**Meeting of LIU SPS-BD WG on 26/04/2012**

**Present:** Theodoros Argyropoulos, Hannes Bartosik, Nicolo Biancacci, Alexey Burov, Chandra Bhat, Thomas Bohl, Fritz Caspers, Roland Garoby, Brennan Goddard, Giovanni Iadarola, Mounir Driss Mensi, Elias Mètral, Mauro Migliorati, Alexander Molodozhentsev, Nicolas Mounet, Juan Esteban Muller, Giovanni Rumolo, Benoit Salvant, Elena Shaposhnikova, Adrian Ulsrod, Vittorio Vaccaro, Carlo Zannini;

**Presentations:**

**Carlo: SPS Impedance modeling**

The SPS impedance model should include the 19 kickers, the 106 BPHs and 96 BPVs, the 200 MHz and 800 MHz travelling wave cavities. The latest model includes also the enamel flanges and the resistive wall impedance of the different SPS vacuum chambers.

As a first step, the SPS kickers were modeled in CST *Particle studio* simulations as a simplified structure consisting of two parallel ferrite plates enclosed in a perfect conductor. Benchmarking the simulation results with the theoretical predictions of Tsutsui’s model showed very good agreement and gives thus confidence in the simulation method. The theoretical model was then extended taking into account the C shape of the kicker magnets. In comparison to the simple Tsutsui model, the refined model predicts a significant increase of the horizontal impedance below a few hundred MHz as the TEM propagation becomes comparable to the magnetic circuit length. In the next step these simulations were refined taking into account the segmentation of the kickers. The large number of segments of the MKP magnet has a huge effect on the transverse impedance. The segmentation of the MKE kickers on the other hand seems to play a minor role. The serigraphy of the MKE kickers yields the desired drastic reduction of the real part of longitudinal impedance.

*In fact, a reduction of the real part of longitudinal impedance of the MKE kickers with serigraphy by a factor 6 was expected, which is in good agreement with the simulations.*

*It was pointed out that the assumptions on the magnetic permeability are based on 8C11 ferrite.*

The peak in the longitudinal impedance around 45 MHz caused by the serigraphy can be explained by a quarter-wavelength resonance.

*It was discussed if the geometry of the serigraphy (like changing the period) could be further optimized with the help of CST simulations. This could be of particular interest, since these kicker magnets will stay in the machine for a long time.*

The CST simulations show that the serigraphy leads to similar peaks also in the transverse impedance. In particular, the vertical driving (dipole) impedance exhibits a peak around 95 MHz and the detuning (quadrupole) impedance a peak at 45 MHz. Thus, the generalized vertical impedance shows two peaks below 100 MHz. The central frequency of these peaks depends thereby strongly on the length of the fingers applied during the serigraphy.

The simulation results were compared with bench measurements. In the case of the MKP kicker, the CST simulations including the segmentation are in reasonable agreement with the measurements for both the longitudinal and the vertical impedance. Comparing the measurements of an MKE-L kicker with serigraphy with the CST simulations show very good agreement apart from a shift of the low frequency resonance. Different error sources were investigated by simulating only a single kicker cell. First, limitations of the coaxial wire method used for the bench measurements might explain the discrepancy with respect to the simulations. Thus, the bench measurement was simulated in CST placing a long wire inside the kicker structure. Although the broadband behavior is well reproduced, the low frequency part can still not be represented correctly. Another error source could be the model of the ferrite used in the simulations. Thus measurements of the ferrite were performed in order to validate the model of the complex permeability of the 8C11 ferrite used in the simulations.

The model of the SPS resistive wall impedance was also improved: as opposed to the old model based on a single type of vacuum chamber, the different chambers are now taken into account weighted by their respective length and the corresponding beta-functions. The iron in the magnetic yokes is also taken into account. The effect of the iron is clearly visible on the longitudinal wall impedance at 10 kHz and at 40 kHz.

Elements not included in the SPS impedance model so far are the pumping ports with their shielding, the electrostatic septa (ZS) and the two RF systems.

In the next months, Carlo will concentrate on the improvement of the longitudinal impedance model. A few slides were presented on the present status of the longitudinal impedance model including the resistive wall and the contributions from all kickers and their serigraphy.

*A good model for the longitudinal impedance is crucial for understanding the observations in the machine.*

*It was asked if the last MKE kicker presently being treated with the serigraphy could be installed already during the year if it is ready. However, the installation would take a few days in addition to conditioning and pumping and seems thus not being feasible before the long shutdown.*

**Benoit: First results of ZS simulations with CST**

The status of the ZS simulations with CST was presented. Simulations with a simplified model without shielding yield a different impedance spectrum compared to the measurements performed in 2001. They can be better reproduced using a refined model, which is based on the geometry imported from the CATIA drawings including the shielding. The thin wires of the septum remain a problem in the simulations as they make a proper meshing quite tricky.

