170th Meeting of the Machine Protection Panel

The meeting took place on September 28th 2018 in 774/1-079.
Participants:
A. Butterworth, W. Bartmann, L. Carver, R. Calaga, A. Drees (BNL), D. Lazic, A. Lechner, B. Lindstrom, Y. Nie, M. Pojer, L. Richtmann, B. Salvachua, C. Schwick, J. Uythoven, M. Valette, C. Wiesner, J. Wenninger, D. Wollmann, 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/760267/

1.1 Approval of MPP#169's minutes

- Actions from the 169th MPP (https://indico.cern.ch/event/756389/):
    - Action (M. Solfaroli & N. Magnin): test items of procedure related to LBDS after TS2.
    - Action (D. Valuch, MPP): request functionality to open up excitation window of ADT and prepare OP sequence for scraping the full LHC beam.
- No additional comments have been received on the minutes; they are therefore considered approved.

1.2 Summary of MKBV flashover (14.7.2018) and implications for the LHC dilution failure cases (C. Wiesner)

- Christoph presented a summary of the MKBV flashover event which occurred on the 14th of July 2018, its implications of potential MKBH flashover, and the possible mitigation strategies.
- In the current LHC dilution system, there are 4 MKBHs and 6 MKBVs. In the failure case of pre-firing, a new common-cause failure, namely, the pre-firing of more than one MKB was identified during the tests in 2016, which could be mitigated by reducing the generator voltage and installing a MKB retrigger system in LS2 (see relevant presentation and minutes in the 163rd MPP). In the failure case of a flashover, the worst case that had been considered so far was a loss of 50% dilution during dump execution due to the flashover of 2 MKBHs that are located in a common vacuum tank.
- On the 14th of July, a new failure mode of the MKBV flashover occurred during a programmed dump at 6.5 TeV. The flashover happened first in magnet MKBV.C when the magnet current was zero (40 μs after the magnet was triggered), and then propagated 10 μs later to another magnet in the same vacuum tank, MKBV.D, when its magnet current was close to the maximum. A comparison of the simulated and measured dilution patterns confirmed that the magnetic field persisted after the flashover, differing from the previous assumption, i.e. no current in the magnet after a flashover. The dilution of MKBV.C was lost, while MKBV.D had a high magnet current in antiphase to the remaining 4 MKBVs. As a result, the last part of the sweep pattern showed an

equivalent loss of 2.8 vertical dilution kickers, which was worse than the previously assumed worst case scenario for the MKBVs (loss of 2 out of 6).

- A similar event in the horizontal plane would be more critical than in the vertical plane, since we could potentially lose the dilution strength of up to 3 MKBHs out of a total of only 4 horizontal dilution kickers. For the flashover of 2 MKBHs, simulations have been performed to estimate the bunch density at the TDE and at the upstream and downstream window, assuming that the delay between the first and the second flashover was 10 µs and the magnet current stayed constant after the flashover. The slow current decay of 8% over 50 µs, as shown by PSpice simulation, was ignored. The starting time of the flashover was scanned from 0 to 86 µs. The simulation results showed that the sweep path would overlap if the starting time was 16 or 39 µs. The maximal bunch density at the TDE would correspondingly increase to 214% compared to the nominal pattern. The flashover of 2 MKBHs in antiphase leading to an overlapping sweep path is now considered to be the new worst-case scenario.
  - Daniel asked if the time delay between the successive flashover of the two magnets in the same vacuum tank is fixed or random. Christoph replied that the reason and exact location of the flashover was not clear, and the propagation speed of the plasma effect was very fast (about 300 km/s in the event on 14th July). It is difficult to predict the exact time delay. But in the simulated cases, the overlap of the sweep path appeared, presenting already the worst situation.
  - Jan asked if we could withstand a similar event in the horizontal plane. Wolfgang and Christoph replied that these relative effects were under study via simulations, but mitigation measures would certainly be needed to improve the performance of the dumping system.
- The effect of adding 2 more MKBHs has been studied and presented. If all the 6 MKBHs were operated at 67% voltage (to provide the same total dilution as the current 4 MKBHs), the probability of a similar flashover would be reduced significantly, and the maximal bunch density at the TDE in a flashover failure would be limited to 189% compared to the nominal pattern. If all the 6 MKBHs were operated at 80% of the current nominal voltage, the maximal bunch density at the TDE would be 171% compared to the current nominal pattern.
  - Christoph said that these were preliminary simulation results. Different filling patterns and flashover behaviors need to be checked. Additional FLUKA and thermo-mechanical studies are equally required.
- To reduce the probability of a flashover, the operating voltage has already been reduced in July by 20% at MKBV.C/D.B2, and the insulation of HV busbars will be further improved during LS2 or LS3. Note that the probability of a flashover is higher for the MKBVs due to the higher voltage at the magnet level. Both the probability and the impact of a flashover would be reduced if two additional MKBHs per beam were added in LS3. Adding two MKBHs would also provide additional margin to increase the total dilution, so as to reduce the energy density in the TDE during both nominal operation and flashover.
  - Daniel said that the addition of two MKBHs is not foreseen during LS2. He asked if an intermediate mitigation is foreseen in Run 3, where the

