184th WP2 Meeting

Tue 10th Nov. 2020, 10:00 – 12:00

Chair:	Gianluigi Arduini, Rogelio Tomás
Speakers:	Riccardo De Maria, Lorenzo Giacomel
Participants (zoom):	Hannes Bartosik, Roderik Bruce, Xavier Buffat, Rama Calaga, Ilias Efthymiopoulos, Hector Garcia Morales, Massimo Giovannozzi, Gianni Iadarola, Sofia Kostoglou, Elias Métral, Nicolas Mounet, Yannis Papaphilippou, Konstantinos Paraschou, Marta Sabaté-Gilarte, Benoît Salvant, Francisco Sanchez-Galan, Pablo Santos Diaz, Guido Sterbini.

AGENDA

MEETING ACTIONS

Gianni, Lorenzo	Evaluate the heat-load from e-cloud in the crab cavities.
Rama	Crab cavity phase error from beam loading after set up at low intensity.

GENERAL INFORMATION (GIANLUIGI ARDUINI, ROGELIO TOMÁS)

Rogelio reviewed the minutes of the 183th WP2 meeting. There were two talks, by **Ezio Todesco** and **Marta Sabaté-Gilarte**. Good news was reported by **Ezio** on the field quality. For the MQXF, the b6 - which was out of tolerance in the past - could be reduced as expected. There is a slight change of b3, which **Ezio** thought to be coincidental, but has to be monitored in the future. New measurements were performed after the meeting, on the transfer function of quadrupoles of identical cross-section, giving 19 units of difference - a rather good news (updated slides are already on the 183th WP2 meeting indico page). Regarding the MBXF optimization, it also depends on the energy which is still to be decided - further discussions will take place. There will be an update early next year.

The presentation of **Marta**, about a possible rigid shift of the triplets, showed the possibility of improving the magnet life-time by 15 to 20%. A lengthy discussion followed on the risk, as the magnet strength is limited, in particular for the MCBXFs which need to be better understood; there is also the mitigation action to add extra stress on the collar. In general, the consensus is to avoid adding extra constraints on the MCBXF magnets. Also, the alignment of the bellows has to be discussed in the alignment working group.

Gianluigi then announced that he is leaving the ABP group at the end of the year, as he will become the deputy of the new BE department head. Hence, he has decided to step down as WP2 package leader. **Rogelio** has agreed to become the next WP2 leader. **Gianluigi** warmly thanked and congratulated all the team for the work done in a very collaborative spirit. The next meetings will be chaired by **Rogelio**, **Gianluigi** being also present when possible. **Rogelio** then announced that **Elias** accepted to become the new deputy WP2 leader.

The schedule of the meeting then followed as foreseen.

1 MAXIMUM CRAB CAVITY BUMP NON-CLOSURE DURING THE CYCLE FROM APERTURE CONSIDERATIONS (RICCARDO DE MARIA)

This talk aims at showing the impact on the aperture of a possible non-closed crabbing bump. When the crab bump is closed normally, the crab dispersion is significant only close to IP1 and 5, and remains negligible everywhere else. On the other hand, if the crab bump is not closed (due to one crab cavity being at a lower voltage than expected), the crabbing leaks in the machine as an orbit distortion, proportionally to the missing voltage, and the crabbing angle at the IPs is reduced. The beam size is then modified at the IPs (and elsewhere) as a function of the non-closure (note that slide 5 was updated after the meeting as there was a typo in the formula and table - one has to replace C_{IP} by C_{NC}, which means that 10% of missing voltage actually ends up as C_{NC}=0.14 which in turn gives a beam size change of 1%).

Assuming one does not change the collimator settings, i.e. that the crab dispersion at collimators remains a small perturbation, the impact on beam size could, in principle, consume part of the available margin on the protected aperture, and hence reduce the β* reach. With round optics, up to 50% of voltage reduction can be accepted in a cavity before reaching the margin (still, at the expense of an unaffordable loss in luminosity). On the other hand, with flat optics (or any optics already at the limit for aperture), the voltage reduction would have visible effect already when reaching 20% of missing voltage (leading to around 5% reduction in β* reach).

