187th Meeting of the Machine Protection Panel

The meeting took place on **April 3rd 2020** via Vidyo.

Participants: Andrea APOLLONIO (TE-MPE), Wolfgang BARTMANN (TE-ABT), Andy BUTTERWORTH (BE-RF), Chiara BRACCO (TE-ABT), Federico CARRA (EN-MME), Yann DUTHEIL (TE-ABT), Cedric HERNALSTEENS (TE-MPE), Dragoslav-Laza LAZIC (EP-UCM), Anton LECHNER (EN-STI), Filip MOORTGAT (EP-CMG) , Brian PETERSEN (EP-ADT), Stefano REDAELLI (BE-ABP), Belen SALVACHUA FERRANDO (BE-BI), Benoit SALVANT (BE-ABP), Viliam SENAJ (TE-ABT), Andrzej SIEMKO (TE-MPE), Matteo SOLFAROLI CAMILLOCCI (BE-OP), Jan UYTHOVEN (TE-MPE), Christoph WIESNER (TE-MPE), Daniel WOLLMANN (TE-MPE), Markus ZERLAUTH (TE-MPE)

The slides of all presentations can be found on the website of the Machine Protection Panel and on Indico.

1.1 Minutes from the 185th MPP meeting

- No comments on the minutes of the last MPP meeting on LHC topics (185th MPP) have been received. The open actions have been added to the MPP homepage.

1.2 TL steering with full train and bunch intensity interlock for LBDS intercepting devices (Chiara Bracco)

- Chiara presented the expected limitations for the LBDS intercepting devices and the possible interlocking requirements for the expected Run3 intensities.
- Chiara started by recalling the possible missing dilution scenarios after LS2.
    - The risk of **erratic firing of a dilution kicker** (MKB) will still be present but the probability will be reduced due to the upgrade of the MKB generators allowing to operate at lower generator voltage.
    - The consequences of multi-erratics, which can lead to the loss of more than half of the dilution in one plane, will be mitigated by implementing a **retrigger system for the MKB**. However, the delay between the MKB erratic and the triggering of the extraction kickers (MKDs) leads to a change in the dilution pattern, which has to be studied in detail.
    - In addition, a **high-voltage flashover** inside the MKB tank can lead to an equivalent loss of more than two MKBs as well as an overlap of the sweep path.
- Chiara then discussed the expected effects on the **LHC dump core** (TDE).
    - Currently, a temperature of 1500°C is considered acceptable for the dump core, but further studies on the damage levels are ongoing.
    - In the **worst-case scenario for a flashover in the horizontal plane**, the peak temperature inside the dump core for a bunch intensity of 1.8e11 protons per bunch (ppb), 2748 bunches and 1.8 µm emittance would reach more than 2600°C, which is above the characterised range of the material in the centre part of the dump (Sigraflex).

  - The worst-case flashover scenario, for which the beam path overlaps, could be avoided by **not injecting the last bunch train**. Chiara stressed that this mitigation cannot be applied for the scenario of 2 missing MKBs, where instead a **limit on the bunch intensity** would be required.
  - Chiara recalled that there is an open LMC action for EN-STI to provide a recommendation of the maximum allowed bunch intensity for the dump.
  - Anton commented that the proposal for the **first year of Run3** would be to **limit the intensity to 1.4e11 ppb** to study the mechanical behaviour of the dump assembly with the newly installed instrumentation like strain gages, LVDTs etc. concerning vibrations and displacements. Based on this experience and further simulation studies, one could then increase these limits for the next years of Run3.
  - Daniel asked if the flashover patterns have also been studied for an intensity of 1.4e11 ppb. Chiara replied that this is still under investigation. The required characterisation of the dump material is still pending with results not expected within the coming months.
  - Markus asked if the mechanical integrity of the dump vessel is also a concern. Anton replied that the main concerns are rather the effects of vibrations triggered by the shower-induced heating of the vessel than the integrity of the vessel itself.
- **Energy-deposition studies for the TCDQ** were performed for different bunch intensities and different TCDQ gaps.
  - For the studies, the TCDQ gap, i.e. the distance between the TCDQ and the beam, was assumed to be 1 mm smaller than the set value in order to account for tolerances. The present Run3 optics foresees a gap of 3.5 mm (set value).
  - A temperature of 1500°C in the CfC blocks of the TCDQ is considered acceptable.
  - The studies showed that there are no constraints in the minimum TCDQ gap width for an intensity of up to 1.8e11 ppb.
  - For gap widths above 4.5 mm (set value), intensities of up to 2.3e11 ppb are acceptable.
  - Answering to Benoit, Chiara stated that the TCDQ gap during Run2 was set to around 3.8 mm.
- For the **septum-absorber TCDS**, plastic deformation is expected at the downstream titanium blocks for intensities above 1.7e11 ppb.
  - Considering that the TCDS is positioned far from the circulating beam, and, thus, small deformations are not supposed to be critical, also intensities of 1.8e11 are considered acceptable.
  - An upgrade of the TCDS is part of the HL-LHC baseline but is not foreseen before LS3.
- Daniel highlighted that for the presented cases for the TDE, TCDQ and TCDS, a limitation of the total beam intensity is not sufficient, but the bunch intensity needs to be limited. This implies that a bunch-intensity interlock (with adequate reliability) is implemented. Chiara agreed that this is indeed needed for the protection of the devices.

