NON-LINEAR TRANSVERSE BEAM DYNAMICS STUDIES IN THE SUPER-ACO STORAGE RING*

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Abstract

Experimental turn by turn beam position measurements were performed in order to investigate the non-linear beam dynamics in Super-ACO. The aim of these experiments is to get a better understanding of the aperture limiting effects of non-linearities and to check the model used in tracking studies. The amplitude-dependent tune shift measurements allow to highlight a strong octupolar-like component due to quadrupoles fringe field missing in the model. In addition to this point, an analysis which enables to make the distinction between a physical and a dynamic aperture limitation is also described.

1 AMPLITUDE DEPENDENT TUNE SHIFT MEASUREMENTS

Having the well predictive accelerator model is increasingly a necessity to achieve the design performance of synchrotron light sources especially the 3rd generation ones. Measurements of various parameters on existing machines and their comparison with simulation code predictions can be particularly helpful to establish the model-experience agreement. One of these important parameters is the tune shift with amplitude.

Turn by turn beam position measurements have many useful applications. They allowed here a precise measurement of the amplitude dependent tune shift and have been relevant to the Super-ACO model improvement. Henceforth, an octupolar-like component due to quadrupoles fringe field has to be taken into account in the model.

Experimental procedure: A coherent horizontal oscillation is excited by a single kick and the horizontal position of the centre of charge of the bunch is observed over 1024 consecutive turns. The first plot of figure 1 shows such a 1000-turns measurements of one BPM. The moment of the kick is clearly visible. A precise analysis of the 1000-turns data with NAFF[1] technique[1] allows to calculate the horizontal tune ν_x. This analysis is reproduced for several kicks in order to obtain the detuning with amplitude curve (see Fig. 2). The experiment was carried out with a single bunch at low current in order to minimise the collective effects and for two different optics of Super-ACO[2]: the routine[2] operating mode and a mode where the harmonic sextupoles (which correct the non-linearities) are OFF. Table 1 resumes the experimental conditions for these two modes.

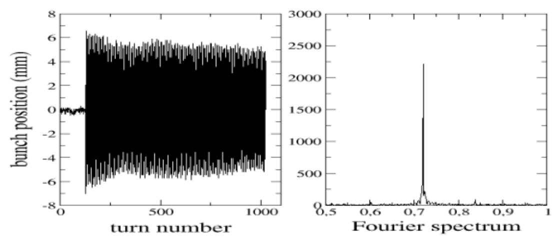

Figure 1: The beam position signal at the location of the BPM for a kick of 8.47kV and its Fourier spectrum.

Experimental conditions		
Tunes $\nu_x = 4.72$, $\nu_z = 1.70$		* Single bunch mode * Open undulators
Sextupoles values		
Routine mode	**H1 = H2 = 0 mode**	* C.O corrected to 0 in all BPMs
H1 = 54A H2 = 100A H3 = 211A H4 = 204A	H1 = 0A H2 = 0A H3 = 211A H4 = 204A	* Minimum of coupling * P4 injection kicker
Chromaticities $\Delta\nu / (\Delta p/p)$ $\xi_x \sim \xi_z \sim 1.5$		* measurements on BPM24 (section without dispersion)

Table 1: Experimental conditions for the two studied optics.

Following the experimental procedure described above, we present in figure 2 the results obtained for the routine operating mode.

The experimental curve shows an increase evolution of the tune ν_x with respect to the horizontal amplitude x whereas the theoretical curve calculated with the BETA code[3] shows an opposite evolution. This suggested the fact that some non-linear components are missing in the model of Super-ACO. In figure 3, we plot the horizontal tune dependence with the Courant and Snyder Invariant $U_x = x^2/\beta_x$.

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[1] NAFF technique is a numerical method developed by J. Laskar and based on a refined Fast Fourier Transform (FFT). Its high precision of $1/N^4$ (using a Hanning window) makes it particularly powerful to determine the fundamental frequencies of a quasi-periodic signal.

[2] Contrary to the user's routine mode where the undulators are closed, we study here a basic situation with open undulators.

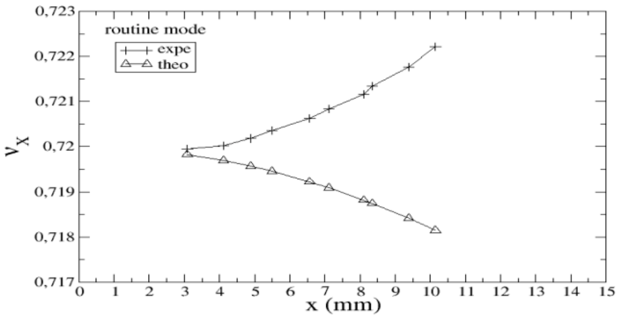

Figure 2: Experimental and theoretical horizontal tune shift with amplitude.

