DUMP SYSTEM PROTECTIONS

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Abstract

The protection functionalities of the various systems connected to, and associated with, the LHC Beam Dump System (LBDS) are covered in this talk, in particular the dump channel protection (TCDQ), Beam Position Monitors (BPMs) and Abort Gap Monitoring (AGM). System changes planned for Long Shutdown 1 (LS1) are described, and the machine protection implications are detailed in terms of the improvements in the system safety and also in terms of changes to the operational procedures and expected performance. Run 1 (LHC operational period 2009-2012) experience is reviewed concerning aperture and tolerances with an outlook to 7 TeV. Some other ideas to improve operational availability without compromising safety are explored, together with possible improvements to the validation procedures for the dump protection.

TDE THERMAL RESPONSE

In LHC Run 1 the maximum beam energy deposited in the dump block TDE was around 140 MJ. The TDE thermal response has been inferred from the pressure data, where the pressure of the N_2 gas containment was logged throughout the year. The temperature change is estimated from the logged pressure P through the ideal gas law. The results are shown in Fig. 1 and give a 10 K peak average temperature rise for a single dump, which is reasonably consistent with the expected average temperature rise of the dump block plus steel jacket (we would expect about 22 K if all the energy were absorbed and instantaneously spread out).

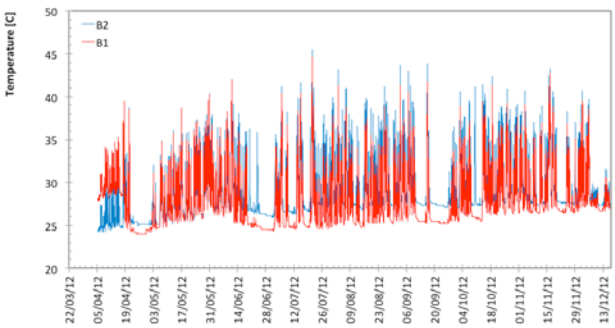

Figure 1: Calculated TDE temperature rise in 2012.

The thermal time constants of the TDE could also be derived from the data, Fig. 2, and these are about 4.5 hours for both dump blocks.

Repeated dumping of the full intensity beam was seen to push the temperature rise to about 20 K. Further analysis of these results was used to extrapolate to Run 2 and High Luminosity (HL)-LHC performance expectations – the main concern is the N_2 pressure, which may exceed the 1.3 bar limit and thus require an active gas handling system. The maximum delta T was ~5 K per 10^{14} protons, which for 6.5 TeV will increase to ~8 K per 10^{14} protons. We would expect about 27 K delta T for a full nominal intensity 25 ns beam, with maybe 55 K for repeated dumps corresponding to a delta P of 233 mbar, to around 1.45 bar. This already indicates that in Run 2 some N_2 may be vented in case of repeated dumps.

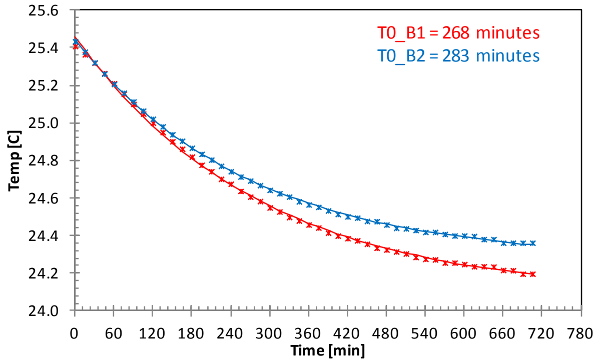

Figure 2: Thermal cool-down for TDE blocks.

CHANGES IN LS1

The changes which are foreseen for LS1 are listed below, with a discussion of their implications.

TCDQ Upgrade

The existing 6 m long graphite TCDQ (in 2 tanks) are being replaced by 9 m long CfC diluters (3 tanks), Fig. 3. The upgraded version [1] is designed to be robust to $2.5 \cdot 10^{11}$ p^+ per bunch with 2808 bunches at 25 ns spacing, corresponding to the HL-LHC maximum. Other improvements include the replacement of LVDTs with potentiometers, and a modification of the motorisation to increase the stroke and angle range to ±1.1 mrad.

