

193rd Meeting of the Machine Protection Panel

The meeting took place on **June 19th 2020** via zoom.

Participants: Andrea APOLLONIO (TE-MPE), Wolfgang BARTMANN (TE-ABT), Roderik BRUCE (BE-ABP), Federico CARRA (EN-MME), Mario DI CASTRO (EN-SMM), Cedric HERNALSTEENS (TE-MPE), Dragoslav-Laza LAZIC (EP-UCM), Anton LECHNER (EN-STI), Jerome LENDARO (EN-MME), Richard MOMPO (TE-MPE), Filip MOORTGAT (EP-CMG), Yannis PAPAPHILIPPOU (BE-ABP), Axel POYET (BE-ABP), Stefano REDAELLI (BE-ABP), Adriana ROSSI (BE-BI), Belen SALVACHUA FERRANDO (BE-BI), Brad SCHOFIELD (BE-ICS), Guido STERBINI (BE-ABP), Arjan VERWEIJ (TE-MPE), Andreas WAETS (EN-STI), Christoph WIESNER (TE-MPE), Daniel WOLLMANN (TE-MPE), Christos ZAMANTZAS (BE-BI), Markus ZERLAUTH (TE-MPE)

The slides of all presentations can be found on the [website of the Machine Protection Panel](#) and on [Indico](#).

1 Minutes and Actions

- D. Wollmann recalled the open actions from the last MPP meeting on LHC topics (191th MPP). He announced that the minutes for the meeting will be circulated in the coming week.
- D. Wollmann reported that the proposed template and procedure for **Reports on Major Machine-Protection Events**, as discussed in the [190th MPP](#), was approved by the [LMC](#) on May 13th 2020 and by the [IEFC](#) on May 29th 2020. C. Wiesner added that the two sample reports have been shared as draft for discussion on EDMS and invited the system experts to review and comment them:
 - MKBV flashover: <https://edms.cern.ch/document/2372985>
 - Linac4/PSB incident: <https://edms.cern.ch/document/2374025>

2 Overview of damage limits of all collimator materials for the asynchronous beam dump case (Federico Carra)

- F. Carra gave an overview of the damage limits of relevant collimator materials and compared them to the expected energy deposition in case of an asynchronous beam dump or an injection error.
- He started by recalling the damage mechanisms and the **two main parameters affecting the damage onset**: the **energy density peak e_p** (relevant for the localized material response) and the **average energy per target section \bar{e}_s** . (relevant for the global material response).
- **Three damage thresholds** have been defined for collimator materials:
 - **Threshold 1**: onset of damage (plasticity, cracks, local material ablation, ...), but no need to displace the collimator jaw with the 5th axis.
 - **Threshold 2**: surface damage that requires correction with the 5th axis (heavy plastic deformation, internal delamination, important material ablation, ...)
 - **Threshold 3**: damage that cannot be corrected with the 5th axis (significant material erosion, plastic deformation in the jaw, material fracture, face delamination with loss of flatness, ...).
- The damage thresholds have been derived by combining numerical simulations (energy deposition and thermal/hydrodynamic behaviour) and experimental tests. For this purpose, five different experiments have been performed between 2012 and 2017 at the HiRadMat facility.
- The **resulting damage thresholds for the energy density peak e_p and the average energy per target section \bar{e}_s** , together with the expected values in case of an injection error or an asynchronous beam dump (ASD), **are summarized on Slides 13 and 14**, respectively. The values for Run 3 (assuming a

maximum of 1.8×10^{11} protons per bunch) as well as HL-LHC parameters are given. The following observations were made:

- In general, the values of e_p and \bar{e}_s are higher for an injection error than for an ASD.
- When comparing the **metallic materials** used or proposed for tertiary collimators, CuCD appears to be more robust to the beam impact than Inermet. In case of an ASD with direct impact on the jaw, an e_p value just above Threshold 2 and well below Threshold 3 is expected for CuCD. For Inermet, in contrast, the value would be clearly above Threshold 3 for HL-LHC as well as for Run 3 parameters. This would imply that the jaw has to be replaced.
- For **graphitic materials** (CFC, graphite, MoGr), the expected e_p in case of an ASD is below or close to Threshold 1. For a beam injection error, it would remain below Threshold 2. Therefore, no functional defect of the collimator is expected.
- The energy deposited in the **metallic coatings** of secondary collimators during a beam injection error or an ASD could provoke a damage equivalent to Threshold 2, which would need to be recovered with a 5th axis movement.
- The expected values for \bar{e}_s are well below Threshold 1 for both failure scenarios and all considered materials.
- For the **embedded BPMs**, no issues are expected for the TCPMP and TCSPM (MoGr tapering), while further studies are required for the TCSP (Glidcop tapering) since during the HRMT-23 experiment the BPM reached a temperature of 900°C and ceased working (Slide 9).
- A. Lechner commented that the **energy-deposition values for the ASD should be revised** based on the most recent studies. Federico replied that these values have been obtained by assuming an equivalence of 1 LHC bunch to 24 SPS bunches, and not from FLUKA simulations based on beam-impact distributions.
 - **Action (F. Carra/EN-MME, A. Lechner/EN-STI): Update expected energy deposition based on the newest FLUKA studies for the case of an asynchronous beam dump and an injection error for the relevant collimator materials.**
- A. Lechner mentioned that the **load on the BPM inside the TCSP** should be re-assessed based on the new type-2 MKD erratic, which had not been considered for the original studies.
 - F. Carra replied that it should indeed be studied, even though a large margin exists before reaching the damage threshold.
 - D. Wollmann commented that the TCSP will be shadowed by the TCDQ during normal operation, however, this might not be the case for special configurations and MDs. Therefore, it would be important to establish a clear damage limit in order not to risk the BPM functionality.
 - A. Lechner highlighted that in case of an ASD only one TCSP jaw is in the shadow of the TCDQ, while the other jaw will be exposed to the particle showers, with the upstream BPM receiving the highest load.
 - R. Bruce added that even in normal operation, due to the limited alignment precision, there is a certain risk that the TCSP is positioned slightly further inwards than the TCDQ and might thus be impacted by a small number of primary protons in addition to the secondary showers from the TCDQ.
 - **Action (F. Carra/EN-MME, A. Lechner/EN-STI): Reassess the temperature load on the BPMs in both TCSP jaws in case of an asynchronous beam dump considering the worst-case (type 2) erratic.**

