WP2 Meeting #152

Tue 2 July 2019, 09:00 – 12:00

Chair:	R. Tomás
Speakers:	A. Alekou, R. Calaga, E. Cruz Alaniz, T. Levens
Participants:	S. Antipov, P. Baudrenghien, X. Buffat, F. Giordano, M. Giovannozzi, W. Hoffle, G. Iadarodla, R. Jones, N. Karastathis, S. Kostoglou, M. Krupa, T. Lefevre, E. Maclean, E. Métal, N. Mounet, S. Papadopoulou, Y. Papaphilippou, A. Rossi, B. Salvant, G. Sousa, G. Sterbini

AGENDA

The meeting, held together with Beam Instrumentation and RF colleagues, was devoted to different aspect related to crab cavities.

MEETING ACTIONS

Androula	Determine the expected error in the beam-based measurement of the kick and of the minimum detectable non-closure from beam measurements with BPMs
Rama	Review the need for transverse BPMs attached to crab cavities in HL-LHC.
Tom, Androula	Prepare a table with locations and crab orbit excursions for HT monitors at top energy, including the current HT positions and the suggested new locations in the opposite side of IP4. This should also be done for the V crossing in IP1 and for the flat optics.

Elias	Estimate the effect of electron cloud, impedance, and beam-beam force on the observed crabbing
Emilia	Update the results on dynamic aperture with crab cavity multipoles for the baseline scenario (H crossing in IP1), taking into account the latest multipole tables from Rama. Determine the maximum value of the b2 that would allow operation one IP with CC and the other - without.
Rama, Yannis	Plan a reference measurement of the impact of the feed-down of octupoles and sextupoles in the SPS without crab cavities before repeating the a3 measurement with crab cavities ON.
Gianluigi, Yannis	Make sure the crab cavity multipole values quoted in the Beam Dynamics chapter of the HL-LHC TRD are consistent with the WP4 chapter.

GENERAL INFORMATION (R. TOMÁS)

Rogelio reviewed the minutes of the previous meeting. Comments from **Francesco** and **Marta** have been received. In particular, that the Q4-assembly has changed from v1.3 to v1.5 optics: there are 4 MCBYs in v1.3 while only 3 in v1.5; therefore, they are not comparable. The comments have been implemented.

Massimo also made a comment that it is the MCBXF magnet, whose b3 component has to be lowered, while a reduction of MCBRD b3 would be welcome if possible. **Massimo** will meet with Ezio to discuss the plan of action.

1 CRAB CAVITIES AND HL-LHC INSTRUMENTATION (A. ALEKOU)

Numerical study of crab cavity (CC) kicks for HL-LHC has been performed using v1.4 optics, assuming 2 cavities per IP side, and treating the two (in reality separated by approximately 1 m) as one. During commissioning the CCs will be operated one at a time at 1 MV. The rms bunch length was assumed to be 7.5 cm, a value of 9.0 cm will be used in the future.

Measuring beam emittance with wire scanners reveals that the CC kicks will lead to a comparatively small increase of normalized emittance, of the order of 10^{-8} m, because of the small bunch length.

Based on SPS experience, when comparing the simulation data to the measurements beam position monitor (BPM) filtering has to be taken into account, since crabbing changes the frequency content of the signal observed by BPMs. In LHC with a low frequency cutoff at 70 MHz the filtering reduces the signal by a negligible amount (compared to a factor two reduction from the 200 MHz filter in the SPS's MOPOS BPMs). The averaging over the bunch length when the crab cavity is operated as an orbit corrector reduces the crest value by a factor of 0.8. While in operation the BPM signal should be 0 if the cavities are phased correctly, during commissioning the phase will be swept to look at orbit distortions. Numerical simulation suggest that the BPM reading should be well within the average orbit resolution of both normal BPMs and HT monitors in normal phase operation at injection energy. Similar measurement can also be performed with a synchrotron radiation (BSRT) or a beam gas vertex (BGV) monitors.

In conclusion, **Androula** raised a question if it is possible to have two head-tail (HT) monitors per beam per plane with a 90 deg phase advance between the BPM pair.