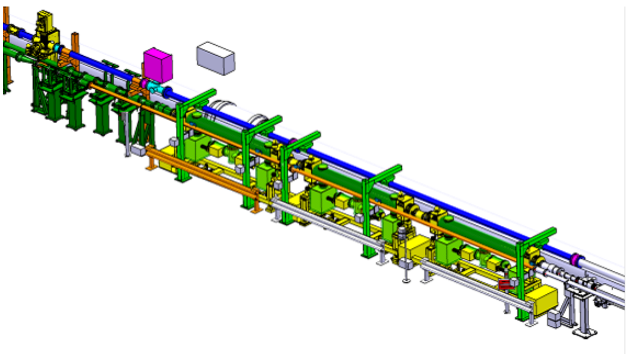

Figure 3: Layout of upgraded TCDQ with 3 tanks.

Additional TCLAs (not for LS1)

Space has been left in the lattice between the collimators TCDQM and TCSG for additional horizontal and vertical TCLA type absorbers. These are intended to reduce cleaning losses on Q4, and to reduce the peak load on Q4 after an asynchronous dump. The energy deposition in Q4 was simulated [2] with the new TCDQ and the HL-LHC beam parameters. The maximum energy density was 20 J/cm^3 in the Q4 coil, Fig. 4, and 40 J/cm^3 in the Q5 coil, leading to the conclusion that these additional absorbers are “not needed for the operation after LS1 from the magnet protection point of view”. Their installation has therefore been postponed pending further study.

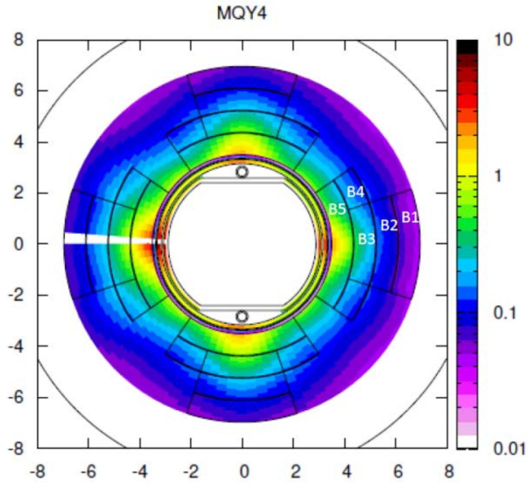

Figure 4: Energy deposition (in J/cm^3) in Q4 coil with new TCDQ.

TCSGP in IR6

New TCSGP (secondary collimators with button pickups in the jaws) will be installed in IR6L/R, replacing the existing TCSGs. The jaw BPMs will allow more accurate setting-up of the TCSG without touching the beam.

Presently a tolerance of 1.5 sigma is needed between TCSG and TCT collimators for the asynchronous dumps, which limits the minimum beta*, although the main contribution is orbit instability and not setting-up accuracy. It will be difficult to immediately ‘use’ the tolerance gained to improve the beta* reach as TCSGP and TCDQ would need to dynamically follow the orbit.

The present Software Interlock System (SIS) interlock on the beam position at the TCDQ can be moved to TCSGP to improve the accuracy. It should be investigated whether a hardware implementation could be possible to avoid any software or communication related issue.

The main gain from the TSCGP will be in setting up time and accuracy, and in interlock accuracy. As time is needed to gain experience with the new system, there are no immediate plans to have the collimator jaw positions dynamically follow the orbit, even though this would give the most benefit.

TCDQ in the BETS

A major change for the Beam Energy Tracking System (BETS), Fig. 5, is the addition of the TCDQ jaw positioning, to generate a dump via a hardware interlock when the jaw position is out of tolerance. The system will demand a synchronous dump if the position reading goes out of (an energy dependent) tolerance.

New electronics are needed to allow masking this input to the BETS when the Setup Beam Flag is TRUE, otherwise it is not possible to set up the TCDQ with low intensity beam. Alternatively, this can be achieved by connecting the BETS to the BIS, instead of directly to the Timing Synchronisation Unit (TSU). This option has already been suggested for the TDI.

The implementation details (electronics, fibres, …) remain to be worked out after the MPP workshop.

Interlock Beam Position Monitors

The interlock BPMs in IR6 (BPMS) were a frequent source of dump triggers – for good reasons. The system has a simple logic for dumping the beam, with N wrong counts in a window of M turns, where N includes also bunches with bad readings. There were many “correct” dumps when the beam was unstable, but the reading also suffered when the bunch intensity dropped below threshold.

Several interventions were made to adapt the attenuators to increase the dynamic range – in each case a beam measurement was needed to scrape beam and check the response. The single channel limits (N) were relaxed on a few occasions with ions.

