79th Meeting of the Machine Protection Panel

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1 Presentations

The slides of all presentations can be found on the website of the LHC and SPS Machine Protection Panel:

http://lhc-mpwg.web.cern.ch/lhc-mpwg/

1.1 The new BETS on MSI, TDI and TCDQ. (N. Voumard, J. Uythoven).

Nicolas explained that one of the follow-ups from the Machine Protection Workshop in Annecy (March 2013) was to implement energy dependent interlocks for the MSI current and the gaps of the TDI and TCDQ via the Beam Energy Tracking System (BETS). Therefore the required tolerances had to be reviewed.

In his presentation Nicolas addressed the following questions.

- Injection Septum:
  - ✓ The absolute current of the injection septum (MSI) will be interlocked by the BETS and connected to a maskable channel of the LHC injection BIS. This will inhibit the SPS extraction within a few microseconds if the wrong current is measured.
  - ✓ The proposed tolerances are: 7 μrad angle = 1 σ oscillation = 5e-4 tolerance on the MSI current (~0.5 A). The stability of the MSI current needs still to be confirmed.
  - ✓ MSI power converter will **possibly** be upgraded from mugef to LHC FGC.
    - ? Jan asks if there will be an interface to get the signal for BETS and if a general LHC FGC control will be introduced during LS1 already (or during LS2 as planned).
    - ? Verena summarizes that there will be no mugef after LS1, it will be upgraded to FGC-like control (both for LHC and SPS).

- BETS on the Injection Absorber TDI.
  - ✓ The BETS will interlock on the gap between the jaws and will have two channels (upstream, downstream). The threshold function will inhibit injection for energies above and below 450 GeV.
  - ✓ The TDI BETS will be connected to a maskable input at the LHC Injection BIS and will use the same input as the MSI BETS. The proposed tolerance is ± 1 σ on the gap at 450 GeV, i.e. about ± 0.6 mm.
  - ✓ Note there is no redundant gap measurement available. Furthermore it is difficult to transmit the presently calculated gap to the BETS with a sufficient resolution. ➔ May be overcome by an inferometric measurement proposed by Alessandro's (see next presentation).

- BETS on the Dump Absorber TCDQ.
  - ✓ The TCDQ is single sided; therefore its absolute position will be interlocked on two channels (downstream, upstream). The BETS interlock will be connected to an additional maskable channel of the LHC ring BIS.
  - ✓ Note: the present BETS on the LBDS is connected directly to the TSDS and will remain unchanged.

- BETS cables and connections.
  - ✓ MSI and TDI: MSI and TDI BETS will be installed in a single VME crate by BE/CO and connected via a standard CIBU to the BIS (crate installation pending). A request to pull the fibre optical cables has been transmitted to EN-EL. For the TDI this is straight forward (~20m from MKI racks), whereas it is more complex for the MSI, as the power converters are placed at the surface.
  - ✓ **Action**: Fibre optics cabling demands for the MSI should be repeated, as the requests were not yet confirmed.
  - ✓ TCDQ: The BETS will be installed in a VME crate (to be installed by BE-CO), which will be connected to the BIS via a standard CIBU. The pulling of the ~30m cables can be done by TE-ABT. The same accounts for the fibre optics connection.

- ✓ Nicolas shows schematics of the BETS layout for the TDI/MSI and for the TCDQ.
- Nicholas shows the planned BETS beam energy transfer functions for the TDI and the MSI. These functions cannot be changed remotely.
  - ? Verena mentions that the gap and therefore also the limits had to be changed several times during the 2012 run, due to the heating and, therefore, deformation of the TDI jaws.

Questions and comments:

- ? Markus reminds that in case of fibre optics it is the responsibility of TE-ABT to check the status and push forward.
- ? Markus asks if the request for BIS channels has been sent and is confirmed.
- ? Stéphane answers that the demand for cabling was sent, but not yet for the CIBU.
- ? Markus reminds to check that there are sufficient maskable and unmaskable channels available in the BIS.
- ? Stéphane responds that the channels have been already reserved on the CIBM. The installation of the CIBU is pending.
- ? Markus adds cables are also needed for the MSI.

- o **Action**: Check the status of the cabling request with Guillaume (Stéphane).
  - ? Markus adds that the LHC FGCs perform automatic calibrations, when there is no beam. Therefore it is needed to use also the DCCT OK signals to check the obtained values.
  - ? Alessandro asks why the interlock settings cannot be changed remotely but one needs to go into the tunnel.
  - ? Jan responds that this is done for safety, to minimize the risk of accidentally implementing the wrong limits.
  - ? Alessandro asks what happens if the potentiometer fails in the TCSQ?
  - ? Etienne responds that it needs to be changed. Jan adds that the table needs to be adjusted after a change of the potentiometer.
  - ? Etienne asks if we really need an interlock window for the TCDQ? In principle we would not need to interlock the inner position of the TCDQ.

