Minutes of the SPS Studies Working Group
(SSWG)

13^{th} meeting 4^{th} December 2001

Present: G. Arduini, P. Baudrenghien, T. Bohl, O. Brüning, H. Burkhardt, P. Collier, K. Cornelis (chairman), B. Dehning, J. Gareyte, M. Giovannozzi, L. Jensen, J.-P. Koutchouk, T. Linnecar, D. Manglunki, F. Roncarolo, G. Rumolo, E. Shaposhnikova, J. Tückmantel, L. Vos, J. Wenninger, F. Zimmermann (secretary)

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1 SPS Start-Up Schedule next Year (K. Cornelis)

K. Cornelis reported that the requested one week of scrubbing time at the start of next year's run has been approved. Preceding this week are 3 days for setting up the machine, comprising the weekend of Whitsunday.

2 Evaluation of the LOCO Program on the SPS (J. Wenninger)

LOCO stands for *Linear Optics from Closed Orbits*. It is a code written by J. Safranek at BNL almost 10 years ago, which has been successfully applied at many light sources, in order to arrive at a correct model of the linear optics. The input to the program are closed orbits taken for different corrector excitations. The differences between the measured and predicted orbit responses are minimized by fitting for the corrector-strength errors, BPM calibrations, and an arbitrary number of optics parameters, *e.g.*, the strengths of the main quadrupoles and skew quadrupoles, magnet roll errors, etc. The fit minimization is performed using an SVD algorithm.

An overall scale constant remains undetermined. In the horizontal plane this scale factor can be inferred from a separate measurement of dispersion, knowing the change in rf frequency. J. Wenninger mentioned that for the vertical plane one could determine the scale factor from that found for the horizontal plane, exploiting linear coupling.

The LOCO code iteratively arrives at an improved optics model by applying step changes to all the fit variables. It automatically prepares the MAD scripts for each iteration step.

The size of the matrices to be treated can become huge. A full set of data for the SPS would amount to 22 Mio. BPM readings, rising to 750 Mio. samples for the LHC. This implies that only a part of the ring could be processed at a time.

At the end of the 2001 SPS run, J. Wenninger took a set of SPS BPM data in sextants 1 & 2, at 66 GeV and 2010 ms into the cycle. The correctors were excited to ± 20 μrad. Various checks of the LOCO code were performed on these data, *e.g.*, when fitting with the wrong tunes, LOCO found the correct tune values. After 7 iterations a satisfactory optics model was obtained, which reproduces all the sampled orbit data. The strength of the vertical correctors are 96% of the nominal, the scale factor for the vertical BPM readings 93% of the nominal (this could be shifted by a common factor, so that only the relative difference of 3% is significant). In the horizontal plane, the BPMs look even better, only deviating by 2% from the nominal value. However, the horizontal correctors appear to be divided into two groups, for one of which the scale errors are substantial, less than 80%. O. Brüning asked whether this grouping could be the result of a beta beating.

A small disagreement was observed between the horizontal dispersion that was measured (which did not serve as an input to LOCO) and that predicted by the model. The measured dispersion was systematically higher, or lower, than the model prediction in every other sextant.

Next, J. Wenninger has performed an analysis including coupling, by including the six skew-quadrupole strengths as fit variables. The measured cross-plane orbit coupling could not be perfectly reproduced by adjusting the skew quadrupoles. This shows that other coupling sources are dominant in the machine, such as rotated quadrupoles or, as proposed by F. Zimmermann, orbit offsets in sextupole magnets. It also shows that the existing coupling cannot be perfectly corrected using the skew quadrupoles. J. Wenninger also reported further simulations, which have unambiguously demonstrated that minimizing the coupling resonance (closest tune approach) and minimizing the cross-plane coupling yield different results.

Given the less good fit for the linear coupling, not suprisingly the vertical dispersion was not perfectly reproduced by the model either.

J. Wenninger will take more LOCO data in the next run, and the SPS orbit program will be modified to facilitate the data acquisition. An interesting study item will be the tune split optics, in particular the phase advance between the two target areas. The LOCO data could be taken for example during the electron-cloud scrubbing test.

3 Resume of the Last MDs & Status Report (T. Linnecar)

This year, feedback and feedforward systems were active for all cavities. The results of the impedance reduction program were also noticable.

