**Meeting of LIU SPS-BD WG on 30/05/2013**

**Present:** Theodoros Argyropoulos, Hannes Bartosik, Thomas Bohl, Alexey Burov, Fritz Caspers, Heiko Damerau, Jose Ferreira Somoza, Wolfgang Höfle, Juan Esteban Muller, Brennan Goddard, Elena Shaposhnikova, Mauro Taborelli, Helga Timkó, Jose Varela, Carlo Zannini;

**Excused**: G. Arduini, E. Metral, G. Rumolo, B. Salvant

**Presentations:**

**Helga: Bunch lengthening at the SPS flat top**

It was observed during the LHC MDs, that it was not possible to extract single bunches with different intensities but with the same bunch length from the SPS, even if the longitudinal emittance and the bunch length at injection were practically constant. In fact the bunch length at flat top was increasing with intensity and this was also observed in both the Q26 and the Q20 optics during the MDs for the AWAKE experiment. In all cases, the 800 MHz cavity was switched on with the usual voltage program for beam stabilization. The bunch lengthening was observed not only after the bunch was getting longitudinally unstable, but even without significant dipole or quadrupole oscillations (like in Q20 for intensities below 3e11 p/b). A possible explanation for this effect could be the Potential Well Distortion due to an inductive impedance, which above transition results in an reduction of the effective voltage seen by the bunch and thus a bunch lengthening with intensity.

Laclare’s formula was used to fit the experimental observations. The bunch length at zero intensity was obtained from a specific data set with large intensity range measured in the Q20 optics, where it was determined as τ0=0.95 ns. Using this value and the correspondingly scaled value for the measurements with Q26 (best agreement when using τ0=0.7 ns), the imaginary constant impedance found from the best fitting of different data sets (obtained with both optics) is about Z/n≈15 Ω. In comparison, estimating Z/n from the intensity dependent synchrotron frequency shift at injection yields about 4-5 times smaller values. One possible reason of the discrepancy between the two methods could be the fact that a constant Z/n is assumed in Laclare’s formalism. A more likely explanation is a microwave instability causing the observed bunch lengthening (see talk of Theodoros) while the potential well distortion giving only a small contribution.

*The bunch length measured at the SPS injection was practically independent of intensity. However, since the bunch is rotated in the PS before extraction, this bunch length measurement in the SPS corresponds more to the momentum spread of the bunch in the PS. Thus, if there was already bunch lengthening in the PS, one could not easily observe it in this measurement.*

*Although there is also potential well distortion on the flat bottom, no strong dependence of the bunch length on intensity was observed after filamentation (tbc => Helga & Theodoros)*

*In order to disentangle potential well distortion from longitudinal emittance blow-up, one would need to measure not only the bunch length but also the momentum spread at the same time. However it’s not easy to measure directly the momentum spread for a bunched beam, especially in the absence of a longitudinal Schottky monitor.*

**Theodoros: Effect of the 1.4 GHz impedance on a single bunch at the SPS flat top**

As presented at the last SPSU-BD meeting, the measurements of the bunch spectrum, when injecting long bunches in the SPS with RF off, reveal a resonance at 1.4 GHz. Macro-particle simulations showed that this is caused by the impedance with high Rsh and low Q.

*The characterization of the impedance from the beam measurements gives the effective Q. In reality it can result from staggering of several (or many) high Q resonators.*

Now the effect of this impedance at 1.4 GHz on a single bunch is studied in macro-particle simulations, taking into account also the longitudinal impedance of the RF cavities and the SPS kickers. An initially matched longitudinal distribution with an emittance of 0.4 eVs is created iteratively for RF settings like in the bunch rotation measurements at flat top in the Q20 optics. In the simulations with the impedance at 1.4 GHz included, a micro-structure pattern is building up after a few hundred revolution turns followed by a sharp emittance blow-up. The final bunch length after the blow-up agrees quite well with the bunch lengthening observed during the bunch rotation measurements. Just for comparison, the simulated bunch length increase was used to estimate a constant imaginary impedance, assuming that the bunch lengthening would be caused only by potential well distortion (using Laclare’s formula like it was done in Helga’s studies). Also here the best fit of results is with Z/n≈15 Ω, although the reason for the bunch lengthening in the simulations is of course the emittance blow-up due to the microwave instability driven by the impedance at 1.4 GHz.

Without the 1.4 GHz impedance, the bunch is much more stable and emittance blow-up occurs slowly and at higher intensities.

