Special WP2/WP5 Meeting

Tue 23rd Feb. 2021, 9:00 – 12:00

Chair:	Rogelio Tomás, Stefano Redaelli, Elias Métral
Speakers:	Benoît Salvant, Carlo Zannini, Nicolas Mounet, Adnan Kurtulus, Carlotta Accettura
Participants (zoom):	Nicolo Biancacci, Roderik Bruce, Xavier Buffat, Rama Calaga, Federico Carra, Ilias Efthymiopoulos, Paolo Fessia, Alex Fomin, Massimo Giovannozzi, Anton Lechner, Michele Martino, Daniele Mirarchi, Joao Oliveira, Yannis Papaphilippou, Konstantinos Paraschou, Stefano Redaelli, Elena Shaposhnikova, Galina Skripka, Guido Sterbini, Natalia Triantafyllou, Frederik Van der Veken

AGENDA

MEETING ACTIONS

Frederik	Show the impact on DA of a full distribution of b3 imbalance between the two D2 apertures.
Stefano, Benoît	Check with BI for the status of the design of the BGC.

Nicolas	Revisit the wake model of the electron beam in the HEL.
Nicolas	Check the impact of the electron beam impedance on stability, in multibunch configurations.
Nicolas, ABP/CEI	Start a multispecies, macroparticle tracking simulation effort, to model the coherent effects due to the electron beam in the HEL.

GENERAL INFORMATION (ROGELIO TOMÁS)

Rogelio reviewed the minutes of the 187th WP2 meeting, on February 9th. No comments were received.

The first presentation, by **Natalia**, shed some light on the SPS measurements of the emittance growth due to the crab cavity. One action is to update the crab cavity noise and emittance growth estimates for HL-LHC, as it is likely to be larger than anticipated in the CDR - this should be covered within the next couple of months by **Philippe**.

Then, the second presentation by **Frederik** provided new DA results from the b3 and b5 multipolar errors of the D2. A small imbalance of b3 between the two apertures appears to be an important criterion now (with an action to **Ezio Todesco** to pass the message to the production); **Frederik** also has an action to check the effect of a possible extreme asymmetry in b3. In the meanwhile, **Ezio** sent a document updating the acceptance criteria, with the b3 acceptance left unchanged, while b5 is increased to 4 units. A sentence was also added in the paragraph on Procedure 7: "The shimming shall aim at minimizing the difference in b3 between the two apertures". **Rogelio** asked **Frederik** if this sentence is fine, knowing the acceptance of b3 (-6.7 /+6.7 units). **Frederik** answered that he has observed differences of 10 units (yet not systematic), and the correction still works. **Rogelio** concluded that the document is ok. **Frederik** commented that it is too soon to worry about the imbalance; one should investigate only if a very strong asymmetry appears. **Rogelio** confirmed, and proposed to come back with a quick update at a later meeting, to show the impact on DA of a full distribution of imbalances (Action: **Frederik**). He added that in the meanwhile we will accept the statement in **Ezio**'s document. He concluded that the first prototype will tell us what the situation is.

Finally, a first two-dimensional model of field quality in the MCBXF was shown by **Ezio**. An action is on **Frederik** to send **Ezio** the foreseen operational region with Full Remote Alignment System (FRAS), in order to optimize the operational phase space.

After the review of the minutes, the schedule of the meeting followed as foreseen.

1 IMPEDANCE OF HOLLOW E-LENS DEVICE (BENOÎT SALVANT, CARLO ZANNINI)

The presentation reviews the status of the impedance of the hollow electron lens device, excluding that of the electron beam itself (which will be dealt with in the next talk). A new design was provided in August 2020, from which a number of comments were made: bellow and pump should be shielded, the BPM is non-standard (hence studied), the Y chamber volume could be reduced, and copper coatings should in principle be imposed on the plain tubes. As an important note, there is also a new request to have two additional bellows around the beam gas curtain (BGC), which has to be studied; the design of the latter is ongoing and not available yet.

