THE BOM 1000 TURN DISPLAY : A TOOL TO VISUALIZE THE TRANSVERSE PHASE-SPACE TOPOLOGY AT LEP

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Abstract

The LEP BOM 1000 Turn facility enables the User to acquire the position of the beam at each beam position monitor over a number of consecutive turns. By kicking the beam and acquiring the first 1000 turns after the kick, the dynamic behavior of the beam in such a condition can be studied. In particular, by selecting a position monitor and plotting the position of the beam at a given turn against the position shifted by one (or n) turn(s), the evolution of the beam in the phase-space can be observed. Fixed points in the phase-space can be put in evidence, as well as the beam behavior in their neighbourhood. Quantities like the beam damping, or the beam detuning as function of the position amplitude can also be studied in this way. Significant examples from real life will be shown.

1 INTRODUCTION

The natural radiation damping of beam oscillations at Lep opens the road to many experiments based on the observation of the behavior of the beam after receiving a kick. In fact, being the damping time inversely proportional to the third power of the energy, it normally takes a few thousands turns at injection energy (22 GeV), and only a few tenths turns at top energy (100 GeV) for the beam to recover its initial state. The Beam Orbit Measurement (BOM) system is made of about 500 Beam Position Monitors (BPMs), each of which can record the horizontal and vertical positions of each bunch in the beam for more than 1024 consecutive turns. The data acquisition is synchronized all around LEP, so that the same 1024 turns are recorded by every BPM. These data have already been exploited to evaluate the real optics functions at LEP by measuring the phase advance of a coherent betatron oscillation from BPM to BPM [1],[2]; in the present paper we show a different exploitation of the 1000 Turn system.

2 BASIC PHASE SPACE REPRESENTATION

The traditional way for representing the phase space using BPM position data consists in finding two BPMs separated by a phase advance of 90 degrees, and plotting the position at one BPM against the position at the other BPM. The idea is that the position at the second BPM represents well the derivative of the position at the first one. This method would give good quantitative results only if the phase advance was exactly 90 degrees, and this is practically difficult to achieve. Therefore we follow another approach, which consists in manipulating the FFT data from a single BPM to create a "virtual" BPM shifted by 90 degrees. For every frequency, we rotate by 90 degrees the vector whose elements are the sinus and cosinus amplitudes of the FFT spectrum at that frequency, and we perform a reverse FFT operation to get an array of positions corresponding to the virtual pickup (see also [3] for a similar approach). Due to the discreteness of the data, and on the finiteness of our sampling, an error is introduced by this operation. This error can be made smaller by using some weighting technique on the rotated spectrum: a simple improvement consists in applying a linearly decreasing weight to all components below a minimal frequency threshold and above a maximum threshold. Our frequency spectrum goes from 0 to 0.5 in tune units: we apply the weight to all frequencies below .12 and above .39. This method has the disadvantage of not being rigorously correct but, as simulations show (see fig. 1), significant errors occur only in the first and last few turns of the virtual pickup : elsewhere the errors are lesser than 1%. Fig. 2 show the real and the virtual BPM data for a particular kick, fig. 3 the corresponding FFTs. We can now apply this method to different real data sets from LEP, and give examples on how different things can be visualized, and different quantities studied.

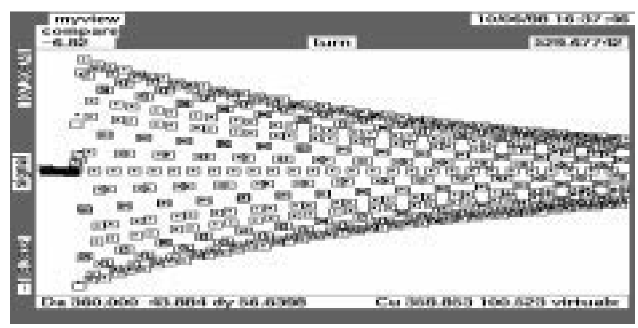

Figure 1: Comparison between a virtual BPM (boxes) and the exact result (dots)

3 PHASE SPACE PLOTS

By just plotting the real pickup versus the virtual one, we obtain a phase space plot. An example of such a plot when kicking the beam close to the third order resonance is shown in fig. 4 . Notice the three arms of the plot, emphasized in fig. 5 by joining every third point. This technique allows the User to better follow the evolution of the phase-space trajectory.