*Simulations are done for flat top only and a sharp emittance growth is observed with the 1.4 GHz impedance. In reality the emittance blow-up is not so sharp, since the threshold for different intensities is reached at different energies before the flat top and thus there is a smooth growth. Therefore the observations in the measurements were at first not associated with this instability.*

*The longitudinal emittance of 0.4 eVs was chosen because it is close to the measurement (at injection this value corresponds more to the LHC beam rather than to the single bunch); It should be checked how much would the results change if a smaller emittance is chosen (=> Theodoros).*

*Can the impedance be localized from the beam measurements? Unlike in the transverse plane, the motion in the longitudinal plane is too slow in comparison with revolution period and so it is practically impossible to localize the source using the same approach as in the transverse plane.*

*Remark on the formula for the potential well distortion: it is assumed that the longitudinal emittance is constant; if the longitudinal emittance is not constant, for example due to mismatch at injection, the formula is not correct any more. 🡪 This is true, but for higher intensity the bucket would become more matched and so this should give less blow-up due to filamentation and less bunch length increase (opposite to what is observed).*

**Jose Varela: SPS Enamel Flanges Simulations and Measurements**

A new model of the flanges has been established in CST starting from the work of Benoit. The different length scales relevant for the electromagnetic calculations (i.e. the beam radius of 156 mm compared to the separation between the flanges of 2.5 mm) are difficult to handle correctly in the simulations, for example with respect to proper meshing. The model consists of cylindrical beam pipes (instead of the elliptic chamber in the machine) on both sides of the clamps and does not include yet the bellow. Inconsistencies between different boundary condition options have to be sorted out: using a Perfect Matching Layer (PML) gives not the same impedance spectrum as the waveguide port, which is using analytical calculations and thus depends on how many modes are taken into account (here the first 50 allowed modes). Nevertheless, in both cases resonances are observed around 1.4 GHz and 3.4 GHz.

*It is not clear if the two different methods should give exactly the same result. In principle, both methods should absorb all energy at the boundary. Further checks of this effect should be done with the simplified model of Benoit.*

*The present simulation model is computationally quite heavy as it uses already 30 million mesh cells. In this case there is at least one mesh cell in between the flange and the isolation. The possibility of a variable meshing is not implemented automatically in CST but is in principle possible.*

*The vetronite used in practice to protect the enamel coating is not taken into account in the model. However it is not expected to change the results significantly (but on the other hand is rather difficult to model).*

First attempts to measure the impedance of these flanges have been performed, but several difficulties have been encountered. In some cases the enamel is scratched resulting in a direct contact between the two flanges when the clamp is put on. Furthermore, the ensemble of the flange and the bellow has many resonances around 1.4 GHz which are not easy to disentangle (the bellow behind the flanges forms a small cavity). The peak observed at the moment cannot be clearly associated with the impedance itself, but could also be related to the measurement setup. These first studies were performed with a lab flange. Further measurements will be performed on a flange without bellow, in order to establish clean measurement conditions. An alternative approach could be to study directly the impedance of the full configuration of flanges plus the neighboring equipment as in the machine. These elements could also be included in the CST model and simulated.

Additional information can be deduced from the work of *G. Dome*, who made a theoretical study and performed measurements on the SPS bellow and beam pipe configurations in the 70s, including a table with the cut-off frequencies for different modes.

*The impedance of a single flange has to be multiplied by the total number of flanges. Stephane Cettour-Cavé is making an inventory of the enamel flanges in BA3. It can be extrapolated that there could be around 1500 flanges around the machine. Approximately 400 of those are installed around the BPMs. Even if there are 1500 of these flanges, they would still not yet account for all the impedance needed to reproduce the beam measurements in the simulations: the 1500 flanges with 40 Ω each give 60 kΩ, while we are looking for a total of around 300 kΩ.*

*It was discussed if a crash program for reducing this impedance should be launched. Since any such campaign would involve major work, we have to be really sure about the source (is there anything else apart from these flanges?) of the impedance but also if it is really harmful for the beam. Therefore reliable measurements of the impedance need to be performed and the simulation models further developed. Nevertheless, it could be discussed with the vacuum group what would be the latest date for any intervention during LS1. This will depend of course on the type of action needed.*

*Fritz is asking if we need these isolated flanges at all and if one could use other clever grounding schemes for avoiding these isolated flanges, or maybe just reduce the number of isolated flanges. 🡪 The issue is not so trivial. There are problems due to grounding where we should not have it, but also because we don’t have grounding where it should be …*

*The present status of the shielded pumping ports should also be investigated. During the impedance reduction campaign for the pumping ports, about 80% of all pumping ports were shielded. However, it could be that the shielding is not working properly in some cases, as the shielding was mechanically difficult to design and its installation was tricky. Non- (or non-properly) shielded pumping ports could also contribute to an impedance at 1.4 GHz. The corresponding peak in the bunch spectrum was measured already right after the installation of the shielding.*

Minutes written by Hannes Bartosik