- Replying to a question by Jan, Chiara and Anton confirmed that the bunch-intensity limit is rather required for trains but not for single bunches.
- Daniel asked if the bunch-intensity limit for the dump might be increased beyond 1.4e11 ppb in case the LHC is not completely filled. Anton answered that this still has to be studied in more detail, but that one would expect in this case a less stringent bunch-intensity limit for the TDE than for the TCDQ/TCDS.
- Benoit asked if the intensity limit concerns the maximum bunch intensity or the average bunch intensity within a train. He stressed that using the maximum value would be very limiting because intensity spreads of up to 40% are observed during operation. Chiara replied that the implementation is not yet fully clear but that it would probably be sufficient to interlock on the average bunch intensity per train and allow a certain spread.
- Replying to a question by Benoit, Chiara confirmed that the transverse emittance is less relevant for the criticality of the presented failures.
- Daniel asked how the intensity interlock should be implemented and if a software interlock should be envisaged. Jan clarified that the bunch intensity is presently not transmitted via the SMP. This is foreseen for the upgraded SMPv2 but it will not be available for Run3. Therefore, the bunch-intensity interlock needs to be implemented in the SIS in addition to being enforced by procedure by the operation crews. The interlock is not required to be fast as its main purpose is to stop that trains with too high intensity are ramped.
- Matteo commented that the algorithm has to be defined for this case but that there should be no technical issue to implement the required interlock in the SIS.
- Chiara agreed that a software interlock with its larger reaction time is sufficient since it is only needed at full beam energy. Jan added that in a first stage a software interlock would also be sufficient in terms of reliability since the SIS interlock would only be a second layer of protection for the case that a wrong bunch intensity is requested and injected by the operator.
- Action (MPP, J. Wenninger/BE-OP): Investigate the implementation of a SIS based interlock of the integrated intensity of consecutive bunches. Define the maximum number of bunches that have to be taken into account for averaging the bunch intensity.

- Chiara presented the **steering procedure for the LHC injection lines and possible changes for Run3**.
  - Before LS2, a 12-bunch train had to be injected after each steering to verify the applied changes.
  - Up to now, when new current values were sent simultaneously to several Power Converters (PC) during transfer-line steering and one of the values was out of limits for the PC the other values were still accepted and applied by the remaining converters. This transactional behaviour should be fixed during LS2 with the implementation of the new FGC3s in all PCs in TI2 and TI8.