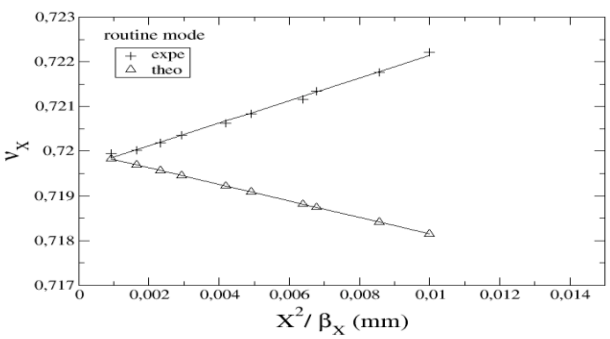

Figure 3: Experimental and theoretical horizontal tune dependence with the Courant and Snyder Invariant.

These curves are perfectly fitted linearly and the slopes give the following contributions:

$\Delta\nu_x^{exp} = \mathbf{252}\ U_x$ and $\Delta\nu_x^{theo} = \mathbf{-185}\ U_x$ (U_x in meter)

This discrepancy suggested to look for an additional non-linear contribution in x^2 due to an element missing in the model. Except sextupoles (to second order), octupolar components or pseudo-octupolar components induce a detuning with x^2. Because the octupolar component is not systematic in Super-ACO quadrupoles (the magnetic measurements showed that its field component is negligible), we turned towards the calculation of the pseudo-octupolar component, which origin could be the quadrupoles fringe field (QFF).

Using a hamiltonian theory of perturbation[4], the tune shift induced by the quadrupoles fringe field is:

$$\Delta\nu_x^{QFF} = \mathbf{323}\ U_x \quad (U_x \text{ in meter})$$

The addition of this contribution to the theoretical predictions of the horizontal detuning with amplitude, leads to a satisfying agreement with the experimental measurements for the two studied optics[5].

The next step was to track particles including this effect in the simulation code. This was performed using a symplectic integrator developed by L. Nadolski [6]. The principle is to construct a second order integrator where the fringe field is approximated by a hard edge model[7].

[4] The septum represents the smallest physical aperture in Super-ACO.

The obtained results are very satisfactory for the two studied optics (see Fig. 4).

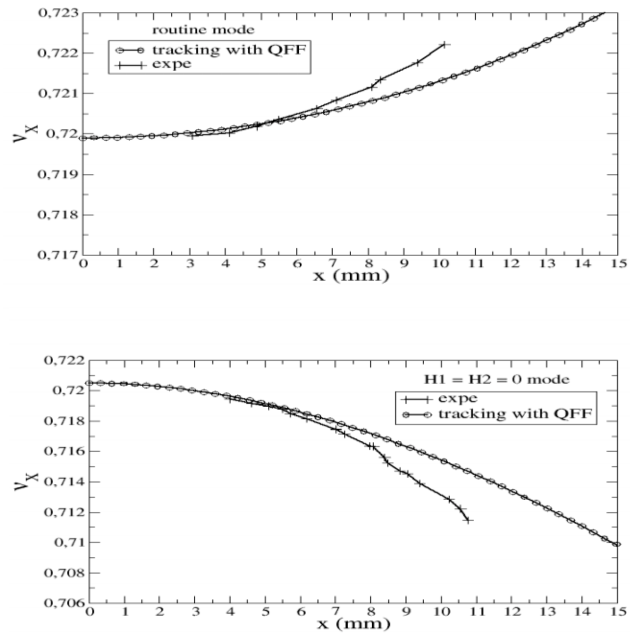

Figure 4: Experimental variation of $\nu_x = f(x)$ and comparison with the tracking results including the contribution of QFF.

We conclude that the horizontal amplitude dependent tune shift experiments allowed to highlight a strong octupolar-like component due to quadrupoles fringe field missing in the model of Super-ACO. Adding this component to the model leads to a satisfying agreement with the experimental measurements for two different optics of the machine. This was well confirmed by the tracking of particles using a symplectic integrator.

2 DETERMINATION OF THE APERTURE LIMITATION

In the transverse plane, the stability of the beam can be limited by the physical or the dynamic aperture.

In this section, we will present a simple experimental method based on turn by turn records which allows to know if in a given machine, the aperture limitation is physical or dynamic.

The experiment was performed on the Super-ACO storage ring using turn by turn current measurements with an annular electrode, one of the injection kickers and a photomultiplier (PM) located near the septum[4].

