Joint WP2/WP4/WP5 Meeting

Tuesday 7th June 2022, 9:30 – 12:00

Chairs:	Rama Calaga, Stefano Redaelli, Rogelio Tomás
Speakers:	Marta Sabate Gilarte, Birk Emil Karlsen-Baeck, Natalia Triantafyllou, Rama Calaga, Guido Sterbini
Participants:	Hannes Bartosik, Roderik Bruce, Xavier Buffat, Rama Calaga, Riccardo De Maria, Paolo Fessia, Massimo Giovannozzi, Helene Guerin, Pascal Dominik Hermes, Cedric Hernalsteens, Giovanni Iadarola, Ivan Karpov, Bernadette Kolbinger, Conor Euan Charles McFarlane, Lotta Mether, Elias Métral, Nicolas Mounet, Joao Oliveira, Konstantinos Paraschou, Stefano Redaelli, Guido Sterbini, Helga Timko, Rogelio Tomas, Daniel Wollmann, Markus Zerlauth

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MEETING ACTIONS

Rogelio, Elias	Organize a follow-up of the TCLM4 mask design in September.

(see action list on the WP2 webpage, for the complete list of current actions)

GENERAL INFORMATION (ROGELIO TOMÁS, RAMA CALAGA, STEFANO REDAELLI)

Rogelio mentioned that the minutes of the previous WP2 meeting (indico link) have been compiled and will be circulated before the next WP2 meeting.

Rama explained that the main purpose of today's meeting is to have a wrap-up of the emittance growth MDs with crab cavities in the SPS, including a brainstorming for the upcoming MDs in September. Concerning technical news, **Rama** mentioned that the series crab cavities built at CERN have been tested with some good results. The UK collaborators announced a slight delay with the cryostating of the crab cavity module that should go into the SPS (present estimation is December this year), which might push the installation into the SPS by one more year (YETS 22-23 → YETS 23-24).

Stefano mentioned that there is also a ColUSM meeting scheduled for this afternoon, which is devoted to the follow-up of operational activities and crystal collimation progress. He also reported on the good results from measurements of the new crystals that were installed in the LHC at the end of last year. Channeling could be established quickly (by Marco and Daniele) even at top energy (6.8 TeV) and preliminary loss maps were measured. The team is issuing an installation ECR (for the horizontal crystals) for installation at the end of this year.

1. TCLM4 DESIGN OPTIMIZATION STUDIES (MARTA SABATE GILARTE)

- There are three MCBYs dipole correctors in the Q4 assembly. As they are not as radiation resistant as the Q4 in the same assembly, FLUKA simulations have been performed to optimize the shape of the TCLMB masks to reduce the radiation loads from the p-p collision debris.
- A configuration with larger aperture of the mask to mimic mechanical/alignment tolerances has been compared with a version with smaller aperture to better protect the MCBYs. This has an important impact on the dose distribution. The larger aperture version (reducing available tolerances for alignment errors) would be desirable for optics and collimation, but not acceptable for radiation. The reduced aperture (for better protecting the MCBYs) is OK for radiation, but not for optics and collimation requirements.
- For vertical crossing angles, the peak of the dose distribution is located at an angle of about 45 degrees. Therefore a new design with an additional inermet shielding at 40-45 degrees, as proposed by Riccardo, resulting in a more symmetric octagonal shape was considered to mitigate the hotspot at the 1st MCBY hotspot, together with a slight increase of the vertical aperture. This helps reduce the peak dose for vertical crossing angles, however for horizontal crossing angles the increased vertical aperture results in enhanced dose rates at the top and the bottom part of

the MCBY. Overall, this new design with an increased aperture results in about 30% smaller dose for vertical crossings, but about 30% higher dose for horizontal crossings compared to the reference case, which would be an issue for the IR with horizontal crossing.

