Minutes of the 121st WP2 Meeting held on 22/05/2018

Participants: D. Amorim, S. Antipov, G. Arduini, X. Buffat, R. Calaga, L. Carver, , R. De Maria, M. Giovannozzi, N. Karastathis, S. Kostoglou, E. Maclean, E. Metral, J. Mitchell, N. Mounet, F. Plassard, B. Salvant, , G. Sterbini, R. Tomas, F. Van der Veken E. Yamakawa

AGENDA:

1 GENERAL INFORMATION (G. ARDUINI)

The minutes of the previous meeting have been circulated and accepted with no comments. **Gianluigi** summarized the outcome of discussion at the previous WP2 meeting on additional uses of electron lens. While there are potential benefits of using it for head-on beam-beam compensation and Landau damping, further studies are required to understand all aspects of dynamics, i.e. transient effects, noise. Since the lens is not in the baseline at the moment, the priority shall be given to traditional methods of beam stabilization.

2 TRANSVERSE OFFSET AND TOLERANCE STUDIES FOR HL-LHC CRAB CAVITIES (E. YAMAKAWA, J. MITCHELL)

Emi presented the status of her studies and preliminary results on beam loading of the crab cavities. The beam loading could result from two potential sources: PACMAN effects and injection oscillation. Its impact is quantified in terms of power required to compensate the voltage induced by the beam. For the PACMAN effects, an offset of ±180 um has been considered, based on the input from **Xavier**. At this level the induced power is found to be negligible compared to the power generator capabilities for all bunches in the bunch train.

The impact of injection oscillations was computed assuming the same orbit offset for all bunches in a train and a 2 mm maximum offset in the crab cavities at injection. The peak induced voltage is found to be less than 70 kV.

Jamie presented several studies on beam offset, higher order modes (HOMs), and multipole fields for the Double Quarter Wave (DQW) design of crab cavities. The maximum tolerable beam offset is limited by available power supply. The initial specification 80 kW could accommodate up to ±2 mm beam offsets at the cavity. The specification was reduced to 40 kW that leaves only a few kW of margin for power amplifier saturation for the nominal settings. Induced voltage scales with the beam current. Apart from lowering the current, some margin can be added by reducing the carb cavity voltage, which is also not desirable. Alternatively, the amplifier could deliver a higher power over a short time in a transient regime, to be tested at SPS.

Beam induced heating has been numerically studied with a full HOM spectrum, obtained from the measurements of test cavities. HOM frequencies and quality factors were varied stochastically to represent manufacturing uncertainties, according to the measured spread in test cavities. With the new couplers the beam-induced power stays below the limit of 1 kW for all offsets: ± 5mm in the non-crabbing plane and ± 1mm in the crabbing plane.

Only the odd multipole field components have significant strength for the DQW design, according to numerical simulation in CST. The value of b3 component is a factor of two below the threshold of 1000 units set in the TDR.

- **Gianluigi** noted that one should quantify the PACMAN effect in terms of its impact on the overall safety margin, taking into account the tolerance for alignment and orbit adjustment (0.5 mm each). **Rama** replied that the cumulative effect of all the offsets has not been studied yet, and mentioned that compared to the 30 kW extra power required for 1 mm beam offset at the crab cavity the PACMAN effect would be at the noise level.
- **Gianluigi** raised a question whether the 2 mm injection offset at the crab cavity locations is a conservative estimate. **Riccardo** answered that injection oscillations could be larger – up to 2.4 mm, due to the large beta-function in crab cavities of about 280 m (only in one plane). **Gianluigi** pointed out that the analysis has to be updated with the exact values from the optics team.
- **Rogelio** asked if the kicks that injected bunches receive and the resulting emittance growth can be computed. **Emi** noted that due to the phase advance between the cavities (about 220 deg for the V1.3 injection optics) their kicks do not cancel out. At this stage of analysis the cavities are assumed to be at 0 nominal voltage, but the induced crab voltage is taken into account at each turn. **Rama** pointed out that now the tools are ready to make a study and proposed to come back later with an update.
- **Gianluigi** inquired if there is a preferred direction of beam offset to minimize the beam induced power load. **Rama** confirmed, but pointed out that one needs to know the actual transverse offsets of the cavities in order to optimize the induced power. **Rogelio** suggested that the induced voltage could be minimized experimentally. **Rama** agreed and mentioned a plan to perform an offset sweep in the SPS test stand.
- **Rama** noted that having a better control of the orbit would be beneficial for reducing the beam induced voltage and emphasized that a zero orbit offset is the safest option (a cavity might quench

if the induced voltage is too high) and is desired in the end. **Riccardo** replied that there are not enough knobs to control the orbit in the crab cavities without affecting the orbit in IP.