For the Y-chamber, the longitudinal and transverse impedances were studied, showing very moderate contributions with the current model, compared to the total impedance budget. If needed, the longitudinal impedance could be reduced by adding a shielding blade, but it is not clear if it is feasible with such a complex geometry. Moreover this would also have detrimental effects on the first vertical mode at 1.85 GHz (which would increase from 4 to 30 kΩ/m).

Regarding the beam position monitors (BPMs), longitudinal and transverse impedances were simulated with both the wakefield and the eigenmode solvers - a good agreement between the two methods was obtained. A broad-band level of 3 kΩ/m was found in transverse, and significant high order modes (HOMs) at a frequency above 350 MHz, in longitudinal and transverse. The transverse HOMs are found to be one order of magnitude below a threshold value that would lead to an increase in octupole current of 10 A, hence are expected to have a negligible impact on stability.

Nevertheless, the results are not definitive, as the design is not finalized yet. In particular, the BGC and the BPM terminations are not integrated in the CATIA model.

- **Elena** confirmed that the HOM of the Y-chamber at high frequency is well below the threshold (in the longitudinal plane).

- About the feasibility of adding a shielding blade in the Y-chamber, **Elias** asked about the actual constraints or issues that EN/MME raised. **Benoît** answered this depends on the process. EN/MME has several ideas to treat this, one of them being 3D printing. The point is that one needs a good reason to impose such a difficult modification.

- **Rogelio** asked further details about the request of two additional bellows around the BGC. **Benoît** mentioned that the current design, analysed here, contains only two bellows at the ends, while this new request concerns the center (see circled part in slide 8). There is very little space at this location, hence the shielding is not trivial (as well as the design of the bellow). **Rogelio** concluded that this means the impedance team will get a new design. **Benoît** answered in the positive, and added that the results might not be as nice as they are now. **Stefano** asked when this new design will come. He also wondered about the need for an independent alignment of the BGC. **Benoît** said he does not know. **Stefano** concluded that one has to ask BI (after the meeting, **Stefano**

checked with **Diego Perini** that an independent alignment of the BGC cannot be avoided, both for alignment purposes and for concerns related to vacuum). He also pointed out that the gap should not be too large, because the solenoid field would go down. He wondered if there is a constraint on the shortness of the gap from the impedance point of view. **Benoît** replied that it depends how it is done, in particular if the aperture has to be reduced. **Stefano** asked whether we are ok from the impedance point of view, if we put aside the issue with the two BGC bellows. **Benoît** answered in the negative: one cannot conclude until a design is available for the BGC. **Stefano** & **Rogelio** concluded that we have to wait for the design to be finalized, which should be followed up with the BI team (Action: **Stefano, Benoît**).

2 A PRELIMINARY STUDY OF THE ELECTRON BEAM IMPEDANCE (NICOLAS MOUNET)

The presentation reviews the situation regarding potential coherent effects triggered by the electron beam of the hollow electron lens (HEL). One known impact includes the depletion of the transverse distribution tails, which reduces Landau damping; this is already taken into account in all stability predictions since tails are cut at 3.2 σ. While the impedance of the device was studied (see previous talk), the one of the electron beam itself requires special attention, as it could trigger TMCI-like instabilities, according to previous studies done for the Tevatron electron lens.

Previous work on such instabilities was reviewed, and showed that in the case of HL-LHC they can be strongly mitigated with the solenoid field, since B=0.1 T should be enough to avoid TMCI due to the electron beam alone; this was confirmed by PyHEADTAIL simulations. Hence the nominal B field of 5 T should provide enough margin for this kind of instability. Nevertheless, the simple wake model used there shows that coupled terms in the electron beam wake function are larger than those of the full HL-LHC model, hence a possible concern remains. Still, single-bunch instabilities in a standard operational configuration (Q'=15, damper 100 turns) seem not to be affected by such coupled wake, even when reducing the solenoid field to 1 T or the x-y tune separation to 5e-3.

Several shortcomings of the model still need to be addressed, in particular 1) the respective size and transverse shape of the protons and electron beams have to be modelled better (Action: **Nicolas**), and 2) potential multibunch effects have to be looked at (Action: **Nicolas**).