Experimental procedure: Following a deflection by a single horizontal kick, we record the beam current turn by turn. This was done for gradual increasing kicks till the total loss of the beam. At the same time, we count with a PM, turn by turn, the conversion photons induced at the location of the septum after a beam loss. The results (see Fig. 6) are presented for two optics of the machine: the routine operating mode and the mode where the harmonic sextupoles are OFF (refer to Table 1). In fact, the choice of these two modes is not arbitrary because in the first one, the optimisation code predicts a physical aperture limitation while in the second one, it predicts a dynamic aperture limitation (see Fig. 5).

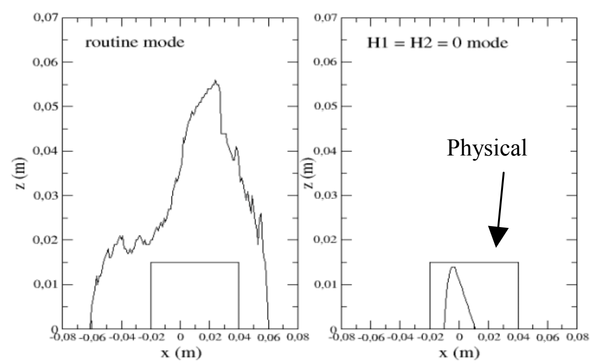

Figure 5: The predicted limitations for the two studied modes calculated with the BETA code (without QFF) in the injection section.

For both modes, as long as we didn't loose the beam, the current is constant over the 1024 turns and the PM didn't record any photons.

For the routine operating mode, at the moment we lost the beam, we observed a sharp decrease of the bunch current on just one turn. At the same turn number, the PM counted a large number of photons at the location of the septum which is seen as a single high peak in the photon spectrum. This is a signature of a beam loss on a physical hitch and this agrees well with the theoretical simulations which predict a physical limitation in this machine optics.

For the second optics where the harmonic sextupoles are OFF, we observed a gradual loss of the beam over a large number of turns (~ 250 turns) and the PM registered many small peaks in the corresponding turns range of the beam loss. This is a signature of a dynamic process with no sharp boundary which lasts a certain number of turns. It agrees well with the BETA simulation which predicts a dynamic aperture limitation in this optics case.

One can conclude that it is of great interest to see that with a simple experimental procedure, we can differentiate if one operating machine is limited by the physical aperture or the dynamic aperture.

3 CONCLUSION

In this report, the necessity to take into account the effect of quadrupoles fringe field in the simulation model of Super-ACO has been demonstrated. The study concerned only the horizontal motion and was performed using the turn by turn beam position measurements. Investigations in the vertical plane and in presence of coupling have been undertaken and are still on development.

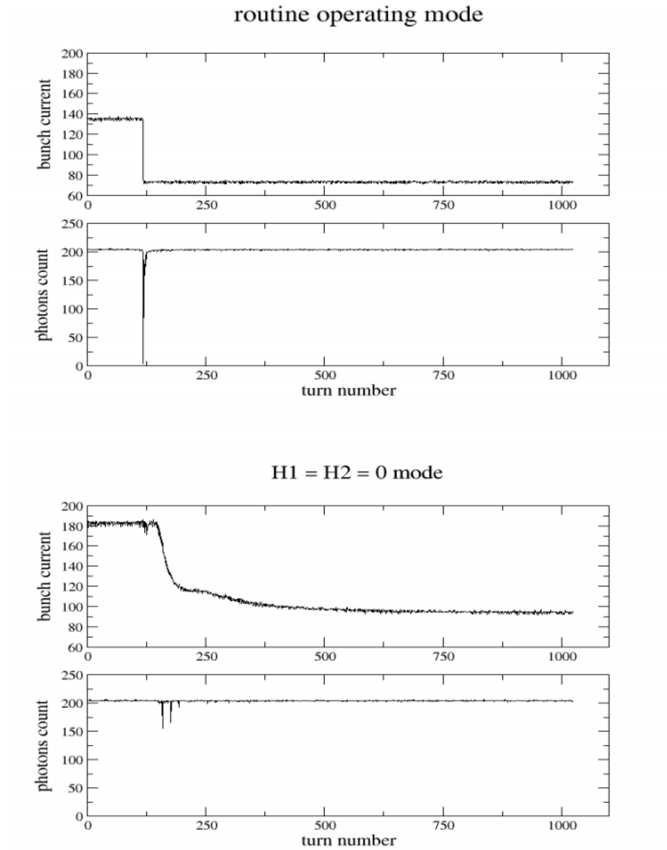

Figure 6 : The beam current and photons count– in arbitrary units– in the case of the optics1 and 2.

We also showed a simple experimental method which allows to know if the transverse motion of particles in a ring is limited by the physical or the dynamic aperture.

4 KNOWLEDGMENT

We would like to express our thanks to our colleagues L. Cassinari and J. Darpentigny and all the operators group for their help during these experiments.

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