bunch intensity will already become much higher than now. Jorg added that a bunch intensity of 1.7-1.8 x 10^{11} p is to be expected in Run 3.
  - Christoph replied that the energy density in the TDE depends significantly on the filling patterns in the first/last part of the machine, so a potential mitigation (however implying a performance decrease) would be to remove the first three injections (12b + 144b + 144b) to avoid the overlap of the sweep path when a flashover occurs.

1.3 SPS-CC: plans for the October MDs, additional interlocks etc. (A. Butterworth, L. Carver)

- Andy presented the newly implemented RF phase interlock between BA3 and BA6.
- After re-phasing, the SPS frequency is locked to the reference Crab Cavity frequency (with a factor 2). The phase between the two signals is then measured continuously and a beam interlock is generated when the phase difference is above a set threshold. A schematic of the circuits is detailed in the slides. The interlock was successfully tested with beam on 27.09.2018.
- Andy noted that a more detailed test should be done to determine the delay between the RF system issuing the interlock and the execution of the beam dump.
  - Daniel asked if there is a buffer saving the timestamps. Andy replied affirmatively and mentioned that the delay should be sub-ms.
  - Lee asked how the phase interlock is specified. Andy replied that it is set by an analog system and that the total frequency shift must go above a certain threshold to trigger a dump, meaning that a slow frequency shift will take longer to trigger a dump as seen from the start of the frequency shift. But, for slow shifts the impact on the beam should also be smaller.
  - Jan asked how this is operated between different parts of the cycle. Andy replied that it is controlled by the timing, such that it is automatically programmed into the cycle. He also mentioned that it can only be switched on after rephasing.
  - Jan continued that it should be synchronized with the CC voltage.
  - Jörg pointed out that the LTIM is easy to disable, hence the triggering timing events should be retested ahead of each MD and then left untouched for the day.
  - Daniel mentioned that a quick test to show it works should be conducted before high intensity beams.
  - Verena added that it is not operational and must therefore be tested and retested.
  - Andy replied that it is a temporary measure and that it will be tested at the beginning of the MD.
- Lee presented the tentative program for MDs 6 and 7. The main part of these MDs is to increase the intensity above the 'safe' limits, at injection energy in MD6 and 270 GeV in MD7. The purpose is to study strong beam loading, cryogenic heat loads, cavity performance and stability and higher order modes.
- The prerequisites are to

