TURN BY TURN DATA ANALYSIS AT THE DIAMOND STORAGE RING

R. Bartolini[1,2], I. Martin[1], G. Rehm[1], J. Rowland[1],

[1]Diamond Light Source, Oxfordshire, UK
[2]John Adams Institute, University of Oxford, OX1 3RH, UK.

Abstract

The Diamond storage ring has been recently equipped with a set of two pinger magnets that can excite betatron oscillations to large amplitudes in both planes of motion. In conjunction with the turn-by-turn capabilities available at all BPMs, the system provides a powerful diagnostic tools for the characterisation of the linear and non-linear beam dynamics of the electron beam in the storage ring. We report the first results on the application of the Frequency Map Analysis and the measurement of the resonant driving terms at the Diamond Storage Ring.

INTRODUCTION

The performance of third generation storage ring light sources depends crucially on the correct implementation of the nominal optics. Both the linear optics and the nonlinear optics are usually the result of a long and complicated process of optimisation of the beam dynamics to achieve the small emittance typical of these machines with a large lifetime.

While the correct implementation of the linear optics has been substantially eased by fitting algorithms such as LOCO[1], the calibration of the nonlinear ring model of the storage ring still lacks an analogously comprehensive approach. The experimental analysis of the nonlinear beam dynamics relies on apertures and lifetime measurements which offer quite a limited knowledge of the detailed nonlinear model of the ring. Important steps forward were made with the introduction of the Frequency Map Analysis (FMA)[2] which offers clear information on the detuning with amplitude and the resonance structures excited in the storage ring. More recently, the frequency analysis of the betatron motion has been proposed to measure the driving terms of the resonances [3-4] that affect the beam motion, to establish their azimuthal dependence along the ring [5] and ultimately to calibrate the nonlinear model of the storage ring [6].

A prerequisite for this kind of analysis is a system of two independent single turn kickers capable of exciting betatron oscillations to large amplitudes in both planes independently and, most importantly, a BPM system with turn by turn capabilities all along the ring. The use of a continuous excitation with an AC dipoles [7] has been suggested mainly in the framework of hadron colliders and it can provide analogous information possibly with higher precision by-passing the problem of the decoherence of the turn-by-turn data.

Diamond has recently installed a system of two pinger magnets to generate horizontal and vertical kicks independently. The stored beam can also be continuously excited with a well defined harmonic signal by the recently installed TMBF system, although the amplitude of the excitation is limited. Several experiments have already been performed to characterise both the linear and the nonlinear beam dynamics from the frequency analysis of the betatron oscillations. The preliminary results are reported in this paper.

KICKERS AND BPMS SYSTEM

Two independent kickers are used to excite large amplitude betatron oscillations. The kick angle is sufficient to deflect the beam to the vacuum chamber so that a full scan of the available aperture can be performed.

The kickers are based on solid state switches technology and deliver half sine pulses with a total pulse length in between 3.0μs (strong pulses) and 3.4μs (very weak pulses). This is almost two turns and the kickers timing is adjusted to kick the beam at the peak of the half sine pulse. A careful timing of the BPM data acquisition makes sure that turn by turn data from all BPM data can be aligned with the turn number. Also, particular care was taken in order to align the time window within a single turn so that the beam signal at a given turn does not leak to the neighbouring turns. The kickers were calibrated recording the maximum oscillations as a function of current and correcting the BPMs nonlinear response with two polynomial fits one for the horizontal direction and one for the vertical plane of motion.

All the 168 BPMs can all deliver turn-by-turn data with a buffer of 2048 turns updated at 5 Hz from all the 168 BPMs. With an externally armed acquisition it is possible to store up to 524288 turns at all BPMs. The precision of the system in turn-by-turn mode is 10 μm rms at 10 mA.

A typical example of the spectrum of the signals acquired at all BPMs is shown in Fig. 1 where we report the colour plot of the amplitude of the FFT of the 168 BPM signals. The betatron tune lines are clearly visible as intense red lines showing up at all BPMs at the normalised frequency 0.22 (top picture) in the horizontal plane, which is the horizontal tune Q_x, and 0.36 in the vertical plane (bottom picture) corresponding to the vertical tune Q_y. At the same time one can distinguish the horizontal betatron tune $Q_x = 0.22$ appearing in the vertical plane, as well as the vertical betatron tune $Q_y = 0.36$ appearing in the vertical plane, both signature of linear coupling in the storage ring. Fainter lines seen at the normalised frequencies 0.44 ($2Q_x$) in the horizontal plane and 0.14 ($Q_y – Q_x$) in the vertical plane are related to nonlinear resonance driving terms [4].

The frequency analysis based on high accuracy super-FFT techniques [9] is mandatory in this type of analysis.

