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MEASUREMENT OF RESONANCE DRIVING TERMS FROM TURN–BY–TURN DATA

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Abstract

It has been shown that the Fourier analysis of recorded turn–by–turn tracking data can be used to derive resonance terms of an accelerator. Beside the resonance driving terms, the non–linear one–turn map can be obtained with all non–linearities arising from magnetic imperfections and correction elements. This could be interesting for the LHC which will be a machine dominated by strong non–linear fields. The method works very well for tracking data and is expected to work equally well for turn–by–turn beam data. The precision to which these terms can be determined relies on the frequency analysis tool. To demonstrate the feasibility of the method, measurements of real accelerators are presented in which the beam is kicked once and the beam oscillations are recorded over several thousand turns. Besides the tune, the strengths of resonance driving terms have been measured and the results are compared with numerical calculations.

1 INTRODUCTION

The application of perturbative techniques for the analysis of tracking and also of experimental data has proven to be difficult since it requires a detailed knowledge of all the magnetic elements in the accelerator lattice. Checking such a model experimentally [1] may prove even more difficult.

More recently it has been shown [2] that frequency analysis à la Laskar [3] of tracking data does allow to derive all driving and Hamiltonian terms in an order–by–order procedure without any knowledge of the accelerator model [4].

In 1998, first experiments at the SPS and LEP have been performed to show the feasibility of this method using turn–by–turn data from pickups instead of tracking. Eventually, the goal is to measure simultaneously the following information:

1. Phase advance between pickups
2. β–beating
3. Linear coupling [5]
4. Detuning versus amplitude
5. Driving terms of resonances
6. Full non–linear model of the accelerator

Once the method has been proven to work reliably in the case of real accelerators, it will be possible to use it for feed–back control of linear coupling, but also for the planned LHC b_3 and b_5 spool piece correction.

2 EXPERIMENTS

Several measurements were carried out in 1998. One with LEP and two with the SPS [6, 7]. We show the detuning as a function of the linear invariant $I_x = \epsilon_x/2$ and the three first–order horizontal spectra lines which are due to sextupoles in both machines. These are the (3,0) resonance (f_{3000} term) and the (1,0) resonance (f_{2100} and f_{1200} term) [2].

2.1 *SPS experiment*

The SPS is an ideal test bed for this kind of investigation. The machine has practically no multipolar components so that particles exhibit mainly linear oscillations. Moreover, closed orbit, linear coupling and chromaticity have been well corrected. This “ideal” machine is made non–linear with the use of eight strong sextupoles.

In the experiment, the beam is kicked to various amplitudes and the turn–by–turn data is recorded by all pickups in one sixth of the machine (to which the SPS turn–by turn recording system is presently limited).

As expected from earlier experiments [1] the detuning as a function of the linear invariant (Fig. 1a) is very well predicted by tracking (all solid lines in Fig. 1 are tracking results obtained with SIXTRACK [8]). Very promising is the agreement between the tracking and the experiment for the (3,0) resonance (Fig. 1b), the experimental data are systematically lower by a few percent only. When studying the first (1,0) resonance (Fig. 1c) a problem of the closed orbit measuring system becomes apparent. This line is the amplitude dependent offset of the FFT signal after the kick. To calculate this line one has to measure and subtract the signal offset before the kick which was not possible with sufficient precision. Moreover, the number of data samples were limited to 170 turns and there had been unavoidable electronic spikes. Lastly, we present the other (1,0) resonance (Fig. 1d)) which should suffer less from the limitations of the measurement system. Indeed, we find less noise signals in that case. However, there is a significant discrepancy with the tracking data which remains to be understood.

2.2 *LEP experiment*

The electron storage ring LEP was used for another experiment. Five different cases were studied with the 90/60 optics used for physics runs in 1997: one tune close to the (3,0) resonance and two tunes at increasing distance to that resonance. In the latter two cases the beam was kicked to 2