Another example is shown in fig. 6, where, helped by the stroboscopic effect, we can follow the tune slightly above 2/7. In fact, every time the tune is close to a rational fraction with a small denominator, nicely identifiable arms appear in the phase space plot.

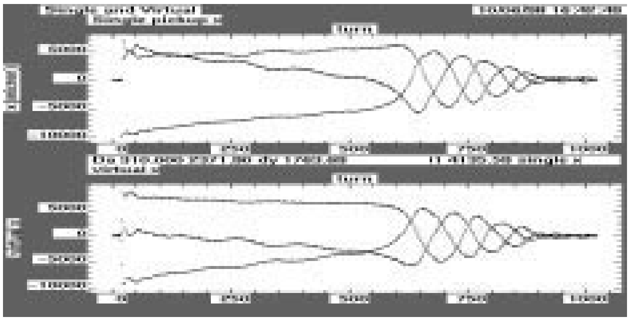

Figure 2: X positions for the real and the virtual BPM over 1024 turns

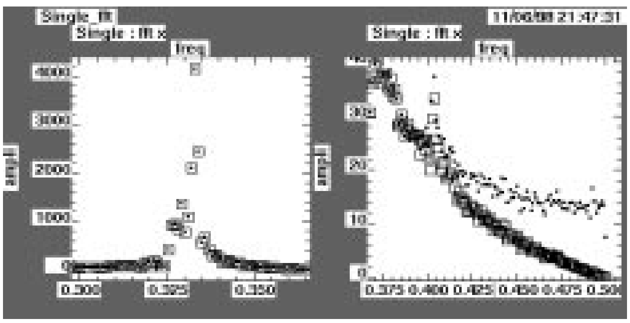

Figure 3: The FFT spectrum of the real (dots) and virtual (boxes) BPM. On the left the central part of the spectrum is shown, on the right a detail from the upper tail

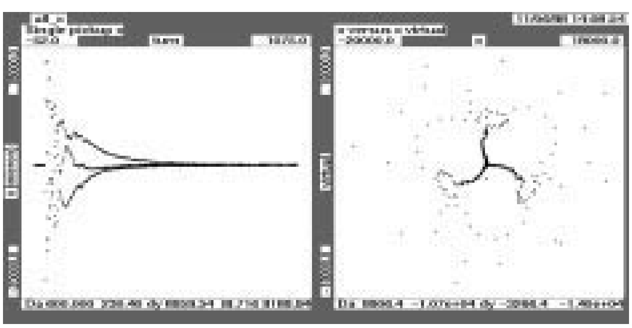

Figure 4: Beam close to 3rd order resonance : x position and phase space plot.

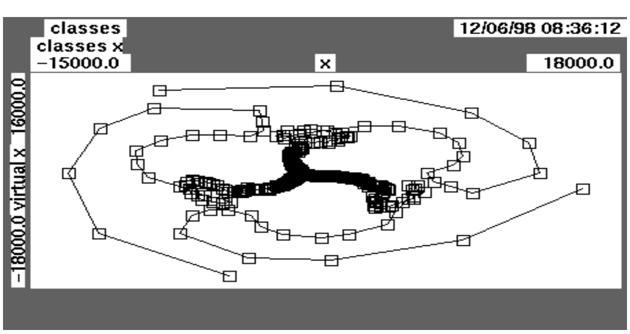

Figure 5: Every 3rd point is connected.

