Minutes of the 96th WP2 Meeting held on 13/06/2017

Participants: A. Alekou, S. Antipov, F. Antoniou, G. Arduini, F. Baudrenghien, X. Buffat, R. Calaga, L. Carver, E. Chapochnikova, D. Gamba, G. Iadarola, S. Kostoglou, R. De Maria, L. Medina Medrano, E. Metral, Y. Papaphilippou, D. Pellegrini, G. Sterbini, H. Timko, R. Tomas, F. Van Der Veken.

Excused: M. Giovannozzi.

General Information (G. Arduini)

The minutes of the previous meeting have been circulated. Gianluigi summarises the outcomes and the actions of the previous meeting.

Update on CC RF noise and operational aspect (counter-phasing, full detuning) (P. Baudrenghien)

--- Summary of analytical estimations and expected growth rate from amplitude and phase noise.

Philippe presents analytical formulae (assuming Gaussian bunches) for the estimation of the effect of phase and amplitude noise on the emittance growth. The “geometric factor” term shows opposite dependencies against the bunch length for the two kinds of noise.

The ADT can reduce the emittance growth due to the CC phase noise. Amplitude noise does not result in a displacement of the centre of charge and cannot be attacked by the ADT. The effectiveness of the ADT against the phase noise is better for shorter bunch lengths. An analytical expression for the reduction factor is given.

The parameters used to estimate the actual growth rates are summarised. It is clarified that the ADT gain corresponds to 50 turns.

The noise spectra for phase and amplitude are scaled from the main RF system. The resulting emittance growth is 16 %/h for the phase noise (including the reduction from the ADT) and 63 %/h for amplitude noise. Estimations for an improved demodulator noise level (challenging but possible) are 0.9 %/h and 3.7 %/h for phase and amplitude noise respectively, the latter still being dominant.

Rogelio notes that the assumed value for the betatron tune spread (3e-3) looks too small. Elias comments that it was given a long time ago. Yannis adds that this depends also on the settings of octupoles and IR8. A more realistic value should give larger emittance growth from phase effects. Philippe replies that the computation can be repeated with the correct setting. It was reminded that the spread considered here is not the full tune spread, but the average over the beam distribution. **Action: Elias, Xavier to provide this value for the nominal scenario and document it in the operational scenarios with a brief description of the considerations that lead to this value.**

Gianluigi asks if it would be possible to provide the phase noise spectrum in units of radian. Xavier adds that dB can be handled as well.

--- CC as transverse feedback

Measurements of the transverse displacement of the head and of the tail of the bunches can be fed back to the CC phase (head+tail signal) and amplitude (head-tail signal). The CC then effectively becomes a damper capable of attacking also external noise sources.

The emittance growth rate is plotted as a function of the gain for different noise levels. Gianluigi asks about the scale of the noise, this is not clarified.

The plan would be to use the pickups of the damper. Gianluigi asks if a non-perfect closure of the crabbing bump could create issues, Philippe replies that this is not different from the ADT case.

Rogelio asks about the optics settings, in particular the value of beta at the pickups, which would strongly influence their resolution. Rama adds that the signal-to-noise ratio is optics independent. Philippe stresses that a similar system is in place for the ADT. Gianluigi points out that the ADT has a resolution of about 1 um while the estimations in the plots are for 0.1 um. It is not clear if this level could be achieved combining the information from multiple pickups.

Gianluigi asks about the number of CCs used, Philippe confirms that they are 2 per beam and IP side.

--- Operational Scenario

Philippe reports that the cavities will be kept on all the time (from injection to dump) with strong RF feedback and tune control. Gianluigi asks if this means that the frequency of the crab cavities is tracking the main RF 400 MHz cavity frequency. Rama replies that this is the case but it is not a concern as the process is very slow.

Before collision the two cavities on the same side will be operated in counter phasing resulting in a vanishing effective voltage. In addition at injection the voltage will be a factor 10 lower. Gianluigi wonders if in case of failure this voltage would result in a significant kick. Indeed the beam rigidity is 15 times smaller and even taking into account the betas smaller by a factor ~20 at the crab cavity at injection, the kick in the worst case scenario may still not be entirely negligible.

Elias asks if the counter-phasing mode will be tested in the SPS. Rama adds that this will be done, but the delay will be faked.

--- Full Detuning

The crab cavities field cannot be modulated at the revolution frequency, therefore there will be some phase slippage. Philippe reports a loss of luminosity (NOTE: errors in the slides) of 2% for 100 ps and 8% in 200 ps phase slippage due to the RF curvature. A shift of one beam only, by 100 ps, results in 6% loss. An upper limit to the RF phase control is set to 35 ps.

Update on CC performances and tolerances (R. Calaga)

Rama presents a table showing the voltage reached for the vertical and horizontal cavities built at CERN and in the US. All of them reached significantly higher voltage than the nominal 3.4 MV, the shunt impedance being also very good, but he stresses that the nominal voltage is not changed and operation at higher voltage is not foreseen. In addition a quench was observed at 2.8 MV with the HOM coupler mounted. Investigations are on-going in order to determine if this was the actual cause.