Discussion:

- **Stefano** thanked EN-STI for their work and for coming up with creative ideas. He asked if the worsening of the peak radiation in the MCBY for the horizontal crossing angle operation would be acceptable, as it is not negligible. Paolo commented that with this proposed modification the replacement of the MCBY would need to be advanced because of a reduced lifetime when running with horizontal crossing angle.
- **Rogelio** stressed that it would be important to keep the freedom of choosing the crossing plane in both IPs and not being limited by radiation concerns. **Francesco** commented that the new design is suitable for both IPs, solving the issue for vertical crossing, but the limitations for horizontal crossing would become worse.
- **Riccardo** asked if the decision of not rotating Q4 could be revised in view of the potentially increased dose for horizontal crossing angles. **Paolo** said that in principle this can be revised, but it will require resources to study the full impact and feasibility, as for example the magnetic center might need to be shifted.
- **Rogelio** asked if changing the crossing angle in the middle of HL-operation would help to increase the lifetime of the MCBYs. **Francesco** confirmed that this would help. **Paolo** commented that one would gain some time, but would not allow reaching the end of life of HL-LHC without exchange of MCBY. **Francesco** added that the magnet group is assessing more precisely the radiation limit of the coils. Swapping the configuration will result in average of the two. However in both cases the hotspot is in the vertical plane at similar positions (where also part of coils are located). **Rogelio** stressed that it would be interesting to also perform the calculations for the rotated Q4.
- **Riccardo** mentioned that the vertical plane is more exposed because of the TCL4 protection and asked if there is a possibility to intercept debris in another location. **Francesco** explained that the dose comes from photons, neutrons and only an additional collimator could help.
- **Rogelio** asked about the timeline when the acceptable limits of dose will be known by the magnet group. **Markus** explained that the radiation test results are delayed due to Covid and are now expected for the end of this year. Therefore the question of rotating Q4 should be put on hold until then.
- **Markus** proposed to investigate the possibility of finding a unique solution for round optics and then change the mask further down the line if flat optics is needed. In this way one could profit from optimization possibilities, i.e. fixed designs optimized for certain optics configuration, and the optimized design to be installed depending on the optics needs. **Rogelio** commented that reducing aperture would impact the flexibility of optics. **Paolo** asked how long in advance would it be known that one would like to move from round to flat optics? **Rogelio** explained that it could even be that we need to start with flat optics in case of a delay of crab cavities. This is not easy to answer, as flat optics are also part of back-up scenarios.
- **Rogelio** proposed that the tolerances are reviewed if they can be tightened, and together with the results from the magnet tests we could aim for a decision towards the end of this year.

Francois Xavier explained that this strategy is different to what was announced and requires a slight re-organization of resources internally. The plan is to launch a market survey this year. Paolo commented that for the market survey probably the final design is not needed. **Francois Xavier** agreed and added that the mask assembly was planned for the end of 2024.

- **Rogelio** confirmed that the strategy now is to have a closer review of all options and reconvene at the end of the year. In the meantime **Riccardo** will continue discussing with everybody involved to explore options to not compromise aperture. Riccardo proposed to include other correctors in this analysis, if anyhow some of them need to be exchanged, then maybe saving another one is not worth it. **Action:** **Rogelio** and **Elias** to organize a follow-up of the TCLM4 mask design after September.
- **Paolo** commented that it seems that some of the discussion and decisions to be made here are beyond the scope of HL-LHC, and proposed to keep the hierarchy of groups in the loop. **Markus** agreed that the TCC and the magnet group need to be included in the decision.

