AUTOMATIC POST-OPERATIONAL CHECKS FOR THE LHC BEAM DUMP SYSTEM

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Abstract

In order to ensure the required level of reliability of the LHC beam dump system a series of post-operational checks must be performed after each dump action. This paper describes the various data handling and data analysis systems which are required internally and at different levels of the LHC control system, for post-operational checks, and the experience from the commissioning of the equipment where these systems were used to analyse the dump kicker performance.

INTRODUCTION

The LHC Beam Dumping System (LBDS) is designed to fast extract the beam in a loss-free way from the machine and to transport it to an external absorber, located several 100 m away. Fifteen extraction kicker magnets MKD will horizontally deflect the beam into the aperture of 15 vertically deflecting steel septum magnets MSD. Four horizontal and 6 vertical dilution kickers MKBH/V will be used to sweep the beam in an "e" shaped form across the TDE dump block, which will absorb the beam. TCDS and TCDQ diluters serve to protect the machine elements from a beam abort that is not synchronised with the beam free gap.

Each dump is followed by an Internal and External Post-Operation Check (IPOC and XPOC, respectively) which are launched automatically. The IPOC verifies locally that the LBDS hardware operated correctly, while the XPOC runs on an external server. The latter analyses waveforms with tighter limits than IPOC and performs also the kicker analyses based on beam measurements.

LBDS EXTERNAL DIAGNOSTICS

The aim of the XPOC analysis [2] is to check that the executed beam dump was performed without faults, for example to check that all the MKDs kick waveforms are as expected. In addition, the salient features of each dump action must be recorded by the LHC Post-Mortem system, which will have its own generic retrieval facility. For long-term analysis purposes, the data associated with the LBDS operation are stored in a logging database. Finally, a number of LBDS systems will generate alarms and warnings which will be incorporated into the CERN alarm system.

Reliability

The LBDS is a safety critical part of the LHC machine protection system. To a large extent, the safety is guaranteed by the redundancy within the different subsystems. IPOC and XPOC analyses make sure the whole LBDS including its redundancy is working correctly. The diagnostics should ideally guarantee that the system is in an "as good as new" state. They play an important role in ensuring the safety of beam dump system.

Data Storage and Archiving

The data acquired for each beam dump action is stored and retrieved on an "event" basis, where all data associated with a particular beam dump is identified as such. The raw XPOC acquisition data is stored in Self Describing Data Set (SDDS) files [3]. The XPOC results are archived in the LHC logging system based on an Oracle logging database.

XPOC FUNCTIONALITY

The LBDS XPOC will:

- be triggered after every dump action requested the Beam Interlock System (BIS); a dump can also be generated by an LBDS internal device fault, which in turn can also trigger the BIS;
- inhibit the beam permit via a software channel to the BIS as soon as it is triggered and keep the inhibit in place while it is analysing data;
- acquire the LHC configuration data associated with each dump action (energy, intensity, emittance, LHC mode, filling pattern, etc.);
- acquire equipment data (BTV images, kicker waveforms, BLM signals, etc.) from the hardware;
- access supplementary data, from the logging database or from the measurement database;
- test the measured data against references, which may change as a function of LHC configuration;
- give the beam permit via the BIS if the dump action was as expected and passed the comparison tests;
- display a summary of the comparison results and allow a diagnostic of identified problems;
- provide summary data to the LHC logging;
- provide a facility to retrieve and compare "reference" dump actions and archived dump actions;

Faults the XPOC Must Detect

The XPOC must detect possible LBDS faults and stop operation if they occur. Typical faults include an asynchronous dump, an MKD pre-trigger, a missing MKD, an energy tracking error, a missing MKD redundant branch, a non-working retrigger branch, orbit in IR6 out of tolerance, etc. After such a fault the operation is stopped and can only be resumed after hardware verification by an equipment expert.

