WP2 Meeting #165

Tue 10 Dec 2019, 09:00 – 12:00

Chair:	G. Arduini
Speakers:	L. Mether, K. Paraschou, L. Sabato
Participants:	S. Antipov, X. Buffat, R. De Maria, G. Iadarola, E. Métral, N. Mounet, F. Plassard, R. Tomás, G. Skripka, F. Van der Veken

AGENDA

MEETING ACTIONS

Sergey	Clarify the minutes on the last meeting with respect to Riccardo's MD proposals
Gianni, Yannis	See how the study of the change of distribution resulting from beam-beam effects can be pursued.
Gianni	Report on the use cases of *cpymad* at the computing WG
Lotta	Research the state-of-the art status and experience in simulating dense plasmas to see if the encountered problem of numerical noise can be overcome
Lotta	Study the effect of a solenoidal field on 16L2
Luca	Extend the stability study to bunch intensities below 2.3×10^{11} p, (e.g. for 1.7×10^{11} p) which are important for HL-LHC start-up

GENERAL INFORMATION (G. ARDUINI)

Minutes of the previous meeting were circulated and no comments have been received so far. **Gianluigi** briefly went over the action items.

Riccardo reported that according to Chiara the lower limit on β-function at the beam dump is 20 km.

For the coupling knob, **Riccardo** will clarify with Yannis what is available and could be useful for their studies. Riccardo raised a question whether assuming a 1.7 μm emittance is not too pessimistic. **Gianluigi** explained this is the values used for consistency in all the estimates for the BCMS beam; although it corresponds to the emittance at Injection, it is safe to assume this value since the source of emittance blow-up is unknown and therefore it cannot be relied upon.

Gianni will check the limits on numbers of bunches for the MD day, both at Flat-Top and at Injection.

Riccardo made a comment that he had two separate MD proposals: one to simulate the non-closure of the crabbing bump, and the other – to study larger off-momentum dispersion. It is the last one that requires collaboration with the Collimation team. **Gianluigi** asked to clarify this in the minutes (Action: **Sergey**)

1 STATUS OF THE STUDIES ON ELECTRON CLOUD INCOHERENT EFFECTS (K. PARASCHOU)

Numerical implementation of electron cloud kicks underwent significant improvement. Previously a linear interpolation was used to compute a kick at a given location, which is not symplectic. In order to improve the tracking one had to interpolate the scalar potential of the electric field in a symplectic way. A solution has been found, that is based on a Tricubic interpolation method in 3D.

After reducing the noise with macroparticle averaging the only problem remained – the interpolated solution was inaccurate at large gradients. This problem arises from the finite difference computation of partial derivatives used in the method. In order to improve the method a solution was found to use a finer spatial grid to solve Poisson equation. This approach reduces the interpolation error by an order of magnitude on an analytical test case.

In particle tracking, the novel scheme yields a more regular motion with less diffusion in phase space compared to the old approach. The computationally intense algorithm requires specialized hardware to run efficiently. It is currently being ported into SixTrackLib code and being tested on GPUs in Bologna. Benchmarking on beam-beam studies, SixTrackLib yields results identical to SixTrack in terms of tune footprint and dynamic aperture.

In terms of performance, it takes around 5 days to simulate 20 million revolutions (around 30 min) in LHC, tracking 10 000 macroparticles on the presently available GPU hardware. That already allows comparing loss pattern for different collimation settings to the observations, and qualitatively, the loss rates are reproduced. The next step involves repeating the exercise with electron cloud.