- Chiara recommended to continue using 12-bunch trains for steering during Run3 and proposed to foresee two trains of 12 bunches in the filling scheme for this purpose (as was already done in the past).
- However, based on the improved PC controls, the possibility of allowing **steering with full trains** could be considered for the case that the applied correction values stay within the defined tolerances of the Fast Extraction Interlock (FEI). The injection of a 12-bunch train remains mandatory if the FEI limits have to be changed or re-centered.
  - Answering to a question by Daniel, Chiara explained that the FEI limits cannot be accumulated, and that they are absolute values set around the reference PC current.
  - Jan raised concerns that the new procedure would become more complex and, thus, that there is a higher risk of making mistakes. Matteo commented that he considered the proposal acceptable and that he considered a protection by procedure sufficient.
  - Daniel asked if it could be the case that the new current settings are not sent. Matteo replied that this is the same process as applying a trim in the LHC, which always includes a confirmation from the device level of the correct application of the trim. This feature has never failed so far.
  - Daniel summarised that the new method has to be verified during commissioning and one should start by relying on the updated procedure and then evaluate the implementation of a more automatized protection. Chiara agreed to this process.
  - Action (C. Bracco/TE-ABT): Based on first operational experience after LS2, review the steering procedure and evaluate the possibility of steering with full trains.
- Chiara reported on ongoing studies to compute the required steering directly from the SPS orbit, in which case a single 12-bunch train would be sufficient.

1.3 New MKB capacitors (Viliam Senaj)

- Viliam presented the **planned changes for the capacitors of the MKB generators**.
- He summarized the **flashover event that occurred in the vertical dilution kickers (MKBV)** of Beam 2 on July 14, 2018, during a programmed dump at 6.5 TeV with 2556 bunches. The flashover started in magnet MKBV.C and propagated in approximately 10 µs to magnet MKBV.D that is located in the same vacuum tank. The analysis of the dilution pattern showed that the equivalent deflection of nearly 3 out of 6 MKBV was missing at the end of the sweep path. This can be explained with a plasma discharge acting as a current freewheel, leading to a slowly decaying field in the MKBV.D that at the end of the sweep path was in antiphase with the field of the remaining MKBVs.
- Different **potential causes for the flashover** have been investigated: beam losses, flashover in the vacuum pump, outgassing, bad contact, and field enhancement due to a foreign object in the vacuum chamber. However, none of them could be

confirmed during detailed investigation during LS2. The cause for the flashover is, thus, still not fully understood.
  - The static vacuum level in the MKBV.C/D tank was around 3e-8 mbar, which corresponds historically to a very good value.
  - The visual inspection of the tank did not bring any conclusive results. Small signs of breakdown near the feedthroughs were observed but, contrary to expectations, no localised damage was found.
  - A voltage breakdown inside the insulation is excluded because this would have had a significant impact on the vacuum level, which was not observed.
- Several improvements for the high-voltage stability, e.g. the insulation of the conductors in the tank and geometrical adjustments, are under preparation but not feasible during LS2.
- Therefore, the **proposed solution to reduce the breakdown probability** is to decrease the voltage applied to the MKB by increasing the internal capacitor values. The capacitance of the MKBV would increase from 20 µF to 23.5 µF and the capacitance of the MKBH would increase from 23.5 µF to 25 µF.
- With the proposed solution the **voltage at the MKBV and MKBH magnets** would be reduced by 8.4% and 3.1%, respectively.
  - Daniel asked how the voltage reduction affects the breakdown probability. Viliam answered that this is not easy to quantify but that usually a scaling with the power of 10 or 11 is assumed. For the MKBV this would imply a reduction of the breakdown probability by more than a factor of 2.
  - Daniel asked if the gained voltage margin will be counteracted by the increased beam energy. Viliam replied that this is indeed the case and that the MKBV voltage at 7 TeV with the new capacitor will be similar to the voltage with the present system at 6.5 TeV.
- The change of capacitance results in a **decreased oscillation frequency** of the kickers from 13.9 kHz (MKBV) and 13.1 kHz (MKBH) to 12.7 kHz and will, thus, lead to a modified dilution pattern.
  - Christoph asked, since the loss of dilution is less critical in the vertical plane, if the main motivation for the proposed modifications was the concern that successive breakdowns could degrade the MKBV on the longer term. Viliam confirmed that indeed the reliability of the MKBV is the main concern. He added that for the given current levels one would expect damage during a flashover.

1.4 MKB changes: impact on dilution pattern (Yann Dutheil)

- Yann presented the **impact of the proposed MKB changes on the dilution patterns**. For the study, MKB waveforms from Run2 were used and rescaled. The exact waveform will be measured when available.
- To evaluate the new sweep patterns, the **maximum proton bunch density** on the dump was computed within a characteristic radius. The characteristic radius had been determined previously by comparing with FLUKA simulation results.
  - Anton commented that for the effects on the dump windows more detailed studies might be required.

