**Meeting of LIU SPS-BD WG on 30/01/2014**

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**Agenda:**

1. Momentum slip stacking for ions – T. Argyropoulos
2. ZS impedance measurements – H. Day
3. Analysis of schemes for doublet production – J. Esteban Müller

**1. Theodoros: Momentum slip stacking of the nominal I-LHC beam in the SPS**

The possibility of producing an ion beam with 50 ns bunch spacing by means of slip stacking of two batches with 100 ns bunch spacing was studied in particle tracking simulations. The procedure of slip stacking consists of a change of the RF frequency in opposite directions for the two batches, i.e. one of the batches is slightly accelerated and the other is decelerated so that they approach each other azimuthally and eventually overlap. In the second stage, the RF frequencies are brought closer together again such that the buckets of the two batches are almost touching but are still completely separated, which is approximately the case if the difference in RF frequency is more than four times the synchrotron frequency (ΔfRF/fs=α≥4). This last step, together with the recapture at the central RF frequency has been studied in simulations. Only the case of slip stacking at flat top was considered. The parameters varied in the study are the frequency difference ΔfRF, the time of the manipulation for bringing the frequencies together, the time for the recapture and the capture voltage. The phase space of a selected bunch at the moment of capture was shown for different cases. So far the best capture efficiency was achieved with 1 MV starting from a frequency separation of ΔfRF/fs<4, for which the losses were about 7%. The obtained final longitudinal emittance in this case is about 0.3 eVs/A (blow-up by a factor 2 compared to initial emittance), which is close to the limit for extraction to the LHC even with the higher voltage available after the major LIU SPS 200 MHz RF upgrade. Reducing the capture voltage results in smaller final longitudinal emittance, but increased losses (and vice versa). A reduction of the losses was achieved by increasing the total time used for the RF manipulations. Further studies are needed for optimization of the parameters.

* *The possibility of performing the slip stacking at an intermediate energy plateau should be investigated in view of reducing the final longitudinal emittance.*
* *In case of performing the slip stacking at top energy, the time for filamentation needs to be taken into account for evaluating the total time required for the slip stacking manipulations.*
* *The present LLRF allows only programming a single RF frequency for all 200 MHz cavities and it is therefore not possible to experimentally test the full slip stacking procedure (this will be possible only after the LLRF upgrade).*

**2. Hugo: ZS impedance measurements**

Coaxial wire measurements and measurements using probes were performed on a single ZS tank and a single pumping port module in order to determine their longitudinal impedance. The results were compared with simulations. There are 6 pumping modules interleaved by 5 ZS tanks installed in the SPS. Thus, resonant modes forming along the multi tank structure in the machine cannot be measured with the present bench setup. Furthermore, resonant modes above the cutoff frequency of the connections flanges (≈586 MHz) can propagate across multiple tanks and can thus have different fres, Rs/Q and Q in the test setup with a single tank, i.e. the measurements are not fully representative of the impedance seen by the beam. The presented studies are therefore not fully representative of the impedance seen by the beam in the machine.

The real part of the longitudinal impedance of the ZS tank measured with the coaxial wire is observed to depend on the type of termination used for the different circuits of the ZS (such as the ion trap, the septum anode), in particular in the frequency range below 200 MHz. Most of the resonances found in this range are strongly suppressed with the operational settings of the ZS circuits. A strong resonance at 38 MHz has been found independent of the termination used. Strong resonances are also measured between 600 and 800 MHz, which are probably caused by the high voltage structure of the septum. A table of the measured longitudinal resonances was presented. A simplified model of the ZS has been used to simulate the wire measurements in CST. The simulation results depend strongly on the frequency scan parameters used for the iterative solver and the simulated model does not represent the real device sufficiently, as all measured resonances below 200 MHz are missing in the model.

* *It is not clear if the family of strong resonances around 600 MHz is caused by an actual impedance or if they are an artifact of the measurement setup.*
* *An open question is also how the impedance spectrum of the full set of 5 ZS tanks and 6 pumping modules above the cutoff frequency can be determined.*

A set of probe measurements of the ZS tank were performed with varying probe depths. The S11 and S22 measurements identify many of the resonances observed in the coaxial wire measurements. It remains to determine the Q factors of the modes and match them to the wire measurements.

The presented CST Wakefield simulations using a detailed model of the ZS (without shielding) reproduce most of the measured resonances below 200 MHz and between 500 and 800 MHz. However, the simulation results do not agree well with the measurements in the frequency range above 1 GHz, in particular in the region from 1 to 1.2 GHz. Simulations of the wire measurements with this detailed model are presently being worked on.

