201st Meeting of the Machine Protection Panel

The meeting took place on **December 11th 2020, 8.45-10.00,** via zoom.
Participants: Enrico BRAVIN (BE-BI), Marco CALVIANI (EN-STI), Mario DI CASTRO (EN-SMM), Luigi Salvatore ESPOSITO (EN-STI), Matthew FRASER (TE-ABT), Cedric HERNALSTEENS (TE-MPE), Verena KAIN (BE-OP), Filip MOORTGAT (EP-CMG), David NISBET (TE-EPC), Andrzej SIEMKO (TE-MPE), Frank TECKER (BE-OP), Jan UYTHOVEN (TE-MPE), Francesco VELOTTI (TE-ABT), Christoph WIESNER (TE-MPE), Daniel WOLLMANN (TE-MPE)

The slides of all presentations can be found on Indico and on EDMS.

1 Minutes and Actions

D. Wollmann recalled the open actions from the last MPP meetings on injector topics (199th and 200th MPP) and announced that the minutes will be circulated soon.

2 Crystal installation at SPS: Operational scenarios and failures cases (Francesco Velotti, Matthew Fraser)

- The slow extraction process at SPS is based on third-integer resonance excitation. This intrinsically leads to **beam losses at the wires of the electrostatic septum** (ZS), which is located in LSS2.
- Presently, approximately 3% of the circulating beam is lost during the slow extraction process. These losses and the corresponding activation are currently the **main limiting factor to the deliverable protons** on target to the North Area.
- **Bent Si crystals** can be employed to "shadow" the ZS, i.e. to reduce the particle density in the region that impacts the ZS wires and, thus, decrease the beam losses. Three **main interaction regimes** between beam particles and crystal can be distinguished:
    - **Amorphous**: incoherent scattering
    - **Channelling**: coherent kick within a narrow angular acceptance
    - **Volume reflection (VR)**: coherent kick, but smaller than and to the opposite direction of the channelling kick
- A **prototype crystal (TECS)** has been installed in LSS2 to test the concept of **local shadowing** during dedicated MDs and OP tests (see ECR).
    - The tank housing the crystal is installed 7 m upstream of the ZS in LSS2. The crystal is 0.8 mm thick and 2 mm long. It can achieve a 170 µrad deflection for 400 GeV protons in channelling mode, and 15 µrad in volume reflection. The channelling efficiency is ~50%.
    - A loss reduction of a factor of 2 has been predicted from beam simulations. Measurements performed in 2018 showed a **loss reduction of 40% in channelling mode and 20% in volume-reflection mode**.
- The following three main **operational scenarios** are currently foreseen for the use of crystals at SPS:
    1) ***Use of the TECS in LSS2 as operational device from 2021 on***
        - The TECS in LSS2 is foreseen to be used as OP device in 2021. It is first planned to be used in VR mode, which should be directly achievable. In a second step, it could be used in channelling mode, which, however, requires additional commissioning steps and adaption of the TT20 optics for the extracted beam.

- In both cases, a **modification of the present interlock logic** is required (see M. Di Castro's talk).

2) Installation of new crystal tank assembly in LSS4 with a single crystal setup

- To further reduce the losses, it is foreseen to install a crystal in LSS4, at a more favourable phase advance and better exploiting the effect of the extraction sextupoles. For this non-local shadowing of the ZS, using a single crystal in channelling, a loss reduction of a factor 4 is expected from simulations.
- The plan is to install the assembly during the YETS 2021/22. It would be used as an MD device with a single crystal in channelling mode during 2022, with the aim to make it operational before the end of 2022. (See Space Reservation Request and Functional Specification).
- For the interlocking, a gonio control system, based on a standard collimator system, will be used, and a CIBU connection to the BIS in BA4 is required.
    - C. Wiesner asked about the status of the BIS connection. M. Di Castro replied that the cabling has been done and that the CIBU request will soon be sent to MPE-MI.
- In principle, the same interlocking approach as for the TECS in LSS2 is proposed:
    - The SIS will be used to interlock on the linear position ranges. However, no interlock is foreseen for the angular alignment because the LVDT reading is not considered accurate enough to maintain the correct channelling angle.
    - A maskable hardware interlock on the end-switch will be connected to the BIS.
    - Limit switches will be used to avoid the crystal moving into the circulating beam.

