LBDS AND ABORT GAP CLEANING

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Abstract

A number of possible failure scenarios and estimated occurrence were defined for the LHC Beam Dumping System (LBDS). An analysis of the LBDS performance during the first year of the LHC operation is presented and compared with respect to requirements and expectations. Several qualification tests have been regularly performed to assess the protection provided by the system in the eventuality of a failure. Possible hardware upgrades and improvements of machine protection tests and operation procedures are explored. Abort gap cleaning deployment, related diagnostic and interlocking are discussed.

INTRODUCTION

The LHC Beam Dumping System consists of 15 extraction kickers (MKD), 8 dilution kickers (MKB), 15 septum magnets (MSD), 1 absorbing block (TDE) and 4 protection elements (TCDS, TCSG, TCDQ and TCDQM) per beam [1]. Continuous monitoring of all the system elements and redundancy, at several levels, of the kicker generators guarantee the reliability of the system. Redundancy and surveillance make the system safer but more complex, affecting the number of false dumps and machine unavailability time. Detailed studies showed that 3.4±1.8 false dumps per beam per year are expected [2].

Any time a beam dump is triggered, an automatic post-mortem is generated and a series of internal (IPOC) and external post-operational checks (XPOC) is made [3]. These checks allow to control the LBDS status and recover an "as good as new" state after every beam abort.

The LBDS was designed taking into account some acceptable failure scenarios. The beam can be dumped, without inducing machine damages, when the MKDs are not synchronized with respect to the abort gap (asynchronous beam dump) or when one MKD module is missing [4]. Both events are estimated to occur once per year of operation, corresponding to 400 fills of 10 hours. Several validation tests have been performed, when changing machine and beam conditions, in order to asses the protection provided by the LBDS in case of a fault. Special tests have been dedicated to abort gap cleaning studies. Abort gap population must be minimized to avoid to overload the elements downstream of the dump insertion, even in case of normal operation of the extraction kickers.

LBDS PERFORMANCE

A limited number of LBDS failures, in agreement with requirements and expectations, were registered during the first year of the LHC operation. In particular:

- One Beam Energy Tracking System (BETS) error [5]. The deflection strength of each active element of the LBDS has to change with the beam energy in order to guarantee the correct extraction trajectory under all operational conditions. The BETS acquires the beam energy and checks that the MKD and MKB charging voltages follow the reference signals within defined tolerance windows. An instability of a 35 kV power supply induced a beam dump at the end of the first ramp to 3.5 TeV.
- One asynchronous beam dump at 5 TeV and two at 7 TeV, triggered while performing energy scan tests for machine checkout without beam. These events were due to sparks on the outside of a gate turn-off (GTO) thyristor. This problem depends on the operational energy and does not affect the system at 3.5 TeV, that was the nominal maximum energy foreseen for the 2010 run. Insulators will have to be installed before moving to higher energy.
- Four internal triggers induced by false pressure readings on the MKB for Beam 2. An internal interlock was added to the LBDS, as a redundancy to the LHC vacuum interlock, to stop the kickers and trigger a beam dump in case of pressure over thresholds. This redundancy was removed due to the high level of noise of the internal signal.
- Two beam dumps induced by TCDQ faults for Beam 1. In one case, collimator jaw and thresholds were at the wrong settings during injection and the beam was dumped by the losses in point 6 (dumping insertion). In the second case, a glitch in the resolver signal triggered a beam dump at the end of a ramp because of jaw position out of thresholds.
- One asynchronous dump with beam caused by a power driver failure which provoked the self-triggering of two MKD generators. Details of this event are explained in the following section.

None of these failures induced any quench or damage of the LBDS system and the downstream elements. Globally, the system behaved as expected and no major machine protection related issue was encountered.