The changes foreseen for LS1 are to improve the Post-Mortem diagnostics, to be able to trace the origin of the dump (bad bunch reading, position out tolerance, …) and to add this into the External Post Operational Check (XPOC) system. Improvements on the system to increase the dynamic range will also be tested. Another suggestion is to make a calibration every fill – at present this is only done when the Front-End Computer (FEC) is rebooted.

POSSIBLE AREAS TO IMPROVE AVAILABILITY AND/OR SAFETY

BPMS tolerances and settings

The BPMS trigger level is set to allow ±4 mm maximum orbit excursion at the septum protection TCDS and the septum MSD, to ensure a clean dump with low transverse losses. This was checked during the initial LBDS commissioning at injection, and indeed was found to be an acceptable range. The beam also needs to be extracted cleanly with only 14 of the 15 kickers MKD available – this was tested in 2010 commissioning, but not in combination with a 4 mm orbit offset as these failures are considered to be independent.

The BPMS thresholds are now set to about ±3.0 mm around the measured orbit, allowing ±1 mm for fast dynamic orbit changes plus the initial uncertainly on the BPMS reading.

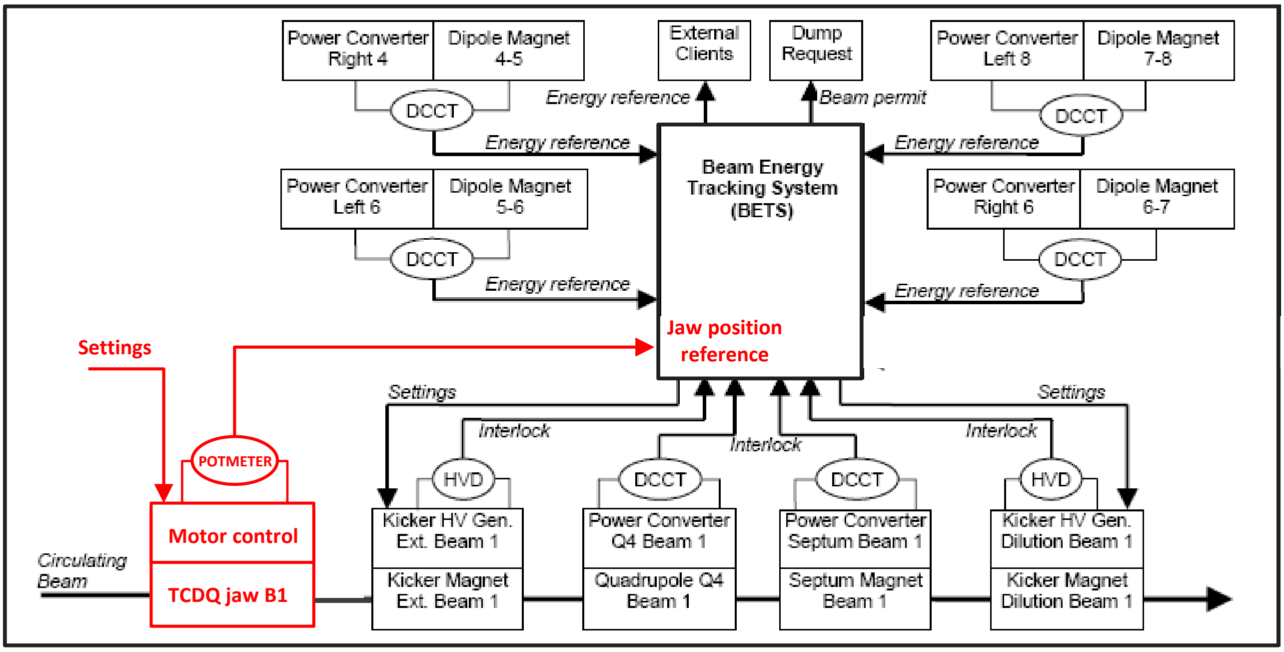

Figure 5: LBDS BETS showing the additional TCDQ functionality.

The question arises whether we still need the full ±1 mm for the orbit. Post-mortem data of positions at the BPMS at dump would help to decide.

Opening the thresholds to the maximum would give a larger margin for bad bunches, and assuming 2 µm emittance we might gain ±2 mm. But we would need to then 'interlock' on beam emittance (or rely on the losses at TCPs). Furthermore the TCDS protection of the MSD also depends on the maximum local orbit excursion [3]. Finally, the BPMS response is very non-linear, so that we would only gain a small fraction in dynamic range.