4 DETUNING WITH AMPLITUDE

We can use the phase space plot to directly compute the tune at every turn, and plot its evolution against the square of the distance of the corresponding point from the origin of

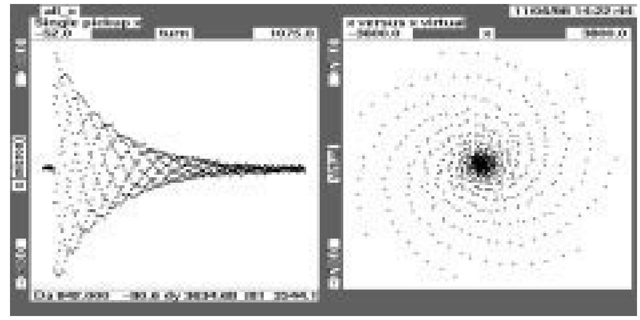

Figure 6: Tune close to 2/7

the phase space. If normalized, this latter quantity is nothing but the Courant-Snyder invariant. In fig. (7),8 we plot these 2 quantities against eachother, (and the beam position from which the plot was computed), obtaining a graph of

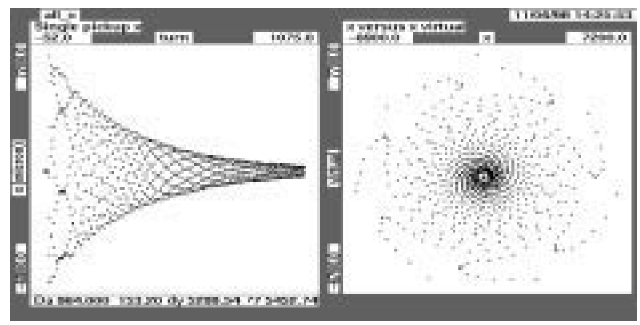

Figure 7: Smooth data set

Figure 8: Detuning with amplitude

the detuning with amplitude[4].
Note however that close to a resonance the detuning does not behave in this simple way, as shown by fig. (9),10. In this figure, the right part of the plot (corresponding to the first 100 turns after the kick) shows a detuning smaller than the left part (corresponding to turns 100 onward), where the beam has unlocked itself from the 3rd order resonance and moves down to a tune of about 0.24 .

5 BEAM TRAPPED INTO RESONANCES

This tool has been particularly used to study the behavior of the beam close to the third order resonance. The beam, originally at a tune below 1/3, is kicked stronger and stronger, and the behavior after the kick is recorded and analysed[5]. Fig. 11 shows one of these measurements, together with its phase space plot. From the plots , one might think that the oscillations were damped very rapidly. In reality this is due to the fact that we can only observe the cen-

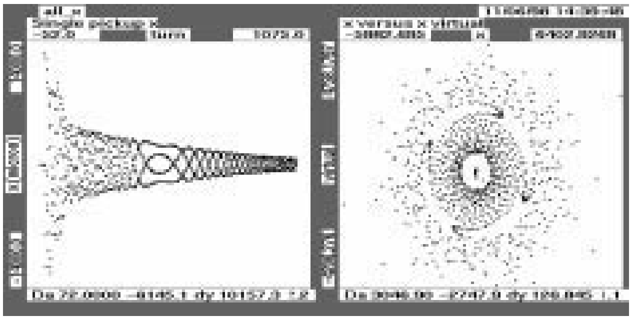

Figure 9: Exciting too close to a resonance

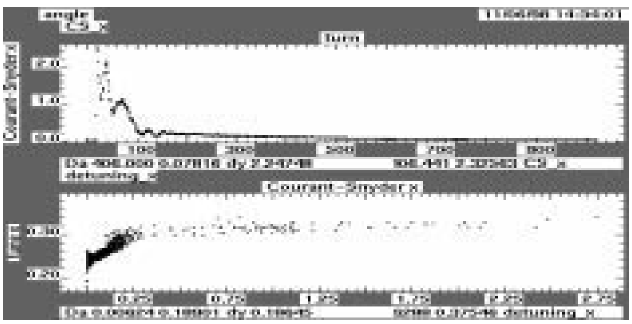

Figure 10: Detuning with amplitude : resonance influence

ter of mass of the beam, In fact, as we can see in fig. 12, the beam current was steadily decreasing, as a significant fraction of the beam was hitting the vacuum chamber at every turn. The individual particles were certainly still oscillating far from the center, but, probably due to filamentation, they spreaded all over the phase space, so that the center of the distribution was rapidly moving toward the center.

