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Recent Results from the Dynamic Aperture Experiment at the SPS

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Abstract

Since 1986 dynamic aperture studies [1, 2, 3, 4] have been performed at the SPS in view of the LHC, the projected superconducting proton accelerator in the LEP tunnel. The aim of these experiments is to understand the aperture limiting effects of non–linearities and to define a model which allows the prediction of these effects in tracking studies. To this end the SPS, which is a very linear machine, is made non–linear in a controlled manner by 8 strong sextupoles powered in such a way that high order effects prevail. In this machine the short–term particle losses after seconds are well understood and in agreement with simulations. It has also been shown previously that power supply ripple in conjunction with the non–linearities can cause long–term losses after minutes. The 1992 experiment was aimed at providing enough data to allow a more quantitative comparison with a simulation model. Much care had to be taken to achieve stable and reproducible machine conditions and to perfect the instrumental tools needed for these delicate investigations.

1 Introduction

After a series of technical failures we finally managed to have one successful experimental session in 1992 which allowed some data taking with good machine conditions. Last year numerous 8 hours shifts, which are now reserved each week at the SPS, were used to test and commisson two instruments: BOSC, the turn–by–turn data acquisition system [5] and the linear wire scanners [6]. The progress of our experiment was set back by the fact that at first we did no longer recover the agreement between tracking results and experimental data which we had found in previous years. In the second section we will report on a new calibration of several of our instruments to resolve this problem. The disagreement could finally be attributed to an aging of the kicker. In the third section we will present the measurements done in the experiment of November 1992. And finally, in section four, we will present results and compare them with tracking simulation. As we were looking for precise quantitative agreement we made every effort to include detailed knowledge of the real machine in the tracking model.

2 Calibration of the Equipment

The kicker calibration done in 1988 proved no longer valid. Therefore we made an effort to do this calibration again and relate it to other instruments, namely horizontal and vertical scrapers and one rotational and two linear wire scanners.

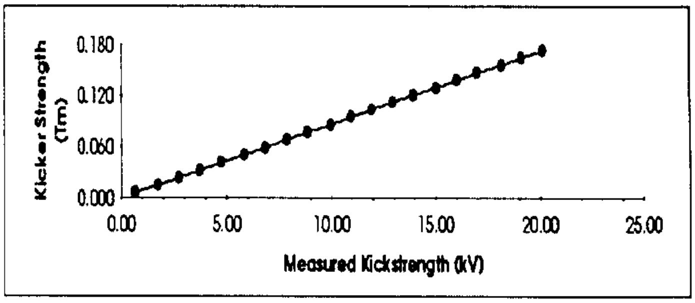

Figure 1: Kicker Calibration

Firstly we measured the current through the kicker magnet as a function of demanded kicker strength in kV. We found a good linear behavior down to small kick strengths (see Fig. 1).

Secondly we tried to relate the different instruments. The rotational wire scanner shows a rather linear behavior up to 60% of the kick strength that we use in our experiment. The linear wire scanners have a satisfactory linear response over a wide range of kick amplitudes. However, the later seem to underestimate the calibrated kick strength by 15%. The different scraping experiments also show the same discrepancy of 15% with the wire scanners. All measurements are consistent with the exception of an apparent difference of calibration factors between the wire scanners and the other instruments. This difference still needs to be resolved.

Thirdly we evaluate the error introduced in the tune measurement by the fact that we kick a beam of finite emittance instead of a single particle. At maximum kick strength this introduces in our case a tune shift of only 1.3×10^{-4}. However, due to nonlinear (mainly quadratic) chromaticity there is also a tune shift due to momentum deviation which amouts to 6×10^{-4} and is only marginally dependent on transverse kick strength.

3 Measurements

The experiment demands a very careful setting up of the SPS. The closed orbit is corrected in both planes below 0.4mm rms, the linear coupling is compensated so that the closest tune approach is 2×10^{-3}, the linear chromaticity is well compensated (Q' below 1). The energy is set to

120GeV where the linearity is neither disturbed by space charge effects nor by saturation of magnets. The machine is made nonlinear in a controlled manner by 8 sextupoles in a way which leaves chromaticity unchanged to first order and the neighboring third order resonance only weakly excited. We work at a small intensity of 2×10^{12} protons and normalized r.m.s. emittances of $2.5\pi \times 10^{-6}$m.