2. MODELING SPS AND LHC CAVITY LOOPS (BIRK EMIL KARLSEN-BAECK)

- The goal of the study is to understand if the HL beams can be captured without much beam losses. For this purpose both SPS and LHC cavity loops are modeled to simulate the capture process.
- The SPS model consists of the one-turn delay feedback (OTFB) and feed-forward (FF). Some discrepancies were found between theory and simulations of the OTFB, which were related to the uncompensated real part of the voltage with beam. A benchmark of the simulation model with measurements with the 25 ns standard beam showed some discrepancies, which could be due to uncertainties in the power (20%) and the antenna voltage (~11%). A change of the resonant frequency of the traveling wave cavities due to added HOM dampers can impact the results. It was tried to recreate the transient behavior with the SPS OTFB, showing qualitative agreement with the discrepancies mentioned above.
- The LHC cavity controller consists of the radio-frequency feedback (FB) and OTFB. It features a coarse and fine grid (2.5 ns), time domain filters and low/high pass filters with one-turn delay feedback. For the LHC cavity loop benchmark the open loop and closed loop responses of the RF feedback were compared with measurements without beam and both open loop transfer function and closed loop transfer function are in good agreement with measurements.
- Waiting now for data from the SPS to benchmark feedforward and then simulate the injections into the LHC. A final refinement of the LHC OTFB and benchmark with beam measurements.
- In conclusion, the SPS OTFB is now extensively benchmarked and shows good agreement with measurements and theory. The SPS FF implementation agrees with the design, to be benchmarked with beam. The LHC RF-FB shows good agreement.

Discussion:

- **Ivan** clarified that it was not the BCMS beam but the 72 bunch beam for the SPS measurements.

3. RESULTS FROM RECENT SPS MDS ON CRAB CAVITY NOISE INDUCED EMITTANCE GROWTH (NATALIA TRIANTAFYLLOU)

- The crab cavities are a key component of the HL-LHC, providing a head-tail kick to the beam to compensate for the geometrical effect of the x-angle. However, noise in the voltage/phase can increase the emittance and result in undesirable loss of luminosity. Due to emittance growth induced by noise in the crab cavities, we need to define limits of crab cavity RF noise to limit emittance growth to acceptable levels.
- First measurements using the crab cavity prototype modules in the SPS in 2018 showed the correct noise power scaling, but a factor of 4 smaller than predicted by the theory developed by T. Mastoridis and P. Baudrenghien.
- Simulation studies indicated that this could be due to an effect of the transverse beam impedance (due to the separation of the coherent tune from the incoherent spectrum as validated by a kind of Schottky noise analysis, resulting in a suppression of noise induced emittance growth). Similar phenomena were also observed in beam-beam modes.
- Simulations also showed a clear dependence of this emittance growth suppression effect on the tune spread induced by octupoles.
- The suppression of the emittance growth was validated in the 2022 experimental campaign with an octupole scan, showing a qualitative agreement with the expected behavior.
- Further studies will be needed to refine experimental observations and test the quantitative agreement.

Discussion:

- **Xavier** commented that the space charge tune shift is of the same order as the tune shift from octupoles in the SPS experiment and could thus also have an impact on the quantitative discrepancies seen between measurement and simulations.
- **Rogelio** proposed to summarize the measurements and simulations in one plot for better comparison.
- **Rama** suggested highlighting in the presentation that this is a very complicated MD and not a trivial experiment to do. Even a qualitative agreement as seen during the MD gives reasonable confidence in the simulations for the HL-LHC predictions.

4. DISCUSSION ON FUTURE CRAB CAVITY MDS IN THE SPS (RAMA CALAGA)

- Two slots (September 12 & 15) are foreseen for crab cavity MDs before the annual HL-LHC meeting this year, MD with COAST and high intensity at injection. A list of potential topics were

presented for brainstorming and further details need to be worked out in the course of the following months. In case of incompatibility with COLDEX, we might have a slot on September 21.

Discussion:

- **Rogelio** asked if there were any plans for MDs on machine protection aspects. **Rama** explained that this was not discussed yet with machine protection. The aim would be to induce failure and record observables, but it is not yet clear how to implement all this.
- **Rogelio** proposed to perform measurement of multipoles in the crab cavities as a follow-up of the studies of M. Carla, even though it is not clear who could do that.
- Concerning instability studies with crab cavities, **Nicolas** said that it is not clear what could be done. Instead it could be more interesting to test the cavity feedback on the fundamental mode.
- **Stefano** mentioned that it would be nice to organize loss map measurements, and **Rama** confirmed that any collimation measurements would be valued.

