WP2 Meeting #140

Tue 29 Jan 2019, 09:00 – 12:00

Chair: R. Tomás

Speakers: L. Carver, M. Carlá, J. Mitchell, S. Antipov, G. Iadarola

Participants: A. Alekou, S. Antipov, H. Bartosik, R. De Maria, G. Iadadola, T. Levens, E. Maclean, E. Métral, J. Mitchell, N. Mounet, Y. Papaphilippou, F. Plassard, B. Salvant, G. Skripka, G. Sterbini

AGENDA

The meeting was devoted to different aspects of crab cavity performance. In the end of the meeting Gianni presented his considerations related to filling scheme optimizations (not related to crab cavities).

MEETING ACTIONS

Riccardo	Evaluate the crabbing angle corresponding to 5 degrees at injection and non-closure for a 10% voltage uncertainty
Massimo and Yannis	Impact on DA with and without beam-beam in the presence of noise at injection for the above levels of uncertainties on counterphasing and voltage and determine maximum acceptable level

Michele	Perform further analysis and present the measurement results of b3 in common units of multipole strength that are used in beam dynamics and RF groups for comparison and further analysis of its impact
Michele	Define and use common units of multipole strength that are used in beam dynamics and RF groups
Jamie	Provide an estimate of the b5 multipole strength
Rama, Elena Sh.	Investigate the impact of the increased longitudinal impedance of the 580 MHz DQW HOM on longitudinal beam stability
Jamie	Obtain a more precise estimate of the 1.92 GHz shunt impedance
Francesco, Sergey	Supplement the heat load and beam stability analysis with the 8b4e beam

GENERAL INFORMATION (R. TOMÁS)

Minutes of the previous two meetings have been uploaded and will be reviewed at the following meeting.

1 SUMMARY OF THE SPS CRAB CAVITY TESTS IN 2018 (L. CARVER)

Lee covered topics related to emittance growth in his previous WP2 presentation on 25.09.18. This talk concentrates on orbit measurements and transparency. Orbit measurements were performed in MD7. Several quantities were observed: output power, by shape on the head-tail monitor, closed orbit with MOPOS Beam Position Monitors (BMPs), and orbit shifts by crab cavity (CC) kicks with DOROS BPMs. MOPOS BPMs make 1 measurement per cycle, while the DOROS ones measure continuously but average the signal over 2 sec time intervals.

Voltage measured from BPMs is significantly lower than measured by power sensors and implied from headtail: around 0.7 vs 1 MV. The likely key to this discrepancy is the bunch length. Intra-bunch motion combined with the relatively large bunch length leads to an effective reduction of the BPM signals due to low-pass filtering (200 MHz) embedded in the BPMs. When the filtering is reverted the BPM values agree with other methods on the order of magnitude. For LHC with its relatively short bunches the effect is expected to be smaller, not exceeding 20%.

For the transparency test, the CC’s were counter-phased to see if one can cancel the kick by the cavities. In the test the cavities were powered to 1 MV and the kick cancellation was observed at the 5 deg level.

- **Rama** pointed out that a 10% error on the voltage is normal and is caused by calibration errors; it is typically between 10 and 20%. **Sergey** asked what would be an estimate for HL-LHC. **Rama** replied that better than 10% is hard to achieve. **Gianni** asked how one can be sure the bump is closed. **Lee** replied it is done by a beam-based measurement.
- **Rogelio** raised a question if BPM calibration errors and if a linearity error in particular have been taken into account in the analysis. **Lee** replied that there is no an accurate estimate of this at the moment, but it is planned for future work.
- **Rogelio** inquired if there is any experimental data confirming the effect of bunch length on the measurement of crab kick orbit offset by BPMs. **Lee** replied it could be an interesting topic to study in future MDs. **Rogelio** emphasized it would be beneficial to verify the magnitude of the effect experimentally, also in view of the LHC. **Tom** noted that in LHC the low pass cut-off frequency is lower – around 70 MHz.
- **Rama** noted that the counter-powering demonstrated in the test is the baseline for making the cavities transparent in LHC. One can also switch the cavities off, but the downside of this approach is the inability to compensate the beam-induced voltage that would be present in any case.

Reviewing the minutes of this meeting, **Gianluigi** added that the corresponding crabbing angle at injection has to be evaluated (Action: **Riccardo**). Also it is important to know what the impact on DA with and without beam-beam in the presence of noise at injection for the above levels of uncertainties on counterphasing and voltage is and determine maximum acceptable level (Action: **Yannis** and **Massimo**).