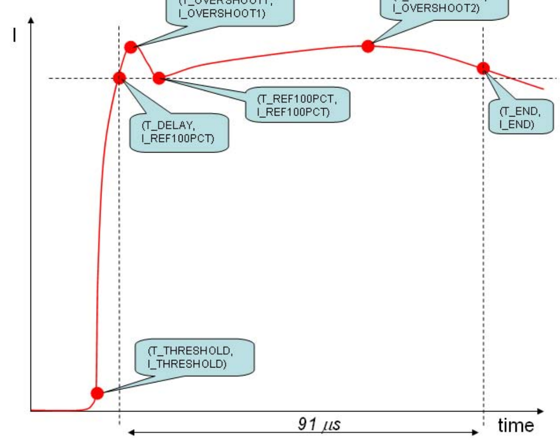

Figure 1: MKD characteristic points. [4]

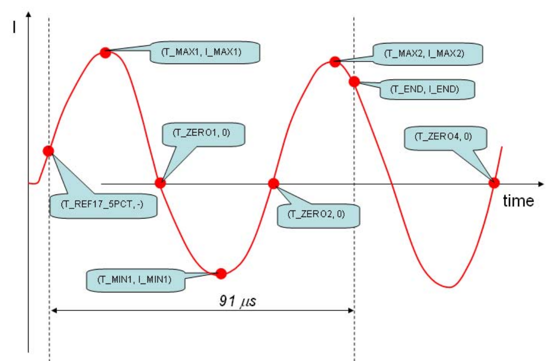

Figure 2: MKB characteristic points. [4]

DESCRIPTION OF ANALYSIS

Kicker Analysis

The aim of the kicker analysis is to survey characteristics points of the MKD and MKB generator waveforms, see Fig. 1 and 2.

The offsets and cable attenuation are removed with numerical filters. The characteristic point coordinates are calculated using fits to the raw data, Fig. 3.

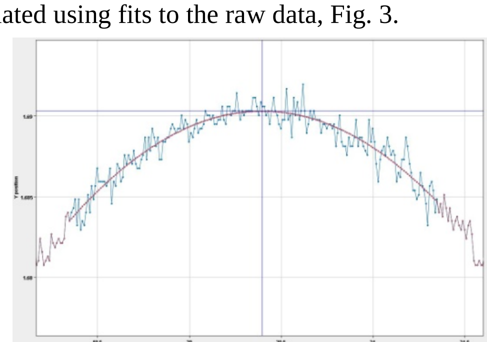

Figure 3: Second order fit to measured data at a characteristic point.

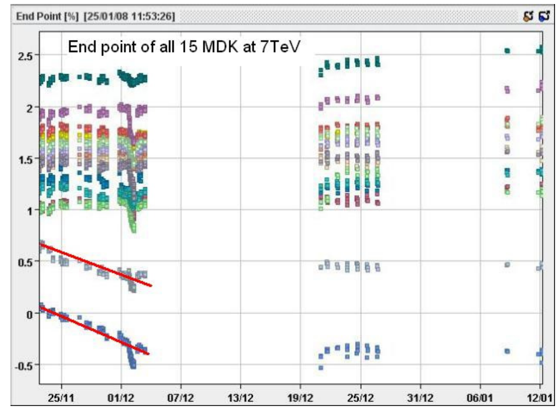

Figure 4: History of MKD "End" point in % relative amplitude, for 2007 running.

Once the coordinates of the characteristic points are defined, the derived values like rise time and relative overshoot are calculated. The XPOC analysis compares these values to reference values and decides if the generators have worked correctly inside the limits (±0.5 % on relative amplitudes and 50 ns on time). The analysis for the MKDs has been working for most of the tests performed in 2008. The results of the end point amplitude for 15 different MKD systems over 1 month are shown in Fig. 4. Thanks to this tool, trend for two generators could be observed, which disappeared after repair of these generators.

BTVDD Analysis

The goal of the BTV image analysis is to quantify the measured sweep of the bunch from a BTV image, Fig. 5. Different filters are applied to the picture to obtain the sweep. Averaging filters are used to reduce noise and a Laplace filter is used to find variations in the picture. Hysteresis and skeleton functions are use to analyse the filtered picture, to produce an image as shown in Fig. 6. The width, height, centre, length and start of the sweep can then be defined. The XPOC compares the measured values with expected values and decides if the dump was correctly executed.

