185th WP2 Meeting

Tue 24th Nov. 2020, 9:00 – 12:00

Chair:	Rogelio Tomás
Speakers:	Sofia Kostoglou, Lotta Mether, Konstantinos Paraschou
Participants (zoom):	Hannes Bartosik, Xavier Buffat, Rama Calaga, Riccardo De Maria, Ilias Efthymiopoulos, Lorenzo Giacomel, Gianni Iadarola, Sofia Johannesson, Elias Métral, Nicolas Mounet, Yannis Papaphilippou, Giovanni Rumolo, Benoît Salvant, Kyriacos Skoufaris, Guido Sterbini, Frederik Van der Veken, Carlo Zannini.

AGENDA

MEETING ACTIONS

Riccardo	Report on the aperture reduction due to the new transition bellow from the TAXN to the TCTPXV.
Sofia K.	Check the impact of a crab cavity tilt on DA.
Hannes, Gerd Kotzian	Devise tests in the SPS to measure e-cloud tuneshift of single excited bunches.
Ilias	Compute the tolerance on CC non-closure from the luminosity point of view.

GENERAL INFORMATION (ROGELIO TOMÁS)

Rogelio reviewed the minutes of the 184th WP2 meeting. The first presentation, by **Riccardo,** showed that 20-30% of imbalance in the crab cavity voltage are still well within the margin for aperture. There still remains one action for **Rama** about the estimation of the crab cavity phase error from beam loading, after set-up at low intensity. The second talk, by **Lorenzo**, was a fully self-consistent study of electron cloud in crab cavities. Results are very promising and show no electron cloud build-up at nominal voltage, but maybe some build-up at intermediate voltages. There is one action for **Lorenzo** and **Gianni**, about the computation of heat load due to e-cloud in the crab cavities. The last talk was presented by **Riccardo** and concerned the TAXN new physical aperture (inner diameter of 88 mm) and tolerances. Everything is ok from the WP2 side. The update of the aperture and tolerances was then passed to two committees: alignment and energy deposition. **Riccardo** pointed out that both discussions took place since then. The alignment committee confirmed the last version of the tolerances (4.9 mm). A study on energy deposition was presented by **Marta Sabaté-Gilarte** and **Francesco Cerutti** at the WP5 meeting on Friday, Nov. 13th, showing that the dose will increase but will still remain acceptable, hence there is no immediate issue. The next step is the full validation with WP8, and the writing of an Engineering Change Request. On the same general topic, **Riccardo** mentioned also last-minute discussions that took place on Friday 20th and Monday 23rd, about the possibility to increase the aperture of the bellows of one or two collimators, in order to simplify the transition from the TAXN to collimator tapers - an issue was identified with one bellow that is smaller than the stroke of the TCTPXV. **Riccardo** checked the implications of the reduced aperture and proposed a change to WP5. **Luca Gentini** made a first assessment on the feasibility and the issue will be discussed within WP5. **Riccardo** proposed to report it to one of the following meetings (Action: **Riccardo**). **Rogelio** concluded that this is a nonconformity that is being fixed.

Nicolas also mentioned one correction to the minutes by **Elias**, after their publication: an answer to a question from **Roderik Bruce** about the first talk by **Riccardo** was erroneously saying that the "crab dispersion follows the phase space" - it was the "phase advance" that was meant there. The minutes have been corrected.

The schedule of the meeting then followed as foreseen.

1 IMPACT OF CRAB CAVITY BUMP NON-CLOSURE ON DA DURING COLLISIONS (SOFIA KOSTOGLOU)

In this presentation, the impact on dynamic aperture (DA) of a crab cavity bump non-closure is evaluated in collisions, at the end of leveling. This follows the talk by **Riccardo** during the previous WP2 meeting (in which the margin with respect to physical aperture was evaluated in a non-closure configuration).

The study was performed with standard end-of-leveling parameters: optics v1.5, β*=15 cm, 1.2e11 protons per bunch, emittance ε=2.5 µm, coupling C^-=1e-3, octupole current +300 A, chromaticity Q'=15, working point (0.31, 0.315) and half-crossing angle 250 µrad. Numerous sanity checks were done, e.g. on the crabbing angle (-190 µrad) at the IP, and on the orbit (for different longitudinal position, namely z=75 and 200 mm), both at the IP and outside of it (the crab cavity bump being either closed or not). In particular, a missing voltage of 200% (i.e. a crab cavity with a voltage opposite to the nominal one) in one cavity, means the crabbing angle is fully suppressed at the IP, while the leakage in the rest of the machine is at its maximum. Non-closure at one IP is also shown to leak as a crabbing angle in the other IPs, as expected.