- Regarding the multipole field components, **Rogelio** noticed the presence of a significant quadrupole component b2 in the latest DQW design and pointed out that it could lead to a potentially dangerous tune modulation. The specification for b2 was a few tenth of a unit maximum and the specification on b3 was aimed to minimize the tune modulation resulting from feed-down. **Rama** commented that the b2 comes from the asymmetry of HOM couplers and suggested that the present value, 20 times greater than that of the previous design, could be a numerical error. **Gianluigi** emphasized that the b2 error cannot be corrected by an orbit offset. **Rogelio** mentioned that the b3 component could be used to compensate b2, but that would require large mm-scale offsets. **Gianluigi** inquired what the situation with multipole fields for the Radio Frequency Dipole (RFD) design is. **Rama** replied that the issue of multipole fields is smaller for RFD; in the pessimistic scenario b3 could be around 1000 units.
- For the crab cavity HOMs, **Rama** asked if the ±5 mm offsets in the non-colliding plane are consistent with the machine aperture. **Riccardo** replied affirmative. **Benoit** asked if there are HOMs with shunt impedance above 1 MΩ/m, reminding they could be dangerous for the transverse beam stability. **Jamie** replied that in the latest design there is a mode with a shunt impedance slightly above 2 MΩ/m; its impedance went up in the latest version of CST simulation software, checks ongoing.

ACTION (Rama, Emi): Quantify the impact of PACMAN offsets in term of the overall margin for the crab cavity power supplies.

ACTION (Rama, Emi): Update the calculations of beam loading voltage using the latest data on injection oscillations from R. De Maria.

ACTION (Rama, Emi): Estimate the turn-by-turn beam-induced kick acting on the beam as a result of the injection oscillations and orbit offsets at injection so that the potential emittance blow-up can be estimated..

ACTION (Rama, Jamie): Check the values of multipole field errors for the latest DWQ and RFD designs and in particular the quadrupolar component

ACTION (Rama, Jamie): Check whether offsets in the non-crossing plane can induce HOM with large shunt impedance.

3 EFFECT OF NOISE ON INSTABILITIES (E. METRAL)

Noise may play an important role in beam instabilities in LHC. Simulations show that an instability with latency time of several min arises when a dipolar noise of 10^{-4} rms beam size is added. In LHC it is expected that the noise comes from two major sources: feedback and power converter ripple. The feedback noise is believed to have been triggering instabilities in the recent Beam Transfer Function (BTF) MD. The destabilizing effect of damper noise has been demonstrated in a dedicated MD by **Xavier** et al. who observed an instability with a latency time of 40 min in a single bunch at a stabilizing octupole current above the nominal octupole threshold. The observation is consistent with marcoparticle simulations in COMBI.

A dedicated MD is proposed to study the long-term stability in the presence of noise by introducing in a controlled way via damper (ADT) acting on different bunches. The current ADT system allows up to four different channels.

- **Benoit** raised a question if the effect of crab cavity (CC) noise can be studied as well, since this source of noise is now well understood. **Xavier** replied that the phase CC noise can be added to simulations in COMBI.
- **Gianluigi** asked what the characteristics of the noise used for the study are. **Xavier** replied that only dipolar noise is studied at the moment, can be extended. **Gianluigi** noted that for the PC noise the frequencies are known and can be avoided. **Xavier** replied that at the moment a white noise is used with a magnitude corresponding to the maximum values (assuming the frequencies cannot be avoided); that is a pessimistic scenario.
- **Gianluigi** pointed out that the effect of feedback noise can be separated by setting the ADT gain to 0. **Elias** replied that the past measurements at 0 gain are being summarized and emphasized the importance of confirming the effect of damper noise in an MD. **Xavier** reminded that the damper plays many roles: while it increases the noise level, it also acts on the instability and reduces the emittance growth. **Gianluigi** asked to clarify what the MD plan is to study the effect. **Xavier** explained that the plan is, first, to study the octupole current threshold for single bunches and different gain settings (up to four gains allowed simultaneously by ADT), and then to study the noise level threshold for a given octupole current. **Rogelio** noted that there will be another BTF MD that is related.
- **Gianluigi** inquired about the progress on understanding how the beam distribution and stability diagram are changed due to noise and whether non-linearities (e.g. octupoles) can enhance the changes. **Xavier** replied that, qualitatively, the distribution changes because the phase space drift velocities vary for different particles. The presence of the damper is key for this mechanism to take place. It is not completely clear if one can act on this process of 'drilling a hole in the distribution'. **Elias** commented that effects like synchrotron radiation damping and intra-beam scattering might also play a role.

ACTION (Xavier): Estimate the effect of crab cavity noise on stability.

ACTION (Elias, Xavier): Perform an MD on the effect of damper noise on the long-term beam stability (planned this year).

ACTION (Elias, Xavier): to summarize the stability threshold measurements without damper.

4 Round Table

Next meeting will be held on the 29th of May.