- **Gianluigi** raised a question if a change of distribution arising from beam-beam effects can be seen in simulation. Such a feature would also be of interest for studies of Hollow Electron Lens. **Kostas** replied it can be included. **Gianni** noted that Kostas should also start the study of the electron cloud incoherent effects and will need some help for the study above (Action: **Gianni, Yannis to see how this study can be pursued**).
- **Rogelio** pointed out the use of cpymad in the SixTrackLib, emphasized that many people used this code and proposed informing Laurent. **Gianni** commented that without cpymad the tracking exercise presented today would take too much effort, becoming prohibitively difficult. **Gianlugi** proposed bringing up the issue at CWG, pinpointing where it is used and why it is useful (Action: **Gianni**).
- **Riccardo** mentioned that developing on a local GPU machine speeds up code development significantly. **Gianni** commented the group can easily use around 60 cards in HPC, but one needs double precision GPUs; procurement is in discussion. **Riccardo** mentioned one could potentially collaborate with the Swiss computing center.

2 IMPACT OF ELECTRON-INDUCED IONIZATION ON HEAT LOAD AND BUILD-UP (L. METHER)

The motivation for this study are the 16L2 events in 2016-17 when air frozen in the beam chamber gave rise to a complex beam-electron-ion instability with extremely high rise times. Modelling it numerically required multi-species electron cloud simulations, where one cannot assume that electrons and ions do not influence each other when their densities become high. Qualitatively, a fast instability could be observed in simulation, although a large gas density, 2-3 orders higher than expected, was needed. A potential source of this discrepancy could have been electron-induced ionization.

Electron-induced ionization has been implemented in the model, assuming a uniform gas density and only single ionization processes. With this mechanism in place simulations predict significantly larger electron and ion densities. The results seem unrealistic though: energy grows after the passage of the last bunch and between bunch passages, indicating that the simulation suffers from numerical heating – a known effect in PIC codes. An extensive convergence study campaign was undertaken. The analysis shows that regeneration of macroparticles seems to introduce noise in the system, with the number of particles increased from 250 000 to 8×10^6 the numerical breakdown shifts later in time. Currently, the numerical model is limited by 50-60 bunch passages for a gas density of 10^{20} m^{-3}, although the cross-ionization increases the build-up already at $10^{17}m^{-3}$. Ion currents and ion energy spectra have been determined and could be used in future simulations of surface chemistry.

- **Gianluigi** suggested reaching out colleagues who perform similar simulations or have relevant experience to see if they face similar limitations of the PIC method and if there are any ideas to overcome them (Action: **Lotta**).
- **Elias** asked how the situation would change with a solenoidal external field. **Gianni** replied the solenoid's main purpose was to prevent the flakes of ionized material from getting into the beam. **Lotta** commented adding an external field can be tried. (Action: **Lotta)**

3 ELECTRON CLOUD STABILITY: SINGLE BUNCH EFFECTS (L. SABATO)

Electrons in the arc quadrupoles are expected to be the strongest contributors to the overall electron cloud at Injection. In order to study the impact of this electron cloud on beam stability an extensive numerical campaign was undertaken. It focused on two beam intensities: 1.2 $\times 10^{11}$ p (as in the present-day LHC) and 2.3$\times 10^{11}$ p (HL-LHC baseline). The secondary electron yield was scanned in the range from 1.3 to 1.4 units. Before proceeding to stability predictions and vast convergence study was performed to verify the input numerical parameters.

Numerical simulations show that increasing the RF voltage makes the beam more stable with the dominant stabilizing factor being the resulting change of the synchrotron tune.

For a HL-LHC bunch intensity of 2.3$\times 10^{11}$ p no instability is observed due to lower electron density at the bunch location than for a lower nominal intensity of 1.2$\times 10^{11}$ p. For the nominal LHC intensity no instability is observed for $Q' > 12.5$. Other stabilizing mechanisms such as transverse feedback and octupole tune spread are inefficient for suppressing the instability. The intra-bunch oscillation pattern changes with time as the instability develops. Mostly the modes 1 and 2 are unstable, which explains the ineffectiveness of the transverse damper.

Looking at the simulated beam spectrum one can observe that the electron cloud is shifting the tune spread, created by the octupoles, away from the unstable frequencies. Instability rise times seem to be correlated with bunch population and the frequencies of unstable modes.