- Regarding additional HT monitors, **Rhodri** mentioned two monitor per beam and plane are foreseen with the novel electro-optical BPMs. A streak camera is also in the baseline, it measures at ~100 fs rate, allowing observing crabbing directly. **Thibaut** pointed out that the BSRT is installed at an unfortunate location to observe orbit distortion due to CC kicks.
- In case the electro-optical BPMs would not be adopted the proposal was to install new HT stripline monitors in addition to the existing ones as discussed in next section.
- **Thibaut** raised a question if having DOROS BPMs attached to CCs proved to be useful in SPS, as a similar set-up is not foreseen in HL-LHC. **Rama** replied the BPMs were useful during set-up, if the orbit is well known the BPMs attached to cavities are not needed. **Rogelio** recalled the CCs have been demonstrated to work as excellent BPMs and it is up to WP4 to decide on the need for

additional instrumentation. **Rogelio** proposed reviewing the requirements for transverse BPMs at CCs (Action: **Rama**).

- After the meeting **Gianluigi** pointed out that the expected error in the beam-based measurement of the kick and of the minimum detectable non-closure from beam measurements with BPMs remains to be determined (Action: **Androula)**.

2 WHAT IS POSSIBLE WITH BCT AND HEAD-TAIL MEASUREMENTS? (T. LEVENS)

LHC HT monitor is composed of four 40-cm-long stripline detectors connected through a hybrid and installed in a location with optimal β-functions. Experience at SPS demonstrated that HT monitors can be used for CC diagnostics.

In SPS the monitor was calibrated before making a measurement with CC un-phased or off, this procedure is not applicable in LHC. Moreover, the location of the HT could have a sub-optimal phase advance with respect to CCs in IP1 and IP5. With that in mind, 1 m of space is reserved between Q5 and Q6 for new pick-ups: 1 per beam and plane.

Ideal residual crabbing should be visible with the current HT pick-ups in nominal operation: it produces a minimum of about 10 μm closed orbit distortion with a 1 μm pick-up resolution in average mode. With only one cavity operating at full voltage the distortion can reach 100 μm.

- **Androula** requested Tom to provide her with the four extra location reserved for HT monitors in order to update the estimates (Action: **Tom**).
- **Sergey** pointed out the calculations fall apart if one decides to exchange the crossing planes. **Rogelio** stressed that the cavities were designed modular so that he crossing plane could be changed if needed and emphasized all operational modes will be safe with 2 HT per plane and beam with 90 deg phase advance to CCs. **Tom** replied that finding the right positions is challenging and proposed repeating the study for the other crossing (Action: **Tom**).
- During a discussion on the options for additional HT pick-ups **Tom** proposed keeping the existing monitors since some of them seem to be installed at favorable locations. **Rogelio** noted this way there will be 2 pick-ups per plane per beam, but not necessarily at 90 phase advance with respect to the cavities. **Rhodri** mentioned that if the electro-optical BPMs do not work for any reason, standard pick-ups will be installed in addition to the existing ones. **Rogelio** concluded that the current best compromise would be to install the new ones in the opposite side of IP4. The phase advance is not always 90 degrees (often 40 deg) but based on the presented results the resolution and this compromise seem acceptable. To be checked.
- **Rama** inquired if it is possible to introduce an optics distortion to maximize the signal, considering also a possible a CC feedback. **Tom** replied, based on analysis presented by Androula, the signal level is acceptable. **Gianni** pointed out the overhead should be minimal when qualifying the system at low intensity. **Rama** proposed defining the minimum signal HT can measure. **Rhodri**, in turn, asked to provide the minimum that can be acceptable from beam dynamics point of view in order to guide the design. Possible locations with large beta functions could be in IR1 and IR5.

Massimo recalled that there is one BPM that might be removed, freeing the location for this use (Action: **Androula, Tom**).

- **Thibaut** noted that other effects such as electron cloud might affect the crabbing and the measured signal. **Rogelio** proposed estimating the effect of e-cloud, beam-beam, and impedance on the measured crabbing (Action: **Elias**). **Elias** thanked Thibaut.