- ? Verena responds that the energy dependent interlock is in addition to the normal jaw position interlocks, which increases protection.
- ? Jan adds that with an interlock window one also checks the correct movement of the device.
- ? Brennan and Markus add that the interlock window is also used in other collimators and therefore this approach should also be used for the TCDQ.

Markus summarizes that the work of interlocking the MSI, TDI and TCDQ in the BETS should go ahead.

Action: summarize the specifications in an ECR document and circulate (Nicholas et al.)

1.2 Precise TDI gap measurement for BETS interlock. (A. Masi)

- As already discussed in the previous presentation the BETS shall interlock on the TDI gap (upstream & downstream), to inhibit injection for energies below and above 450 GeV.
- Therefore the gap width should be measured redundantly by an independent device. This device should not introduce additional false interlocks.
- Alessandro reminded how the TDI gap measurement and interlocking is currently performed.
  - ✓ 4 LVDTs are installed per jaw at the TDI to measure the axis positions;
  - ✓ The gap is indirectly calculated from the positions of the related axes (upstream, downstream);
  - ✓ Accuracy of the position measurements is ~ 1 μm;
  - ✓ The motor control (MCS) and position interlocking (PRS) is done independently. The PRS is connected to the different BICs. No failure on the low level control system experienced in the last 3 years of operation has compromised the machine safety;
  - ✓ Currently there are interlocks implemented for the upstream and downstream position of the jaws and the calculated gap between the jaws; In addition, there exists and independent energy dependent gap interlock.

- In 2012 a deformation of the TDI jaws has been observed during operations. With the available LVDTs it was not possible to measure the real deformation. This lead to lengthy beam based re-alignments. Furthermore the thresholds for the gap position interlocks had to be adjusted several times in 2012 to avoid unnecessary beam dumps or delays of the next injection.
- Alessandro presents four different possibilities how to implement the gap interlock via the BETS. These are summarised in the table below:

Solution	Direct connection of the TDI PRS system to the BETS	Additional PRS system for the BETS gap measurement	Additional PRS system for the BETS gap measurement + 2 additional LVDTs for upstream and downstream gap measurement	Interferometric position sensor heads installation at TDI
Cost	few tens of KCHF	roughly 130 KCHF	roughly 300 KCHF	200 KCHF
Time	1 month	1 month	Several months - Not sure to be ready by the end of LS1	Approximately 6 months - it should be ready by the end of LS1
Pros	Cost and implementation time	Implementation time	Well known measurement solution	• Direct jaw aperture measurement. A real deformation can be detected without false interlocks; • Additional measurement in the middle of the jaw; • Fully redundant solution (measurement principle, hardware and software); • This solution represents a prototype to be used for future TDI collimators.
Cons	• NO hardware redundancy; • Risk to increase the false interlocks and the LHC downtime (due to the jaw deformation problem); • Limited added value.	• NO hardware redundancy at the sensor level; • Gap measurement not redundant and affected by the same problems experienced in 2010-13 operation; • Risk of increasing the false interlocks and the LHC downtime (because of the jaw deformation problem).	• Cost; • Implementation time; • Gap measurement affected by the same problems experienced in 2010-13 operation • Risk of increasing the false interlocks and the LHC downtime (because of the jaw deformation problem)	• Solution never installed in the LHC but extensively tested in the lab and in radiation characterization campaigns. • The same solution will be used on the Crystal Piezo Goniometer to be installed in IP7 by the end of LS1.
Additional safety for the machine	No added value	Additional gap monitoring	Additional gap monitoring	More effective gap measurement system + additional monitoring
Experience	Already installed in the machine and successfully operated			Successfully tested in the lab and deeply characterized, but no experience in real operation.
Risk of false interlocks	High	High	High	Very low
Redundancy	No redundancy	Reading electronics	Sensor + reading electronics	Sensor + reading electronics

- Details of the Solution 4 (Interferometric position sensor heads installation at TDI).
  - ✓ The interferometric position sensors allow to directly measure the aperture of the gap by measuring the phase shifts of the two sine waves – injected and received.
  - ✓ The installation of 3 sensor-heads e.g. on top of the jaws (beginning, mid and end of the jaw) would allow to measure a deformation of the jaws and give additional redundancy for the gap measurement.