3 Machine-protection aspects of BBLR operation in Run 3 (Adriana Rossi)

- A. Rossi recalled that **wire collimators will be installed for both beams in IP1 and IP5** in the respective crossing plane in order to compensate the beam-beam long-range (BBLR) effect. It is foreseen to use them during normal operation in Run 3 after the end of the β^* levelling.
- The **Long Range Beam-Beam Compensator Wire (BBCW) will be interlocked via the WIC**. Each BBCW system has **two input connections to the WIC**: one input is the Power Converter (PC) status to signal internal faults which stop the converter, and one to receive the signal in case of overheating of the wire. The latter is detected by measuring the voltage drop over the wire. The voltage threshold (of presently 2.7 V) is set locally at the hardware level.
- In case one of the input signals goes to FALSE, the **WIC immediately triggers a beam dump via the BIS**, and then **cuts the power to the BBCW** with a 1.2 s delay.
- A. Rossi presented the **draft procedure for “BBCW Commissioning and Revalidation after Failure Recovery” (EDMS)**.
- The BBCW can be operated with positive and negative current up to ± 350 A. However, during routine operation only the use with positive current is foreseen. Therefore, **the allowed operational envelope in the PC should be restricted to between 0 and +350 A** by setting accordingly the operational limits I_POS and I_NEG. In addition, A. Rossi proposed to keep using the SIS interlock on the PC current. During commissioning and revalidation the **interlock should be verified for both polarities**.
 - **Action (A. Rossi/BE-BI, J. Wenninger/BE-OP): Review the necessity to keep the existing SIS interlock on the BBCW PC current.**
- The **wire has to be aligned with respect to the beam orbit by using the 5th axis** movement. The 5th axis movement will be tested, first, locally in the tunnel, and then remotely from the control room.
 - D. Wollmann asked if the 5th axis position will be changed during the operational year. A. Rossi replied that it would be set up during commissioning and normally does not have to be readjusted during operation.
 - D. Wollmann asked if in case of a 5th axis movement, e.g. during MDs, one could reliably revert back to the nominal position. A. Rossi confirmed that this is the case as long as the collimator controls did not lose power, in this case a re-calibration is required by the experts from EN-SMM.
 - D. Wollmann asked if the 5th axis position is interlocked. A. Rossi replied that a hardware interlock is based on the end switch. B. Salvachua added that an additional interlock is included in the collimator controls on the FEC level, which is then connected to the BIS.
 - B. Salvachua asked what would happen to the BBCW operation in case of an accidental scenario where the 5th axis has to be used. A. Rossi answered that in this case the BBCW cannot be used for further operation. D. Wollmann recommended to include this information in the commissioning document.
- During BBCW commissioning, the **absence of earth leaks and the correct wire polarity has to be verified** (see section 4.3 of the procedure). In addition, it has to be demonstrated that the measured **temperature at the connectors** does not exceed 70°C after having applied 350 A for 15 min, while the **jaw temperature** does not exceed 35°C after having applied 350 A for at least 30 min.
- In order to **verify the interlock that protects against wire overheating**, the current has to be increased for up to 2 min to 375 A to exceed the voltage threshold. For this test, the PC current limit of 350 A has to be removed or masked.
- A reduced set of qualification tests might be required after a TS or a YETS.
 - **Action (A. Rossi/BE-BI): Define required qualification tests for the BBCW after a TS and YETS.**

- The following **BBCW hardware failures**, including the intervention and revalidation procedures, were discussed.
 - **Failure of the PC**
 - The TE-EPC piquet has to be called for intervention.
 - **Overheating of the wire**
 - The WIC interlock will cut the power to the wire, and the interlock will be automatically cleared at the level of the WIC after the measured wire voltage drops below the threshold.
 - BE-BI (A. Rossi, A. Frassier, +TBC) has to be called and will react on a best-effort basis. In addition, in case of a loss of collimator coolant, the EN-STI piquet has to be called.
 - **Action (A. Rossi/BE-BI, M. di Castro/EN-SMM, EN-STI): Confirm revalidation procedure for the BBCW after loss of collimator coolant.**
 - **Failure of the wire control card**
 - BE-BI (A. Rossi, A. Frassier, +TBC) has to be called to replace the card.
 - For revalidation, the voltage interlock against overheating has to be tested as during commissioning (see above).
 - The WIC interlock will remain active until the failure is fixed, blocking operation even after the power to the BBCW has been switched off.
 - **Loss of electrical contact at wire connector or damaged cable (open circuit)**
 - The failure signature is the same as for a control card's failure. Therefore, BE-BI (A. Rossi, A. Frassier, + TBC) has to be called to replace the card.
 - Only when the failure persists after the card replacement, the loss of electrical contact will become evident.
 - A. Rossi asked if an open circuit would be detected by the PC. R. Mompo replied that the WIC will not detect it, but that the PC should show an overvoltage fault and/or regulation error as it cannot maintain the requested current. M. Zerlauth added that an open circuit would indeed be detectable due to the overvoltage caused by the very large circuit resistance. However, a degraded contact in a circuit with initially very low resistance might easily be overlooked.
 - Also for this failure, the WIC interlock will remain active until the failure is fixed, blocking operation. Therefore, **if the fault persists** after re-checking the electric connections, **LHC operation should resume without BBCW**. This requires, however, to clear the corresponding WIC interlock, while ensuring that the BBCW will not be powered.
 - **Action (A. Rossi/BE-BI, R. Mompo/TE-MPE): Propose safe and reliable solution to force the BBCW user input to the WIC to TRUE in order to resume beam operation without BBCW.**
- **Action (A. Rossi/BE-BI): Update and circulate the procedure for "BBCW Commissioning and Revalidation after Failure Recovery" and then upload it on EDMS for approval.**

