CHANGES TO THE LHC BEAM DUMPING SYSTEM FOR LHC RUN 2

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Abstract

The LHC beam dumping system performed according to expectations during Run 1 of the LHC (2009 – 2013). A brief overview of the experience is given, including a summary of the observed performance by comparison to expectations. An important number of changes are applied to the beam dumping system during the present Long Shutdown in order to further improve its safety and performance. They include the addition of a direct link between the Beam Interlock System and the re-triggering system of the dump kickers, the modification of the uninterrupted electrical power distribution architecture, the upgrade of the HV generators, the consolidation of the trigger synchronisation system, the modifications to the triggering system of the power switches and the changes to the dump absorbers TCDQ.

INTRODUCTION

During past operation of the LHC, all requested beam dumps were executed correctly and no damage to the accelerator related to the LHC Beam Dumping System (LBDS) occurred [1, 2]. An updated analysis of the availability of the LBDS was carried out [3], and more specifically of the kicker system and the Trigger Synchronisation and Distribution System (TSDS) [4].

During the 2010 – 2012 operational period 29 beam dumps were triggered due to internal faults detected by the beam dumping system. Reliability studies before operation predicted 24 so-called 'false dumps' (8 ± 2 per year) [5]. The failure modes were classified and compared to the initial model. The updated LBDS safety model predicts a SIL3 safety level, which is more conservative than predicted in 2006 because of the contribution of new failure modes, but nevertheless acceptable. All statistics, including availability and safety, show a positive trend, which attests an improvement in operation.

The repairs to interconnections of the LHC main dipoles taking place during the present Long Shutdown 1 (LS1) will allow increasing the beam energy of the LHC from 4.0 TeV to approximately 6.5 TeV from 2015 onwards. The increased energy means higher operational voltages of the beam dumping system and could have a negative effect on the operational availability and safety. Modifications applied to the LBDS, with the aim of maintaining the good results presented above, are detailed in the following sections.

CHANGES TO THE LBDS SYSTEM

Link Between the Beam Interlock System and the LBDS re-Triggering System

It was noted that the beam dumping system is very sensitive to any unidentified failure mode of the Trigger Synchronisation Unit (TSU). In case of failure of the TSU, and despite the large redundancy within it, any external beam dump request, of the Beam Interlock System (BIS) would not be executed. To reduce this sensitivity a direct link is established between the BIS and re-triggering system of the LBDS [6].

The BIS is responsible of transmitting a Beam Permit along the LHC through the use of optical fibres loops. The Beam Permit signal is interrupted when any of its Users removes its User Permit. The CIBG board generates the signal and the boards managing the User Permits are called CIBM (Fig. 1).

The new link between BIS and LBDS consists of an electronic board (CIBDS) that follows the same principle as the board mounted on the TSU (CIBO). It is included in the optical loops, and generates a dump request when it fails to detect the Beam Permit.
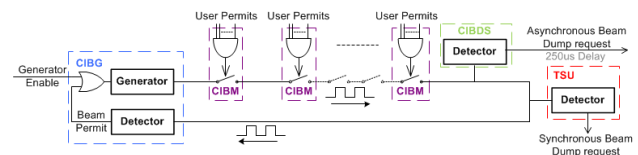

Figure 1: Example of a Beam Permit loop.

In normal operation, the dump trigger is issued by the TSU synchronously with the beam abort gap. To cover a possible failure of this synchronous trigger, an asynchronous dump request is systematically generated, by the TSU. As up to 90 μs (one beam turn) can be necessary to trigger a synchronous dump, the asynchronous dump request is delayed by 200 μs. The CIBDS generates an additional asynchronous dump request, delayed by 250 μs.

A detailed reliability analysis of the CIBDS has been performed in order to ensure the LHC safety increase without significantly reducing its availability [7]. The specification was to not add more than 1 asynchronous dump per beam over 10 years, and no more than two synchronous dump per beam per year. The analysis predicts about 0.02 asynchronous dump for both beams over 10 years and 0.01 false synchronous dumps for both beams per year.

MKD and MKB Magnet Generators

Two additional vertical dilution magnets MKBV and their HV generators were installed per beam, bringing their total number to the full complement of six per beam.

