176th Meeting of the Machine Protection Panel

The meeting took place on **March 29th 2019** in 774/1-079.
Participants: A. Apollonio, R. Bruce, D. Lazic, B. Lindstrom, B. Petersen, S. Redaelli, B. Salvachua, J. Uythoven, J. Wenninger, D. Wollmann, C. Wiesner, M. Zerlauth, O. Aberle, M. Di Castro, F. Moortgart, Y. Papaphilippou, A. Rossi, B. Salvant, G. Sterbini

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

1.1 Minutes from the 175th MPP

No comments have been received for the Minutes from the last MPP. The open actions resulting from the discussion on the SPS dI/dt interlock have been added to the MPP homepage.

1.2 LRBB wire: results of failure-case study (Bjorn Lindstrom)

- Björn presented the results of the failure-case studies for the **Long Range Beam Beam Compensating Wires (BBCW)**. The BBCW presently consists of a straight wire embedded in each of the two jaws of the tertiary collimators TCTPV.4R1.B2 and TCTPH.4R5.B2. During LS2, they will also be installed for Beam 1, i.e. either in TCTPV.4L1.B1 and TCTPH.4L5.B1, or optionally in TCTPH.4L1.B1 and TCTPV.4L5.B1. The wire in the jaw is about 1 m long and has a 2.5 mm diameter. The maximum operating current is 350 A. The two wires of one TCT are hard-wired in series and powered with a single power converter (PC).
- With the nominal TCT settings of 7.8 sigma, the **distance between the centre of the wire and the centre of the two collimator jaws** ranges from 9.9 mm to 11.2 mm. However, the optimal compensation of the beam-beam kick would be achieved with a distance of 5.7 mm between wire and beam.
    - Jan asked whether there are plans to operate with the BBCW at their optimum position of 5.7 mm. Jorg clarified that this is not foreseen because it would lead to very tight TCP settings. Yannis added that there are no plans to use these settings in operation, but that tests during MDs should not be excluded.
- As long as the wires are powered in series with the same polarity, the **field produced by the wires** has no direct dipole contribution, but only quadrupolar, octupolar, dodecapolar, and higher order contributions. However, a beam that is not centered with respect to the collimator jaws will still receive a transverse dipolar kick.

- Three **potential failure scenarios** were presented. The numbers have been calculated for both beams with the 2018 pp 25 cm collision optics.
  - **1) PC trip**: The current in both wires drops with the decay time constant of the circuit, which leads to beta beating, tune shift and, if the beam is not centred in the TCT, also to a distortion of the orbit. The maximum values, reached after approximately 50 ms, are the following:
    - Beta beating up to 7.5% in the horizontal plane and 5.5% in the vertical plane.
    - Tune shifts of -0.011 in Q_x and +0.008 in Q_y.
    - Kick of 0.16 sigma for an assumed beam offset of 1 mm in the TCT.
  - **2) Short of a single wire** while the other wire remains powered: This leads to beta beating, tune shift and a dipolar kick of 0.8 sigma. However, this scenario is not deemed likely because the wires are connected in series. In case of changes to the connection scheme, the system has to be re-commissioned with low intensity beam.
  - **3) Incorrect polarity on one wire**: This would lead to a 14 mT field level and a strong dipolar kick of 1.6 sigma. Therefore, this scenario should be detected and corrected during commissioning. To ensure this, a detailed procedure for commissioning and post-intervention is required. → Action (Adriana/BE-BI): Write commissioning procedure for the BBCW with and without beam, including reliable check of the wire polarities.
- The following aspects were discussed in more detail:
  - For the failure studies, a **maximum beam offset** of 1 mm in the TCTs was assumed. Jan asked if the 1-mm tolerance is relative to the collimator centre or relative to the reference beam orbit, which might differ from the geometric machine centre. Jorg clarified that the TCT jaws are aligned symmetrically around the beam by using the BPMs. However, during operation the beam position might drift, with 1 mm being a pessimistic assumption. He estimated that a drift of 0.3 sigma to 0.4 sigma is realistic over longer time periods.
  - **Beam kick in case of a PC trip**: Daniel reminded that the full kick is only reached after 30 to 50 ms. Therefore, if the beam is dumped after a few milliseconds, the beam displacement will be much smaller.
  - **Beta beating**: Stefano commented that, on top of the calculated value for the wire failure, one has to add the presently assumed 10% beta beating. Yannis confirmed that this would indeed be an extra contribution to the beta beating. Replying to a question by Daniel, Roderik stated that currently a 10% beta error is assumed, even though the realistic value is around 5%.
  - **Collimator margins and phase advance:** The beta functions and thus the failure consequences are similar for all the relevant TCTs. However, the collimator margins change as these depend on the phase advance from the wire to the collimator in question. The TCT-to-TCDQ margin for a PC trip is worst for failures in TCTPH.4L5.B1 and TCTPH.4R5.B2, with the horizontal margin decreasing from 0.5 sigma to 0.08 sigma