- **Roderik** asked if the information on the crab dispersion at collimators is available (see slide 5), as it would be the first step to understand the size variation at the collimators, hence possible hierarchy violation (for instance). **Riccardo** answered this information lies in the right-bottom plot of slide 3 - it essentially follows the phase advance. From the formula in slide 5 it is then easy to get the beam size from the crabbing.

- **Roderik** asked what value should be plugged in the table of slide 5, i.e. what is realistic for operation. **Riccardo** answered that even 10% is a pessimistic value (giving C_{NC}=0.14), and the effect on beam size is then still negligible (1%). An extreme case would be to operate with only one cavity (this would be a failure scenario), but the impact is still only 30% in terms of beam size (on the other hand, the impact on luminosity would be dramatic). **Roderik** said that one should make a distinction between failure scenarios and operational ones - most probably one does not want to operate in such an extreme, failure case when one cavity is totally off. **Gianluigi** mentioned that here the idea is to identify what happens with a non-closure, but definitely not to operate with only one cavity.

- **Roderik** asked if the tables in slide 6 include the crabbing dispersion. **Riccardo** answered in the negative: these numbers show the margins without crab dispersion, in order to be compared directly with the effect on beam size for each non-closure scenario, i.e. with the bottom row of the table in slide 5.

- **Rogelio** commented that one has to look carefully at the numbers. **Riccardo** mentioned in particular the extreme conditions, which have to be checked carefully (crab kissing or anti-kissing). **Rogelio** also mentioned the effect on dynamic aperture (which will be checked by **Yannis** et al).

- **Roderik** concluded that if we can expect no more than 10% of missing voltage in operation, then the effect on beam size is negligible. **Rogelio** said that 10% is a reasonable number but there is no official number. **Rama** mentioned that 10% is rather pessimistic in terms of direct measurements of RF voltage (error from cables, transfer function, etc.). In principle, with the beam, the value should be much smaller - 10% represents only the uncertainty on the measurement for a single cavity. **Gianluigi** mentioned the study by **Androula Alekou** which showed that we might not be able to disentangle voltage differences of less than 10% from beam based measurements (see 162th WP2 meeting). **Rama** answered that here we are talking about the leakage. There is indeed a 10% error in the measurement of the RF cavity voltage, but from the beam we will get less than that. **Rogelio** argued that still, from previous discussions considering beam loading, it is still not answered if it may be 10% or above. **Rama** answered that one can operate a cavity in deflecting mode and measure the closed orbit. Still, he agrees that 10% is good as an upper limit.

- **Rama** mentioned the study by **Yi-Peng Sun** et al (Phys. Rev. ST-AB, 2009), which was illustrating the possible hierarchy violations with leakage (this was also discussed with **Stefano Redaelli**, in particular for the tertiary collimators). He added that one should perform a rematching including the effect of crab dispersion, instead of a perturbation of the optics as shown here in the presentation. **Roderik** argued that 2% on the beam size is anyway small. **Rama** asked if the effect could be higher in IRs. **Riccardo** answered that the triplets are close to the peak - it cannot be larger in the rest of the machine (including in the crab cavities). **Rama** asked if it is the case also for off-momentum particles. **Riccardo** answered in the positive: it follows the dispersion, which is small. **Rama** asked if it is possible to rematch including the crab dispersion. **Riccardo** answered it is unnecessary and probably not possible. He mentioned that one can match the phase advance, such that the peak is placed at a given location, but the invariant will remain constant, as it depends only on β^*, on the voltage and on the small phase advance between the two sides.