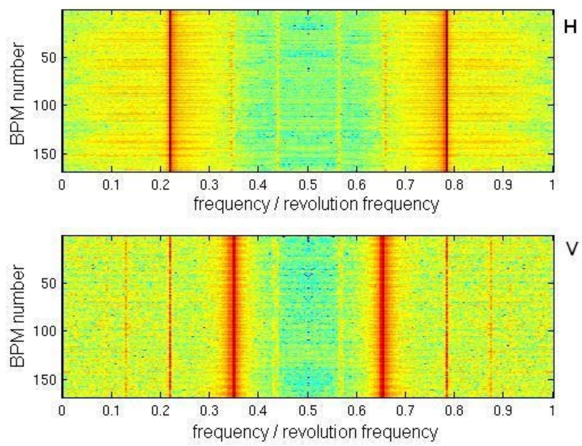

Figure 1: Colour plot of the FFT of the signal acquired at all BPMs after a horizontal kick (top) and a vertical kick (bottom) (see text for explanation).

LINEAR OPTICS STUDIES

The analysis of the amplitude and phase of the frequency lines associated to the betatron tunes provides a wealth of information about the linear optics of the machine. As an example following the amplitude variation of the betatron tune lines at the various BPMs will provide a signal proportional square root of the β function in the two planes, from the usual expression for the uncoupled betatron motion

$$z(n) = \sqrt{\varepsilon_z \beta_z} \cos(2\pi Q_z n + \varphi_z)$$

where z can be horizontal x or vertical y. In Fig. 2 we report an example of initial comparison of the amplitude of the horizontal tune line with the model. The agreement with the square root of β_x is within few % at most BPMs except the BPMs in the straight section which have a different geometry and appear to provide lower optic function by 10-15%.

The direct use of this information to reconstruct the linear lattice of the ring is hampered by the imprecise knowledge of the BPM gains. The strategy adopted was to rely on the BPM calibration provided by LOCO. If one is interested only in the linear coupling or the nonlinear resonance driving term one can alternatively free the data from the lack of a reliable knowledge of the BPM gains by defining quantities which are normalized to the amplitude of the tune line [5].

In order to test the agreement between the measured amplitude of the spectral lines and the linear machine model, we performed a series of controlled experiments where we deliberately offset the nominal linear optics of the storage ring. After offsetting a single quadrupole by 5% we were able to accurately reproduce the β-beating of the machine as shown in Fig. 3.

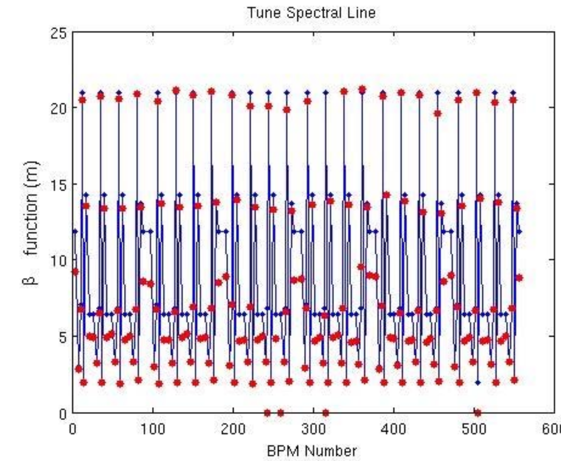

Figure 2: horizontal beta function from the square of the amplitude of the horizontal tune spectral line (red) and from the model (blue).

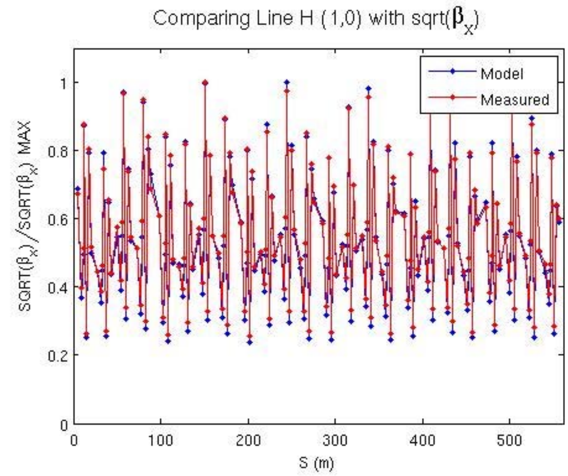

Figure 3: Same as Fig. 2 with β-beating introduced by a single quadrupole offset by 5% from its nominal value (horizontal plane).

After powering a single skew quadrupole to full strength we could accurately reproduce the contribution to the linear coupling resonant driving terms to the horizontal tune spectral line Q_x detected in the vertical plane. This experiment was performed on a storage ring optic which was previously corrected with LOCO to generate a very small linear coupling of 0.2% as measured by the system of two X-ray pinhole cameras used for the emittance measurements. The coupling with the skew quadrupole mispowered is above 2%.

The effect of the mispowered skew quadrupole on the coupling spectral line is shown in Fig. 4 where we report the amplitude of the Q_x spectral line detected in the vertical plane for the corrected lattice and the lattice with the offset quadrupole. In fig. 5 we report the comparison of the measured amplitude of this line with what is obtained in the model by mispowering the same skew quadrupole. Again, the agreement between the machine and the model is very good.