- ✓ The HW installed in the TDI for this measurement is purely passive. An optical fibre will transport the signals to the electronics.
- ✓ Depending on the gap width the system can only work if the tilt angle of the jaws is limited, as the sensor will not receive any signal from the opposite stainless steel mirror:
  - Injection: gap=10mm, max tilt angel: +-35mrad. Should not be a problem, as the maximum tilt angle due to the TDI mechanics is +-5mrad.
  - Parking: gap = 110mm, max tilt angle: = +-3.5mrad. Should normally not be a problem, as tilt angles were always set to 0, when the jaws were in parking position.

    - ? Chiara comments that mechanical problems were observed, when the TDI was moving from parking position to injection position with tilted jaws. Therefore, the jaws are normally moved without any tilt angle, which is applied when the jaws are at injection position.
    - ? Markus proposes to measure the tilt angle at the parking position to monitor a possible deformation of the jaws.
  - There is no experience with such a system in the LHC. Furthermore, the installation timeline is very tight. To be ready by the end of the LS1 the funding and the green light should arrive before September.

Questions and comments:

- ? Daniel asks where this sensors heads for solution 4 would be installed in the TDI and if there is a need for a mechanical redesign.
  - Alessandro answers that the redesign will be very limited. It is planned to put the sensor heads on top of the jaws, thus, no re-design of the jaws needed. Optical cables need to be. If this proposal will be accepted, the implementation will start by the end of September. Then there is a good chance to have it ready by the end of the LS1.
- ? Daniel asks if heating of the device could be an issue.
  - Alessandro answers that the device is certified up to 300° C.

  - Markus adds that the device is on top of the jaw and not inside, so the heating should be limited.
- ? Markus asks about the radiation hardness in case of fast losses.
  - Alessandro answers that up to few kGy there is no problem, but this was not tested for the case of direct irradiation of the sensor-head.
  - Jan adds that there is no electronics in or close by the TDI.
  - Alessandro says that the lasers are ~1 km away.
- ? Markus asks if all the 3 sensors on the jaw are needed for calculating the position.
  - Alessandro answers that they are redundant.
- ? Daniel asks if it is planned to change the interlocking strategy of the jaw positions, when implementing the optical gap measurement and connecting it to the BETS.
  - Alessandro answers that the current interlocking strategies will not be changed.
- ? Jan comments that currently there are no problems with the LVDTs expected. In case of any, the configuration will have to be changed and redundancy will have to be reduced.
  - Verena says that the proposed measurements will only provide information about the gap and not about the position.
- ? Markus asks what would be the preference for OP?
  - Verena stresses that the direct gap measurements are very important. The decision-making process should be based taking into account the radiation hardness of each solution.
  - Alessandro comments that various tests have been performed with the proposed interferometric position sensors were done. So far they have shown high stability. The solution under development for the past 4 years.
- ? Verena asks how hard it would be to switch back in case of a failure of the proposed solution.
  - Jan answers that there is no way to go back, the respective BETS will have to be disabled.
  - Daniel asks if it will be possible to change the back to use the data from the other LVDTs in such a case?

- ? Markus concludes that for the worst case if the sensors fail, there should be a backup solution.
- ? Stéphane asks what kind of radiation was used for the tests.
    - Alessandro answers that it was γ-radiation and adds that there is no electronics inside the sensor head, so there is no degradation of the material.

Actions:

- ✓ Clarify how to finance the implementation of the optical gap measurement system into the TDI (Alessandro / Jan).
- ✓ Study accidental scenarios: What happens if the TDI jaw is hit by 144 or 288 bunches? What happens if the optical head is hit directly?

1.3 Proposed implementation of redundant BIS-LBDS trigger channel (S. Gabourin).

- Stéphane reminded the audience on the functioning of the current configuration of the LHC Beam Interlock System (Beam permit loops). Furthermore Stéphane shows the schematic of the current LBDS system with the paths and trigger signals in case of synchronous and asynchronous beam dumps.
- The new BIS Asynchronous trigger has been requested by MPP to introduce a direct link between BIS and the retriggering lines of the dump kickers.
- The new link will trigger a dump 250us after the opening of the BIS loop was detected.
- The new link will be implemented on a new hardware board (working name CIBDS), which will be based on the current CIBG of the BIS. Thus there will be no changes made on the CIBG, which is in the core of the BIS and has been running reliably over the past years.
- The key part of this new board will be the CPLD, which detects the opening of the beam permit loop. The CLPD will have the same Matrix code as the one on the CIBG.
- Special care needs to be taken, as the optical BIS loop has to be opened to introduce the new board. In addition a new VME connection, new FESA classes and JAVA code have to be prepared.
- As the new board will be based on the CIBG it will have the same problem of obsolescence hardware components in the coming years. Therefore spares need to be prepared to keep the system running up to LS2.