  - install and test the RF interlock (explained by Andy)
  - check that the 26 GeV crab cycle allows 4 injections (Done)
  - set the RF on timing to 100 ms after the synchronization between BA3 and BA6, except for multi-batch injections in which case RF on and synchronization is to be set after the 4th injection.
- The steps to be taken during the MD were then detailed. In particular, the RF phase interlock should be tested at the start of the MD. The RF off interlock to the BIS, including its delay, should also be checked at the start of the MD. The crab cavities should then be set up with safe beams, after which the intensity ramp starts, with revoked RBAC settings such that no changes to the CC parameters can be done without first going back to safe beams.
- At the end of MD6, the RF phase interlock should be tested at 270 GeV.
  - Lee mentioned that the CCs should perhaps be switched off at the start of the intensity ramp-up.
  - Daniel said that this needs to be clearly defined beforehand and that it is important not to change any parameters during the ramp-up.
  - Jan asked about a voltage ramp-up.
  - Lee replied that they could start with 0 volts, then go on to 300 kV.
  - Rama added that what they will do, is to first fix the same phase of the cavities since both have not been used in parallel before. Then, for the intensity ramp-up, start with safe beam, perform voltage and phase scans, and after that continue adding 12 bunch batches. As the intensity is increased, the RBAC is removed such that no CC parameters can be changed. If any changes are to be done, they go back to 12 bunches first.
  - Jörg commented for the 450 GeV part with single bunch in MD7, that with SFTPRO one can only have batches, not single bunches, and also that the energy is 400 GeV.
  - Rama and Lee replied that the idea was to copy another cycle for simplicity. The reason for this test is to have a single short bunch (at 450 GeV), and that it is unrelated to the intensity ramp-up.
  - Daniel asked about the RF interlock at injection.
  - Rama replied that it is switched on 1s into the cycle using a fixed delay wrt to an initial timing event. He then asked what the requirements would be to continue from MD6 to MD7, considering that there is no MPP meeting between them.
  - Verena replied that what is required from the OP side is not only producing a procedure, but also setting up requirements for continuing and defining where and when to stop.
  - Daniel added that there are two important items to be kept in mind:
    - if fast losses occur, stop and step back to safe intensity
    - If slow losses occur, stop and understand why before continuing. One should also stop if the CCs are not behaving as expected.

1.4 Update on machine protection requirements for high intensity operation with CC in the SPS (D. Wollmann)

- Daniel presented the machine protection requirements for proceeding to unsafe beam intensities. The limits considered 'safe' are 6×10^{12} p at 26 GeV and 2.4×10^{11} at 270 GeV.
- Reliable operation of both cavities at high voltage is still a work in progress, but the CC parameters follow programmed functions that provide some protection against typing errors.
- Beam instabilities due to crossing the betatron resonance are the fastest failures predicted, and have been also observed, for the SPS CCs, leading to critical losses in ~50 ms as measured at 26 GeV. With high intensity beams, criticality would be reached ~20 ms after the onset of losses.
- The slow CC-RF interlock causes a dump within 8 ms (mainly due to internal delays and electro mechanic components), if the problem is detected, whereas the ring BLMs in the SPS have a minimum interlock time of 20 ms. Also, 2 adjacent BLMs must exceed the threshold to trigger a dump. The foreseen fast RF phase interlock would only mitigate the danger of resonant excitations at flattop (after RF synchronization).
    - Verena commented that the BLMs in LSS are much faster and that one could choose a loss location in a specified area of an arc by putting a vertical bump
    - Jörg added that a bump would not be very big at 270 GeV due to the limited orbit corrector strength
- Tune spread in the beam seems to play an important role for damping the rise time of the losses, and the rise time is not expected to be significantly slower at 270 GeV. A measurement is therefore required.
- MP requires that:
    - Loss rise time at 270 GeV be measured
    - BLM thresholds at expected/observed loss locations be verified
    - RF phase interlock be ready and tested for reliability with safe beams
    - In case of using both cavities, the IOT interlock be put in series such that dump is triggered if either IOT is switched off
        - Rama commented that both serial and parallel IOT interlocks are possible and that they are still discussing what is better. One option is to leave it as it is and only operate with one cavity on at a time, in MD6.
    - CCs be off during the energy ramp, since the phase interlock is activated only at FT
    - All parameter changes are verified using low-intensity beams and intensity is increased in steps
    - RF expert RBAC roles are revoked, tuners inhibited and stable communication link between the CCC and BA6/BA3 is established before high intensity beams
    - A detailed test procedure be prepared in EDMS and checked by SPS-OP / MPP beforehand