Other Analyses

Besides the kicker waveform and the BTVDD image, the XPOC system also analyses:

- the beam position measurement in the beam extraction region and in the beam dump line;
- beam loss in the beam extraction region and the beam dump line;
- the measured total dumped beam intensity in comparison with the measured circulating beam intensity;
- the beam population of the abort gap;
- the status of the beam energy tracking system;
- the current of the MSD extraction septa;
- the beam position of the TCDS and TCDQ absorber;

These analyses are not yet fully implemented.

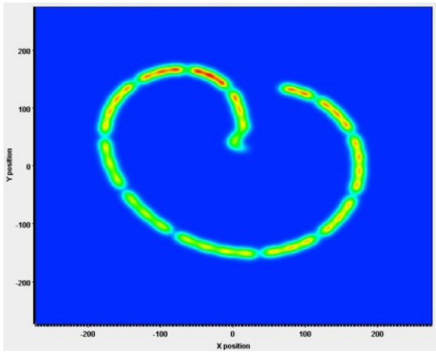

Figure 5: BTVDD screen-shot, with simulated data.

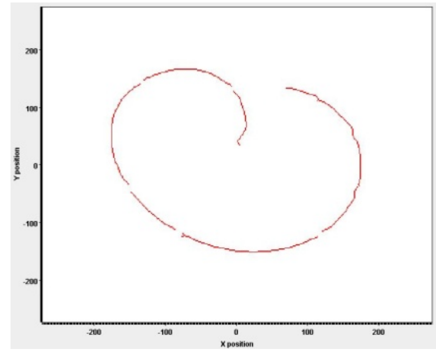

Figure 6: BTVDD image after filter and skeleton method.

XPOC Implementation

The XPOC is implemented with the standard tools and infrastructure used in the CERN accelerator control system (Java, Swing, the Spring Framework and the Controls Middleware CMW). It is structured into three parts: (1) the XPOC analysis packages that contain the algorithms described above; (2) the XPOC server, a central daemon process that executes the analysis routines and interacts with the timing system, the LBDS devices, the Graphical User Interface (GUI) and the LHC sequencer; (3) the XPOC GUI, which displays the XPOC results and allows to manually trigger an analysis in the server, should this be necessary.

When the XPOC server receives a “beam-dumped” event from the timing system, it acquires raw data from the devices, executes the analysis routines, logs the results into the LHC logging system and transmits the results to the XPOC GUI and the LHC sequencer. If no analysis error is found, the XPOC server returns “Finished OK” to the LHC sequencer, which then automatically arms the XPOC server again, making it ready for the next dump event. If anything fails during the XPOC (acquisition, analysis, etc.) the XPOC returns “Finished FAULT”. In this case, the sequencer inhibits beam injection and tells the LHC operator to request a more advanced manual analysis to understand the beam dump fault. After the analysis and possible hardware verifications or repairs, the operator can manually arm the XPOC, bringing it back to the initial “ready” state.

Following each XPOC, the GUI retrieves all available data about the dump from the server: raw input data from the devices, the characteristic points calculated in the analysis, the thresholds used, and of course the final results. This allows the operators and experts to view the results and study possible beam dump faults.

XPOC Application Deployment

The LHC reliability run [5] is using the XPOC analysis to quantify changes detected on kicker waveforms. During the reliability run, some kickers have produced failures which have been correctly detected by the XPOC analysis, following which the LHC sequencer was stopped.

Analyses based on beam measurements, like BTVDD and BLM, are now being tested on expected dummy data where possible. Occasionally dummy data with faults are sent to the XPOC analysis. It has been shown that the analysis finds the faults correctly and diagnoses the simulated problem.

Some analyses remain still to be programmed and added. The analyses have to be re-tested when real data are available.

In addition a robust and safe method of managing the complex references tables of the XPOC process must be developed and deployed.

CONCLUSIONS

The XPOC analysis of the LHC beam dumping system has to guarantee the correct execution of the last performed beam dump by analyzing hardware signals and beam measurements. This puts the system back in an “as good as new” state for the next beam dump, which is a requirement for safe operation of the beam dumping system. Every beam dump event and its analysis is archived in the LHC logging database and in SDDS files.

The system has been used extensively during the reliability run of the beam dumping system and proven to be functional for detecting failures and trends in the kicker waveforms. The analysis of BTV image data has been performed with simulated data and the analysis of beam position, beam loss and beam intensity data are presently under development.

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