**Meeting of LIU SPS-BD WG on 11/07/2013**

**Present:** Theodoros Argyropoulos, Hannes Bartosik, Thomas Bohl, Stephane Cettour-Cave, Heiko Damerau, Juan Esteban Muller, Roland Garoby, Simone Gilardoni, Wolfgang Höfle, Giovanni Iadarola, Kevin Li, Giovanni Rumolo, B. Salvant, Elena Shaposhnikova, Helga Timkó, Jose Varela Campelo, Carlo Zannini;

**Excused**: Gianluigi Arduini;

**Agenda:**

1. Simulations for high-bandwidth feedback system in the SPS – K. Li
2. Threshold for microwave instability of the LHC beam – T. Argyropoulos
3. Follow-up of the SPS vacuum flanges: measurements and simulations J. E. Varela
4. Update on the SPS impedance: new wire scanners – B. Salvant
5. SPS intensity limitation without the 200 MHz RF upgrade – E. Shaposhnikova

**Presentations:**

**Kevin: Simulations for high-bandwidth feedback system in the SPS**

A detailed model for all components of the high bandwidth feedback system under study has been implemented in HeadTail, including the pickup transfer function, pickup noise, FIR filters, kicker noise and kicker transfer functions. The 5 five previous turns for each bunch slice are taken into account for calculating the correction kick. The simulations are done for a single bunch beam only, since it is the intra bunch motion that is of interest. The model parameters for the transverse impedance and the electron cloud density are chosen to lie in the unstable region. Chromaticity is always corrected to zero. The longitudinal parameters are defined through the bunch length and the momentum spread; the synchrotron motion is modeled by linear restoring force.

*Maybe the longitudinal emittance used in the simulations (>0.5 eVs) is a bit too large. Realistic values are more like 0.35 eVs at injection and 0.42 eVs after filamentation.*

In case of electron cloud instabilities (ECIs) with a central electron density of 6x1011 e**-**/m3 (where the unstable modes are 0, -1 and -2), it seems that there is not enough margin for stabilizing the beam with a feedback bandwidth of 200 MHz as the system becomes unstable for high gain settings. A bandwidth of 500 MHz and a gain setting of 0.6 are sufficient to damp the instability.

*As suggested by Elena, a more general approach could be to look at the wake field induced by the electron cloud and the corresponding frequency components. At higher beam energies, the wake field may have higher frequency components. This would be important for defining the specifications of the feedback system. The most critical parts of the cycle need to be studied in more detail, as for example during the ramp when the bunch length is minimal, i.e. just before the controlled longitudinal emittance blow-up. It is however not clear which is the most critical part of the cycle with respect to electron cloud instabilities.*

A gain scan was performed also for the case of a broad band resonator impedance (resonance frequency 1.3 GHz, 15 MΩ shunt impedance) driving a transverse mode coupling instability (TMCI). Less gain is needed for higher bandwidth and the gain acceptance becomes very small. Consequently, the feedback is driving the beam unstable for too high gain and high bandwidth. This could be related to problems with the phase response of the system and will be investigated further.

*Different resonance frequencies of the broad band impedance should be studied. A more realistic longitudinal distribution should also be studied in the simulations, since the bunches are longer and the longitudinal emittance is smaller at injection where the TMCI happens.*

The effect of exceeding the available kicker strength (“saturation”) is studied in the case of the ECI for a wide range of electron densities and gain settings and for different bandwidths. If the available kick strength is too small, only a very narrow window of operation without saturation is obtained. In particular, for high gain settings the feedback is driving the beam unstable again due to the saturation of the kicker. In addition, more noise is getting into the system for higher bandwidth and this makes the feedback “blind”. It is found that the kicker should provide a kick strength of a few 10-4 eVm/s to allow for a large enough operating region. Open questions concern mostly the generation of the longitudinal particle distribution and the corresponding beam parameters.

