TURN-BY-TURN DATA ANALYSIS FOR PETRA III

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Abstract

PETRA III is a 3rd generation synchrotron radiation light source which started commissioning in April 2009. Turn-by-turn capabilities are available for all 227 BPMs installed in the storage ring thus providing a powerful diagnostic tool for the characterization of the linear and nonlinear motion of the stored beam. We report on first results of beam dynamics studies using multiturn data acquired at PETRA III and first steps towards a calibration of the linear and nonlinear lattice model of the storage ring.

INTRODUCTION

Optimal performance of third generation light sources require a careful control of the linear and nonlinear optics. While linear optics measurements and corrections are routinely performed using closed orbit response methods and powerful fitting algorithm like LOCO [1], a comparable comprehensive and efficient approach for nonlinear optics calibration is lacking. The analysis of nonlinear beam dynamics typically relies on aperture and lifetime measurements which only provide rather indirect information of the actual status of the nonlinear optics. Global information like detuning coefficients and resonance structures are provided using frequency map analysis techniques [2]. The most ambitious approach to gain insight into the nonlinear beam dynamics of a storage ring relies on multiturn capabilities of all beam position monitors distributed in the ring [3, 4]. A frequency analysis of the betatron motion typically reveals a number of spectral lines affecting the nonlinear dynamics of the particle beam. Each of these spectral lines is (at least to first order in perturbation theory) proportional to a specific resonance driving term. Hence, this method allows to determine the azimuthal dependence of resonance driving terms [5] and to calibrate the linear and nonlinear model of the storage ring [6, 7, 8].

We report on the first measurements using the turn-by-turn capabilities of the BPMs installed in PETRA III made during the commissioning. At the time of data taking all damping wigglers were installed and several iterations of linear optics corrections using closed orbit response methods have been performed. The chromaticity was set close to zero slightly below their nominal values of 0.5 in both planes to minimize the decoherence of the turn-by-turn data.

KICKERS AND BPM SYSTEM

The analysis of turn-by-turn data requires two independent kicker magnets to excite betatron oscillations with the desired amplitude in the horizontal and vertical plane. At PETRA III any of the three injection kickers can be used for the horizontal plane while for the vertical plane a dedicated kicker magnet has been installed. They are triggered with the (same) injection trigger so that diagonal kicks are possible. All kickers are based on solid state switches technology and deliver half sine pulses of approximately 12 μs length slightly varying with the strength of the pulses. Given a revolution time of 7.68 μs this pulse length corresponds to almost two turns. Therefore, the kicker timing is adjusted to kick the beam at the peak of the half sine pulse to ensure amplitude control and to provide equal amplitudes to all bunches in the case of multibunch fills. The maximal length of a multibunch fill is chosen such that all bunches stay in the flat region close to the peak of the kicker pulse. The maximum kick angle exceeds the physical aperture of the machine so that a full scan of the available aperture can be performed. The kickers were calibrated using the maximum oscillation measured as a function of the kicker high voltage, where the nonlinear response of the BPMs as well as their frequency response has been taken into account. The result has been cross checked against a calibration using scrapers.

All 227 BPMs installed in PETRA III can deliver turn-by-turn data. The injection trigger is used as an arming trigger for the measurement. This allows, in principle, an acquisition of several ten thousand turns from all BPMs. Due to the notorious problem of decoherence the data acquisition has been limited to a typical value of 1024 turns. The timing of the internal trigger delay of the BPMs has been carefully adjusted to align the data with the turn number and to minimize the leakage into neighboring turns. The nonlinearity of the BPMs is corrected using an 11th order fully coupled polynomial fit. The resolution of the BPM system in turn-by-turn mode is of the order of 10 μm rms for a current of 5 mA.

MEASUREMENTS

Figure 1 shows a typical example of the spectrum of the BPM signals collected at all monitors for a moderate diagonal excitation of $\varepsilon_x = 1.225$ mm mrad and $\varepsilon_y = 0.85$ mm mrad. The upper picture is a colour plot of the amplitude of the FFT of the oscillations in the horizontal plane while the lower picture corresponds to the vertical plane.

The horizontal and the vertical axis label the fractional tune and the monitor numbers along the ring, respectively. The betatron tune lines are clearly visible in both planes at all BPMs. The horizontal betatron tune ν_x appears at a normalized frequency of 0.125, while the vertical tune shows up at $\nu_y = 0.2844$. Both lines can be recognized in the horizontal as well as in the vertical plane reflecting a residual coupling either present in the machine or created by BPM tilts and/or crosstalk in the electronics. The residual coupling derived from this measuremnt using

$$|f_{1001}| = \frac{1}{2}\sqrt{\frac{\text{line}(0{,}1)_h}{\text{line}(1{,}0)_h}\frac{\text{line}(1{,}0)_v}{\text{line}(0{,}1)_v}}$$

is 3.5% which is in good agreement with the emittance ratio measured at the optical diagnostics beam line.

