151st Meeting of the Machine Protection Panel

Participants: A. Apollonio, M. Blumenschein, J. Boyd, R. Bruce, D. Hugle, T. Ladzinski, B. Lindstrom, N. Magnin, C. Schwick, M. Valette, J. Wenninger, D. Wollmann, C. Zamantzas, M. Zerlauth.

The slides of all presentations can be found on the website of the Machine Protection Panel:
http://lhc-mpwg.web.cern.ch/lhc-mpwg/

1.1 Functional Specifications for the TED interlocking for LIU beams (V. Kain)

- Verena presented a summary of the interlocking needs for the transfer line beam stopper (TED) with respect to the future LIU beams. They are also summarized in the ECR document SPS-OTH-ES0001. The document is open for review until September the 8th.
- The TDE is operated in air and designed to withstand the LHC ultimate intensities and emittances at 450 GeV. Studies have shown, that the current TED can only withstand 144 LIU bunches, more than this could lead to cracks in the graphite.
- The two pairs of TEDs can move in and out of the beam near the extraction and injection points and inhibit beam extraction if they are moving.
- Proposal: keeping the current design, with 4 TEDs, which includes two spares and limiting the extractable intensity to 144 bunches when the TEDs are in line. This would be implemented with a new SPS_TBF flag, which would be true if the beam intensity is below 144 LIU bunches. Thus, the beams could be extracted with the TED in IN position, as long as the SPS_TBF is TRUE.
- Verena then presented a list of BICs affected by this change. This flag would be provided by the existing SMP based on the currently existing BCTs.
  - Markus commented, that this change will affect other equipment. It needs to be ensured that high intensity beam is not sent down the wrong beam line. He added that some of the interlock logic would be in the TED user permit, i.e. outside the BIS, which is not the standard procedure. Verena answered that the flag conditions are usually verified in the hardware, which produced then the user permit.
  - Jan asked if there were also modifications foreseen on the software/controls side, which would add another layer of protection i.e. inhibit movement by the control system, if the conditions are not fulfilled. Verena answered that this will be implemented in LS2. The current control system allows mode management but does not prevent TED insertions although it should not be inserted when LHC beam is extracted.
  - T. Ladzinski asked if the current TEDs would still absorb sufficiently for personal protection in case of more than 144 bunches. Verena

answered they would but this can only be guaranteed once. Such beam impacting the TED would lead to cracks as these energies deposited are not safe anymore. With the same reasoning 288 pre-LIU bunches should also be fine.

1.2 Effect of spurious quench heater and CLIQ firing on the LHC and future HL-LHC beams (M. Valette, B. Lindstrom)

- Matthieu presented a summary on the effect of quench heater (QH) firing in superconducting magnets in the LHC and HL-LHC on the circulating beam. This study was initiated by observations of vertical orbit oscillation and beam losses before dumps caused by beam induced quenches. This was confirmed during a dedicated MD in 2016.
- The main dipole QH are made of two circuits powered with a maximum of 80 A and connected in a skew dipole way. The associated kick can reach up to 1 σ at injection energy and 0.28 σ at 6.5 TeV. Some magnets in the LHC are protected by QH powered with up to 300 A and others in the HL-LHC will be protected by up to 12 QH circuits. In HL-LHC the triplets and the individually powered dipoles are the most critical magnets since they are long magnets with large local β-functions, leading to large kicks of far above 1 σ at top energy. Simulations showed kicks of up to 52 σ due to the firing of all quench heater circuits in one new triplet magnet (MQXF, inner and outer layer QH). One must therefore ensure that the beam is dumped before the QH are fired for the HL-LHC upgrade.
- Possible mitigations also include lowering the kick from the quench heaters by powering them in a quadrupole way or by compensating the dipole field in the beam area using the different circuits. Since these mitigation methods might affect voltage distributions on the coil and magnet protection assumptions, they will be brought up to the HL-LHC magnet circuit forum. An additional MD on the MQX quench heaters will be performed at the end of the 2017 run.
    - Roderik asked, which beam emittance was used for results presented here. Matthieu responded, that they were calculated assuming 2.5 µm transverse emittance which is the HL-LHC baseline.
    - Jan asked how large the quadrupole or residual dipole strengths would be using alternative connection schemes. These were not simulated but preliminary analytical calculations suggest a gradient 3 orders of magnitude lower than the MQ for the 11 T dipole with quadrupole QH connexion and a reduction of the dipole field by a factor 10 for the MQXF using compensation.
- In the second part of the presentation, Björn presented a study on the effects of a spurious CLIQ discharge on the circulating HL-LHC beam. He first introduced the CLIQ system, which quenches the magnets by discharging an oscillating current of up to 2 kA directly in the coil of the magnet. The effect of a discharge of the CLIQ units protecting one of the Q2 magnets would lead to a 2% reduction of the focussing strength. A discharge of one of the CLIQ units protecting both Q3 magnets or both Q1 magnets would lead to an