- **Gianluigi** asked if a phase error had been considered. **Riccardo** answered that it would be like an orbit error and could be compensated by orbit correctors nearby, in the case of a static phase error. **Rogelio** asked then what a relevant number would be for the static phase error. **Rama** said that it depends on the measurement of the closed orbit, and its resolution. In the SPS, one can rephase the two cavities (by performing a manual phase scan). In the LHC one would not do it manually, but one can do a fit and refine more precisely. If one were to scan the phase from 0 to π, one would see a pure sine wave. **Rogelio** argued that from a small phase offset it is not so easy to see where the zero is. **Rama** answered that the static phase could be set up based on low intensity measurements, then re-adjustments for some intensity-dependent phase offset (such as the orbit shift along the train) can be performed from orbit measurements. WP4 should provide estimates of phase errors due to beam loading after setting-up at low intensities (Action: **Rama**).
- **Riccardo** mentioned that the RF cavity will not work in full detuning mode, hence there will be a bunch-by-bunch jitter around the crab cavity center (or, in other words, a dynamic phase error). **Rama** and **Rogelio** said this represents only a small offset, identical for both beams, hence it is not very significant.

2 ECLOUD BUILD-UP SIMULATIONS IN THE CRAB CAVITIES (LORENZO GIACOMEL)

This presentation provides a detailed account on the recent studies and simulations of the electron cloud build-up within HL-LHC crab cavities. In such cavities, standard 2D quasi-static Particle-in-Cell (PIC) codes such as PyECLOUD, are not able to model all the physics of the build-up, because of the possible longitudinal motion of the electrons within the cavity, and because of the need for an electromagnetic (EM) solver to compute the electrons rapid motion due to the cavity fields, as well as the fields themselves. Hence, a 3D electromagnetic PIC solver is needed, and a collaboration was started to interface PyECLOUD with the 3D PIC code “Warp” developed at LBNL.

The combination of the two codes (“Warp-PyECLOUD”) now allows simulations of full 3D geometries with externally applied fields. It was benchmarked in the case of a 1 m-long dipole where the 2D quasi-static approach is sufficient, showing a perfect agreement with PyECLOUD. Also, non-self-consistent simulations of the RF fields were able to simulate properly the crabbing of a proton bunch.

Self-consistent simulations were then performed for various cavity voltages, with a simplified cavity geometry, and in two different ways: either with the full 3D solver from Warp for all EM fields (RF fields, beam-induced fields and e-cloud self-fields), or with precomputed RF fields as well as 3D, quasi-static e-cloud self-fields. Both ways provide very similar results, which gives good perspectives for the computations of realistic, curved geometries that cannot be handled properly by Warp, but for which the electrons' self-fields can be instead computed using the electrostatic solver while the RF fields would be provided externally.

Results of the self-consistent simulations are shown for the simplified geometry studied. Beam-induced multipacting is observed at low voltages (up to a few hundred volts), while for medium voltages the RF fields suppress the multipacting. Conversely, at high voltages (up to the nominal value of 3.4 MV) a much stronger RF-induced multipacting arises. Carving the corners of the cavity seems to prevent multipacting in the case of the nominal voltage, but not for slightly lower values.

Work is ongoing on a more realistic geometry for the double quarter wave (DQW) cavity, using RF fields computed with the CST code.

- **Rogelio** and **Gianluigi** congratulated **Lorenzo** and the team for the work performed, and in general for the outcome of the collaboration with LBNL.

- **Benoît** asked about the possible impact of the couplers, and if it is possible to include them in the simulation. **Lorenzo** answered it is difficult to say at this stage, because the shape of the fields is complex; one could try to simulate them indeed.