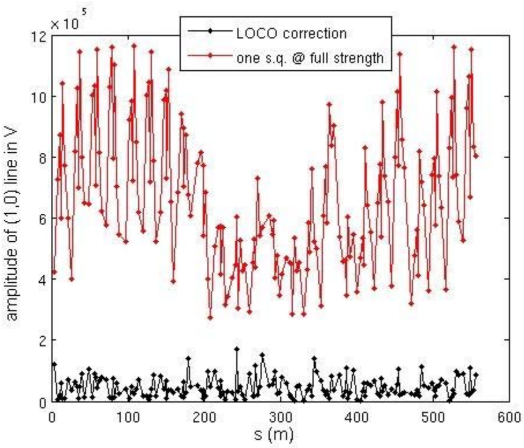

Figure 4: comparison of the amplitude of the Q_x spectral line measured in the vertical plane for two machine optics (see text for explanation).

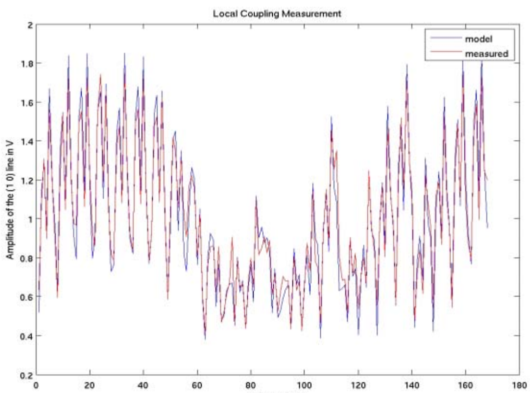

Figure 5: Amplitude of the tune spectral line Q_y detected in the horizontal plane measured (red) and model (blue).

NONLINEAR OPTICS STUDIES

The analysis of the excitation of the higher order spectral lines, given by linear combination of the betatron tunes, provides information about the nonlinear resonance driving terms. At Diamond we were able to detect the azimuthal dependence of several spectral lines driven by nonlinear resonances. Tracking data show that these lines have amplitudes which are generally two orders of magnitude smaller than the amplitude of the betatron tunes.

In Fig. 6 we report the spectral lines given by the linear combination $Q_x - Q_y$ detected in the vertical plane and its comparison with the model. According to [4] this spectral line is associated with the driving term of the $Q_x - 2Q_y$ resonance excited by the sextupole in the ring. Again there is a remarkable agreement showing the good quality of the data recorded by the BPM system. Similar results are obtained with the spectral line given by the combination 2Qx (Fig. 7) detected in the horizontal plane. This line is excited by the resonant driving term of the $3Q_x$ resonance again excited by the sextupoles. The agreement of this last line is less striking but the general behaviour of the line, with its periodicity and peaks is well reproduced.

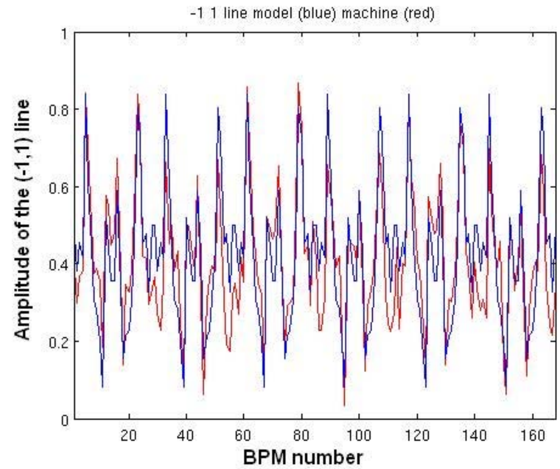

Figure 6: Comparison of the amplitude of the (-1, 1) spectral line excited in the vertical plane: blue is obtained from tracking with the nominal optics red is measured.

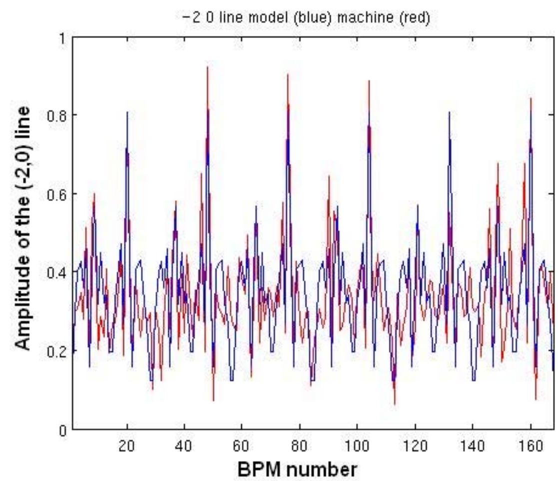

Figure 7: Comparison of the amplitude of the (-2, 0) spectral line excited in the horizontal plane.

LIMITS AND CONCLUSION

The techniques for the frequency analysis of the betatron motion require a very good signal to noise ratio to be effective. Therefore the BPM signal precision is a crucial issue. At the same time the quality of the data can be limited by decoherence of the oscillations and BPM nonlinearities. Nevertheless, we believe that the BPM quality at Diamond, is sufficient to perform fitting algorithms to correct the nonlinear machine model [6] and improve the performance of the storage ring.

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