* *The individual ZS anode wires were not simulated (they are very difficult to include due to the completely different scale of the wire diameter compared to the ZS dimensions). They were replaced by a thin conductor.*
* *The impedance spectrum in the simulations changes if the vacuum chambers on both ends of the ZS are included.*

Inserting a shielding or “grill” at the entrance flange towards the ZS septa (as presently installed only in the test ZS in the SPS) results in suppression of most resonances below 600 MHz in the coaxial wire measurement, apart from the ripples that are due to a residual mismatch of the matching resistors. However the shunt impedances of the resonances between 600 and 800 MHz are increased and additional resonances between 1.2 and 1.35 GHz are excited.

* *The shielding was installed in the test ZS with the aim of reducing the ZS impedance. Further studies are needed before deciding if the shielding should be inserted in the 5 operational ZS modules installed in the machine. The reason for installing the shielding would be a reduction of the beam coupling impedance. It seems however that the longitudinal impedance of the ZS is not big, so if there is no other motivation (like transverse impedance for example) maybe it should not be installed. The question is if it is worth to suppress the resonances below 500 MHz but having the risk of creating additional resonances at higher frequencies. On the other hand, these resonances could also be a feature of the measurement (e.g. trapping of modes because the structure is closed in the measurement). Measurements of the complete ensemble of a ZS tank plus a pumping module with and without shielding need to be performed and the results compared with simulations in order to take the decision of whether or not to install the shielding in the operational ZS modules.*
* *For evaluating the transverse impedance, a set of wire measurements with different transverse displacement would need to be done. Any difference of longitudinal impedance for different wire position results then from a transverse impedance. These measurements are usually difficult and will be performed only if requested.*

**3. Juan: Analysis of schemes for doublet production**

Different options of creating “doublet beams” for improving the scrubbing efficiency in the LHC have been investigated in numerical tracking simulations without taking into account intensity effects.

The first option consists of injecting long bunches (about 3 ns full bunch length) into the LHC on the unstable fixed point between two buckets with low RF voltage. Each bunch can then be captured in two neighboring buckets by quickly increasing the voltage after about a quarter of a synchrotron period. The main issues to be looked at are losses and the achievable emittance after filamentation. With a voltage step from 3 MV at LHC injection to 4 MV at an optimized timing the obtained losses are about 2% and the final longitudinal emittance about 0.9 eVs when injecting a bunch with 0.5 eVs. However, losses of more than 20% are to be expected after 3 more injections due to the required voltage steps, which are affecting the circulating beam. Some optimization can be done, but in general this issue remains critical. Another concern is the large emittance blow-up.

* *Due to the high beam intensity required for a high scrubbing efficiency, RF power limitations might necessitate a slower ramping of the RF voltage than considered in the simulations.*
* *The minimum RF voltage (3 MV) is determined by beam loading considerations.*
* *A voltage step to 4 MV is used, since larger voltage results in larger final longitudinal emittance*

Performing a similar splitting as before but in the SPS results in 5 ns doublet spacing, which is more efficient for electron cloud production and scrubbing. The option of injecting long bunches (10 ns full bunch length) was already tested in experiments in 2012 and 2013 using the Q26 optics and a voltage step from 1 MV to 3 MV. The same settings and beam parameters used for these experiments were applied in the simulation, yielding good agreement with the experimental observations. The final emittance of each doublet bunch is less than 0.45 eVs with losses of about 1% for a single injection and a total of 8% including also the voltage dips for 3 subsequent injections. In practice, these losses could be compensated by injecting higher intensities from the PS. The main disadvantage of this scheme are electron cloud effects at low beam energy, which could result in significant losses and/or transverse emittance blow-up.

* *The final longitudinal emittance is mainly determined by the bucket area during the capture.*
* *The baseline would be using the standard 25 ns, but maybe it becomes necessary to use the BCMS beam if the transverse emittance is too large due to the required high intensity.*
* *The sensitivity to the incoming longitudinal emittance is not clear, however the final longitudinal emittance scales probably proportional to the injected emittance.*
* *The SPS transverse damper is being upgraded during LS1 to work during this splitting at injection and with the resulting 5 ns doublet beam.*

Other possibilities of doublet creation in the SPS by performing a 180˚ jump of the stable phase at either 200 GeV or at flat top have also been investigated for the Q20 optics. In both cases a voltage step from 1 MV to only 2 MV is considered, as a larger step would result in larger final emittance. Both schemes are less favorable compared to the splitting at SPS injection, due to higher losses (occurring at higher energy!), larger longitudinal emittance and higher bunch length at extraction resulting in losses and ghost bunch creation at LHC injection, and the special RF hardware required for the phase jump.

* *It is concluded that the option of splitting at SPS injection is the most favorable and probably also the only realistic option. Further studies of this option for the Q20 optics will be performed. The choice between Q20 and Q26 will depend on beam stability, available RF voltage and RF power considerations.*

Minutes written by Hannes Bartosik