# 166th Meeting of the Machine Protection Panel

The meeting took place on July 13th 2018 in 774/1-079.
Participants:
A. Apollonio, R. Calaga, L. Carver, L. Kevin, B. Lindstrom, D. Lazic, T. Medvedeva, Y. Nie, B. Petersen, C. Schwick, G. Vandoni, F. Velotti, D. Wollmann, C. Wiesner, 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/ and https://indico.cern.ch/event/742780/

## 1.1 Approval of MPP#165's minutes

- Actions from the 165th MPP (https://indico.cern.ch/event/734703/):
    - None.
- No additional comments have been received on the minutes; they are therefore considered approved.

## 1.2 Observed and tested failure cases of CC in SPS - time scales and criticality (B. Lindstrom)

- Bjorn presented a summary of previously simulated failure cases for the Crab Cavities in the SPS as well as some observed failures during the recent SPS MDs.
- The failure cases that have been considered previously are voltage drops, phase jumps and detuning (phase change over several consecutive turns).
- The worst case is a detuning on resonance with the betatron tune, which could kick the beam into the aperture in ~100 SPS turns and have a rise time of losses in the order of some 10's of turns.
- If a phase change is driven by the CCs, the maximum change per turn is limited by the power of the IOTs, meaning that a betatron resonance can only be achieved for voltages < 0.5 MV per cavity.
- Two types of failures have been observed during the past SPS MDs so far:
    - A slow failure with ~half the beam lost over the cycle (19 s) due to a CC tuner adjustment. These losses are slow enough for the SPS ring BLMs to react (max 20 ms)
        - Daniel asked if the BLMs recorded this event.
        - Bjorn replied that due to the low intensity (single bunch) and low energy, no BLM recorded any increased losses.
    - A fast failure where the whole beam was lost in ~1.3 ms at the beginning of the ramp. CC1 was accidently set to 1 MV before the ramp. As the beam energy is increased, its revolution frequency changes such that the difference between the CC frequency and the main SPS frev crosses the betatron tune, leading to fast orbit excitations and beam losses. Switching ON the voltage of the CC only once FT was reached and the rephrasing completed successfully mitigated the problem.
- Bjorn presented a simulation of the fast loss event, in order to estimate the losses depending on different CC voltages and beam energies. At 26 GeV,

significant losses should be seen with a total CC voltage of roughly 100 kV or more, whereas the limit at 270 GeV is roughly 1.2 MV. The rise time of the losses is roughly 50 turns at 26 GeV and 20 turns (450 µs) at 270 GeV, meaning that the SPS ring BLM system cannot react in time.

  - Francesco commented that there are some fast BLMs in specific locations of the SPS (extraction, aperture bottlenecks…) with a reaction time of about 1 ms.
  - Daniel commented that this would still not be fast enough to protect against these resonant failures, since losses are only seen at the end of the excitations, and not when the excitation starts, leaving only a short window of time between reaching detectable losses and critical losses.
- Bjorn concludes that MP critical failures have been observed during the first CC experiments, confirming that appropriate interlocks must be implemented for beams above the specified safe intensity limits.
- During the energy ramp, the voltage should be set to < 50 kV per cavity.
- The CC phase or the CC RF – SPS RF synchronization could be interlocked to avoid resonant excitations, or a low voltage limit could be set at 270 GeV.
- Phased operation at 26 GeV should be limited to 1.5 MV per cavity.
  - Lee asks if 1.5 MV limit at injection really is necessary.
  - Bjorn replies that this limit is to avoid the risk of significant losses at injection for pure voltage failures.
  - Daniel reminds that this limit would only be required for non-safe beams, i.e. beam intensities > 6e12 protons to make sure that we do not risk causing beam losses in the machine above the safe limit.

### 1.3 Experience with crab cavities during first set of MDs, status of low level RF and (fast) interlocks (R. Calaga)

- Rama showed the SPS-CC interlocks and automation, which includes one PLC and one fast interlock to control each IOT per cavity, one table interlock relay box and PLC monitoring, one dual RF power interlock for up to 8 HOM signals, one dual motor controller for tuner movement and a dual strain gauge conditioner with interlocks.
  - Daniel asked if we could dump the beam as fast as cutting the LLRF when there is something wrong in IOT1 or IOT2. Rama said that at the moment the beam will be dumped only if both of the IOT1 LLRF and IOT2 LLRF are cut, but we may modify the logic in such a way that the cut of either one of the two LLRF will lead to a dump of the beam. However, this could impact the MDs as it would not allow operating with only one CC functioning.
- During the first set of MDs, slow losses at 26 GeV occurred, due to the CC1 tuner loop setup crossing the vertical tune.
  - Rama mentioned that we could make the tuner faster to limit the beam losses.
- A fast loss failure also occurred during an energy ramp to 270 GeV. The RF frequency was 400.787 MHz (at about 1 MV voltage, before the ramp) for CC1, and 400.528 MHz (cavity off) for CC2. Resonant excitation was observed as we crossed the vertical tune of 0.18. The beam was kicked at 270 GeV equivalent

frequency, while sweeping the beam frequency from 26 to 270 GeV. After the voltage was set only after reaching FT, beam circulated without any issue.