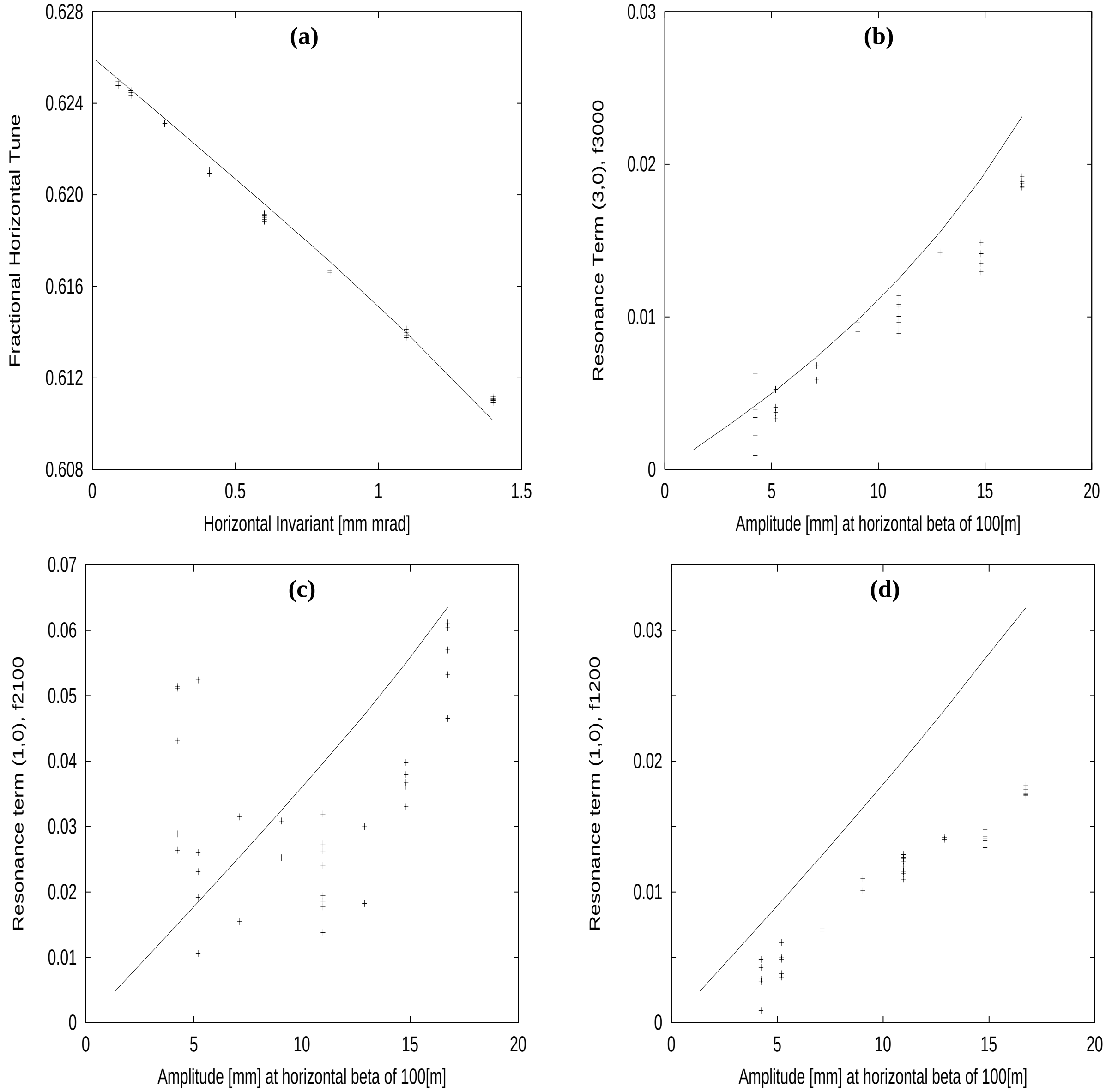

Figure 1: Detuning and First Order Sextupole Driving Terms
Part (a): Detuning versus linear Invariant I_x; Part (b): (3, 0) Resonance versus Amplitude;
Part (c): (1, 0) Resonance (f_{2100}) versus Amplitude; Part (d): (1, 0) Resonance (f_{1200}) versus Amplitude;
–Lines are from tracking –Symbols are experimental data

different amplitudes (each case is represented by another symbol in Fig. 2). In Fig. 2a the detuning curves are recorded with a sliding window in time for two different kick strengths. Both curves lie fairly well on top of each other. The effect of radiation can be directly observed and there is no sign of filamentation [9]. Moreover, the detuning is well predicted by tracking (solid line as calculated with MAD [10]). Both terms of the (1,0) resonance (part (c) and (d) of Fig. 2) show good agreement between the tracking and the experiment after inclusion of radiation (the straight curve in part (c) is obtained without radiation). However, the (3,0) resonance has a significant discrepancy with the tracking data even when radiation is properly treated. We find almost a factor 10 between experiment and tracking. Although we do not yet have a full understanding of the cause of this difference it can probably be addressed to random sextupole components which are not included in the tracking.