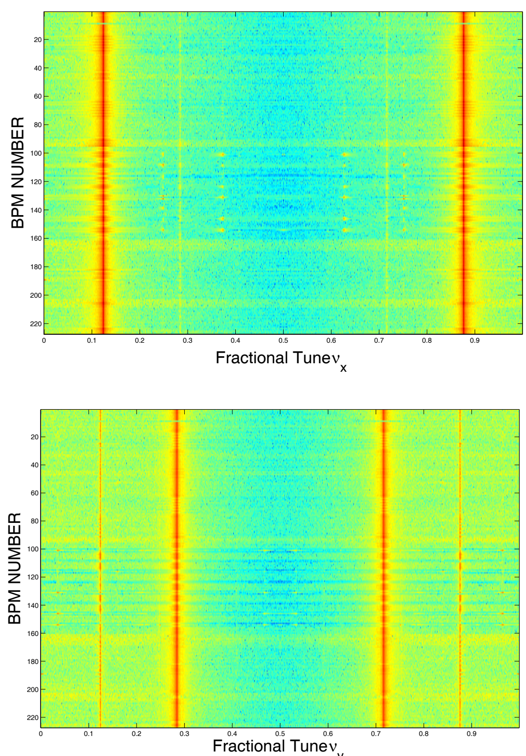

Figure 1: Colour plot of the FFT of the signal acquired at all BPMs after a combined horizontal and vertical kick of $\varepsilon_x = 1.225$ mm mrad and $\varepsilon_y = 0.85$ mm mrad. The horizontal (vertical) spectrum is shown in the upper (lower) plot.

It is well known that the amplitudes of the fundamental lines are proportional to the square root of the beta functions. This fact is illustrated in figure 2 where square of the measured amplitudes of the fundamental lines in figure 1 are plotted against the beta functions of the nominal optics at the BPMs computed by MadX. Again the upper picture corresponds to the horizontal plane while the lower picture shows the vertical plane. The rms beta beating computed from the measurement is 4.3% in the horizontal and 5.2% in the vertical, which is in agreement with data acquired with closed orbit response methods. The agreement in the seven FODO arcs and especially in the wiggler sections is very good. The largest deviations occur at the positions of the center BPMs in the canted undulator sections. Due to their geometry those monitors have a very small range where the signal is reliable limiting their use in this type of measurement.

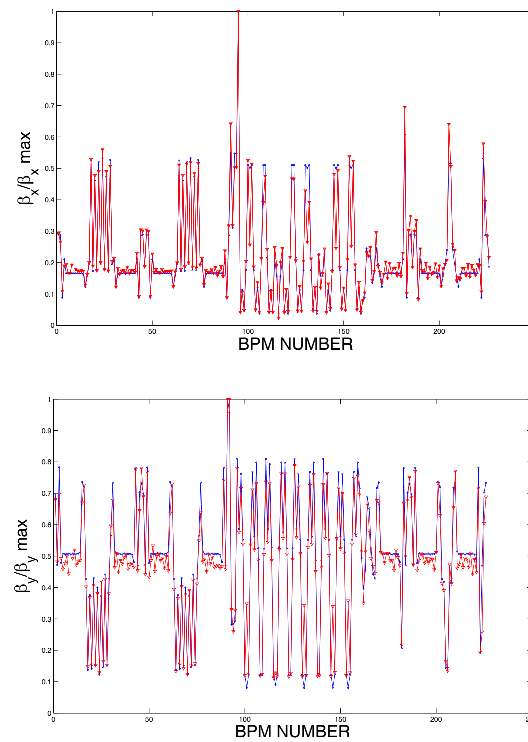

Figure 2: Comparison of the beta functions from the square of the the amplitude of the tune spectral lines (red) and from the MadX model (blue).

Higher order spectral lines corresponding to nonlinear motion of the particle beam can be excited at large (horizontal) kicks. In figure 3 the spectrum of the vertical plane is shown recorded at a diagonal excitation of $\varepsilon_x = 15$ mm mrad and $\varepsilon_y = 0.4$ mm mrad. Several additional lines appear, most relevant is the line corresponding to $\nu_y - \nu_x$ at a normalized frequency of 0.1612. It is associated to the driving term of the sextupole resonance $\nu_x - 2\nu_y$.