*For both TMCI and ECI, the simulations should start from realistic bunches as extracted from the PS to account for the full complexity.*

*In the first stage of the studies, there were some issues related to numerical noise due to the limited number of macro particles. This was solved by using a longitudinal binning with a constant number of macro particles. Up to now, there was no artificial noise injected into the system yet since the numerical noise is larger than the expected noise level.*

*It is important for finalizing the studies to settle the bunch parameters to be used in the simulations. Furthermore, the effect of space charge should be taken into account: the experience in the MD studies shows that for beams with higher brightness the synchrotron sidebands start to overlap and this needs to be studied in combination with the feedback. Also the effect of the double RF system should be taken into account.*

**Action K. Li: Follow-up on simulations with LIU beam parameters including also a realistic initial longitudinal distribution**

**Theodoros: Threshold for microwave instability of the LHC beam**

A follow-up of the simulations of the longitudinal instability caused by an impedance at 1.4 GHz resonance frequency was presented. The properties of the impedance were determined from the measurements with long bunches. The simulations of the instability at flat top are compared with the measurements during the bunch rotation MD, where a bunch length increase with intensity was observed. Further analysis of the data shows that there was no dependence of the bunch length on the beam intensity after filamentation. This indicates that a longitudinal emittance blow-up occurred at some point during the ramp. Simulation results presented in previous meetings were performed for a longitudinal emittance of 0.4 eVs. In order to reproduce the experimental conditions, simulations were repeated for a longitudinal emittance of 0.35 eVs. The obtained bunch length as function of intensity agrees with the observations during the measurements. In particular, the reduced bunch lengthening with higher RF voltage in the Q26 optics was confirmed in the simulations.

*Although the measurements in the Q20 optics were performed up to intensities of 3.7x1011 p/b, the simulations shown here go up to 2.7x1011 p/b only. The simulations for higher intensity are not shown because of difficulties with generating the particle distribution.*

*The reason why the instability itself is not observed but only the resulting increased bunch length at flat top is explained by the fact that in reality the instability can start already before reaching the flat top. As a consequence, the longitudinal emittance is blown up and this is causes the measured bunch length increase. On the other hand, a clear threshold effect is observed in the simulations.*

A comparison of the simulations for the Q20 and the Q26 optics shows a slightly different behavior between the two optics. In the case of Q20, the instability has a higher threshold but it is much faster. It seems that the instability thresholds scale according to the Keil-Schnell-criterion. In reality the situation is more complicated, as the beam suffers from a mixture of the microwave instability and loss of Landau damping.

*It was observed during the MDs that in order to minimize the emittance blow-up the RF voltage has to be kept as low as possible up to some point, where higher voltage was needed again. This could be another indication for the two effects: For the loss of Landau damping longer bunches (or bucket more filled) is better, while for the microwave instability shorter bunches are better since the threshold scales like (Δp/p)2. Further simulations including all known machine impedances are thus needed.*

**Jose: Follow-up of the SPS vacuum flanges: measurements and simulations**

The results of the Eigen mode simulations of the SPS enamelled flanges presented in the previous meeting were very sensitive to small changes of the model. A new approach based on frequency domain simulations as suggested by Alexey Grudiev seems to give more robust results. The method (originally applied to model the transient beam loading in CLIC) is based on plane wave excitation for different frequencies. The obtained peaks in the impedance spectrum are comparable with the results of the Eigen mode simulations used before, in particular considering the resonances at around 1.53 GHz found with both options of boundary conditions of a perfect magnetic conductor (PMC) and a perfect electric conductor (PEC).

*The fields obtained with the frequency domain simulations look like the TM010 mode in a simple pillbox cavity. Thus, the impedance could be mainly caused by the cavity like structure due to the smaller diameter of the vacuum chambers around the flanges, and not primarily due to the electromagnetic properties of the flange itself. It could be tested how big would the impedance were without the enamel layer.*

*Flanges without the enamel layer act like a perfect cavity. With the enamel layer, there are additional modes due to the fields between the flange and the clamp.*

New measurements were performed with a “naked” flange with QD-type vacuum chambers attached on either side. The mock-up used for the measurements has a smaller gap between the flanges compared to the installation in the SPS. The measurement of the transmission coefficient from one side to the other shows a small resonance at 1.8 GHz. The measured lower impedance and the frequency shift can be reproduced with simulations. A first measurement of a complete unit of a BPH with the corresponding bellow was shown. The measurements will be refined to obtain cleaner results.

During a visit of the tunnel, it was found that there are new prototypes of BCTs installed in the SPS. It turns outs that five of these devices were installed in June 2012. Their impedance was not studied prior to installation.

The next steps in the studies include the careful implementation of the post-processing in the simulations to obtain the R/Q, cleaner measurements, completing the general survey of elements with high impedance and the classification and counting of the different flange types in the SPS.