- **Elias** mentioned that the tails of the transverse distribution were cut not only for HL-LHC but also earlier, in particular at the design stage of the LHC itself.
- **Stefano** asked if the electron beam is considered here as a static distribution, and if the electrons are refreshed. **Nicolas** answered in the affirmative to both questions; in particular, the wake is cut after ~52 ns (hence no multiturn effects are considered).
- **Rogelio** asked about the impact of skew quadrupoles and coupling, in relation with the coupled impedance terms. **Nicolas** answered he was not sure, but said that at first sight coupling and effects from coupled impedance terms are not necessarily related.

- **Stefano** wondered if the effect will not be much smaller if the proper hollow shape of the electron beam is taken into account, as the hollow shape is especially designed to avoid spurious effects on the beam. **Xavier** mentioned that indeed there must be a quite significant form factor, especially for Gaussian beams. **Nicolas** said this is indeed one of the next steps.
- **Benoît** wondered whether the solenoid field is zero within the gap that is in the middle of the HEL (see previous talk). **Stefano** answered that the field there is definitely not zero, and even higher than 1 T, at least. **Benoît** then wondered if the resonance condition needed to make instability happen, would be still here when considering a B field that changes over the length of the device. **Nicolas** answered this has to be checked. **Stefano** mentioned that the B field will not change much except in the gap.
- **Rogelio** wondered what would happen if the beam was not round. **Nicolas** answered this should not matter much for impedance, except in the case of quadrupole oscillations, which are not considered at all in the LHC and HL-LHC.
- **Rogelio** asked what the next steps would be. **Nicolas** answered that a better model for the wake is needed. **Rogelio** argued that a more general tracking effort, including both electrons and protons in a single simulation, should be started (Action: **Nicolas**, **ABP/CEI**). **Xavier** confirmed that this would be the only way to address quadrupole oscillations.
- **Elias** mentioned that the future ICFA Beam Dynamics Newsletter (Spring 2021) will be devoted to electron lenses (with **Vladimir Shiltsev** as editor). All the past studies and experience in the different labs should be reviewed there and it should therefore be an important reference for our future studies. **Stefano** recalled that there are three contributions planned from the HL-LHC HEL team to this newsletter: a general paper on the design (**Stefano**), a paper on the electron beam dynamics (**Adriana Rossi**) and a paper on the gun design (**Diego Perini**).
- **Ilias** wondered how much the effect is an e-cloud kind of effect. **Nicolas** said the electrons are not as close as in typical e-clouds (they are not pinched).
- **Xavier** asked if the HEL would be used only during collisions, as one of its main motivations is to avoid damage to collimators in the event of a fast failure of the crab cavities, which could in principle induce a loss of the full transverse halo over a few turns. If the HEL was indeed used only during collisions, stability is in principle much less an issue, as beam-beam head-on tunespread generates a very strong Landau damping. **Stefano** answered that there are other usages of the e-lens: the halo depletion is of importance to suppress possible loss spikes in other parts of the cycle (during the ramp, e.g. in case of flux jumps, or during the squeeze if the orbit drifts significantly). At this stage it is hard to say when the HEL usage will be most critical. **Roderik** added that in the cases mentioned by **Stefano**, the goal is rather to save the beam, contrary to the crab cavity failure case where one wants instead to dump the beam. **Rogelio** wondered if it is baseline to operate the HEL and monitor the halo at low energies. **Stefano** answered that indeed in the original specification the idea was to switch on the HEL several minutes in the ramp, to make sure the halo is depleted at flat top. But recently the flux jumps issue arose, which might result in a change of the specification, hence one might start using the HEL at 800-900 GeV.
- **Rogelio** concluded that we need to study the coherent effects arising from the electron beam, in particular with a better wake model, in multibunch, and using a more extensive multispecies tracking effort.