3 CRAB CAVITY FIELD QUALITY AND ITS IMPLICATION FOR HL-LHC (E. CRUZ ALANIZ)

CCs have high order RF multipoles that may affect beam dynamics. Simulations were done to estimate their impact on Dynamic Aperture (DA). Multipole values were obtained from Rama Calaga and Jamie Mitchell, corresponding to 10 MV of deflecting voltage and assuming DQW-type cavities for both IPs.

In collision DA is above 11 σ both with and without CCs with no significant effect with the table multipole values observed. In particular, b2 has no impact thanks to cancellation between IP1 and IP5 (cavities must be powered with equal voltage and have the same b2). No noticeable effect is observed for larger values of b3 up to factor 50 stronger and b4. Cavity misalignment also does not lead to an obvious reduction of DA for the DQW multipole values.

First results were also obtained for the RFD cavity multipoles, assuming a Vertical crossing in IP1 and Horizontal in IP5. No significant effect on DA is observed. The results for the baseline scenario – with Horizontal crossing in IP1 – remain to be checked.

- **Rogelio** inquired if the 1 mm tolerance is still assumed. **Rama** clarified 0.5 mm is assumed for maximum cavity alignment tolerance and another 0.5 mm for deviations during operation. At 1 mm one operates CCs at the limit of the power system.
- **Rama** noted that the b3 value used for the RFD cavity corresponds to an outdated design that has since undergone pole shaping to drastically reduce the b3 component. **Rama** suggested using the current values when updating the results for the baseline scenario (Action: **Emilia**).
- **Rama** inquired how the signs of multipole components are defined. **Yannis** pointed out a large amount of work has been done by Androula to carefully check the implementation in the code in the framework of SPS. **Androula** commented the DA effect observed in the SPS case was caused by an error in the ramping of CC: the SixTrack code was wrongly implemented to increase the cavity voltage to thrice its nominal value. In reality one cannot induce a DA change with CC in SPS.
- **Massimo** suggested looking also at the time evolution of the DA to get an insight on the long-term DA behavior.
- After the meeting **Gianluigi** stressed the importance of knowing whether the b2 multipole excludes the possibility of operating one IP with CC and the other without as this could be a significant limitation and might imply reducing the b2 multipoles. The maximum value of b2 that would prevent this effect has to be determined (Action: **Emilia**).

4 UPDATE FROM SPS TESTS, IN PARTICULAR A3 MULTIPOLE (M. CARLA)

Androula presented a talk for Michele Carla in his absence.

Skew sextupolar RF multipole component can be measured from turn-by-turn position observation. It is proportional to two spectral lines in the Vertical plane: at $2Q_x$ and at 0 frequency (static offset).

A successful test with a static skew sextupole was performed in 2017. In 2018, however, an a3 far exceeding the expected values was found in the installed cavity. A part of the disagreement comes from the BPM frequency response. After accounting for the BPM filtering both 0 and $2Q_x$ lines agree on the value of a3 around 1 T/m instead of expected 0.2 T/m. Effects such as feed-down from octupoles and normal sextupoles (second order) play an important role in the analysis due to large vertical orbit deviation. A good understanding of nonlinear model of SPS is required in order to make progress on the measured a3 values.

- **Rama** proposed using a reference measurement mimicking the vertical crab orbit with orbit correctors and crab cavity off after the shutdown. **Yannis** supported the idea of such a test. (Action: **Rama, Yannis**)

5 LATEST INFO ON FIELD QUALITY FOR CRAB CAVITIES (R. CALAGA)

Rama presented a summary table with the latest input on CC field quality. The multipoles were numerically computed taking into account all the couplers, field antennas, etc. Numerical simulations are limited at the b4, higher multipoles cannot be accurately computed due to a high noise floor. An EDMS document quoting the values will soon be released.

- **Rama** pointed out that the beam dynamics chapter of the HL-LHC design report quotes the b3 values from the preliminary prototype PoP design. **Rogelio** noted the current value of 1500 (vs 1000) seems tolerable. **Yannis** proposed checking if the Appendix can be adjusted (Action: **Gianluigi, Yannis**).

Reported by S. Antipov