In general, the effect of non-closure on DA appears to be very small: with beam-beam and a longitudinal momentum deviation of 27e-5 (¾ of the bucket height), one needs at least 70% of voltage error to be able to observe a significant DA reduction (-0.5 σ) due to non-closure. Even with 200% voltage error, the DA decreases from 6.5 σ to only 5.8 σ. Two opposite effects, identified thanks to Frequency Map Analyses (FMA), are counteracting each other: the head-on tune spread reduction due to the decrease of the crabbing angle (beneficial for DA), and the increased tune diffusion due the synchro-betatron sidebands (detrimental to the DA) - this latter effect is increasing with z. The effect of the non-closure from either the weak or the strong beam, was analyzed separately in terms of DA of the weak beam, showing that the main contribution to the DA reduction arises from the weak beam. Without beam-beam effects, the DA is reduced by a similar but slightly higher amount (from 7.5 σ to 6.6 σ for a 200% error). The next step would be to include multipolar components to the simulations.

- **Rogelio** mentioned a case simulated by Emilia Cruz-Alaniz with multipolar components. **Sofia K.** said this was to simulate an imbalance on multipolar components. **Yannis** added that this was mainly to check what the effect of the b2 component was. The impact turned out to be very small, without beam-beam. He added this was a rather orthogonal study. In the case of the study of **Sofia K.**, the idea would be rather to include the multipolar components, in order to close the study.

- **Rogelio** concluded that the effect of non-closure is small, as for the physical aperture (see talk by **Riccardo** during the previous WP2 meeting). **Yannis** confirmed and added that an important point is that when beam-beam effects are included, one does not see much impact on the minimum DA, because of the two counteracting effects (head-on tune spread and tune diffusion). Regarding DA, in any case the tolerance is large.

- **Rogelio** asked if one could extrapolate these results to the case of a tilted crab cavity. He pointed out that if a crab cavity in IP1 is slightly tilted, it is similar to a non-closed bump in IP5 without a tilt. Probably there is anyway a large tolerance for the DA. **Sofia K.** answered she can check (Action: **Sofia K.**).

- **Riccardo** wondered about the dependence of the results on the phase advance between IP1 & 5, as it could lead to a different leakage. **Rogelio** said there is no strong motivation for such a study, as the effect is small, except for the luminosity. **Yannis** agreed that the strongest impact seems to be on luminosity: even with a 10% voltage error, the detrimental impact is large, and possibly in several IPs (including IP2 and 8), due to undesired crabbed bunches there. **Rogelio** also mentioned the crab kissing effect (Action: **Ilias**).

2 COUPLED BUNCH STABILITY AND TUNE SHIFTS (LOTTA METHER)

This presentation provides a detailed account on e-cloud simulations of the coupled-bunch tune shifts in the LHC (72 bunches of intensity 1.1e11) and HL-LHC (200 bunches of intensity 2.3e11), performed using the PyECLOUD / PyHEADTAIL / PyPARIS software suite. The tune shifts due to the e-cloud in the dipoles (secondary emission yield SEY=1.4) obtained after kicking the beam as a whole by 0.25 σ, are mainly positive; for the LHC at injection they are much smaller in horizontal (2e-4) than in vertical (3e-3), while for HL-LHC they are similar in both planes (2e-3). The sizable reduction of the vertical tune shift in HL with respect to LHC, is consistent with the reduction of the electron density in the center of the beam pipe, which occurs at high intensities. At collision energy, the tune shifts are more than an order of magnitude smaller: 1e-5 (resp. 2e-4) in horizontal (resp. vertical) for the LHC, vs. 1e-4 in both planes for HL.

An investigation of the effect of the kick pattern was also performed, showing that individually-kicked bunches in the LHC exhibit a very different tune shift in horizontal (negative, and one order of magnitude larger in absolute value, with respect to the case when the full beam is kicked), while it remains almost identical in vertical. In HL-LHC, the effect of the kick pattern is very similar, albeit with a smaller increase (in absolute value) for the horizontal tune shift. This leads to the conclusion that the horizontal bunch-by-bunch tune shift in dipoles is a multi-bunch effect that depends significantly on the motion of the other bunches - this can be explained by the way the electron stripes move with the bunches when they are all kicked in the same way. On the other hand, the tune shift in the vertical plane is mainly a single bunch effect. The impact of the kick amplitude was also tested, but no systematic trend was found; smaller kick amplitudes seem only to increase the noise of the resulting tune shifts. The effect of quadrupoles remains to be studied for both tune shifts and stability.