- **Rogelio** also wondered about another possible failure mode, evoked in the 161st WP2 meeting, where the protons would hit the electrons during a fast instability and provoke some scattering. **Stefano** answered that the maximum kick per turn from the electrons is around one third of a µrad, hence very small. There would only be diffusive losses caught in IR7 in the standard way. He nevertheless still wondered if the instability growth rate could be increased by this effect. **Xavier** mentioned that actually the model presented here applies to this situation. **Rogelio** wondered what would happen for an oscillating bunch. **Stefano** wondered how long a bunch can oscillate at ±3 σ.

3 COMPARISON OF DC AND RF ELECTRICAL RESISTIVITY MEASUREMENT FOR ION IRRADIATED SAMPLES AT GSI (ADNAN KURTULUS, CARLOTTA ACCETTURA)

This presentation reviews the electrical resistivity measurements of collimator materials after irradiation by calcium ions of energy 4.8 MeV/u, in March 2019 at UNILAC-GSI Darmstadt (ARIES collaboration - 113h of beam time). The aim was to investigate the degradation of these materials, using the displacement per atom (DPA) as a measure of the damage level, especially when comparing different experiments. The ultimate goal was to reach the DPA expected in the Mo coating at the end of HL-LHC and get the corresponding impact on resistivity, using two different measurement methods: DC and RF.

The DPA over the HL-LHC lifetime is expected to be between 10^{-3} and 3.10^{-3} for the Mo coating, 4.10^{-4} for the MoGr secondary collimators and 0.3 for the primary collimators - albeit in a narrow region for the latter. In the experiment at GSI, materials could be irradiated at different fluences, which can be associated to different DPA levels in the LHC. The highest achieved fluence ($4{\cdot}10^{14}$ ions/cm^2) corresponds to 1.1e-3 peak DPA in the coating, and 4.4e-2 in the bulk.

For DC measurements of resistivity, the four-probes method was used on a sample whose thickness had been minimized, and the results were interpreted with a parallel resistance model. The resistivity obtained represents therefore an average over the whole irradiated layer. Conversely, the RF method relies on the H011 cavity with a high frequency resonator (24.8 GHz), hence probing the resistivity of the layer only very close to its surface (on a depth of the order of 1 µm).

For graphite, CFC and molybdenum-graphite (MoGr), the resistivity increases with the fluence for both measurement methods. Nevertheless, the two methods are not directly comparable as the DPA levels are very different on the surface and deep inside the material - the maximum DPA being reached between 40 and 60 µm, depending on the material. Comparing the two methods at iso average DPA in the layer considered in each measurement method, is only partly satisfactory because defects may cluster around the location of the peak DPA, which has an impact on the DC measurements, hence the two kinds of measurements seem to agree only when plotting the resistivity vs. peak DPA. In the end, both the peak and the average DPA have to be considered, within the layer concerned by each measurement method, and the two methods are complementary as they cover different DPA ranges (peak DPA up to 3e-4 for RF

and up to 0.03 for DC), which effectively covers both the LHC and HL-LHC expected levels. Up to a factor two increase in resistivity is observed for MoGr (Nb8304Ng) and CFC (FS140) for DPA levels reached in secondary collimators at the end of the HL-LHC lifetime. For the Mo coating, no clear trend with DPA has been observed with DC & RF measurements - in any case the resistivity is never increased by more than a factor of two after irradiation.

Future plans include DC measurements on the CFC collimator taken out after Run II (2021), an ion irradiation campaign in March 2021 (postponed from 2020 because of the pandemic), and a proton irradiation one at BNL-BLIP. Both the ion and proton campaigns will investigate the same materials in order to allow a comparison between them. The ion campaign will study two samples per material and fluence, a new grade of MoGr (Nb8404Ng) and the effect of the DPA rate (damage evolution). Regarding the proton campaign, samples with Mo coating performed by Direct Current Magnetron Sputtering (DCMS) were irradiated in 2018 and the analysis is planned in spring 2021 at CERN; for samples done with High-Power Impulse Magnetron Sputtering (HIPIMS), which typically exhibit a lower resistivity, irradiation is still pending.