TCDQ HW AND SW ISSUES AND POSSIBLE UPGRADES

In case of an asynchronous beam dump, several proton bunches (up to 120) enter in the extraction region when the MKD voltage is still rising and are swept across the machine aperture. Two movable horizontal collimators per beam are located downstream of the extraction septa to absorb part of the swept beam and protect the downstream magnets. The TCDQ is made up by one 6 m long carbon based jaw that is installed at the extraction side of the machine. The TCSG is a standard two sided secondary collimator [6] and is located after the TCDQ. Typically, collimators are moved by means of stepping motors with a 5 μm resolution (minimum step size). The TCDQ uses DC motors and a minimum resolution of ± 50 μm can be achieved. The reproducibility in the TCDQ positioning, over several operational cycles, showed to be better than ± 20 μm. The option of implementing stepping motors to the TCDQ is under discussion but, at present, the resolution seems to be mainly limited by the torque acting on the long jaw. The substitution of LVDT position sensors with potentiometer is also considered.

Position readouts (MDC) and interlocks (PRS), for the TCDQ, are presently installed on the same Central Processing Unit (CPU). This determines potential common mode failures and radiation hard issues. The upgrade of the system foresees to use different CPU and adopt the same low-level control as for the LHC collimation system [7].

Recent studies pointed out that the TCDQ jaw will be damaged by the impact of 28 nominal intensity bunches, spaced by 25 ns, at 7 TeV. This is a major issue since, during an asynchronous beam dump, the TCDQ can be hit by 32 bunches. A new more robust design is under development for this collimator. The upgraded solution will have to be ready to be installed during the shutdown planned for 2012.

THE ASYNCHRONOUS BEAM DUMP

On November the 19^{th} 2010 the first, and unique, real asynchronous beam dump happened. A power driver in one MKD Trigger Fan-Out (TFO) unit of Beam 1 failed and started the self-triggering of two generators (MKD-C and MKD-D). The re-triggering of the remaining 13 generators worked perfectly and the beam was dumped without inducing any quench or damage of the downstream elements. This event generated a fault IPOC and XPOC and was caused by the unexpected breakdown of a standard electronic component (MAX4429EPA). The original design of the LBDS foresaw that only one MKD could fire spontaneously inducing the re-triggering of the remaining modules [8]. According to later studies, redundancy was added between the TFO and the Power Trigger Unit (PTU) in order to reduce the chance of having less than 14 MKDs firing during a beam dump (see Fig. 1). The actual wiring system should then improve the reliability of the system but, at the same time, could determine the pre-triggering of up to 8 generators. This new logic affects the beam sweeping during an asynchronous beam dump and the resulting load on the TCDQ and downstream elements. In particular, as shown in Fig. 2 for up to 4 pre-triggers, the energy density is reduced on elements with an aperture smaller than 7σ (betatron collimators), while is increased on elements with bigger apertures. The TCDQ, that nominally sits at 8σ, would receive up to $\sim 40\%$ more radiation than for the original design scenario. This would worsen the existing robustness problem of the TCDQ, as mentioned above. For this reason and to reduce the load on the downstream magnets, it was decided to change the trigger logic back to the original design.

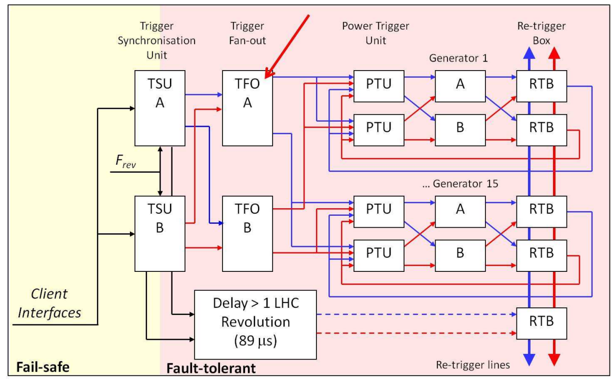

Figure 1: View of the LBDS trigger synchronization and distribution scheme. Redundancy was added to the original design in order to improve the reliability of the system. As a drawback, the new wiring scheme allows the pre-triggering of up to eight generators instead of one.