- **Rogelio** asked about the stability with intensities lower than 2.3$\times 10^{11}$ p. **Luca** replied only 1.2 and 2.3$\times 10^{11}$ p were studied, because of the computational complexity; the studies can be extended to other intensities. **Gianluigi** emphasized this information is important for the HL-LHC start-up scenario. **Luca** suggested a first idea could be obtained from build-up simulations (Action: **Luca**).
- **Gianluigi** noted the octupoles seem to have little impact on stability of single bunches. **Gianni** suggested the octupole detuning might be important for slower instabilities happening on longer

time scales, pointing out that there is an impact on the tune spread. **Gianlugi** suggested that the octupole spread might be important for suppressing the coupled-bunch motion. **Xavier** noted that the coupled bunch motion is not present in the gathered experimental data, although no data with the octupole system off is available.

- Following a question from **Rogelio, Luca** clarified that the second order chromaticity from octupoles is not included in the simulations
- **Xavier** proposed to try using electron cloud wakes to study the instability separately in a semi-analytic approach, such as the circulant matrix. **Gianni** replied this could be done in principle, but one must first perform checks to make sure the behavior observed in simulation is reproduced. He suggested one can start with characterizing the behavior of just one pinch.
- **Elias** made a comment it would be good to see how the simulated instability patterns compare with what had been observed in other machines, in particular in the SPS.
- **Elias** noted that this study concludes the scan of RF voltage and the results can be shared with the colleagues from RF.

4 ELECTRON CLOUD STABILITY AT INJECTION - COUPLED BUNCH EFFECTS (L. METHER)

Bunch coupling through e-cloud is particularly likely to happen in dipoles. Numerically, solving a combined intra-bunch and coupled-bunch problem is a very computationally intense task. A significant speed-up was achieved recently with parallelization, allowing reasonable simulation time scales.

Trains of 144 bunches were studied on CERN HPC cluster, these trains capture well all the significant physics, and longer 288-bunch trains are not required. 800 CPU cores per simulation gave a progress of 100 turns a day with 8 electron cloud interactions per turn. A somewhat too large SEY value of 1.7 was used to speed up the cloud buildup and the resulting instability. Vertical kicks were turned off to avoid single-bunch instabilities in the simulation.

For HL-LHC intensity the stripes of electrons are moved further away from the beam compared to LHC. In the absence of a transverse feedback this leads to a different instability pattern: it develops only in the middle of the first train vs towards the ends of trains in the LHC case. No significant intra-bunch motion was observed for both LHC and HL-LHC intensities, and the centroid motions of the most unstable bunches are similar, with similar rise times.

With a 20-turn or a 100-turn transverse feedback the instabilities are suppressed. Chromaticity also provides a clear stabilizing effect, although it alone is insufficient to mitigate the instability. A traveling wave pattern can be observed in the intra-bunch motion when an instability happens at high chromaticity of $Q' = 15$; the instability can be cured by the damper. The instability can also be damped by octupole tune spread with around 60 A required for the HL-LHC beam intensity.

Next steps include introducing quadrupoles in the simulations to investigate their effect on stability.

- **Gianluigi** emphasized a clear effect of the octupoles on the coupled beam stability observed in the simulations and inquired about the coupled bunch instabilities observed during the scrubbing runs. **Gianni** recalled those events were in the vertical plane, while the numerical model predicts a horizontal instability.
- **Xavier** pointed out that the positions of the affected bunches correlate with the location of the electron cloud stripe in the chamber and in particular the instability seems to occur where the stripes start to move out of the flat part of the beam screen
- **Sergey** asked if it is necessary to have intra-bunch motion in the bunch train simulation. **Gianni** replied that removing the intra-bunch motion will not simplify the problem significantly as the time step is driven by the tracking of the electrons. **Gianluigi** asked if one can come up with an effective model of coupling based on the simulations so to use then simplified models. **Sergey** replied several models exist, for example a broadband resonator model.

5 ROUND TABLE

There will be no WP2 meeting until the end of the year. Agenda of the following meeting will be circulated in due time.

Reported by S. Antipov