3) Upgrade of the LSS4 assembly with a multi-crystal array for MVRA

- A new concept currently being studied is the use of stacked crystals in volume reflection (Multi VR Array – MVRA). The idea is to exploit the more efficient deflection from the volume reflection while compensating its smaller deflection angle by combining several crystals. For this approach, a loss reduction of a factor of 10 is predicted by beam simulations.
- The aim would be to install MVRA crystals in the LSS4 tank at the end of 2022, and study the loss behaviour during dedicated MDs.

- New **interlock functionalities**, which are relevant for the slow extraction, have been introduced at SPS for Run 3, in particular the new BLM interlock on loss rate and the new BCT interlock on the rate of intensity change of the circulating beam.
- The following **failure scenarios**, including their consequences, probabilities, risks, and mitigations, were presented and discussed:
    - **Positioning or angle error of the crystal with respect to the beam** (see Slide 17)
        - In case of loss of ZS shadowing, the beam losses at the ZS would, in principle, revert back to the previous loss levels. This is not desired but acceptable. It would be detected and interlocked by the BLM signals.
        - However, in case that the channelled beamlet would impact the ZS, the losses would locally increase by ~50% compared to previous levels. D. Wollmann asked when the damage level of the ZS wires would be reached. F. Velotti replied that no damage is expected for this case. M. Fraser added that the loss process is slow, in the order of several seconds, as the slow extraction itself. He added that this scenario would be well visible in the BLM signal along the ZS, and that the BLM response has been

already measured during MDs. Therefore, interlocking on the local BLM signals should be sufficient to mitigate this failure.

- **Wrong extraction bump** (see Slide 18)
  - Presently, a software limit for the bump strength is set in LSA, but no hardware interlock exists.
  - In case of a wrong extraction bump, the **circulating beam could be swept on the crystal**. This could lead to a fast extraction of the beam into the TT20 transfer line or onto the machine aperture, potentially damaging the ZS, the targets or machine elements. Since there is no hardware interlock on the bumper magnets, the protection relies on the BCT and BLM rate.
    - D. Wollmann asked **how fast the damage levels for the ZS or the targets would be reached**. M. Fraser replied that it depends on the speed of the failure. If the failure is very fast, the beam will go across the ZS wires and will be partly extracted, which is less critical. However, if the failure is fast but not fast enough to cross the wires, the entire beam could be collimated on the ZS wires. He added that the typical time constant of the bumper magnets is milliseconds, which is close to the expected worst case speed.
  - M. Fraser stressed that the scenario of a wrong extraction bump also exists for the slow extraction without crystal. V. Kain commented that this is indeed a critical failure scenario, against which the SPS is presently not fully protected. She recalled that it had already happened that wrong settings for the bump amplitude resulted in damage at the ZS, which was the reason to introduce hardware BLM interlocks in LSS2. J. Uythoven remarked that the general approach for a critical damage scenario would be to interlock on the source of the problem, in this case the extraction bumpers, and use the BLMs as second safety net.
  - F. Velotti recalled that glitches of the QF magnets had already occurred, which induced fast extraction events. However, no issues had been observed at the targets. M. Fraser commented that these events would now be caught with the new interlocks on BLM and BCT rate.
  - D. Nisbet asked if the existing BLMs already have the required features for the interlocking on loss rate. F. Velotti confirmed that this will be the case for Run 3. V. Kain added that for Run 3 the loss integration will be done in software, while after LS3 this will be implemented in hardware.
  - F. Velotti, M. Fraser, and V. Kain proposed a **dedicated MPP review of the SPS slow extraction** in 2021, including the interlock strategy for the extraction bumpers and the extraction sextupoles. D. Wollmann agreed that this would be useful.
    - Action (MPP, in collaboration with TE-ABT and BE-OP): Prepare and organize review of the SPS slow extraction system, including operational scenarios, failure scenarios and interlock strategy.
- **Failure of the multi-crystal array** (see Slide 19)
  - Wrong alignment could result in one of the crystals going from volume reflection to channelling mode.
    - C. Wiesner asked where the channelled beamlet would impact. F. Velotti replied that it would either hit the ZS or be extracted, but that the kick is not large enough to lose beam on the machine aperture.