After recalibrating our kicker we could achieve a sufficiently good agreement between experiment and tracking. In the tracking we introduced meticulously every detail observed in the experiment: a residual linear coupling corresponding to the observed closest tune approach of 2×10^{-3}, the measured horizontal and vertical emittances and the measured closed orbit.

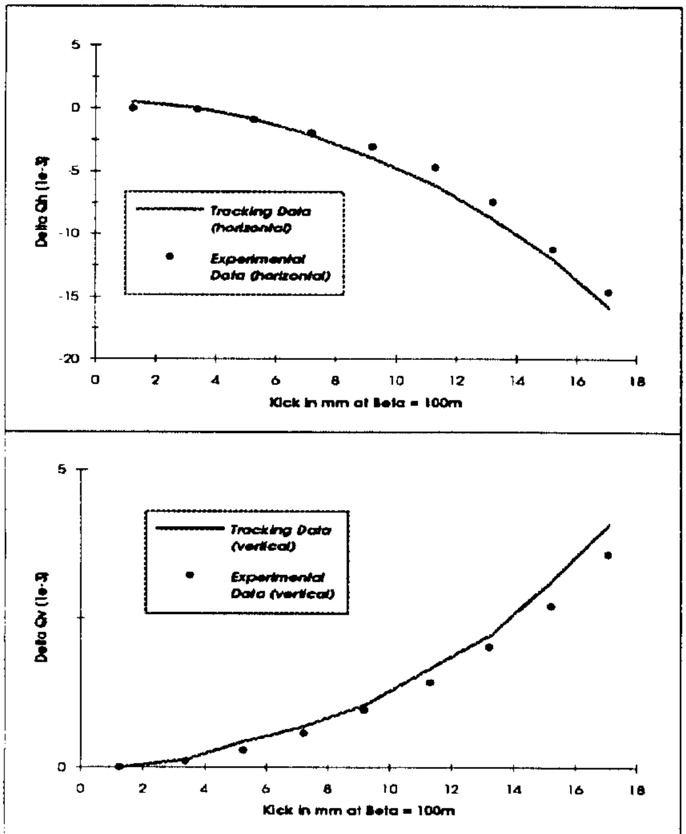

Figure 2: Horizontal and vertical detuning

In Fig. 2 the measured horizontal and vertical tunes are plotted as a function of amplitude and compared with the tracking results. One observes a very good agreement, the discrepancy reaching only 1×10^{-3} in the horizontal and 5×10^{-4} in the vertical plane. By comparison a similar measurement done in absence of the 8 strong sextupoles shows a 10 times smaller detuning. The natural ripple in the horizontal and vertical plane was measured with the continous Q-measurement to be 2.2×10^{-4} peak to peak. A Fourier analysis up to 1000Hz shows seven relevant lines whose added amplitudes account for a total ripple depth of 1.2×10^{-4}. The discrepancy between the total depth and our seven major ripple lines is probably due to very low and/or high frequency components (to be clarified). These seven lines were always considered in the tracking simulations.