5. WIRE SCENARIOS IN RUN 3 IN VIEW OF HL-LHC (GUIDO STERBINI)

- After Run 2, it was proposed to use the wires (2-jaws powered) routinely during the Run 3 operation, and thus 2 out of 4 wire demonstrators (L1 and L5) were moved from Beam 2 to Beam 1 to make the best use of the existing hardware. The aim is to gain operational experience while only a moderate reduction of beam losses are expected with this setup.
- All wires are housed in the TCTs, and thus in the Run 3 operational configuration the beam-wire distance is defined by the TCT settings. Different approaches to place the wires - bx/by=1 or bx/by=?2 or 0.5 or any s-location have been studied. Numerical simulations and experimental results for round optics and the setup used in RUN 2 show that there is not single sweet point but rather a "sweet region" for achieving compensation (of the octupolar beam-beam contribution), and this was also confirmed for the HL-LHC configuration. Simulations also show that it will be difficult to gain more than ~10 urad in the crossing angle at the end of leveling in Run3. Therefore the main aim is to prove smooth integration in operation and machine protection, and confirming the results from Run 2. In 2022 the plan is to turn on the BBWS after reaching 30cm beta*.
- All wire compensator WICs were successfully tested during the hardware commissioning period in 2022. MPP asked to repeat some of the tests with beam. Concerning the SIS, a window of 0-350A is set for the wire current. Furthermore, the SIS PC interlock system needs to be opened on the quadrupoles reference currents to allow the Q-feedforward trim (using the Q4L/R). There is a small impact on the Forward Physics transport matrix, and therefore also another knob including Q13-Q4 (matching section) is prepared to properly rematch the IP optics. This solution is also available and can be tested in MD in 2022.
- Tests of the wires at injection confirmed the wires polarity with beam-based measurements. The effect of the wire on the orbit was clearly seen (when switching ON the BBCW wires in B1 a CO effect is seen on B2 and vice versa). This is probably due to a second order effect in H B1 due to fifth axis misalignments, and a first order effect in H B2, possibly due to the magnetic field induced

by the cable feeding the wire. If the CO feedback is ON, the effect is fully compensated. Further results will be obtained once the 5th axis alignment is done.

- Finally the outstanding aspects to be covered in the September workshop were discussed, such as to quantify the impact of wire compensation on the core-diffusion, update the evolution of the Run 4/5 configurations, checking the impedance of the device and also the beam induced heating of the wire, to verify if the design is vacuum compliant and define a strategy for the vacuum sectorization, verify beam-impact limit and background noise contribution for the experiment, and checking forward physics requirements/conflicts.
- It was also stressed that the Run 4 relaxed TCT settings are challenging for a possible new BBWC design and its application in HL-LHC.

Discussion:

- **Stefano** asked if for the compensation of the wire induced tune shift a clear list of commissioning steps for the cycle phases with wire on have been established. **Guido** explained that the knob was tried in LSA without driving the hardware. The idea is to do a check with pilot beams to measure the tunes and verify the knobs once the 5th axis is aligned, and then continue with the standard commissioning steps as is done for another step in leveling (e.g. beta beating measurements, loss maps, …). A nominal configuration will be tested thoroughly and this should be sufficient for the other configurations. **Stefano** added that the 5th axis alignment will be done once the collision orbit has been established, but some tests could also be done before the alignment of the 5th axis.
- **Rogelio** mentioned the Run 4 configuration, for which we need to start thinking how the wire can be operated, for example running with tighter collimators during physics fills, varying the gap during physics fill (tertiary gaps). **Guido** said that in 2022 we will be running with a constant collimator gap, but in 2023 the plan is to change the gap during the fill, which could be an option to get closer to the beam once the intensity is decayed. In Run 4 on the other hand the collimation settings are dominated by impedance considerations. Since higher currents in the wire compensator are technically challenging, we need to profit from moving the wires closer to the beam and this would require a qualification of the halo population, the aperture and the tightest settings in the rest of the machine.

6. ROUND TABLE AND NEXT MEETINGS (ROGELIO TOMÁS)

The next WP2 meeting will be announced in due time.

Reported by Hannes Bartosik and Rama Calaga