Improving the beam centring in BPMS or updating more frequently the threshold centre w.r.t. the measured orbit would both bring only marginal gains.

Overall, not much can be gained by changing the thresholds, and the best solution is to directly address the issue of the BPMS dynamic range.

MKD tolerances

As mentioned, the dump channel aperture was designed for ±4 mm orbit margin, assuming 3.75 µm emittance at 450 GeV, 0.27 mrad MKD total kick, and either 14 or 15 MKD firing. The aperture was validated under these conditions, including the missing MKD case.

Much effort has been made in stabilising the temperatures of the MKD switches (including a full Peltier cooling system) to reach the specified current stability of ±0.5 – 1.0% (depending on which point on the waveform is measured). This requires a very close control of actuators and sensors (power supplies, voltage dividers, …), but also brings additional operational issues, including either full 24h recalibration, or adjustments of calibration factors in the FEC after an equipment exchange.

Experience from Run 1 shows smaller emittance and a more stable orbit than foreseen in the LHC design. Also there has not been a dump with a missing MKD (yet).

The margin for the MKD/B current error could potentially be increased safely (e.g. by small reduction in BPMS thresholds), and we could conceivably use this margin to stop cooling the switches, and to stop fudging the FEC calibration factors when components are changed.

This would need wider IPOC and XPOC tolerances, and we would then be less sensitive to gradual degradations of switches/connections. The TE-ABT group equipment experts also prefer to keep the constant operating switch temperature, for high voltage reasons.

Overall it is not recommended to stop cooling, despite the need to keep the complex system running.

The question of how to deal with the calibration factors needs to be discussed in more detail – this is a compromise between minimising risky manual updates, and having nice tight thresholds for operational tolerances to spot degradation.

Abort gap monitoring and cleaning

Presently the CCC operators are using the Abort Gap Monitoring (AGM) from the Beam Synchrotron Radiation Abort-gab (BSRA) signal with a "wetware" [4] connection to the Beam Interlock System (BIS), i.e. via the LHC Announcer and the EiC, to launch the Abort Gap Cleaning (AGC) or to dump the beam.

The concept is working well (clean dumps, problems are spotted), but issues include the reliability of this approach (which is very likely SIL0, for example one must not mask/turn down the announcer, and the EiC must be within earshot); no backup system in case of BSRA issues (encountered in 2012 after Beam

Synchrotron Radiation Telescope (BSRT) failure with compensatory measures including periodic AGC); the dependence on BSRT steering.

Possible improvements include automatic calibration of AGM, to improve availability to a level where a software connection to AGC and/or BIS could be foreseen, and the development of a complementary abort gap population measurement, from diamond BLMs in the collimation region or/and from experiments.

The optimum overall approach and the BSRA HW upgrades still need definition – this should be followed up in a coordinated way, and specifications should be discussed and formulated.

For the cleaning, the negative impact on the luminosity remains to be understood and cured [5] – this would allow AGC to be ‘always on’, which would solve the issues of the AGM availability.

Finally, we need to quantify how important AGM/AGC is for safety – e.g. assumptions on the frequency of asynchronous dumps (in coincidence with non-empty abort gaps) which enter into the calculation of the TCT settings.

Dump protection validation

Presently asynchronous dump loss maps, Fig. 6, are made periodically and analysed ‘by hand’. The maps are normally acquired during commissioning, after configuration/collimator changes, and periodically when collimation loss maps are also acquired.

On the loss map measurement frequency, we should standardise when/which asynchronous loss maps are needed, before the run starts, and then stick to the plan.

There is always some beam in abort gap which gives measurable losses on TCDS/TCDQ. This opens the possibility to produce loss maps in collision, although without the 1.2 mm offset at the TCDQ. We should consider updating the XPOC module to check TCDQ/TCT loss ratios, and possible make trending analyses.

More sophisticated tools could also be conceived using Diamond detectors, although development is needed.

Operational procedures

Operational procedures were very complete for the LHC commissioning phase in 2008/9, as there was lots of time to prepare, but were less well defined for regular running, where it was clearly impossible to foresee all combinations of problems, faults and configurations.

The most important aspects are that a) potentially dangerous situations are recognised and communicated and b) that time is taken to discuss before allowing operation to proceed.

This paradigm requires open communication and the availability of experts. It also requires Machine Coordination and Management to take warnings seriously – it is not easy for a potentially junior colleague to insist that “we need to stop the machine while we think”, but time thinking is much better than exposing the machine to potential damage. The restricted Machine Protection Panel (rMPP) should continue as an ‘online’ reactive body, able to provide a consensus on possible issues and to support such warning – reinforcement of the present aging body is important!