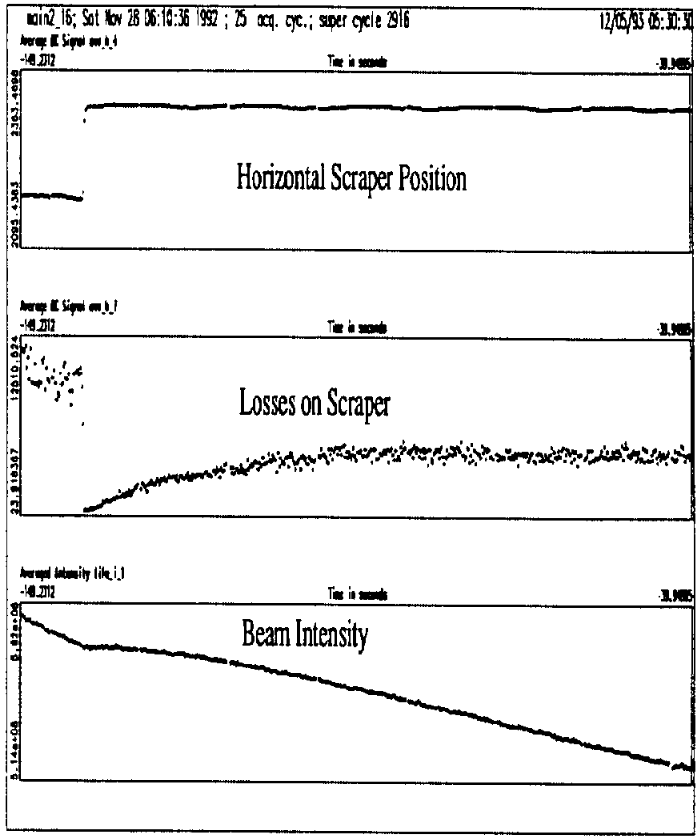

Figure 3: Measurement procedure

For observing the long term stability under the influence of sextupole nonlinearities and tune modulation the following procedure (see Fig. 3) was used: the beam was kicked to obtain a hollow distribution with enough particles at the required amplitude and scraped verticaly and horizontaly to have well defined edges. Then, the vertical scraper was retracted by 10mm and the horizontal by 1mm, and beam intensity and particle loss at the scraper observed. After a sufficiently long period the particles have diffused to reach one or both scrapers. The losses observed when moving the scrapers back to their original position teaches us in which plane the diffusion has preferentially occurred.

The parameters are varied in the experiment:

- Tunes (Q_H, Q_V): (26.0637, 26.5316), (26.605, 26.537)
- Hor. kicks [mm] at β_H = 100m: 12.8, 14.7, 16.6
- Added ripple frequency [Hz]: 9, 40, 180
- Frequency pairs [Hz]: (9, 40), (9, 180)
- Ripple depths ΔQ peak to peak [10^{-3}]: 0.55, 1.1, 1.87

and in the tracking:

- Turns: 2×10^6, about 46s storage time.
- Amplitudes: that corresponds to the scraper *in*–position minus 0, 0.5 and 1mm.
- Apertur: the scraper in the *out*–position.
- Momenta: $\pm 0.75 \times 10^{-3}$ in 5 steps.

4 Results

The first working point is carefully placed so as to avoid 5^{th} and 7^{th} order resonances. Due to non–linear detuning, the particles are distributed along a working line in the tune diagram, which straddles an 8^{th} order resonance. At the other working point the working line crosses stronger 5^{th} and 7^{th} order resonances.

At the first point and for a kick of 14.7mm there was no sign of particles reaching the retracted scrapers over a period of more than 200s when ripple was absent or for the smaller ripple depth. For the medium and larger depth the particle loss sets in after about 200s and (35-60)s respectively. Like in previous years we find that the effect of tune modulation increases more than linearly with the ripple depth.

In the tracking we see that with no added ripple almost all particles are regular and thereby stable, while in all cases with ripple the motion is chaotic and therefore potentially unstable. This holds also for the second working point. Though chaotic, it needs the largest depth in the tracking to barely see some loss which is in good agreement with the experiment (the number of turns is also just marginally sufficient).

For the situation with two frequencies the results can not be compared directly because by accident the medium depth was used in the tracking instead of the small one as in the experiment. Nevertheless in both cases the differences with respect to the case with only one frequency (but same total depth) were not large, though more pronounced in the tracking. The strong effect found previously [4] apparently requires the vicinity of some stronger resonances.

When reducing the kick (small kick, large ripple depth) an immediate particle loss sets in, both in the experiment (too fast to be measured with precision) and in the tracking (in about 2s). The reason for this unstable behavior is that the 8^{th} order resonance is crossed right at this amplitude. This could be seen clearly as a dip in the tune distribution taken with the Schottky system. The presence of this resonance is also responsible for the large losses at larger amplitude (see above).

At the second working point we applied the largest kick, but as we scraped down to the same positions the results are comparable. For the small depth the loss sets in after 17, 14 and 10s for 9, 40 and 180Hz respectively. In the tracking the tune modulation was also much more effective at that second working point. It became however clear that tracking only one or two particles is insufficient, because the loss times can vary by large factors (values up to 40 have been observed) even for close–by particles. We have therefore launched a massive tracking study with 60 particles over 10 million turns (200s storage time in the SPS) for some well choosen cases.

5 Conclusions

Even though the tracking results are still preliminary they seem to agree with the experiment within the limit of our knowledge of the SPS (about 5-10%). We feel therefore confident that tracking studies allow indeed very good predictions provided the non-linearities are considered in conjunction with tune modulation. These studies will be pursued since we are still far from understanding the actual mechanism that leads to slow particle loss.

6 Acknowledgements

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