*The shielding of the ZS septa (end connections) was installed in 2000/2001 during the shielding campaign. It is not clear if the reported measurements were performed on a shielded ZS.*

**Action 🡪 Fritz will check if the ZS used in the measurements was shielded.**

*The ZS are presently still limiting elements in machine operation. It would be very useful to obtain a better understanding of these operational limitations, like the high voltage breakdown. Maybe the location of the voltage break down is related to local heating, which could be estimated from the simulations.*

**Nicolo: SPS transverse impedance measurements**

The impedance of the SPS is calculated in the model using the impedance model presented by Carlo. In particular the resistive wall impedance was calculated taking into account the actual beta function values. Due to the serigraphy applied to 7 out of the 8 MKE kickers, the horizontal tune shift expected from the new model is negative (as opposed to the years before, where only a few MKEs had the serigraphy and the tune shift was positive). The measurements of the imaginary vertical impedance in the years between 2000 and 2011 were compared. Although they might have been performed with different bunch lengths (which might have an impact on the measurement due to different bunch spectra), the impedance was clearly reduced after the impedance reduction campaign in 2000.

*The impedance reduction campaign was addressing mainly the longitudinal component in order to eliminate the microwave instability. The reduction of the transverse impedance came as a byproduct.*

*It seems hard to resolve small changes of the impedance by this kind of measurements. It seems thus crucial to keep at least the bunch length constant.*

Measurements of the horizontal impedance in 2012 show still a positive detuning with intensity, despite the serigraphy applied to 7 MKE kickers. This is in contrast to the refined SPS impedance model, which predicts a negative detuning. Possible reasons for the discrepancy might be other elements, which contribute significantly to the horizontal impedance but are not considered in the model.

*An average bunch length was used in the data analysis, while the actual bunch length should be used.*

*The measurements of 2012 were performed with a large intensity range, while previous measurements were done with much lower intensities. This could also be part of the reason why the negative tune shift was not observed.*

The status of the impedance localization studies was presented. The idea is to use the phase information from all BPMs around the machine to localize significant impedance sources by the intensity depended phase shift with respect to the optics model. During measurements in 2011, only a subset (80%) of the BPMs was working. In addition the noise level did not allow for a clean phase reconstruction. As a result the measured phase shift exceeded even the total tune shift in some of the cases. A proper error analysis should be performed to better understand the limitations of the method. Clearly, more work is needed. In particular, careful calibration of the MOPOS system needs to be carried out in collaboration with BI experts. Furthermore, a proof of principle measurement is planned in the PS, which has a more modern BPM system.

*The vertical tune shift measurements yield very similar results since 2007 (within 15%). Compared to these measurements there are still around 8 MΩ missing in the impedance model. In the horizontal plane the measured tune shift does not match with the expected negative slope.*

**Giovanni I. and Hannes: Short summary of observations during the 2012 SPS scrubbing run**

The actual schedule of the scrubbing run 2012 was dictated by the heating of the one MKE kicker without serigraphy. In previous years the kicker temperature limit was chosen at 70° if the kicker needed to be operational and 90° in case the kicker was not needed. In order to exclude disturbing the filling of the LHC, the kicker temperature limit was set to 60° during the scrubbing run in 2012. The kicker cool down time was then devoted to studies with the 50 ns beam, which is not significantly heating the kicker. It was emphasized again that the main purpose of the scrubbing run was to study the scrubbing effect on the StSt liners in the e-cloud monitors and to accumulate electron dose on the removable sample, rather than scrubbing the SPS itself. Data was taken with the shielded pick-up, bunch by bunch beam position with the bandwidth pick-up, pressure gauges, microwave transmission technique, and the fast wire scanners. The signal on the e-cloud monitors was recorded as function of an orbit bump, for different batch spacing, with uncaptured beam and using the microbatch filling scheme. The pressure behavior close to the long coated chamber was studied. A few measurements of bunch-by-bunch emittances were taken and studies concerning the e-cloud instability were performed.