- **Xavier** asked if the build-up obtained when the crab cavity is off, is prohibitive. **Lorenzo** answered it does not seem so, but one has to check if the build-up saturates with more bunches, (e.g. a train of 72 bunches), as now only a few bunches were included. **Rogelio** commented that there is also the SPS test to look at. **Lorenzo** added that we do not see multipacting with a voltage of a few kV. **Rogelio** said it was 1 MV in the SPS. **Lorenzo** argued that there could be something to check indeed. Another important point is that the secondary emission yield (SEY) parameter (δ_{max}) is quite high here, but in reality, it could be less (between 1.1 and 1.2), which would clearly decrease multipacting. **Rogelio** asked if there are measurements of the SEY. **Lorenzo** answered there are measurements for Niobium, but it might change a lot after running with beam. In the paper, they took as worst case 1.4, and as best case 1.2 - **Lorenzo** confirmed that for δ_{max}=1.2 there is indeed much less concern.

- **Gianluigi** mentioned that it would be good to estimate the heat load for a train (at 2 K), to know if it is sustainable or if we rather need some conditioning at normal temperature. **Lorenzo** and **Gianni** answered that it is planned, as part of the heat-load budget. They will contact **Rama** for feedback (Action: **Gianni, Lorenzo**).

- **Benoît** asked if Warp could be a good candidate to compute beam-coupling impedances, as well. **Lorenzo** answered that it may be indeed, but some improvements have to be done on the EM solver (in particular for curved boundaries, which currently give wrong results). **Gianni** mentioned that there is also work to do on the materials, as everything is modeled as a perfect conductor in Warp, which is too restrictive.

3 AOB: Update on TAXN aperture (Riccardo De Maria)

This presentation evaluates the aperture in the TAXN (and surrounding devices) for various scenarios. The aperture (in beam σ) is estimated for the present baseline design, with an inner diameter (ID) of 85 mm, and for the new design with ID=88 mm (see 86th and 89th WP8 meetings), with various possible tolerances (3 mm for the baseline, updated to 6.7 mm - value on 30/9/2020, or 4.9 mm - latest update since 9/11/2020). The estimates are also done for different optics scenarios: round with β*=15 cm, and flat with β*=7.5/30 cm (with or without crab cavities). The final aperture is obtained from the bare value after successively considering the mechanical / alignment / beam tolerances, and finally offsetting the IP by 2 mm with the full remote alignment system (FRAS). Three criteria are used to evaluate the aperture: from the most to the least significant these are 1) keeping the β* reach; 2) keeping a 1-2 σ margin with respect to the triplets; and 3) the margins should be similar with respect to neighbouring elements.

Overall, the situation looks good with an ID of 88 mm and the new tolerances, as one improves or gets an equivalent situation as the previous baseline (85 mm with the old tolerance of 3 mm). Even for an ID of 85 mm, the increase of the tolerances reduces the margin with respect to the triplets but still at an acceptable level. In all cases, the flat optics gives tighter margins than the round ones, and the TAXN remains the aperture bottleneck in the D2 region. Energy deposition studies are still needed to fully validate the 88 mm option.

Note that the last conclusion slide provides the table with the most up-to-date tolerance of 4.9 mm.

- **Rogelio** asked where the topic will be discussed next. **Riccardo** answered that it will be in the alignment working group for the tolerances, while energy deposition results will come on Friday Nov. 13th at the WP5 meeting (https://indico.cern.ch/event/971121/).

- **Gianluigi** asked if the new tolerances are confirmed. **Riccardo** answered they will be formalized in a discussion taking place the next day (11/11/2020), but the situation is already clear.

- **Ilias** commented that with 88 mm there is less acceptance for the Zero Degree Calorimeters (ZDC), as well as (possibly) for the LHCf detectors, than with 85 mm. **Francesco** answered that all the work was performed assuming ID=88 mm, i.e. with the modified acceptance, for the experiments.

4 Round table (Rogelio)

The next WP2 meeting will be devoted to electron cloud and will take place on November 24th, with the following agenda:

- Coupled bunch stability and tune shifts (Lotta Mether),
- Update on simulations with large gas densities: effect of solenoid (Lotta Mether),
- Incoherent effects from e-cloud with sixtracklib (Konstantinos Paraschou).

Reported by N. Mounet