2 MEASURING THE SKEW-SEXTUPOLAR COMPONENT OF A CRAB-CAVITY FROM TURN-BY-TURN OBSERVATIONS (M. CARLA)

In the past the strength of multipoles has been estimated in simulation. The strongest one is the normal sextupole b3, which corresponds to a skew a3 sextupole for the current vertical crab cavity in the SPS test. This sextupole component was measured using a kick in the horizontal plane that produces an orbit offset and an oscillation at twice the tune frequency (2Q) in the vertical plane. To find the strength of the crab cavity a3, a numerical tracking model was developed. It was tested on a static sextupole produced through the octupole feeddown and showed a good agreement with the measurements. Fitting the model to crab cavity skew sextupole kick (+-1 MV used) shows that it is 3-5 times higher than expected from EM simulation.

Another issue has also been found – an extra phase shift of nearly 90 deg, as if the cavity was 15 m away from its position. This shift is present only in the data at 2Q but not in the orbit offset data, its source remains unknown so far.

- **Rogelio** pointed out an error made in correction of damping of the signal at twice the tune frequency: the same damping rate as that of the tune signal was assumed, whereas amplitude detuning of the 2Q line should be two times faster. **Rogelio** emphasized that one has to look at the source of decoherence in order to estimate the damping rate. **Michele** replied that for the 64 turns used for the analysis the difference should be rather small, taking into account the estimated damping time of 200 turns. (Action on further analysis: **Michele**)

- **Riccardo** inquired if the kick modulation by synchrotron motion has been taken into account. **Michele** replied the model only considers the transverse motion so far; the effect of BPM signal filtering (described by Lee in his talk) has also not been taken into account yet. Crabbing is vertical while a regular kick is applied in the horizontal plane.
- **Rogelio** stressed that the results are likely underestimating the a3 component, since they do not take into account properly signal damping and longitudinal motion, and indicate a serious deviation of the a3 component above a factor 3 to 5 larger than expected. **Rogelio** inquired if the a3 multipole from RF simulations is the final one. **Rama** confirmed it is the final design. **Riccardo** proposed converting the findings in common units of multipole strength that are used in beam dynamics and RF groups (Action: **Michele**).

3 UPDATE ON CRAB CAVITIES: RF MULTIPOLES, HOM (J. MITCHELL)

Jamie reported on a change of geometry of a DQW cavity: a pick-up has been added to split functions of RF pick-up and HOM damper; that required an extra port on the cavity. The simulations of HOMs have been performed using the latest geometry and including the actual materials in simulation, in particular ceramic of the HOM couplers. New HOM table have been presented.

Regarding beam-induced heating, for DQW the 960 MHz mode could lead to up to 1 kW power loss if the quality factor *Q* can vary by a factor 2, and frequency *f* – up to 0.9%, as seen in the SPS test. To face this problem, if it occurs, the length of the feedthrough can be changed to detune the 960 MHz mode away from the beam lines. For the RFD, the 752 MHz could potentially lead to a large power loss up to 8 kW under the same assumptions. This mode has to be closely watched during manufacturing. The designers claim the mode frequency can be controlled to less than one MHz, which removes the issue. Prototypes will demonstrate if it is feasible to control the frequency of the mode at this level.

Regarding the multipoles, for the DQW, a simulated b3 is about 1500 units and b4 – about 1000 units. The reason of the large b3 is likely to the numerous vacuum ports. In a bench measurement the b3 is close to predicted – around 1600 units. For RFD, the multipoles are lower: b3 ~ -450, b4 ~ 100 thanks to pole shaping performed. A similar procedure (although rather demanding) could be done for DQW if needed.

- **Rogelio** recalled that b3 has a tolerance of 1000 and emphasized the impact of larger b3 has to be estimated. **Rama** replied 1500 units was set as the limit for the design. **Rogelio** made a point that the strength of the multipoles for the two designs may affect the choice in which IP to put the cavity. **Rama** suggested waiting for a measurement on a real LHC cavity.
- **Rama** raised the question if the b5 multipole is important and if so, what the tolerances are, noting that now the team has the tools to simulate it. **Riccardo** answered it would be useful to at least know the order of magnitude (Action: **Jamie**).
- **Benoit** pointed out the increase in longitudinal impedance of DQW, e.g. 580 MHz HOM. **Jamie** replied this is due to ceramic in the HOM coupler that has not been simulated before. **Benoit** inquired if the impact on the longitudinal stability has been investigated. **Rama** replied it is planned (Action: **Elena, Ivan**).