4 BBLR wire compensation feed-forward in Run 3 (Axel Poyet)

- A. Poyet presented the **studies on the planned feed-forward system for the BLLR** wire compensators. He recalled that the wires can induce a tune shift of up to $1.4e-2$ and therefore a tune (Q) feedforward system is required.

- During Run 2, the Q4 and Q5 magnets were used for the **Q feedforward**, while for Run 3 it is proposed to use the two Q4 magnets located left and right of the IP. This is beneficial for beta beating and the linearity of the knob. The new feedforward was designed for $\beta^*=30$ cm and a TCT position of 8.5σ , but would also function for a different configuration due to the tele-index independent properties of the knob.
- If the wires are perfectly aligned to the beam, the dipolar component cancels out and the first-order effect on the closed orbit (CO) vanishes. Therefore, **no CO feedforward is foreseen**. The residual orbit effects should be corrected by the existing CO feedback.
- Due to the Q feedforward, a small **beta beating** is induced around the machine **with a peak of around 5%** at a distance of 25 cm to the IPs (Slides 9/10). Presently, no correction of the beta beating is planned.
 - D. Wollmann asked if there were any **effect on the experiments**. A. Poyet replied that the potential effect on luminosity has indeed to be studied. Y. Papaphilippou added that the beta beating is zero at the IP itself, but that there might be an effect on the luminous region. D. Wollmann proposed to discuss this question with the LPC. Y. Papaphilippou agreed that this should be done.
 - **Action (Y. Papaphilippou/BE-ABP, G. Sterbini/BE-ABP): Evaluate together with the LPC the potential effect of BBCW operation on luminosity and luminous region.**
- The expected change of the **phase advance between MKDs and TCTs** is only in the order of $1e-2$ degree, and thus considered negligible.
- The **wires might not be correctly aligned to the beam** due to a) a relative misalignment between beam and collimator jaw, b) a misaligned 5th axis, or c) an incorrect collimator gap setting (Slides 19-25). Assuming all wires are powered at 350 A, this would lead to the following **maximum effects**:
 - a tune shift of $1e-3$, an orbit shift of 70 μm , and an extra beta beat of 1% for up to 1 mm of beam-jaw misalignment (case a),
 - a tune shift of $5e-4$, an orbit shift of 100 μm and an extra beta beat of 0.5% for up to 1 mm of 5th axis misalignment (case b),
 - a tune shift of $4e-3$, a minor orbit shift and an extra beta beat of 2.5% for up to 2 mm of deviation from the correct collimator gap (case c).
- A **ramp time of 1 min** for the Q4 current was proposed in order to give the CO feedback enough time to follow. After the meeting, J. Wenninger commented that the orbit feedback will not correct locally and thus luminosity scans might be required after the BBLR ramp.
- R. Bruce recalled that the TCT positions would vary significantly during the levelling process and asked whether the feedforward would work under these circumstances. A. Poyet replied that, even though the feedforward performance is in principle tele-index independent, it is only foreseen for operational use with a fixed β^* and fixed crossing angle. Y. Papaphilippou confirmed that the **wires will only be powered after the end of the levelling**. D. Wollmann commented that also from the operational point of view it was agreed to use the wires only at the end of the levelling, using an additional sequencer task for the wire and Q4 ramping. (After the meeting, J. Wenninger informed that instead of a sequencer task a manual trim similar to the β^* levelling step would be used.) Y. Papaphilippou added that, nevertheless, an MD with low-intensity could be envisaged to test the feedforward performance with changing β^* , but stressed that this is not an operational scenario.
- R. Bruce remarked that the **jaw misalignment** should be in the order of 50 μm . A. Rossi answered that one also has to consider the uncertainty given by the BPM alignment procedure, which is assumed to be up to 0.5 mm. S. Redaelli added that fill-to-fill orbit variations of up to 200 μm have been observed. He stressed that **the BPM interlock limit**, which is presently close to 1 mm for the TCTs, **should be used as worst-case assumption for the studies**.