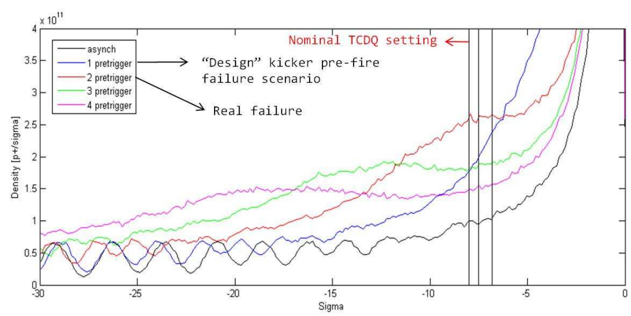

Figure 2: Energy density load as a function of the aperture (in σ units), in case of asynchronous beam dump and pre-triggering of up to 4 MKD modules.

MACHINE PROTECTION TESTS

A full series of tests with beam have to be performed after each shutdown or long technical stop, for machine protection purposes. Additional tests have to be systematically carried out for any change in machine and/or beam conditions (i.e. different optics, energy, intensity, filling pattern, etc.). They are presented in the following.

Asynchronous Dump Test

This test is performed by switching the RF cavities off, so that the beam starts debunching and populating the abort gap, and then triggering a beam dump. A local bump, away from the TCDQ jaw and close to the orbit interlock limit (1.2 σ), has to be applied in order to simulate the worst failure scenario. This check allows to validate the hierarchy of the collimation system and to measure the leakage from the TCDQ to the downstream elements. The post-mortem

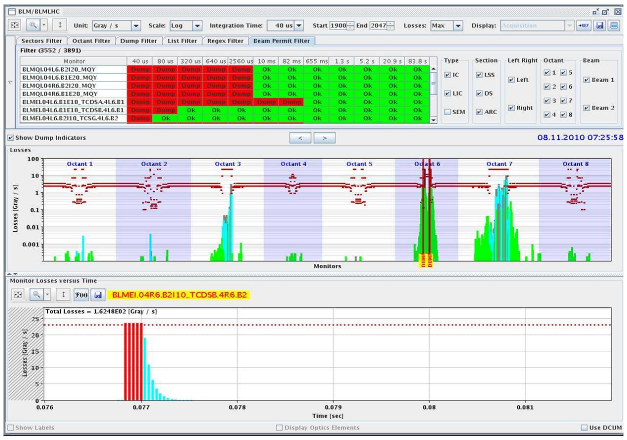

Figure 3: An example of a post-mortem loss map during an asynchronous beam dump test is shown.

analysis of the beam losses around the ring allows to qualify the protection provided by the system (see Fig. 3). The machine is declared safe when losses are concentrated in the extraction region (octant 6 in Fig. 3) and in the cleaning insertions (octant 3 and 7 in Fig. 3). One of the most critical elements is the Beam 2 tungsten tertiary collimator (TCT) in point 5 [9]. This is the first bottleneck encountered by the swept beam, which is not intercepted by the TCDQ. Losses at this element have to be kept as low as possible due to the low damage threshold of tungsten. In particular, the leakage from TCDQ to this element has to be smaller than 10^{-3}.

This is a destructive experiment which needs one dump per configuration. Special tests have to be envisaged for 2011 in order to define the retraction margin between the TCDQ and the TCTs at top energy and for small β* [10]. At least 10 ramps have to be taken into account for these studies.

IR6 Interlock Test

The protection provided by the TCDQ depends on its position with respect to the beam orbit. For this reason, a software interlock exists on the Beam Position Monitors (BPM) in point 6 and checks that the orbit, at this location, is within defined thresholds. Orbit stability was, up to now, better than 1 σ ($\sim$ 0.8 mm at 3.5 TeV) but it should be better than 0.3 σ for nominal operation at 7 TeV ($\sim$ 0.2 mm). Two different controls have to be performed:

1. Destructive: interlock limits are changed, in small steps, so that the BPM readout falls outside the thresholds and a beam dump is triggered. This test has to be performed for any change in the filling pattern scheme.

2. Not destructive: correctness of the readouts for interlocked BPMs and number of injected bunches have to be verified when increasing the beam intensity. No beam dump has to be induced, by changing the thresholds, if the filling pattern stays the same.