4 UPDATE ON TRANSVERSE STABILITY FROM CRAB CAVITY HOM (S. ANTIPOV)

Sergey presented an update on beam induced heating and transverse beam stability for DQW crab cavities. The study concentrated on the Ultimate operational scenario, where the beams are brought into collision at β^* = 41 cm.

Even for the most pessimistic, Gaussian longitudinal profile no heat load issues are expected: the peak load is below 400 W, provided the HOM frequencies do not deviate by more than 0.3% from design values.

There are two transverse modes that require attention: 1.50 GHz with a shunt impedance of 2.0 MΩ/m and 1.92 GHz with a shunt impedance of 2.5 MΩ/m, which both require around 10-20 A of extra octupole current depending on the chromaticity. The first one might be further damped through optimization of an HOM coupler. The second one cannot be efficiently coupled to with the present damper, but is near the cutoff of the beampipe – its real impedance might be lower. The mode seems to be poorly converge in simulation so the upper estimates of its impedance have been used.

- **Elias** inquired whether a reliable estimate of 1.92 GHz HOM impedance can be obtained. **Rama** replied this is challenging due to the mode being so close to the cut-off (2.08 GHz), work is ongoing (Action: **Jamie**). **Benoit** noted that in case a mode extends from the cavity, the surroundings have to be taken into account.
- **Jamie** raised a question if an action should be taken on the 1.50 GHz HOM to lower its impedance. **Rama** pointed out that a complete change of coupler geometry would be required. **Jamie** noted that the impedance will likely further decrease when the actual materials are taken into account. **Rogelio** summarized no action is required at the moment but the mode should be closely watched.
- **Rogelio** proposed adding the 8b4e beam to the analysis of heat loads and stability. **Benoit** inquired whether a full or a mixed filling scheme shall be studied. **Rogelio** suggested to start with a full filling scheme (Action: **Francesco, Sergey**).

5 HL-LHC FILLING SCHEMES: POSSIBLE OPTIMIZATION (G. IADAROLA)

Using a mixed filling schemes, as 72b+24b or 80b+32b, allows increasing the number of bunches and luminosity (up to 5%) or help fighting electron cloud heat load (mixing 8b4e and BCMS). To take advantage of the optimization it is desirable to be able to inject different kinds of bunch trains simultaneously in the LHC.

For example, the current baseline foresees injection of 2760 bunches in 13 4x72b injections, leaving 122 possible injection slots (~3% of LHC) unused. A larger number of bunches has already been successfully injected, but never accelerated. An optimized filling scheme that uses a different pattern from the injectors allows transferring 2844 bunches – 3% more in the same 13 injections. An even greater performance improvement – 5.4% more collisions in ATLAS and CMS can be achieved with an optimized 4x80b injection scheme that leaves only 9 slots unused.

Trains of 48 bunches produce less electron cloud heat load. Should they be required, an optimized 5x48b scheme gives 2744 bunches in 13 injections with 12 unused injection slots, close to the number of bunches in the baseline. The same filling scheme can be used with the BCMS, 25% brighter beam in case of unexpected emittance blow-up in LHC or its injectors.

Finally, if the heat loads become an issue, one can modulate the ratio between 72b and 8b4e to stay within the limit of cryogenic capacity at the cost of a small reduction in the number of bunches. For example, a 20% heat load reduction at the cost of 10% bunches or a 40% heat load for 14% less collisions in IP1/5, the latter requires a special pattern from injectors.

- **Hannes** emphasized it is important to start preparing soon to ensure good injector availability and a smooth and efficient injection process, noting that everything has to be tested. **Yannis** proposed to give the injectors a list of priorities and suggested that according to the present experience, the priority should be on BCMS beams. **Rogelio** replied that nevertheless 72b is the HL-LHC baseline giving the highest number of collisions in the 4 IPs, plus 72b+24b further increases these numbers. The ranking of filling schemes as viewed by the project will be presented in the LIU days in Montreaux mid February.

ROUND TABLE

Next meeting will be held on Feb. 5.