Two situations of bucket shrinkage were identified. At the start of the ramp the Bdot changes quasi-instantly from 0.0198 T/s to 0.0296 T/s, with an accompanying reduction of the bucket area by about 5%, resulting in some beam loss. T. Linnecar suggested as possible cures to either re-calculate the whole Bdot slope or to spread out the change over a longer time interval. K. Cornelis proposed to use the derivatives for control instead of the values. At the end of the ramp, there is a second shrinkage of the bucket area, by almost 10%, due to errors in the saturation table.

Turbulent effects have improved signficantly. In 2000, the peak-detected signal (inverse of the bunch length) decreased strongly with time, measured a few seconds prior to the rf voltage rise, and there was evidence for bunch lengthening. This year the slope of this decrease is reduced by a factor of two, despite of the fact that the new multi-bunch feedback adds further noise.

In the high voltage cycle, the 800-MHz system is used to increase the synchrotron-frequency. The noise introduced by the multi-bunch feedback and the 800-MHz system blows up the emittance, from 0.4 eV at injection to 0.48 eVs at the end of the flat bottom, to about 0.7 eVs at top energy. This is smaller than the LHC target value of 1.0 eVs. The bunch intensity was slightly larger than half the nominal.

A bunch rotation was accomplished by an initial slow decrease in the rf voltage from 6.8 MV to 650 kV followed by a rapid voltage increase. The bunch length was reduced by about 40%. This can be a useful means for injecting shorter bunches into the LHC.

4 First Attempt to Cure Coupled-Bunch Instabilities (P. Baudrenghien)

The bunch-to-bunch phase is measured by passing the signal from a wide-band pick up through a low-Q filter and a limiter, and phase detection using a discriminator. The phase signal is used to determine a fast change in rf voltage a quarter synchrotron period later, establishing the bunch-by-bunch feedback loop. This feedback only acts on the dipole motion and is limited to instability frequencies below 2 MHz.

Turning on the feedback at the flat bottom with half the nominal LHC intensity avoided beam losses which were observed without feedback, and it also suppressed the bunch lengthening. Operating the feedback with a 180° phase shift increased the beam loss.

During the ramp the feedback did not work as well, but it introduced noise blowing up the lomngitudinal emittance. This is attributed to noisy hardware and to the fact that the feedback signal decreases with energy as η/p. The optimum gain should have the inverse shape and, after passing through a minimum, increase again for larger beam momenta p.

Coupled bunch modes at frequencies above 2 MHz are suppressed by Landau damping via the 800 MHz rf system.

With the same set up as described above the bunch phase could be measured along the batch. At the end of the flat top a 110 ps peak modulation was seen in the bunch phase. At the end of the flat bottom, at lower rf voltage, the phase variation amounted to 174 ps. These numbers appear within tolerable limits.

On the first turn the beam injected from the PS showed a constant offset for all bunches which varied from cycle to cycle with an amplitude of ±130 ps. Superimposed were a phase error increasing along the batch with a final amplitude of 50 ps and a 10 MHz modulation of ±50 ps.

A variation resembling this initial 10 MHz modulation was also seen at the end of the flat bottom and at top energy. The question whether this is a remnant from the initial modulation arising in the PS, or newly generated in the SPS coincidentally at a similar frequency, remains to be explored, as are correlations with the bunch-to-bunch intensity fluctuations. The latter possibility was raised by D. Manglunki. P. Baudrenghien mentioned that the magnitude of the intensity variation and the impedance of the rf cavities at 10 MHz are too small to explain the observed phase variation. K. Cornelis, perhaps half jokingly, suggested that one way to solve this puzzle could be that the PS provides a beam without 10-MHz phase modulation and without bunch-to-bunch intensity fluctuations.

It was pointed out that precise measurements of the beam energy spread using wire scanners at dispersive locations are difficult if not impossible in the SPS. O. Brüning proposed to infer the energy spread by measuring betatron tune lines at higher chromaticity.

5 Next Meeting

The next meeting of the SPS SWG will be held in 2002. The agenda will be posted on the web page of the working group http://cern.ch/sl-mgt-sps-swg, and an invitation will be sent by email.

F. Zimmermann, 4th December 2001