- Even if the crystal got stuck in the IN position, the remaining machine aperture would be large enough to not impact LHC beam operation. However, this could lead to downtime for the slow extraction, and would require an access.

3 Crystal installation at SPS: Hardware implementation and interlocking (Mario Di Castro)

- M. Di Castro presented the **goniometer system and the proposed interlock changes** for the TECS.
- The system includes **two independent linear axes with two position end-switches** (IN and OUT) for each axis, and **two LVDTs** to acquire the position.
- The linear stroke of each axis is approximately 95 mm. The nominal crystal position is ~10 mm from the IN switch and ~85 mm from the OUT switch.
- During Run 2, when the device was used during MDs, the position hardware interlock triggered when the crystal was in the IN position, i.e. when one of the two out-switches were not active.
- For Run 3, when the device will be used in operation, **the interlock logic in the FPGA has to be inverted**: The position hardware interlock has to trigger when the crystal is in OUT position, i.e. when one of the two out-switches will be active.
    - D. Wollmann asked why the IN switches are not included in the hardware interlock, given that the nominal crystal position is 10 mm before reaching the IN switch. M. Di Castro replied that this could be implemented without a major effort. M. Fraser and F. Velotti commented that this would indeed be beneficial. M. Di Castro added that, independently, there will be a software interlock before reaching the IN switch.
    - Action (M. Di Castro/EN-SMM): Add position IN switches to the TECS hardware interlock.
- A **software interlock for the crystal position** will be implemented based on the LVDT measurement.
    - D. Wollmann asked why a software instead of a hardware interlock is foreseen for the crystal position. M. Fraser answered that a hardware interlock would be feasible, but might not be required because it concerns a rather slow loss scenario. V. Kain commented that, in case of an issue with the crystal, when one has to reconfigure BLM thresholds, it would indeed be beneficial to add another protection layer to avoid entering wrong values by mistake. M. Fraser agreed and commented that this could be implemented by using a single scaling value for the losses, which would be easy to check. D. Wollmann and J. Uythoven agreed that this would be useful to implement.
    - Action (M. Fraser/TE-ABT, V. Kain/BE-OP): Implement additional software threshold for maximum losses during the slow extraction.
- J. Uythoven asked how close the crystal IN position will be with respect to the circulating LHC beam. M. Fraser answered that the mechanically permitted range of the crystal will be far away from the LHC beam. M. Di Castro commented that this will be ensured by the position of the limit switches. F. Velotti added that in LSS4 an orbit bump is required to bring the beam onto the crystals.
- D. Wollmann asked if, for the crystal assembly in LSS4, one would start with the same interlock logic as now used in LSS2 (interlock when the crystal is in the IN position, but maskable for MDs). M. Fraser confirmed that this is the case.

4 Actions

The actions from the meeting are:

- Action (MPP, in collaboration with TE-ABT and BE-OP): Prepare and organize review of the SPS slow extraction system.
- Action (M. Di Castro/EN-SMM): Add position IN switches to the TECS hardware interlock.
- Action (M. Fraser/TE-ABT, V. Kain/BE-OP): Implement additional software threshold for maximum losses during the slow extraction.