- **Rogelio** commented on the fact that even a very small kick (0.02 σ) seems to have a large impact on the dynamics, since the tune shift is large (see slide 19). **Giovanni** answered that the kick only influences the precision of the measurement that is performed, but actually what is being measured is the effect of the e-cloud build-up that accumulated before. **Elias** commented that the tune shift of the rigid bunch mode is not important for Landau damping, as one has to put the complex tune shifts in the stability diagram. **Rogelio** also wondered about the possible effect of coupling.

- **Xavier** said it would be interesting to get the single-particle tune shifts as well, i.e. the footprint. **Lotta** and **Gianni** answered that the footprint can be easily obtained - see also the work by **Konstantinos**.

- **Rogelio** wondered if the "real" tune shift that should be taken into account is the one obtained with individually-kicked bunches. **Xavier** argued that both numbers are relevant, but for different purposes. **Rogelio** said that for single-bunch instabilities, the single-bunch kicked tune shifts are the ones that seem relevant.

- **Gianni** commented that the results are interesting but not really revealing any potential issue: in no configuration one is getting close to perturbing the tune separation, especially with the injection tunes (0.27 and 0.29). **Rogelio** argued that in some cases a tune shift of almost 1e-2 is obtained (see slide 19 - red points). **Gianni** agreed but commented that the study was done with a large SEY. **Rogelio** wondered if one could get close to a tune of 0.25. **Gianni** argued that we are still far, and we can also move the tunes. One can chase and measure the tune shifts of individually-kicked bunches, but there is no worrying effect. **Rogelio** agreed for top energy, while at injection there is indeed more freedom in the choice of the working point. **Xavier** asked what the incoherent tune shift at injection is. **Gianni** answered it is around 2e-2 (there is cancellation of effects for the coherent tune shift, which makes it smaller).

- **Hannes** said that one should try to measure this effect in an MD, using kicks from the damper. **Lotta**, **Elias** and **Rogelio** agreed. **Benoît** asked whether the damper kicks can be made at the single-turn level. **Xavier** answered that it is possible, but not for high amplitude kicks. **Rogelio** confirmed. **Hannes** wondered about the resolution of the measurement. **Xavier** answered that it worked with impedance, for small tune shifts. **Gianni** said that one cannot switch on/off the damper as in the case of impedance - the ecloud stays. One needs chromaticity and non-linearities, to keep stability. **Xavier** said that one can turn off the damper on single bunches. **Lotta** pointed out that the SEY used here (1.4) is pessimistic, leading to an overestimation of the effect. **Giovanni** also mentioned the need to consider the impedance, as well as the e-cloud from quadrupoles. **Gianni** concluded that one needs to simulate the experiment with impedance and all the ingredients, which is a nice exercise. **Elias** wondered whether one can do such a study in the SPS. **Hannes** answered that the damper features in the SPS are much less advanced - still this could be checked with **Gerd Kotzian** (Action: **Hannes**, **Gerd**).
- **Rogelio** insisted that it would be nice to include the individually-kicked tune shifts in the final summary table. **Lotta** agreed.

3 Update on simulations with large gas densities: stability and effect of solenoid (Lotta Mether)

This presentation is a short update (see 165th WP2 meeting) regarding the ongoing simulation studies on ``16L2`` events, which impacted operation in 2017-2018 and were caused by the beam-induced phase transition of macro-particles of frozen air, leading to high gas densities and ultimately beam instabilities from the electrons and/or ions produced through gas ionization.

Self-consistent, multi-species simulation tools were developed, including a cross-species ionization module, and electron and ion densities now reach values close to those expected to cause instabilities (for a gas density of 10^{20} N_2/m^3). Nevertheless, instabilities have not been reproduced in simulations at injection energy. In collisions, instabilities were obtained but for a state where build-up simulations show an unphysical behaviour; in general, more convergence studies are needed at collision energy.

The effect of the solenoid (which proved to have a mitigating effect during operation) was also evaluated. With a solenoid field of 5 mT, the build-up of electrons and ions is indeed delayed by 20 bunch passages at injection, and an even stronger suppression is seen at collision energy. This latter effect still has to be confirmed as convergence studies remain to be done at collision energy.

- **Rogelio** concluded that the results are very clear and go in the right direction.

