order to minimize the risk of a mistake of the DCS operator and the time needed to send to READY the relevant detectors, a panel has been prepared which groups the subsystems and allows sending the GO_READY command in parallel to the different groups (Fig. 3).

The V0 Rates

The risk of HV trips and potential sub-detectors damage can be estimated using the V0 subsystem. This detector is based on two disks of segmented plastic scintillator (76 cm in diameter) located asymmetrically with respect to the ALICE interaction point (+340 cm, -90 cm).

Due to its enhanced timing performance V0 can detect both beam-beam and beam-gas collisions, thus providing separate numbers of collisions (rates) for luminosity and background. The sum of these rates lets the experiment monitor the amount of charged particles crossing the sub-detectors.

Right after the beam injection and the energy ramp, ALICE and the LHC usually agree on a desired luminosity level. If the sum of luminosity and the background rates is above a fixed threshold for some sensitive gaseous detectors then they should not be sent to READY until the V0 rates decrease below the threshold.

A control is then implemented in the GO_READY panel to alert the DCS shifter not to send to READY the detectors until this condition is valid. The decision to continue or abort the GO_READY command is then left to the shift leader.

If the V0 rates are too high and the detectors are READY, a severe alert is raised and again the SL takes the responsibility to ramp down the different sub-detectors.

THE HANDSHAKE MECHANISM

The Handshake is a communication protocol between the CERN Control Centre (CCC) and the LHC experiments. Its purpose is to inform the shift crews of the experiments about any beam activity to be performed by the machine. Another goal of the Handshake is to obtain permission from the experiments before starting actions like injection, adjust or beam dump. After receiving the notification about the beam activity, the experiments should take necessary actions to prepare the detectors for this activity, to avoid damages that the beam may cause.

The Handshake mechanism is based on the exchange of messages (“LHC commands” and “ALICE responses”) between the CCC and ALICE via DIP. On the ALICE side, the logic of the Handshake is implemented as a finite state machine using SMI scripts from the fwFSM component developed within the JCOP project.

Injection Handshakes

From the point of view of safety, the most critical are Injection Handshakes. Their main purpose is to make all the subsystems SAFE (and if required SUPERSAFE) and to remove the injection interlock. The relations between different phases of the Injection Handshake and protection mechanisms are illustrated in Fig. 5.

When the CCC is ready to inject the beam they publish the “WARNING” message. The ALICE DCS operator, using dedicated control panel (Fig. 4), confirms it by executing the “INJECT_PREPARE” action and then starts to prepare for the injection. During the next 5 minutes the ALICE experiment should be moved to the global SAFE (or SUPERSAFE) state. The operator executes the “CONFIRM_INJECT” action when the experiment is prepared. This command also sends a request to the BCM system to grant the injection permits.

After all the experiments report they are ready the CCC sends the "READY" command and only then the beams can be injected into the LHC. When the injection is completed the CCC publishes the "OK" message, which triggers removal of the injection permits. Starting from this moment ALICE no longer needs to be in the SAFE/SUPERSAFE state.

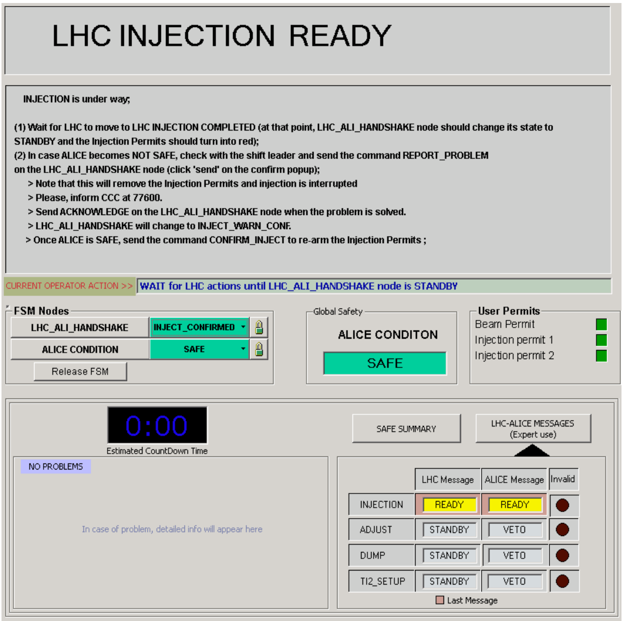

Figure 4: The Handshake control panel.

Emergency Situations

The handshake protocol can also handle exceptional situations, like violation of the SAFE state or a communication problem in DIP. In such situations the state of handshake is changed automatically to emergency state "PROBLEM_REPORTED" in which the injection permits are not granted. This state can also be set manually by the DCS operator upon the shift leader request in justified cases.

CONCLUSIONS

The main task of the central DCS team was to design a system to keep detectors in the safest condition during the most dangerous machine modes (from injection up to adjust) and a monitoring system able to react to anomalous beam conditions. These goals were achieved and the experience gained during 1.5 years of operation has been used to better define the safe states of each detector and values of the BCM dump thresholds.

At the moment, the most dangerous for ALICE are fast beam losses produced during injection by kicker magnet failures since the reaction of the BCM and LHC Beam Loss Monitor systems is too late. Therefore, the proper definitions of the SAFE and SUPERSAFE states are essential. Wrong definitions can lead to serious incidents, like during big beam losses in July 2011, when part of a calibration system of Silicon Drift Detector was damaged and the safe policy had to be reviewed for this subsystem.

On the other hand slow losses related to circulating beams can be detected in due time and beams can be dumped typically within 2-3 orbits before any damage is produced.

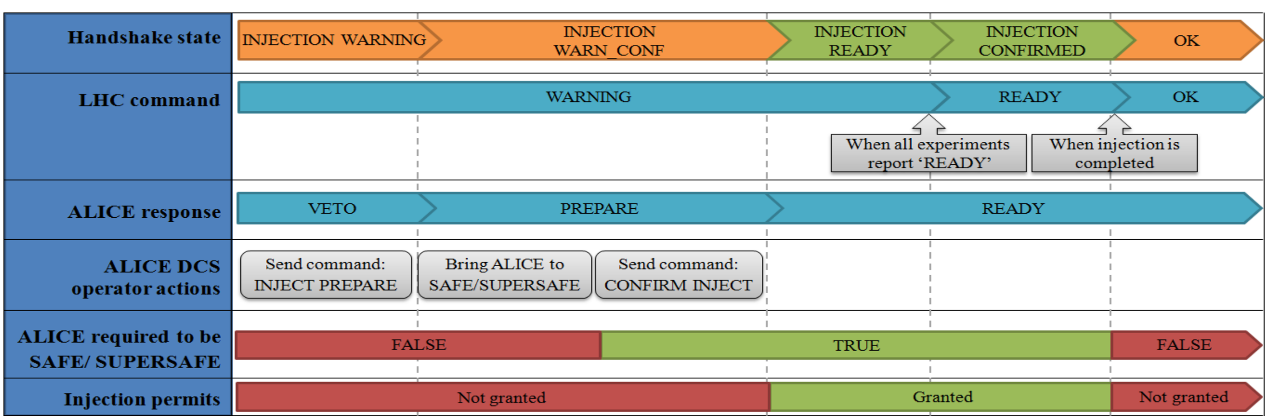

Figure 5: The Injection Handshakes procedure in ALICE.

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