and 0.11 sigma, respectively, assuming the 2018 25 cm beta* optics. Beam 1 is slightly less critical because the phase advance from the MKD to the TCDQ provides an extra 0.1 sigma margin compared to Beam 2, which is not included in the plots. For the optional installation points of Beam 1, the change of the TCT-TCDQ margin is less critical, reaching a margin of 0.18 sigma horizontally for a failure in TCTPH.4L1.B1. In general, the aperture changes in the TCPs, TCSG and TCSP are not critical.

    - Jan reminded that the TCT-TCDQ margin is only relevant for the horizontal plane.
    - Jorg commented that these values will, in addition, strongly depend on the optics and are therefore rather indicative. They have to be checked with the final optics and verified for any significant optics change.
    - Yannis recommended to add a plot showing how the phase advance changes for the different scenarios. Bjorn confirmed that this is available from the studies and will be added to the slides.

- In case of a power-converter trip, the **measured decay time constant of the current**, assuming an exponential decay, is approximately **8.3 ms**.
- Preliminary measurements of the **delay time of the interlock chain** for a PC trip show a total delay of approximately 1.5 ms. The test was performed measuring the opening of a current loop with a dedicated power supply instead of using a real WIC unit, and will, thus, be repeated once a complete WIC unit is available for testing. → Action (MPE-MI): Measure delay time of the interlock chain for the BBCW, including a WIC unit, in case of a PC trip.
- Jan commented that the **failure consequences** presented don't seem to be very critical, given that we can dump the beam within a few milliseconds. However, the studies should be finalized.
- Stefano recommended to organize a **combined meeting of the MPP and the Collimation Working Group** to discuss also other collimator-related issues.

1.3 New collimator temperature interlock logic (Mario Di Castro)

- Mario presented the **status of the LHC collimator temperature interlocks**. The temperatures of the collimator jaws and of the cooling water are continuously monitored using Pt100 sensors. Presently, there are 106 operational collimators in the LHC. All the 'phase 1' collimators (installed before LHC start-up) have 5 temperature sensors each. All the 'phase 2' collimators (installed during LS1 and later) have 10 temperature sensors each. In total, 693 temperature sensors are, therefore, installed in the LHC collimators today. This includes 45 sensors that have been disabled. The sensors are connected via 13 PLCs to the BIS and, in addition, to a UNICOS WinCC OA SCADA system. In general, the interlock is triggered when the **alarm temperature of 50°C in the jaws or 40°C in the cooling water is exceeded for more than 12 seconds**. The sampling rate is 1 second.