asymmetric current distribution and a normal and skew dipole field of 47.5 mT in the beam area. Simulations of the circuit response and magnetic fields were done using the STEAM framework.

- Tracking simulations suggest that the spurious discharge of one of the CLIQ units protecting Q3 would be the worst case and lead to normalized orbit shifts of up to 1 σ, 4 ms after the beginning of the failure, i.e. after ~40 turns. The associated current change in the coils would be 620 A, i.e. 3.8%. After ~120 turns the orbit displacement would reach 3 σ and in the following very quickly increase further, which would lead to a complete loss of the circulating beam. A discharge of the CLIQ unit protecting the Q2b magnet would lead to a β-beating of more than 30% at the primary collimator position in the vertical plane after ~120 turns.
- In conclusion, the triggering of a CLIQ unit in the MQXF should be interlocked against. Alternative connexion schemes may lead to a partial compensation from one of the Q3 magnets to the next but, must be weighed against magnet protection constraints.
    - Roderik commented an increase of the β functions at the TCPs by 30% in 120 turns would be slow enough to rely on protection from the BLMs. One would have to check if the change in β is not larger at other positions in the ring with aperture bottlenecks such as the TCTs and the TCDQ. Since a 4 ms delay to the dump seemed tolerable in the Q3 case, Roderik asked what the level of the β-beating would be 4 ms into the failure in the Q2 case. Bjorn answered it would be in the order of 10%. Roderick concluded this would not be worrying provided the β change is not significantly larger somewhere else.

Action (Bjorn): Verify expected beat beating at critical elements like TCTs or IR6 dump protection in case of a CLIQ mis-firing.

- Jan asked how a spurious firing would be detected and suggested to implement an FMCM like system. Daniel added that the detection of the CLIQ induced quench will take ten+ milliseconds and would be too slow. Thus, it is required to directly interlock on the discharge of the CLIQ units. Which technology is finally chosen for this will need to be decided by the MPE group.

AOB: Following de-activation of SEMs in dump region, mid-term approach for loss detection in dump region and long-term vision for replacement (N. Magnin)

- Nicolas presented an overview of the BLMs located near the dump. There is one IC BLM located downstream of the dump of each beam, the other seven are SEM BLMs, which have been disconnected recently, due to earth faults developing on these detectors.
- An analysis of dumps shows good linearity of the signals with intensity and energy for all B1 SEMs except one, limits are easy to define. The B1 IC BLM shows saturation for intensities higher than 2e14 p+, a small filter might be necessary to monitor high intensity beams.