Finally, a better definition is needed of the actions to take in terms of requalification for different types of equipment intervention (for example, power supply or switch exchange, protection device sensor exchange, …).

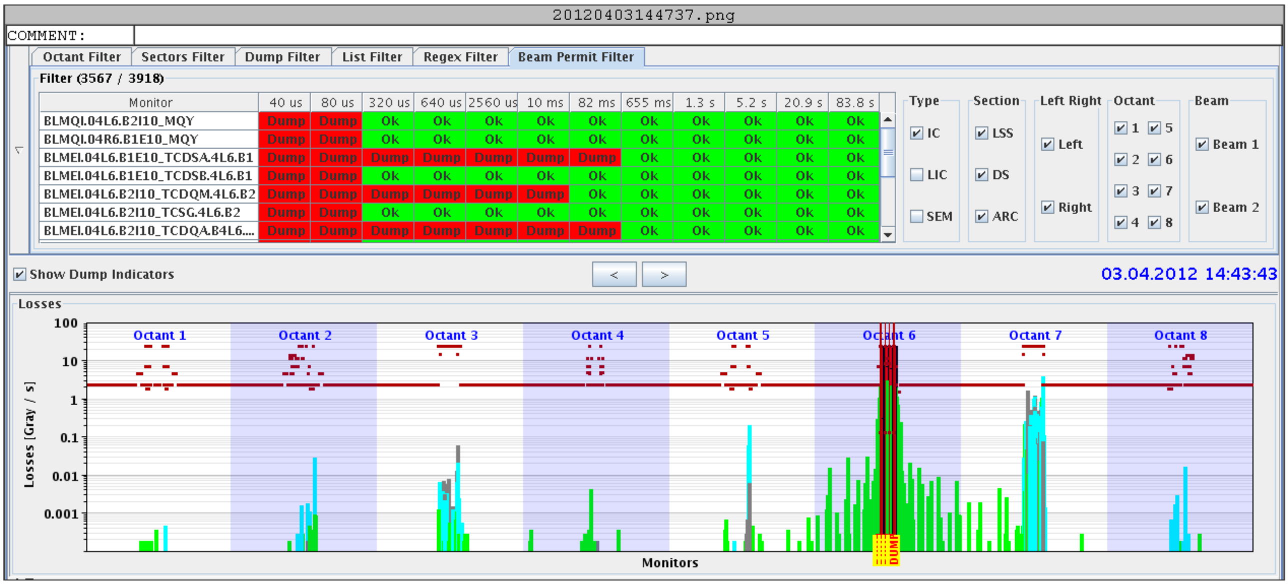

Figure 6: Asynchronous dump validation loss map.

CONCLUSIONS

LHC is still waiting for its first asynchronous dump with a full machine at high energy. However, we must continue to maintain, and even improve the associated protection. Changes to some systems connected to the LBDS will take place in LS1, designed to increase the robustness, safety or availability. These are the new TCDQ absorber, TCDQ input of the BETS, new TCSGP, improved AGM, improved BPMS, and the XPOC module for dump protection validation. Work is needed now on finalising specifications and requirements.

Associated changes in commissioning and validation procedures also need to be considered and documented – the forum for this is not evident – should it be the LHC-wide commissioning team, the MPP or the LHC Injection and Beam Dump (LIBD) team?

Relaxing the tolerances for the MKD current by removing temperature control or to ease recalibration needs could be possible, but may then mask onset of other issues and is not recommended.

SUMMARY OF ITEMS FOR FOLLOW-UP

- When and if TCLAs are needed in IP6;
- Maximum TCDQ-TCSGP6 retraction, and MP issues of orbit 'tracking' ;
- Connecting BETS to BIS, rather than TSU;
- BPMS dynamic range, procedures for threshold changes and calibration improvement;
- Relax some MKD waveform tolerances to gain simplicity in revalidation (but lose some trending 'trigger' ?);
- BSRA availability, and automatic triggering of cleaning and/or dump;
- Alternative abort gap monitoring methods;
- Abort gap cleaning transparency for luminosity;
- XPOC modules to review (asynchronous dump checks, abort gap population, TCDQ/TCSG retraction/setting, …);
- Review of procedures for revalidation after component exchange.

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[5] E. Gianfelice-Wendt et al., LHC abort gap cleaning studies during luminosity operation, CERN-ATS-2012-215.