4 INCOHERENT EFFECTS FROM E-CLOUD WITH SIXTRACKLIB (KONSTANTINOS PARASCHOU)

This presentation provides a detailed account on the implementation and simulation of incoherent effects due to electron cloud, using the tracking module SixTrackLib. Experimental observations in the LHC suggest indeed that slow losses during collision follow a typical e-cloud pattern, which could be explained by non-linear, single-particle e-cloud effects.

Tracking with SixTrackLib can be achieved by computing e-cloud kicks from the gradient of the scalar potential, which itself is obtained through PyECLOUD simulations. An optimized procedure is defined that fully mitigates issues such as macroparticle noise and lack of either accuracy or symplecticity of the scalar potential interpolation; in the end a tricubic interpolation is performed on a refined grid but keeping the information only on a coarser grid, and 2000 simulations are averaged to suppress noise. Within SixTrackLib, full advantage is taken from the GPU tracking, through optimizations of the storage of the e-cloud potential map, and of the matrix multiplications involved.

The full simulation set-up includes 46 e-cloud interactions per arc (in dipoles), and primary collimators to limit the particle oscillations in a realistic, physical region, while also decreasing the memory usage of the e-cloud data. Two tests of the complete procedure were performed: in the first, an RF sextupole is introduced as an external map and compared (in terms of DA) with direct results from SixTrackLib; in the second, the footprint obtained from PyHEADTAIL and SixTrackLib are compared. Both tests were conclusive and confirmed the accuracy of the whole simulation set-up.

Finally, three kinds of simulation were performed (all with 40 A in the octupoles): without e-cloud, with dipoles e-cloud (SEY=1.35) and an intensity of 0.7e11 protons per bunch, and the same with 1.2e11 protons per bunch. The higher intensity case is known to deplete the beam center from electrons (the stripes move away), while at lower intensity a central stripe appears. As a result, the footprint with 1.2e11 protons per bunch is only shifted with respect to the one without e-cloud, while for an intensity of 0.7e11 a strong non-linear detuning appears and resonances are crossed. Similarly, in terms of DA the e-cloud has a visible detrimental effect mainly at low intensity; this is stronger for off-momentum particles. Long-term tracking also gives very significant losses with 0.7e11 intensity (which may be unrealistic given the quite pessimistic SEY assumed), while the no e-cloud and high intensity cases give very similar (and small) losses.

Future studies will include the e-cloud in the arc quadrupoles, and probe various parameters (e.g. SEY, tunes, chromaticity, or intensity). Comparisons with experimental data are also foreseen.

- **Rogelio** insisted on the importance of the comparison with experimental data.

- **Xavier** asked whether the e-cloud is put only where the beams are round in the lattice. **Konstantinos** answered in the affirmative. **Xavier** then wondered if one can expect any difference if the e-cloud are closer to the quadrupoles. **Konstantinos** answered that indeed in the future they want to test this effect by increasing the number of e-cloud interactions per cell.

- **Xavier** asked how much the tune shift is when there is no stripe in the center. He also wondered if an asymmetry in the stripes could generate the footprint shape (see slide 31). **Konstantinos** answered that stripes far away from the center will not create a dipolar field but a linear field, so practically their only effect is a tune shift. **Yannis** asked if the footprints were obtained in 4D (i.e. with $\delta p/p=0$). **Konstantinos** answered in the affirmative. **Yannis** commented that indeed no synchro-betatron resonance is visible.

- **Rogelio** wondered about the 7% difference in beam size, seemingly due to the linear RF in MAD-X (see slide 21). He argued that in MAD-X one would input bunch length and energy spread, and one should get the same value when putting the same distributions in MAD-X and PyHEADTAIL. He therefore asked what bunch length was put there. **Konstantinos** answered that he put the RMS bunch length used to configure the beam-beam lenses. **Gianni** clarified that only the bunch length had been provided to MADX, if the rms $\delta p/p$ is provided to MAD-X the same results would be obtained indeed.

5 ROUND TABLE (ROGELIO TOMÁS)

The next WP2 meeting will take place on December 8th and will be devoted to field quality and MCBXF (it replaces the special WP2/WP5 joint meeting on impedance of collimators which was initially announced but finally postponed to later date). The agenda will be the following:

- Impact of MCBXF strength limitations on orbit control and possible mitigations (Riccardo De Maria),
- MCBXF field quality impact on DA (Frederik Van Der Veken),
- Update on IR magnets field quality: nested correctors and spread of TF in quadrupoles (Ezio Todesco).

Reported by N. Mounet