Only very limited conditioning in the central and the total region of the StSt liner was observed, when analyzing the e-cloud signal at 1.5 s after injection. When injecting the 25 ns beam with ultimate intensity the total e-cloud signal is clearly increased while the central density remains practically constant. The scrubbing effect on the StSt liner was analyzed by monitoring the electron cloud signal at 1.5 s after injection. An unexplained decay of the central and the total e-cloud signals towards the end of the scrubbing run when using the Q20 optics needs to be understood. It is interesting to note that with the ultimate beam (in the nominal Q26 optics), only the total but not the central electron density increased. In comparison to 2012, the scrubbing run in 2008 heated the extraction kickers up to 90 degrees at some point. A clear conditioning effect can be observed in the 2008 data, where the central density is reduced by a factor 5 and the total density by 30%. It remains to be understood why at some point the measured e-cloud current in the previous scrubbing run was much more reproducible.

It was realized that almost the same amount of beam with 25ns bunch spacing as present in the machine during the scrubbing run was used before the scrubbing period for machine conditioning. Thus the “easy part” of the scrubbing was done before the actual scrubbing run.

*The removable sample was accidentally vented during an intervention of UA9. Nevertheless the SEY measured afterwards was about 1.6 in the center and around 1.9 in the outer parts of the sample.*

*It was clarified that the enhancing effect of the uncaptured beam was observed in 2008 on a liner coated with aC, which exhibited in general a very low electron signal. On the other hand the effect of the unbunched beam on the StSt liner was very small. When the uncaptured beam was passing the bunch train, a slight enhancement of the e-cloud signal on the liner was observed. It was pointed out that the uncaptured beam should nevertheless help for scrubbing in the rest of the machine where the SEY is lower than on the liners.*

*The fact that the e-cloud density is reduced more quickly in the center should be studied in the context of low energy electrons: there are fewer electrons in the center of the chamber and they decay faster. A possible explanation could be that the electrons in the central part could have higher energies. It seems that this effect could be important for understanding the overall mechanism of the electron cloud build-up.*

*It was also proposed to study electron cloud effects with injection of a single batch of high-brightness but fewer bunches after 4 regular batches in order to simulate a high brightness regime and study possible electron cloud instabilities. This could also be useful for defining the specifications for the high-bandwidth feedback.*

The beam parameters during the scrubbing run were summarized. The PS delivered 25 ns beam with intensity around 1.25e11p/b, transverse emittance ~ 2.5 μm and longitudinal emittance of ~ 0.3 eVs. At the end of the long flat bottom of the scrubbing cycle in the SPS the measured emittances were between 2.5 μm and 3 μm. Similar values were measured right after injection and at top energy, thus showing no indication for slow emittance growth due to electron cloud effect. An instability provoked by lowering chromaticity after the injection of 4 nominal batches is believed to be driven by electron cloud. Indeed, losses on the last batch were only observed with the nominal batch spacing, but not with a larger spacing between the 3rd and the 4th batch.

There were also some studies with the “microbatch” filling scheme (6 batches, each consisting of 48 bunches with 25 ns spacing) with ~1.2e11 p/b. The emittances in this case were close to 2.5 μm. Less vacuum activity and a better lifetime compared to the nominal filling scheme with 288 bunches was observed, which could be explained by less electron cloud present in the machine.

The 25 ns beam with ultimate intensity, i.e. 1.8e11 p/b, and emittances below 4 μm were extracted from the PS and injected to the SPS scrubbing cycle. For this beam, the emittances measured in the SPS were between 4.5 μm and 5 μm at injection and at the end of the long flat bottom.

**Thomas: Observations during the scrubbing run – unbunched beam**

The beam current over one SPS revolution turn was acquired during the scrubbing run using the wall current monitor and analyzed with a spectrum analyzer in order to measure the unbunched beam components. The measured power of the 200 MHz component of the beam current shows that most of the particles not captured in the RF buckets loose energy, as they circulate with a higher revolution frequency compared to the synchronous particle. When these unbunched particles encounter the bunch train, they pile up and do not pass the part of the circumference filled with bunches. This can be explained by the larger RF voltage measured in the filled buckets, which creates a kind of barrier bucket. The reason for the higher RF voltage is an imperfect beam loading compensation.

**Elena and Hannes: Short summary from MDs in week 17**

Experiments concerning the longitudinal single bunch instability were performed. The goal was to perform measurements with single bunches without phase loop, the case which can be used for comparison with simulation studies. Single bunches in the Q20 cycle with nominal parameters become longitudinally unstable during the ramp for intensities close to 1.7e11p/b with the 800 MHz RF off, while in the nominal optics the threshold is around 1.1e11p/b. It was reminded that even the LHCindiv beam needs the 800 MHz and feed-forward system on for beam stability in operation.

Space charge studies were performed with variable intensity single bunches in the Q20 optics. The performance with different working points was compared. The effect of putting the working point close to the integer resonance in the form of core emittance blow-up was observed.

Minutes written by Hannes Bartosik