These tests took about 1-2 hours per new filling pattern/intensity step last year. The procedure has been revised and a minor time impact is expected for 2011.

XPOC UPGRADE

The XPOC performs a fully redundant analysis of the extraction and dilution kickers waveform with respect to individual references and tight tolerance limits. It analysis also measurements from beam instrumentation in point 6 and in the transfer line (i.e. losses, vacuum pressure, beam position, beam intensity and population in the abort gap). Several upgrades in the XPOC functionality are foreseen for next year. Losses at the TCTs will be monitored in all the interaction points. In addition, the Beam Loss Monitors (BLM) will be grouped in families and identified by one master element (example: TCDQ BLM). Losses of all the BLMs, belonging to a certain family, will be compared to losses at the master element (example: losses at the TCT with respect to losses at TCDQ). This will allow to have a further indication to analyze the quality of each beam dump (example: leakage from the TCDQ to the downstream elements). The possibility to integrate the XPOC with TCDQ position and beam orbit at the TCDQ is under discussion.

XPOC sign off

A faulty XPOC prevents to inject a new beam before the acknowledgment by an expert. At present, both “LBDS expert” and “EIC Machine Protection” Role Based Access Control (RBAC) have the same rights for XPOC sign off. Engineers in Charge (EIC) got the consign to acknowledge a faulty XPOC only when induced by losses above thresholds, due to debunched beam (BLM at TCDS, TCDQ, TCSG, MSDA, MSDC and MQY.4R6), or in case of missing data readings. They should instead call an expert in case of faulty provoked by MKD and MKB failures or unusual faults of any other LBDS component. The question if creating different RBAC roles for EIC and LBDS experts, in order to guarantee a safer supervision of the status of the system, is being addressed.

ABORT GAP CLEANING

Population in the abort gap has to be kept as low as possible (indicatively, $< 10^7$ p^+/m at 7 TeV and $< 10^9$ p^+/m at 450 GeV) to avoid quenches or damages of the elements downstream of the extraction region, during a beam dump. The principle of the Abort Gap Cleaning (AGC) is to kick out resonantly the beam in the abort gap by using the LHC transverse damper system [11]. Tests were successfully performed at 450 GeV with protons and the system is defined as operational at this energy. Further commissioning tests are instead needed at 3.5 TeV to optimize the parameters and finely tune the system. The AGC operation is not compatible with the tune feedback system. The goal is to switch the AGC automatically on via the sequencer, any time the tune feedback is off, and then permanently clean the abort gap [12].

The AGC is not operational for ions since the synchrotron light, that is used to measure the population in the abort gap (BSRA), is visible only for energies bigger than 650 GeV. This problem is under investigation and, when solved, same operational considerations as for protons will be applied.

The BSRA should be connected to the software interlock system (SIS) in order to trigger a beam dump when the population in the abort gap overcomes the thresholds. The system was not designed with this aim and relevant modifications and experience are needed before declaring it operational.

CONCLUSIONS

LBDS failures, which occurred during the first year of the LHC operation, were in agreement and not worse than requirements and expectations. Leakage from the TCDQ to the downstream elements showed to be within specifications and no damage or magnet quench was observed during synchronous and asynchronous beam dumps. Possible solutions for the upgrade of the TCDQ control and interlock system were analyzed. A more robust TCDQ jaw design is under study and has to be ready for the 2012 long technical stop. The logic of MKDs triggering, in case of spurious kicker pre-firing, has to be changed back to the original design in order to reduce the beam load on the TCDQ and downstream elements. Machine protection tests procedures have been revised and checks have to be reperformed, in 2011, for any step in beam energy and intensity. XPOC functionality upgrades and possible changes in the RBAC roles logic for XPOC sign off have been discussed. Abort gap cleaning has been declared fully operational for protons at 450 GeV. The commissioning for operation at 3.5 TeV and with ions has to be completed next year. A solution to connect the BSRA to the SIS has to be finalized.

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