- All SEM BLMs of the B2 dump show degradation for high energy dumps, this might come from a degraded HV cable. The IC BLM also registers zero signal for about half of the dumps. After the disconnection of the SEMs the system is not blind thanks to the backscattering on the dump channel BLMs.
    - Christos suggested the problem with the IC BLM downstream of the B2 TDE comes from sparking and use cables using kapton insulation, which is more radiation tolerant might solve the problem.
- In the recent LIBD meeting it was proposed to add two IC BLMs on each side of the TDE plus two more LICs downstream to avoid using a filter. Planning-wise, one could keep all the SEMs disconnected as is already done, install a filter on the IC BLMs in the next TS to avoid saturation. The XPOC thresholds on the B2 IC BLM should be removed because they would fail often.
    - Jan, Markus and Daniel proposed to summarize the changes, i.e. the de-connection and the installation of the new BLMs in a short ECR.

Action (TE-ABT, BE-BI): Summarize planned changes in the BLMs around the TDEs in an ECR.

AOB: Problem with MKB energy tracking causing beam dump (N. Magnin)

- Nicolas gave a summary on the recent dump due to an error in energy tracking. The monitoring showed a saw tooth pattern of the difference between reference and interlocking energy with increasing amplitude until it reached the 2% dump thresholds of the PLC. Looking at the reference energy only showed plateaus and fast rises with a frequency of about a minute which points to a communication error between the BEM and the PL, both part of the LBDS.
    - Markus asked what kind of communication was used between these devices. They are implemented with a Profibus from Siemens, a digitizer and an optical fibre to the BEM, then to the PLC. The energy is normally updated with a period of a few milliseconds.
- The energy is measured via the currents in the dipoles of two sectors, one measurement is used to set the reference, setting the MKD voltage, the second is used for the interlock, which checks the voltage after conversion to energy via tables. During the described event only the interlock energy was frozen during the energy ramp of the beam. The reference energy was not affected. This means the MKD voltage was correct and the tracking error was due to a wrong reference energy for the interlock. In the other scenario the MKD voltage would have been off, this would have also been detected and dumped with a lower threshold via the internal BEM logic.
    - Daniel asked, what the probability was that the reference energy is wrong and not detected. Nicholas explained that the BETS is independently supervising and interlocking the reference energy. Thus, in case of small discrepancy between the beam energy and the MKD reference energy the beams would be dumped.
- The BEM card can check errors by comparing the received energy with the SCSS but it didn't work because of the missing communication. This is a

known failure mode taken into account in the design and could be fixed in the next YETS using the local BIS loop.

- Markus commented the PLC should realise, if one slave is not sending updates anymore. It is not since it is an asynchronous system with no watchdog. Markus asked how long the Profibus was, Nicolas answered it goes a few racks further.
- Christos added that there is a check in the BLM system between the received value and the value sent via SMP, which is verified every three seconds. After this incident it was checked with OP that the energy was measured and sent properly. Markus answered that the LBDS uses a completely independent energy measurement coming from the neighbouring arcs, which is not registered by any FESA. There is no reliance on a software system on the dump interlock. Diagnostics in this case are only available in the Siemens diagnostics tool.

AOB: ALFA recommissioning requirements in case of special runs in 2017 (M. Zerlauth)

- Markus announced that, due to current problems in the LHC with 16L2, it is envisaged to advance the special run for forward physics from the coming year, which would include with the ALFA ramon pots. The pots would have to be partially re-commissioned since no commissioning was done since 2016. No interventions were performed since the last validation. The question is which re-commissioning steps should be performed for ALFA.
- The upcoming TS2 looks like a good opportunity to validate pot movement and position interlock limits working properly. The verification of all beam mode dependent configurations takes a long time and is not compatible with operations.
  - Jan commented most of the tests can be done easily and is not worried about the beam mode dependant behaviour. Demonstrating that the beam mode is read properly and the reaction is normal on the testable beam modes is sufficient.

AOB - all

- The PostMortem data from a dump this morning was incomplete.
  - Christos commented there was an UFO buster and XPOC trigger shortly before the dump, no exception was recorded in the considered crates so the data should have been sent, he then asked if it was possible that the data was not stored correctly?
  - Daniel asked it is possible to reboot the crates, which might lead to a faster response? Christos confirmed, that this was done. Christos proposed to send a few PM events to verify everything works properly.