- For yet not fully identified reasons, some **temperature sensors fail** for certain periods of time. In these cases, unphysical values (e.g. 3276°C) or very fast temperature changes are read by the PLC. If they persist for more than 12 seconds, the interlock is triggered and the beam is dumped.
    - Markus asked if the unphysical temperature readings are a result of a disconnected sensor. Mario replied that for the value of 3276°C this is indeed the case. However, there are also unphysical temperature spikes of 500°C or 1000°C, for which the reason is not understood.
    - Jan asked if the broken sensors would be checked and repaired during LS2. Stefano replied that this is only possible for the sensors at the cooling circuits, but not for the sensors embedded in the jaws. In the long term an interlocking solution not based on locally installed Pt100s needs to be envisaged.
- **Four** different **cases of sensor behaviour** can be distinguished (see Slide 7):
    1) The temperature is out of range for less than 12 seconds. → *No interlock will be triggered, which is the desired behaviour.*
    2) The temperature increases above the threshold for more than 12 seconds with growth rates and temperature values that are physically plausible. → *The interlock will be triggered, which is the desired behaviour.*
    3) The temperature increases above the threshold, but the growth rate is higher than physically plausible. → *The interlock will be triggered, which is not desired and leads to an unnecessary dump.*
    4) The temperature jumps to an unphysical value and stays at this value. → *The interlock will be triggered, which is not desired and leads to an unnecessary dump.*
- The **number of false dumps** due to a broken temperature sensors were: 3 in 2016, 2 in 2017, and 2 in 2018. Therefore, the overall loss of availability is still low. However, the risk remains that, due to aging effects, these numbers will increase during Run 3. Independently, two dumps were caused by RF issues, where the temperature sensors correctly protected the machine. Belen asked if these numbers include the commissioning period. Mario said that this is not the case and that only events during operation were taken into account. He added that the introduction of a warning system, which sends e-mail/SMS notifications to the experts when a warning temperature level is exceeded, allowed to preventively disable failing sensors and, thus, avoid unnecessary dumps.
- The strategy **for a new interlock logic** was discussed.
    - If the loss of availability is considered acceptable, the current interlock logic could be kept. Otherwise, a new interlock logic is required that filters the unphysical readings without compromising the protection functionality. **Two options for the filtering** were presented:
        1) Filter the readings that show an **unphysically high temperature value** (Case 1 and 4 above) and /or
        2) Filter the readings that show an **unphysically high temperature growth rate** of, e.g., 50°C/s (Case 3 above).

  - Jan asked how often the different cases occurred during LHC operation. Mario replied that Case 1 and Case 4 together account for roughly 90% of the cases. Markus concluded that since Case 1 is already filtered and Case 3 does not occur very often, we should **focus on filtering Case 4**, where we can expect the highest gain in availability and which is also the easiest and safest to implement in the PLC logic.
  - Daniel commented that we have to be careful not to introduce a common cause failure. Thus, he recommended to **check that not several or all of the sensor readings from the same collimator could be automatically disabled by such a new logic**. Jan added that this is important since, otherwise, the collimator would be left unprotected. Benoit pointed out that, nevertheless, this implementation could lead potentially to false beam dumps. Markus replied that, if the same behaviour is observed at all sensors simultaneously, one should not continue to run in this configuration for longer periods in time, but investigate the cause. Mario added that so far it had never occurred that more than one sensor at the same collimator had failed. Stefano remarked that in any case the experts will have to check the situation after the next dump. He reminded that the disabling of a sensor is always discussed on a case-by-case basis and that an expert procedure exists.
  - Daniel asked where we should set the **limit for an unphysically fast temperature increase** and whether an increase rate of 50°C/s could be a real effect. Benoit replied that filtering above a rate of 50°C/s seems reasonable since it is one order of magnitude larger than the fastest rate that we have observed, which has been 5°C/s at the TDI.
  - Daniel asked about the **timeline for the implementation**. He remarked that it would be advantageous to prepare and test the new interlock logic already during LS2. Stefano suggested that, if there are enough resources, one should implement the filter since these are clearly fake temperature readings. Mario commented that the implementation should be smooth and could be carried out together with the already planned updates together with BE-ICS.
- The **MPP recommended to implement the filtering for the unphysically high temperature readings**, but not for the unphysically high temperature growth rates. The MPP asked for the **specifications of the temperature interlock logic and the filtering strategy** to be written down. The final decision should then be taken on the basis of these specifications. → Action (Mario/EN-SMM): Write specification for the temperature interlock logic and the filtering of the unphysical temperature sensor readings in the LHC collimator jaws and cooling circuits, and implement them after acceptance.

1.4 AOB

No AOBs were discussed.

1.5 Open Actions

The actions from the meeting are:

- Action (Adriana/BE-BI): Write commissioning procedure for the BBCW with and without beam, including reliable check of the wire polarities.
- Action (MPE-MI): Measure delay time of the interlock chain for the BBCW, including a WIC unit, in case of a PC trip.
- Action (Mario/EN-SMM): Write specification for the temperature interlock logic and the filtering of the unphysical temperature sensor readings in the LHC collimator jaws and cooling circuits, and implement them after acceptance.