- **Xavier** asked if, for the coated samples (see slide 31), the resistivity increase could be caused by something else than irradiation. **Carlotta** answered that the DC measurements were performed before and after irradiation, hence there is a precise reference. The samples were also not damaged, and the coating was still in good condition. Hence in her opinion the increase is due to irradiation, but because of the lack of statistics, there is no visible trend. **Adnan** confirmed the increase is the effect of irradiation. He also mentioned the absence of reference values for Mo coating done by DCMS on MoGr. **Carlotta** added that the irradiation increased the temperature to 100 °C, which is too low for defect mobility in graphite, but it may not be the case in metals (hence some annealing effects). **Rogelio** commented that the error bars are large, hence there is clearly no trend here. **Xavier** replied that the resistivity is still above the reference. **Rogelio** wondered what the uncertainty on the reference measurement is (grey line in the plot of slide 31). **Benoît** spotted a mismatch between slides 18 and 31, as the reference resistivity was inside the error bars of the RF measurements in slide 18 but not in slide 31. After the meeting, **Carlotta** updated the slides, as indeed the plot in slide 18 was erroneous (while the one comparing DC & RF measurements in slide 31 was correct). **Carlotta** mentioned that the error bar takes into account variation of the Q value.
- **Rogelio** wondered about the impact of such resistivity increase on the stability threshold. **Nicolas** answered that it was checked last year - it is within a few percent (see 176th WP2 meeting). **Carlota** underlined that the specification is at 110 nΩ.m (twice the pristine theoretical value). **Stefano** confirmed, and mentioned also that not all collimators will get the full DPA. He concluded that the effect should be minor, considering also that the maximum will be reached towards the end of life of the HL-LHC. In the worst case, one could also shift slightly the jaw to get an undamaged surface close to the beam, if needed.
- **Nicolas** wondered whether one can hope to obtain the large DPA of the primary collimators (0.3) in the irradiation campaign. **Carlotta** answered in the negative. She also insisted that in HL collimators, a DPA of 0.3 is reached only in a very narrow region (not a full layer), around 100 µm large - outside of it the DPA decreases very fast. Hence one probably doesn't need this

measurement. **Anton** said the peak is even on a few µm only - with orbit fluctuations it is smeared out, hence a lower value.

- **Rogelio** asked what the approach would be for the primary. He wondered if we should try to keep a DPA at the 10^{-3} level. **Stefano** answered we have to identify the collimators where we might see something, and for instance measure tuneshifts on slices of the jaws. He said one should not try to move the collimator jaw to solve any possible problem, before starting to observe any detrimental effect. **Rogelio** then asked if the plan is to monitor this with tune shift measurements. **Stefano** answered in the affirmative. **Anton** said that one rescales the DPA with the real total losses - this exercise is done every year. Hence one cannot yet predict the DPA level. **Carlotta** also mentioned the bake out for the collimators, which anneals the possible damage. **Stefano** said that this is not done every year, unless there is a particular issue. It is typically done only if the machine is opened. **Federico** confirmed, saying this happens only during shutdowns, in general. **Nicolas** mentioned that if the DPA of the primaries is really located in a narrow region, the tuneshift measurements won't show anything. **Rogelio** commented that this would then be fine. **Nicolas** confirmed that it would be fine from the impedance point of view, but also means that one cannot use tuneshift measurements to monitor the state of the jaw, in particular regarding any other possible issue related to irradiation. **Stefano** mentioned there is indeed also embrittlement. He said they are planning to look at the collimators taken out from Run 2. **Benoît** said that one cannot open the collimator, and the region one wants to measure is really inside.
- **Stefano** concluded that what we see with these irradiation measurements is larger than what we will see in the full HL-LHC lifetime, and that they will monitor the situation closely.

4 ROUND TABLE (ROGELIO TOMÁS)

The next WP2 meeting will take place on March 9th, by zoom. The agenda is the following:

- TCDQ movement during the cycle (Chiara Bracco),
- WP2 Structure (Rogelio Tomas Garcia),
- Update on effect of beam screen on field quality (Susana Izquierdo Bermudez),
- AOB - Impact on DA of various distributions of b3 imbalance between the two D2 apertures (Frederik Van Der Veken).

Reported by N. Mounet