Fig . 13 shows better the meaning of being captured by the resonance. Also in this case the beam was slowly lost.

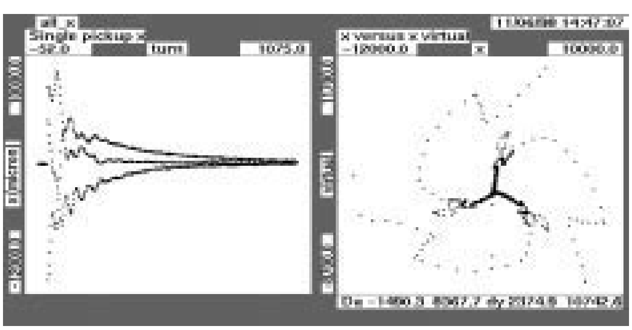

Figure 11: Center of mass damping close to 3rd order resonance

6 CONTINUOUS EXCITATION

The same method can be applied to data obtained by submitting the beam to a continuous excitation of the betatron frequency. In fig. 14 one can observe a linear behavior, while the deformations in fig. 15 point to some non linearities. In fact this latter measurement was taken while the two beams were colliding, and therefore feeling the beam-beam forces.

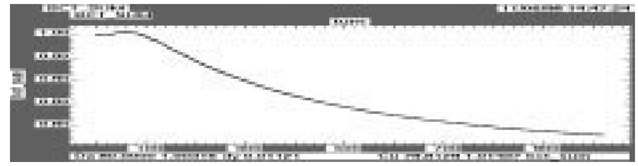

Figure 12: Due to the resonance, current is slowly lost

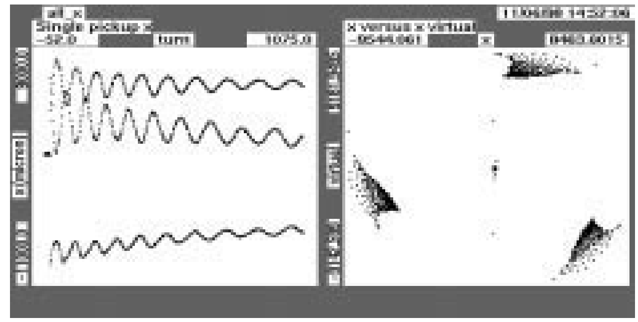

Figure 13: Beam trapped on a third order resonance

7 REFERENCES

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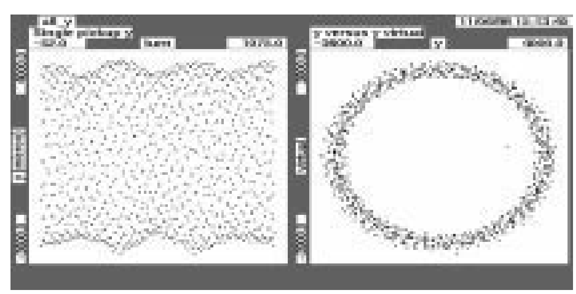

Figure 14: Linear motion

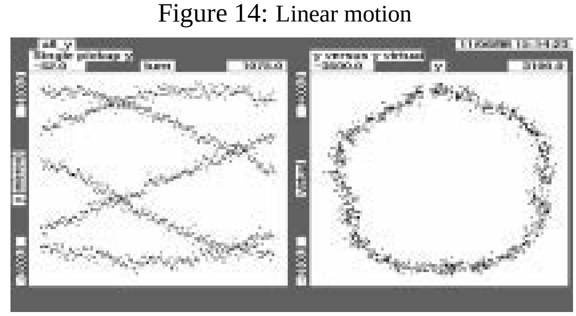

Figure 15: Nonlinear motion