- Bjorn asked what the actual voltage of the cavity is when it is "off". Rama answered that "off" really means off, but that we might require for high intensity beams up to 100 kV in the cavity to keep control due to beam loading effects.

- Two fast interlocks had been discussed. The first one is a frequency synchronization between BA6 and BA3, to avoid resonant excitation in few 10's of turns if the frequency difference between the main SPS RF and the crab cavity is close to the tune (about 8 kHz).
  - For this type of fast interlock, new hardware needs to be produced, since there is only one set of spares available.
  - Rama had a discussion with Thomas Bohl and they believe efforts are needed to realize the concept.
- The second type of fast interlocks could be new interlocks in BA6, e.g. amplitude and phase drifts of the cavities exceeding a maximum value.
  - Detailed studies with MPP in the coming MDs are needed to understand which signals from the LLRF can be robustly used. Then one can clarify what hardware is needed.
  - The implementation of this type of fast interlocks does not feasible for the 2018 run from Rama's perspective.
- The first type of fast interlock has higher priority than the second one. The Safe intensity limit will not be crossed unless one of the two types of fast interlocks can be safely implemented in September.
  - Markus said that the present MDs should also be used to learn about the mechanisms and hardware that could be sued to interlock on these more complicated failure scenarios to prepare the higher intensity MDs for the CCs.

## 1.4 Machine protection requirements for crab cavity MDs with unsafe beam intensities (D. Wollmann)

- Daniel recalled the safe intensity limits for CC MDs in the SPS, and summarized the criticality of CC failures observed during the past MDs and in simulations.
  - Crabbed beam entering the aperture in case of fast voltage ramp, limiting total crabbing voltage at 26 GeV (only).
  - Static dipole kick on beam core, limiting voltage in single crab cavities at 26 GeV (only).
  - Resonant excitation of beam by crab cavities (frequency shift between SPS-RF and CC-RF), leading to the beam being lost in the aperture within 1 ms. We need to interlock on successful re-phasing, interlock frequency difference between SPS-RF and CC-RF, and limit CC voltage during non-phased operation.
    - So far, the resonant excitation is the most critical failure case for the test campaign in the SPS. Further measurements of rise time of beam losses are required.
- The proposed sanity checks and interlocks for high intensity operations are as follows.

  - Implement consistency check of CC LLRF set-parameters. Define as machine critical settings in LSA to ensure keeping settings done during high intensity MDs in the defined operational envelope.
  - Implement fast interlock channel from RF interlock. Dump the beam in case of LLRF switching off.
  - Interlock successful re-phasing of SPS-RF and CC-RF (BA3). Keep CC voltage below 50 kV until confirmed re-phasing at 270 GeV.
  - Interlock frequency difference between SPS-RF and CC-RF (BA3).
  - Validate (fast) interlocks as far as possible before high intensity MD.
- The proposed beam tests before high intensity operation are as follows:
  - Measurement of delay of IOT fast interlock through table interlock matrix to BIC.
    - Rama said that the delay time is several 10’s µs up to a ms (the latter due to the processing by the relay matrix), but we should measure the exact value soon.
  - Verify triggering and reaction time of SPS ring BLMs and identify loss location during failure cases.
    - SPS ring BLMs cannot catch any failure < 20 ms.
    - Daniel remarked that we need to understand the loss locations and which BLMs are most likely to trigger with high intensity beams. If we can ensure that beams are dumped by the (fast) BLMs before critical loss levels are reached, this could ease the use of beams above the safe limit.
  - Measure rise time of losses for resonant excitation at 26 GeV and 270 GeV with different CC voltages (0.5 MV - 2 MV) and compare to simulations.
  - Measure static CC kick at 26 GeV and 270 GeV with different CC voltages (0.5 MV - 2 MV) and compare to simulations.
- Daniel summarized that at high intensity, we approach the real operating conditions, and need fast-enough interlocks to be ready.