The extraction kicker (MKD) and MKB generators use HV semiconductor switches (FHCT – Fast High Current Thyristors). These switches are sensitive to Single Event Burnout (SEB), due to the presence of high energy hadrons (HEH) leaking from the tunnel into the service galleries. An SEB would provoke an asynchronous beam dump with associated beam losses and possible quenches of downstream superconducting magnets. To evaluate the probability of such an event several measurements of SEB cross-sections of the two FHCT families used were made and a significant sensitivity difference of a factor larger than 50 was observed. For this reason the family of switches most sensitive to radiation has been replaced during LS1. This should reduce the probability of an SEB related dump to less than one per year (for an HEH fluence of 10^5 HEH/cm^2/year).

On several MKD and MKB generators an erosion of the electrical contacts was observed. During LS1 all electrical contacts were inspected, cleaned, the surface treatment modified where necessary (adding silver plating, removal of nickel plating) and higher contact forces applied with modifications of materials where necessary (black steel screws).

New or modified HV insulators were installed on critical places (change of materials, increase of radius) in order to avoid electrical discharges observed during the initial reliability runs.

Important modifications of the MKD generator cooling system were made, which will improve the generator output current reproducibility under variable ambient air temperature in the service gallery.

Modifications were made to the trigger system with the aim of increasing the FHCT triggering current while reducing the likelihood of an internal HV switch SEB (increased supply voltage and IGBTs with higher voltage rating). Tests showed that an increased trigger system voltage together with a single FHCT family resulted in a lower dispersion of switching times which makes it possible to use a constant triggering voltage for all generators and all energies.

Modifications to the Powering

Following the LBDS powering review held in 2012, a separated connection to a second UPS located in US65 was implemented for the LBDS and an individual circuit breaker installed for every crate Power Supply Unit (PSU). A monitoring of the state of all the redundant PSU of LBDS crates is now performed, and the Software Interlock System (SIS) will request a dump in case a failure is detected in a PSU.

Moreover, a fast surveillance of the powering of the re-triggering system has been implemented. A synchronous dump request will be issued at the latest 20 ms after a loss of the main power. The existing surveillance, which generates an asynchronous dump request 100 ms after a loss of the mains power, will remain operational as a redundant final protection.

Modifications to the Trigger Synchronisation Unit (TSU)

Following the operational experience gained during Run 1 of the LHC, the external review of the TSU card design performed in 2010, the identification of a possible common mode failure scenario at the level of the distribution of the +12 V inside the TSU crate and the review of LBDS powering, a new hardware design of the TSU card has been carried out and will be installed within the LBDS during LS1.

In order to avoid the +12 V common mode failure, the TSU cards are now deployed over two separate crates. A surveillance of all the TSU internal voltages was added to the card itself, hence the redundant card will trigger in case the first one loses one of its power supplies.

Additionally, an internal continuous surveillance of the CRC of all the TSU programmable logic circuits (FPGA) has been implemented. In case of a Single Event Upset (SEU) corruption of one of the programmable circuits, an incorrect CRC will be detected and a dump request will be issued to the redundant TSU through a dedicated channel.

The diagnostic functionalities have been significantly improved as well, as many additional TSU internal signals will be acquired and analysed by the Internal Post Operational Check system, such as the acquisition of all the redundant dump requests from all the clients or the surveillance of the output current of the synchronous beam dump trigger signals.

Modifications to the Absorber TCDQ

The TCDQ is a single sided movable absorber that intercepts the beam in the case of an asynchronous beam dump or a dump with beam present in the abort gap.

During the LS1, the previously installed TCDQ systems were removed from the LHC. Subsequently, additional space was made available upstream of the original location for the installation of the upgraded TCDQ absorbers [8]. The new TCDQ was extended from 6 m to 9 m and the absorber material adapted to be compatible with future HL-LHC beams. A 10.6 m movable girder was installed on which 3 vacuum vessels containing the absorbing elements are located. New 'large displacement' vacuum bellows connect each movable TCDQ system to the LHC beam pipe.

The radial position of the TCDQ is adjusted as a function of the beam energy. The system features the possibility to approach the LHC (theoretical) central orbit with the absorber (so called zero-gap position) as well as to adjust the angle radially with a virtual rotating axis at the longitudinal centre of the TCDQ. The relevant values and the tolerances of the positions are shown in Table 1.