- S. Redaelli commented that the **closed orbit distortion** might translate into losses at the primary collimators. He added that if the position limit is exceeded, the beam will be dumped by the collimator BPM interlock. Therefore, he didn't consider it a protection issue but a question of operational efficiency. S. Redaelli asked where the **maximum orbit displacement** is located. A. Poyet replied that he would check and report back.
- S. Redaelli suggested to implement a **fixed display or sequencer task that checks the beam position** as measured by the collimator BPMs and issues a warning in case a certain threshold is exceeded. D. Wollmann agreed that this is a good proposal.
 - **Action (G. Sterbini/BE-ABP, S. Redaelli/BE-ABP, J. Wenninger/BE-OP): Evaluate the potential gain and feasibility of evaluating the beam orbit at the collimator BPMs before starting the ramp-up of the BBLR wire current and issuing a warning if required.**

5 AOB

5.1 WIC response-time measurement with FGC2 system (Richard Momo)

- R. Momo presented the follow-up for an action from the 177th MPP ("**Repeat response-time measurement with FGC2 system**").
- The goal of the measurement was to determine whether, in case of a PC fault (PC_Status FALSE), the reaction time of the FGC Controller and its propagation to the WIC would be fast enough to dump the beam in time. The measurement was done by provoking an overcurrent fault and measuring the reaction time until the triggering of the CIBU.
- R. Momo recalled that each BBCW is powered by an LHC type ± 600 A, ± 40 V power converter.
- A first measurement using an **FGC3 controller** had demonstrated a **reaction time below 1.2 ms**. The repetition of the measurement with an **FGC2 controller**, as used for the BBCW, resulted in an even faster **reaction time below 1 ms**.
- It was, thus, concluded that the **reaction time is fast enough to ensure the dumping of the beam in case of a BBCW PC failure**. The action can be closed.
- R. Momo commented that the main delay is determined by the FGC, while the WIC itself can react within microseconds thanks to the use of a parallel Fast Boolean Processor. He added that, in case of a wire overheating, the WIC will first remove the beam permit via the BIS, and, 1.2 s later, send a "fast abort" signal to the PC.

5.2 Update rMPP for Injectors (Christoph Wiesner)

- The proposal for an rMPP for injectors has been approved by the 268th IEFC on May 29th 2020.
- The current members are A. Lombardi, B. Mikulec, C. Wiesner, D. Wollmann, D. Nisbet, F. Tecker, J. Uythoven, J. Wenninger, M. Zerlauth, V. Kain.
- For communication within and to the members the e-mail inj-mp-restricted@cern.ch can be used.
- D. Wollmann highlighted that the installation of an rMPP body for the injectors evidences a more and more coherent machine-protection approach across the CERN accelerator complex.

6 Closing remarks

D. Wollmann concluded the meeting and announced that the next MPP on injector topics will take place on June 26th 2020.

7 Open Actions

The actions from the meeting are:

- Action (F. Carra/EN-MME, A. Lechner/EN-STI): Update expected energy deposition in case of an asynchronous beam dump and an injection error for the relevant collimator materials.
- Action (F. Carra/EN-MME, A. Lechner/EN-STI): Reassess the temperature load on the BPMs in both TCSP jaws in case of an asynchronous beam dump considering the worst-case (type 2) erratic.
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- Action (G. Sterbini/BE-ABP, S. Redaelli/BE-ABP, J. Wenninger/BE-OP): Evaluate the potential gain and feasibility of evaluating the beam orbit at the collimator BPMs before starting the ramp-up of the BBLR wire current and issuing a warning if required.