The loaded Q is optimised to minimise the input power in the presence of microphonics effects and taking into account the maximum foreseen beam offset. The new limitation on the input power (40 kW) fixes the maximum continuous offset in the crabbing plane at 1 mm at full voltage. Larger offsets can be tolerated for periods below 100 us (~1 turn). At injection energy, with lower voltage, the upper limit is fixed at 2 mm. Philippe suggests that at injection the cavity can be detuned to increase the tolerance to injection errors. **It is concluded that the considered injection error of 2 σ, resulting in a 2 mm offset at the crab cavities, can be tolerated, possibly by detuning the cavities at injection.**

The total tolerance from the mechanical installation is 0.5 mm, therefore the remaining margin for orbit effects in is 0.5 mm in collision.

Measurement techniques are in place for the determination of the electrical centre. Good positioning of the centre has been measured, allowing for aperture preservation while maintaining good pole symmetry. The realignment of the cavity will be possible but not trivial, typically requiring a technical stop and potentially emptying the cavity depending on the required adjustment. According to Rama it is planned to install the same RF fingers as for the triplets around the crab cavities to allow for the shear resulting from the alignment of nearby modules. Gianluigi noted that there was a recommendation from the impedance team to use this type of RF fingers in places other than the triplets and in particular at high beta and in the presence of significant relative offsets. This will need to be followed-up with the vacuum team and it should be discussed at the next WP2 meeting. **Action: Rogelio, Elias to address this point with Vincent.**

In the non-crabbing plane there is practically no field and the limits on the offset are given by the HOM loading. An offset of 5 mm causes a load of 25 W in the first HOM at 681 MHz, while the installed coupler allows extracting 1 kW of power. The maximum offset will be confirmed after checking against all the HOMs. Rama wonders what the limits from aperture restrictions are. Riccardo replies that there is substantial margin.

<u>Effective crabbing in v1.3 and reasons for the change (R. De Maria)</u>

Riccardo shows an expression for the horizontal position at the IP due to the crabbing kick. The maximum luminosity is obtained for a crabbing angle larger than the crossing angle by a factor ~1.1 due to the RF curvature. The voltage is tuned to minimise the leakage due to the non-exactly π phase advance between the two sides. Gianluigi asks if the tracking simulations take into account these effects, Dario confirms.

Riccardo shows the layout for two crab cavities. He reports that the betas have been slightly optimised and that the maximum crabbing angle achievable in v1.3 is 380 urad.

It is possible to gain ~5 urad by de-symmetrising the layout. The optics could also be de-symmetrised, gaining few extra microns. Additional gain could be obtained by pushing Q7 and/or by adopting exotic schemes with increased dispersion.

Riccardo plans to renormalise the crabbing knobs to 1 urad as there is no longer a reference crabbing angle.

Rogelio points out that the leaking crabbing bump could be matched (at least for an average value for IP1 and IP5) by tuning the orbit, it is not clear if this will bring sensible benefits.

Review of the tolerances to CC phase noise (emittance blowup, …) (X. Buffat)

In order to predict the emittance growth due to noise effects, Xavier considered both the Weak-Strong and the Strong-Strong model, comparing them. The S-S model gives a smaller emittance growth for small ADT gains, but only for the case in which the coherent modes are outside the incoherent spectrum. As the LHC comes with most of the coherent modes inside the incoherent spectrum, a W-S model can be assumed. Measurements on the LHC were in good agreement with the W-S model. After carefully disentangling the filamentation effect from chromaticity, traces of the reduction predicted by the S-S model were observed. Xavier stresses that we should not rely on this for a design phase of a machine with several coherent modes from the multiple IPs and large chromaticity. The W-S model is used to fix an upper bound.

The beneficial effect of the ADT on the emittance growth requires a pickup resolution below 0.1 um. This could be achieved with multiple pickups and averaging over multiple turns and bunches. Xavier adds that Daniel Valuch is planning to put the hardware into operation. **Action: Gianluigi and Rogelio to ask Daniel and Wolfgang concerning the plans for the LHC transverse damper low-level upgrade and its timescale.**

Xavier reports consistency between his simulations of the emittance growth with the W-S model and the studies from Philippe. Gianluigi asks how far we are from the IBS limit and suggests quantifying the impact on the luminosity by adding the extra blow-up in the luminosity model to define the maximum acceptable blow-up due to crab cavities. **Action: Rogelio and Luis to define the maximum acceptable blow-up due to crab cavities that could produce a visible effect on the integrated luminosity.**

Xavier reports a test with high noise and chromaticity which showed that the chromaticity by itself does not allow to recover the emittance growth, indeed the decoherence process is too slow.