- The Matrix code on the CPLD of the CIBDS will detect the opening of the BIS loop and send a trigger to the trigger delay unit, if the LBDS is not in local mode.
- The asynchronous trigger will be blinded if the LBDS runs in local. This functionality needs to be designed in a fail safe way. It includes, therefore, a read back loop to check the inhibit signal and dump the beam synchronously in cause of inconsistencies via a standard CIBU. Thus, any spurious triggers on this board will cause a synchronous dump (availability issue not safety issue).
    - ? Stéphane asks if the BIS channel for this new CIBU should be maskable or non-maskable.
    - ? It is concluded that the CIBU should be connected to a non-maskable channel.

Questions and comments:

- ? Verena asks if the new link needs to be implemented before the reliability run of the LBDS.
    - Jan responds that the idea is to test the full system including the new link.
    - Markus asks what would happen if it is not finished before the reliability run.
    - Etienne explains that the new link needs to be available for the “dry-run”, also called CCC reliability run, which is planned to start in March 2014 at the latest.

Action: Prepare technical specifications for the new link between BIS and LBDS retriggering lines, including the arming sequence.

1.4 Connection between LHC BIS and LBDS re-triggering system: dependability studies (A. Apollonio, V. Vatansever).

- Andrea summarizes the technical considerations and goals for the new link:
    - ✓ Modify as little as possible the BIS.
    - ✓ Obtain SIL (Safety Integrity Level).
    - ✓ Not more than 1 false asynchronous beam dump in 10 years.
    - ✓ Not more than 2 false synchronous beam dumps per year.

- To ensure that these requirements are fulfilled a reliability analysis has been performed for the new link (CIBDS and Trigger delay unit). The failure rates of the electronic components were taken from the manufacturers, if available. Otherwise they were taken from the military handbook. The different failure modes were checked with the help of p-spice simulations.
- Trigger Delay Unit (TDU): 4 TDUs (one per BIS loop, i.e. two per beam) will be used.
- Three failure modes have been identified for the TDU:
    - ✓ Asynchronous beam dump: Mean Time To Failure (MTTF) 27000 years or 10% failure probability after 2870 years.
    - ✓ System not available on demand: MTTF 390 years or 10% failure probability after 41 years.
    - ✓ Silent failures, failures without effect on the output.
- In summary: the TDU is highly reliable, almost no asynchronous beam dumps are expected, thus, no back link to the BIS loop necessary.
- The Link from the BIS to the TDU (CIBDS) is currently still under investigation. So far the failure modes listed below have been identified:
    - ✓ AND gate "stuck in True / False" mode. This failure will affect machine availability, as the system cannot be re-armed after a beam dump.
    - ✓ Spurious triggers due to failure in the MOSFET drivers. This will cause a synchronous beam dump due to connection to the CIBU/BIS.
    - ✓ Opto-couplers (high variation of failure rates) in the LBDS local mode check loop might cause silent failures.
    - ✓ CPLD: failures in the VHDL code: A quantitative reliability analysis is difficult. As this code has been running in the BIS over the past years an experience base analysis could be performed. But, no failures of this code have been observed so far.
- Assuming the failure of one single component of the CIBDS leads to a failure of the whole device, the MTTF is 71 years or 10% failure probability after 7.5 years.
- The reliability analysis of the CIBDS is still on-going.

Questions and comments:

- Markus asks if it is sufficient to have just a rising edge at the output of the TDU to trigger the retriggering lines (check the cause of the ABD).
  - Andrea answers that the rising edge and half of the voltage are sufficient.
- Markus comments that the VHDL code on the CPLD (-Matrix) remains unchanged.
- Jan asks about the limit of the reliability of the VHDL code from the operational experience of the BIS.
  - No errors in the detection of the BIS frequency and beam permit have been observed in the past years of operation.
- Roberto comments that not a single component will survive 390 years. Therefore the quoted MTTF numbers are meaningless and should be calculated for more realistic time scales, e.g. failure probability per mission.

2 AOB

As requested in the last MPP, Barbara sent the updated table for the installation of LICs and the connection of BLMs to blindable channels in the TI2 injection region.