*The impact of the presence of the bellow on the impedance should be studied in simulations and measurements. Furthermore, it should be checked if really the flange itself is much less relevant for the impedance compared to the “cavity” structure. In this case, it has to be understood how many flanges with the cavity like geometry are installed in the machine.*

*The impedance of the BCT prototypes needs to be studied* ***🡪 Action Impedance team***

**Benoit: Update on the SPS impedance: new wire scanners**

A new wire scanner prototype will be installed in the SPS. In order to shield the wire from beam induced fields in park position, the present design has a continuous beam pipe with only a small gap to let the fork pass through during a scan. This design creates a significant low frequency mode due to the longitudinal gap (at 160 Mhz with shunt impedance of 80 kΩ and a Q of 1300), which is particularly worrying for longitudinal coupled bunch instabilities. A possible mitigation of the problem is shielding with ferrite. The option of installing RF couplers for reducing the impedance is also investigated as long-term solution. An alternative proposal was made by Heiko: instead of using a round beam pipe with a complete longitudinal interruption, the shielding of the wire could be achieved with two parallel plates and the wire passage could be achieved by “U” shaped cuts. A comparison of the impedance of the different options shows that the proposal of Heiko reduces the impedance to the level of the first design with ferrites. However, BI requests that the design allows for a complete rotation of the fork which is not possible in this proposal.

The impedance spectrum of the wires scanners presently installed in the machine has peaks only for higher frequencies. However, the structure is more complicated in reality compared to the drawings, as there are tapers and many plates of ferrite. A comparison with the designs of the new wire scanner under study shows that the wire scanners currently installed in the SPS yield the smallest power loss. The new design has a significantly higher power loss even with the ferrite shielding (which might even require cooling), while the proposal of Heike lies in between.

The work is ongoing: future studies will compare the obtained simulation results with measurements of the presently installed wire scanners obtained by F. Roncarolo et al. (2003). The possibility of using the ferrites for reducing the power loss in the new design will be further investigated and alternative solution will be tested.

*As proposed by Roland, other possibilities of reducing the impedance of the new design could be to load the tank capacitively or to coat the inner surface of the beam pipe with a resistive layer.*

*Since the impedances of the present wire scanners seems to be also not negligible, they should be added to the SPS impedance model.*

**Elena: SPS intensity limitation without the 200 MHz RF upgrade**

The SPS 200 MHz RF system consists of 2 cavities with 4 sections and 2 cavities with 5 sections with a present power limitation of 700 kW per cavity and a total RF voltage of 7.5 MV. Although never tested, the cavities could be used in pulsed mode (if the machine is less than half filled like in case of the LHC beam), which would allow for around 1.0-1.1 MW per cavity. Due to beam loading, the cavities with 5 sections become inefficient for higher beam currents. It was thus proposed to rearrange the existing 4 cavities to 6 shorter cavities (2x4 sections and 4x3 sections). This requires 2 new power plants, which would provide 1.6 MW each.

In MD studies in the end of 2012 with the Q20 optics, it was observed that the bunch length at flat top with the high intensity 25 ns beam was increasing roughly proportional to intensity. The best beam parameters achieved were an average bunch length of 1.63 ns for an intensity of 1.35x1011 p/b.

*The bunch length increase with intensity is partially due to an already increased bunch length at extraction from the PS (larger longitudinal emittance was used intentionally for increasing stability in the SPS). The PS would be able to deliver the same beam intensity within the nominal longitudinal emittance.*

In order to fully profit from the Q20 optics at flat top, higher RF voltage is needed due to the higher slip factor which then results in better beam stability.

For higher beam intensity the required voltage is actually increasing: In order to avoid instability due to loss of Landau damping and microwave instability the voltage needs to be increased proportional to intensity. Furthermore, higher voltage is required to compensate for potential well distortion. Here the scaling depends on the longitudinal particle distribution.

A voltage limitation during the acceleration coud be bypassed by a slower ramp (longer cycle, increased LHC filling time). A voltage limitation at flat top would result in longer bunches and thus increased losses during capture in LHC.

The maximum beam intensity at SPS flat top with the 25 ns beam is given by: 1.35x1011 p/b without any RF upgrade (achieved in 2012), 1.5x1011 p/b when pulsing the existing 4 cavities (1.05 MW per cavity) after the low level upgrade and 2.1x1011 p/b after rearranging the cavities, upgrading the low level and the RF power upgrade with 2 new power plants with 1.6 MW each. These estimations are based on the simplified models and experimental results from 2012.

*The maximum beam intensities discussed here correspond to flat top without taking into account the intensity reduction due to scraping for beam tail cleaning.*

Minutes written by Hannes Bartosik