3 CONCLUSIONS

Since the detuning versus amplitude can be well predicted from tracking (for the SPS as well as LEP) we are confident that our model includes the proper systematic part of the non–linearities. With respect to the first–order sextupole resonances the results are promising, but not yet conclusive. In the case of the SPS one resonance (3,0) is well predicted, but only one of the (1,0) resonances can be measured with sufficient precision but is wrong by a factor of two. For LEP the (3,0) resonance is largely underestimated,

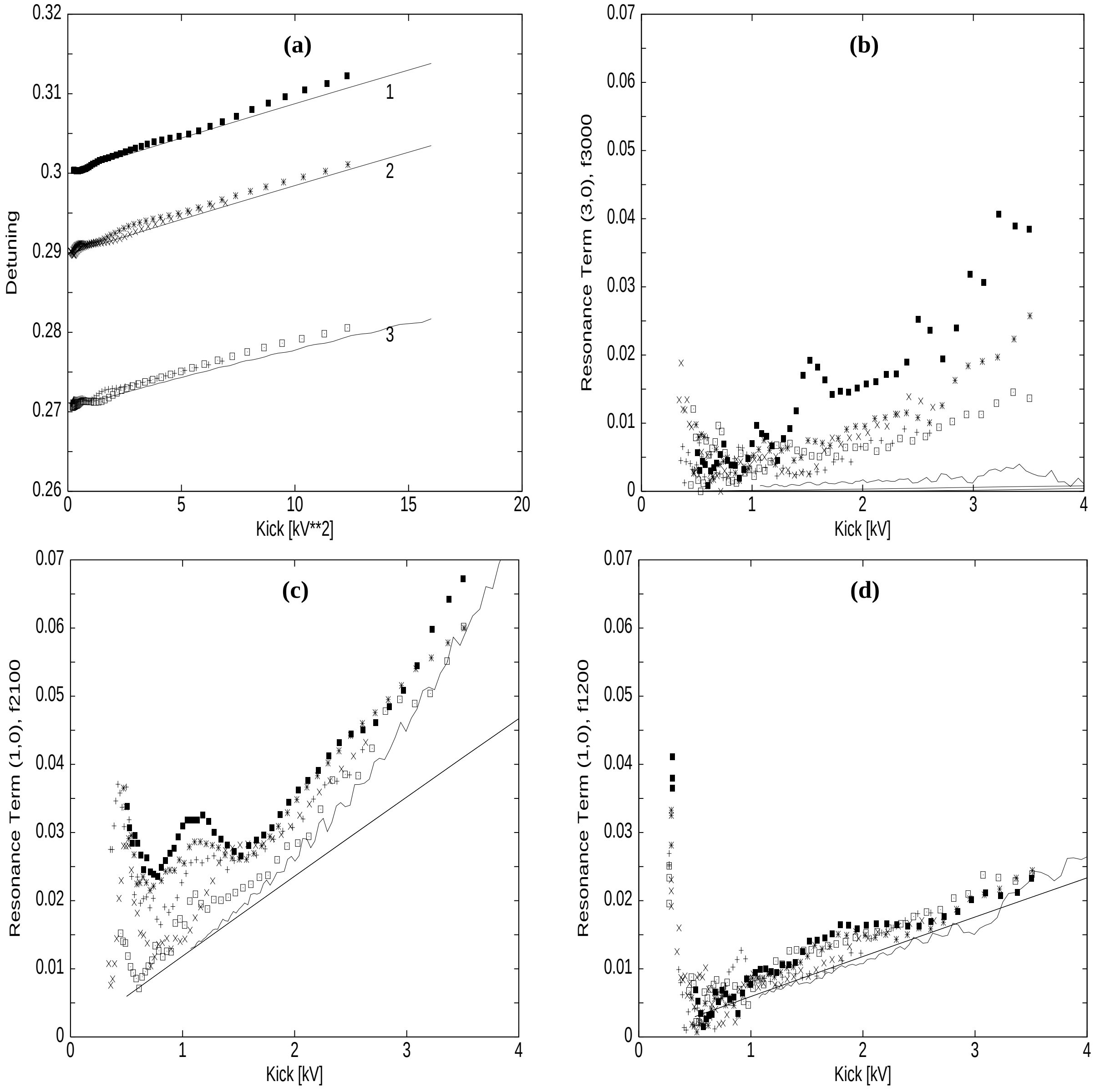

Figure 2: Detuning and First Order Sextupole Driving Terms
Part (a): Detuning versus kick amplitude [kV^2]; Part (b): (3, 0) Resonance versus Amplitude;
Part (c): (1, 0) Resonance (f_{2100}) versus Amplitude; Part (d): (1, 0) Resonance (f_{1200}) versus Amplitude;
–Lines are from tracking –Symbols are experimental data

probably due to the effect of the machine errors which increase the driving terms by more than one order of magnitude as shown in Ref. [11], while the two parts of the (1,0) resonances are in good agreement with the tracking.

We can conclude that there is a large potential for this method. However, more experimental studies and better tracking models are needed to make it a useful tool to measure and correct non–linear effects in real machines.

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