    - Christoph added that the method provides an efficient comparison of a large number of sweep patterns, but that the effect of thermo-mechanical stresses is not included.
- Due to the reduced frequencies the **beam sweep is slowed down** in both planes but mainly the vertical movement is affected.
- The **nominal pattern and the failure patterns** with missing MKBH have similar maximum proton densities for the new and the old waveforms, while the patterns with missing MKBV have higher maximum densities for the new waveforms. For example, the maximum density for the failure case of 2 missing MKBV increases now by 30% compared to the nominal pattern, while before it had only increased by 5%. However, the case of missing MKBH remains more critical with a calculated increase of 80% compared to the nominal pattern.
- Yann presented the maximum expected proton densities for the **MKB retrigger scenario** as a function of the delay time between the MKB erratic and the beam dump. In general, similar results are reached with the new and the old waveforms, even though the worst-case density for the new waveforms increases by ~10%.
    - Christoph commented that only delay times up to ~95 µs need to be considered for the comparison, given by the system reaction time plus a maximum of 1 LHC turn to synchronise with the abort gap.
- Chiara commented that the calculated dilution patterns have already been sent to EN-STI for more detailed studies. Anton confirmed that the studies are ongoing and that first results showed no significant change for the case of 2 MKBH missing. In addition, the vibrational behaviour of the dump vessel is not expected to change with the modified waveforms. Therefore, the **proposed changes seem acceptable**.
- Daniel asked if higher stresses are expected with the new waveforms for the case of 2 MKBV missing due to the different hot-spot position.
    - Anton replied that so far the thermo-mechanical stresses had not been simulated for the case of 2 MKBV missing because it represents a less critical scenario. He added that a modified pattern will only change the local stress contribution on the window and not the other contributions such as the vibration-induced stresses from the dump vessel, which are equally important.
- Christoph asked if the **flashover case**, which was considered as worst case failure scenario, had been simulated with the modified waveforms.
    - Yann explained that it has not yet been studied and asked if the study should focus on the MKBV, where a flashover is more likely. Chiara replied that first the flashover in the MKBH should be studied because it cannot be excluded and has more critical consequences.
    - Viliam commented that the voltage at the magnet and, thus, the flashover probability is not much lower for the MKBH when compared to the MKBV. He added that the MKBH magnets are located upstream of the MKBV and, thus, are the first to be exposed to potential beam losses.
    - Chiara remarked that the worst-case scenario for a MKBH flashover is already not acceptable with the present waveforms. Therefore, a mitigation, as removing the last train of the filling pattern, might be required.

    - Action (Y. Dutheil/TE-ABT, A. Lechner/EN-STI): Study the effect of the modified MKB waveforms on the flashover failure scenario.
- Viliam asked if a mechanical resonance at the dump assembly might be excited due to the modified sweep frequency. Anton replied that it would need detailed studies to answer this question. Daniel remarked that the mechanical Eigen frequency of the vessel should be orders of magnitudes lower to the sweep frequency.
- Stefano stressed that if major limitations in the bunch intensity are required, it should be announced soon, such that the Run3 operational scenarios could be adapted accordingly. Anton replied that this question has already been discussed in the LMC, and the current proposal is to limit the intensity to 1.4e11 ppb for the first year of Run3 and then, depending on the dump behaviour, relax this limit for the coming years.
- Daniel thanked everybody for their contribution to this first virtual MPP meeting and closed the meeting.

1.5 Open Actions

The actions from the meeting are:

- Action (MPP, J. Wenninger/BE-OP): Investigate the implementation of a SIS based interlock of the integrated intensity of consecutive bunches. Define the maximum number of bunches that have to be taken into account for averaging the bunch intensity.
- Action (C. Bracco/TE-ABT): Based on first operational experience after LS2, review the steering procedure and evaluate the possibility of steering with full trains.
- Action (Y. Dutheil/TE-ABT, A. Lechner/EN-STI): Study the effect of the modified MKB waveforms on the flashover failure scenario.