Summary of expected bunch to bunch displacement at the CC with pacman effects (X. Buffat)

Xavier shows the orbits of all the bunches taking into account the missing long range interactions due to the position in the train (pacman effects). The effect is symmetric in the two beams and therefore they do not separate at the IPs. Xavier clarifies that the impact on the orbit scales with the normalised separation. The orbit at the crab cavities is shown, in the worst case an orbit spread of 0.45 mm is observed for IP8 at 3 m beta*. Gianluigi notes that a smaller beta* (as the 1.4m being discussed) will make this worse. Xavier adds that the phase advances between IP8 and IP5 (IP2 and IP1) could be adjusted to reduce the effect. Riccardo confirms that there is some flexibility. Xavier points out that the average orbit (which is subtracted in the plots) has also to be corrected at the CC. This is a dynamic effect that depends on intensity and on the separation between the beams so it might not be easy to correct.

Rama reminds that the variation of the bunch position within a single revolution will not be seen by the crab cavities if their time scale is in the few microsecond scale nevertheless he stressed the need to perform detailed studies. He also asks if it could be possible to increase the separation in IP2 and IP8 to reduce the orbit effects, but Gianluigi points out that this is in conflict with the higher luminosity being asked by LHCb. **Action: Xavier to provide the expected values of the orbit offsets of the various bunches for optics HL-LHC v1.3 for the nominal scenario and separations in IP2 and 8 and evolution during the collision process. Provide this to Rama to evaluate whether the excursions are acceptable in terms of beam loading.**

Riccardo reports that currently the beam-beam lenses do not affect the orbit in the tracking simulations with Sixtrack. It might be important to estimate the impact of beam-beam kicks on the orbit and the impact on DA. Yannis comments that there is no clear need for it, and eventually even a fake orbit distortion could be added.

<u>Review of expected CC heat loads due to impedance (S. Antipov)</u>

Sergey presents a list of the CC HOMs. Some of them have a large impedance and are close to the beam spectral lines. The high beta function and the fact that these are transverse modes, make them more worrisome than the ones of the main RF system.

The total power loss for a completely filled machine can go up to or exceed 1 kW for selected dangerous modes. The actual power loss for the real filling scheme requires delicate estimations and is not readily available.

The power loss also depends on the bunch distribution. A factor 2 reduction is observed by going from a Gaussian to a $\cos^2$ distribution, however this should not be relied upon as the distribution cannot be controlled very precisely.

Considering a worst case scenario with a detuning of 25 MHz, additional modes present a high power loss. In order to keep the power loss to acceptable levels, a separation of 2 MHz between the beam spectral lines and the HOM frequencies is indicated as the minimum for the DQW modes, this is increased to 5 MHz for the RFD cavities.

Concerning the SPS test, taking into account the filling scheme, up to 50 W could be loaded on the RFD cavities and up to 2 kW by the DQW cavities, although the latter is very unlikely due to their very narrow band.

The DQW HOM coupler can extract up to 1 kW. The SPS test will be crucial to verify that enough spectral separation can be provided and that the extracted power will be compatible.

Rama could provide the most updated HOM table. **Action: Rama to provide the latest HOM table. Action: Sergei to update the values of the HOM power for the nominal filling pattern and the expected nominal bunch distributions**

Elena comments that there are limitations to the Q damping as to avoid going broadband. She adds that normally the spectral lines due to the bunch spacing are avoided, but stresses that the frequencies due to the train spacing can also be an issue and should be taken into account. She suggests to use an approach similar to what has been used for FCC to identify possible constraints on the filling patterns

Referring to slide 6, Rama points out that alpha close to 1 is more realistic.

It is pointed out that 25 MHz for the total shift of the modes not realistic and a maximum of 3 MHz should be considered for the DQW modes. Elias replies that this was done in order to find all the possible overlaps between the beam spectral line and the HOMs.

Gianluigi asks if the HOMs can be tuned, **Rama confirms that recommendations on the required distance of the HOM frequency from the beam spectral lines can be respected**.

AOB Impact on luminosity of longitudinal oscillations (L. Medina Medrano)

Luis shows 2D plots for the virtual and integrated luminosity as function of the time offset of the two beams. When the two beams are shifted in the same direction, the loss of luminosity is smaller. In general for offsets of few tens of picoseconds the impact on luminosity is below 1%. **Action: Luis and Philippe to cross check their estimations.**

Gianluigi suggests using the nominal distribution instead of Gaussian for the luminosity calculation. **Action: Luis.**

Dario asks if the optimal filling time is recomputed for every point in the plot for the integrated luminosity, Luis confirms.

Gianluigi asks if we have an idea of the maximum value of the oscillations. Elena replies that this depends on the time spent at flat bottom so it varies from bunch to bunch, she indicates 50 ps as a possible limit to be confirmed.

Philippe asks if for the luminosity computation the beam distribution is modelled at the Crab Cavities and transported to the IP after the application of the crabbing kick. This is not the case but it is not considered to be critical. **Action: Luis and Philippe to discuss this offline**.

Reported by Dario, Gianluigi, Riccardo and Rogelio.