The longitudinal dependence of this line is compared with the result of a tracking run performed with SixTrack in figure 4. PETRA III has sextupoles only in the seven FODO arcs. They are distributed in two families in the 72 degree phase advance lattice so that the first order driving terms cancel after 5 cells. The fourteen peaks corresponding to this scheme are clearly visible in the plot. In the center region the sextupole free new octant is recognized. While the periodicity is reproduced very well the agreement for amplitude is less striking. Both lines have been normalized to the amplitude of the (vertical) tune line to get rid of the dependence on the BPM gains.

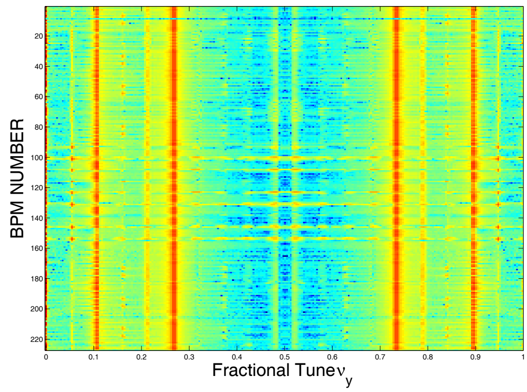

Figure 3: Colour plot of the FFT of the vertical signal acquired at all BPMs after a combined large horizontal and vertical kick of $\varepsilon_x = 15$ mm mrad and $\varepsilon_y = 0.4$ mm mrad, respectively.

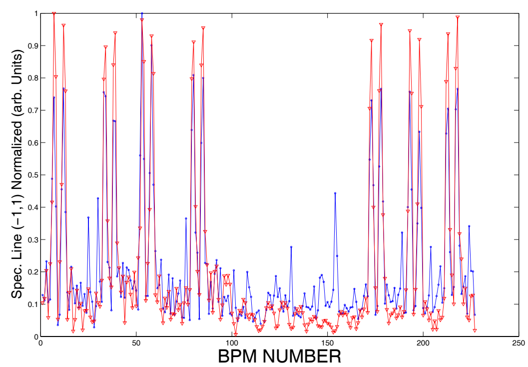

Figure 4: Longitudinal variation of the spectral line (-1,1) excited in the vertical plane: blue is measured, the red curve is obtained from tracking with SixTrack.

Although a correction of the nonlinear response of the monitors is applied in figure 3 not all spurious nonlinearities are removed from the spectrum. In particular the BPMs located in the undulator sections show strong nonlinear behavior. The line corresponding to $2\nu_x$ is presumably mainly arising from the incomplete compensation of the bpm nonlinearity. This effect hampers the identification of the $3\nu_x$ driving term represented by the $2\nu_x$ spectral line in the horizontal plane. Typically, the lines corresponding to sextupole resonances are expected to be two orders of magnitude smaller than the fundamental lines. However, for PETRA III the $2\nu_x$ line is a factor of 4 smaller than the $\nu_y - \nu_x$ line as can be seen in the tracking data shown in figure 5.

CONCLUSIONS AND OUTLOOK

The frequency analysis of betatron oscillations has proven a powerful tool to access a wealth of information about the linear and nonlinear optics of storage rings. Here we presented results from the first measurements of this

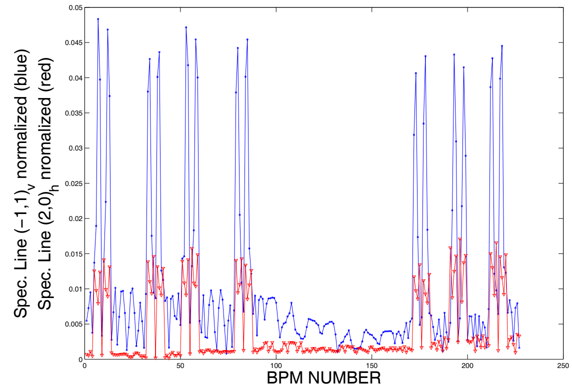

Figure 5: Comparison of the amplitude of the spectral lines (-1,1)(blue) in the vertical plane and (2,0)(red) in the horizontal plane derived from tracking data. Both lines are normalized to the tune lines.

type performed during the commissioning of PETRA III. The results concerning the linear optics are in good agreement with those obtained by standard closed orbit response measurements. The identification of sextupole resonance driving terms from the multiturn data is promising but requires some refinement in view of the BPM nonlinearities in order to be used in fitting algorithms to correct the nonlinear machine model. A further improvement of the data quality by-passing the decoherence problem is likely to be achieved by resonant excitation of betatron oscillations. First tests using the powerful transverse multibunch feedback installed in PETRA III were already performed and stable excitation amplitudes of several millimeters have been achieved.

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