Table 1: Range of TCDQ Positions and Angles Relative to the Central Orbit

	Positions and Angles Tolerances
Radial position	-15 mm
Radial + angular position	-19.5 mm
Measurement table end switch	-20 mm
Motorisation emergency switch	-21 mm
Mechanical end stop	-22 mm
System positioning precision	±0.1 mm
Angular position / range	0 / -1.1 mrad
Angular precision	±10 µrad

The redundant LVDTs used for the position measurements have been replaced by potentiometers. Three potentiometers are now installed above each other, attached to the girder at the same longitudinal position at the entrance and at the exit of the absorber blocks, to avoid the introduction of errors between the read outs. These potentiometers are used for the remote displacement system (one for regulation and a second one for the verification) while the third potentiometer is used for the Beam Energy Tracking System (BETS) [9].
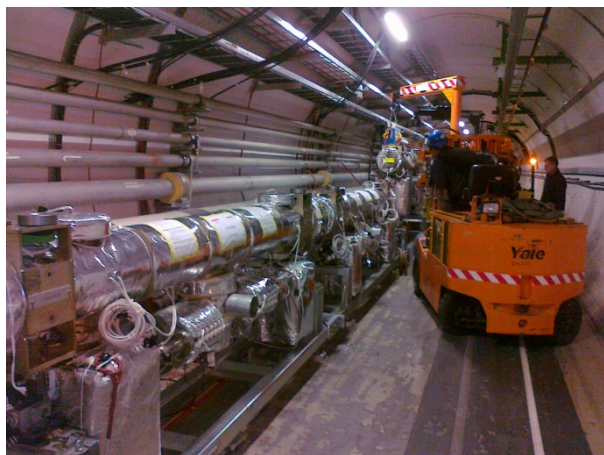

Figure 2: Installation of the last TCDQ tank on the movable girder.

As a result of the review held in 2009 [10], the main improvement at the TCDQ control level will be the dissociation of the Motor Drive and Control (MDC) and Position Readout and Survey (PRS) modules into two separate functional entities, each one based on an independent PLC (Fig. 3).

To add redundancy to the PRS, a BETS is being implemented for the surveillance of the correct position of the TCDQ jaw w.r.t. the beam energy. This BETS will be connected to the LHC Beam Interlock System as an additional maskable channel and will dump the beam in case of an incorrect TCDQ position.
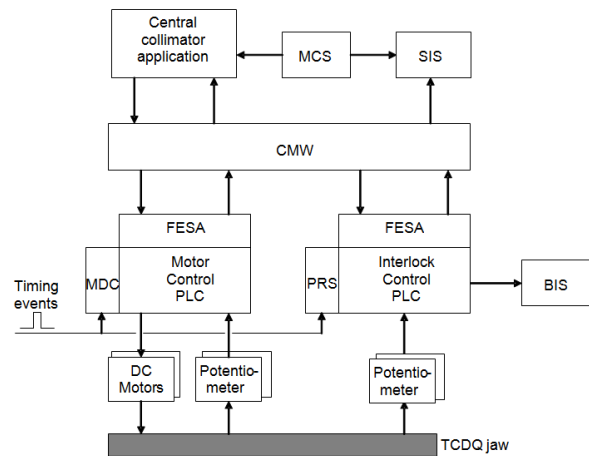

Figure 3: Architecture of MDC & PRS software.

At present both TCDQs (for beam 1 and beam 2) are installed (Fig. 2), aligned and under vacuum. Remote displacement system tests are planned later in 2014.

COMMISSIONING

Considering the important changes to the LBDS system described above a complete commissioning of the system is presently ongoing. First reliability tests showed an increased number of spontaneous triggerings of the MKD generators, the cause of which was found and resulted in the replacement of HV insulators. Presently six weeks of tests operated from the Central Control Room have started with a local BIS loop to test the TSU functionality and the new link between BIS loop and re-triggering system. This will be followed by another three months of testing under high voltage. Towards the end of the year a sector test with beam is foreseen which will include the beam dumping system. At start-up in 2015 a long list of machine protection tests of the beam dumping system, with and without beam, are foreseen.

CONCLUSIONS

Although the LHC beam dumping system performed as expected during the LHC Run 1, an important list of system improvements are being implemented during the present long shutdown. These modifications should allow the safe operation of the beam dumping system at higher beam energies.

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