LINEAR AND NONLINEAR OPTICS ANALYSIS FROM MULTITURN DATA AT PETRA III

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Abstract

At Petra III measuring multiturn beam response to pulsed and continuous excitations allows linear and nonlinear (e.g. frequency maps) optics parameter determination. We describe the measurement setup, approaches to optics parameter determination, and the measurement results for Petra III.

INTRODUCTION

Optics measurement based on multiturn data analysis has been extensively studied and applied [1, 2]. The studies discussed in this paper contain no conceptually new results, but report on a step in the development of the linear and nonlinear optics measurement and correction procedures based on well-known multiturn measurement methods. This is intended to be part of a more general monitoring of multiturn orbit data, which can present a useful tool for real-time on-line optics diagnostics. Such tools are becoming especially relevant in connection with the PETRA upgrade programme ([3]). where the optics has to be controlled to a better degree, and development of faster and less invasive diagnostiocs tools can be of benefit.

First optics analysis for PETRA III based on multiturn data was presented in [4] and [5]. Here we extend this line of work: new measurements were done after the extension project was completed, and the optics measurements based on AC excitation were performed.

While all measurement methods described here work for PETRA, their setup is still too manual for them to be automatically and routinely performed, and more developments are required in this direction.

HARDWARE AND MEASUREMENT SETUP

Several kickers are available for beam excitation: pulsed horizontal injection kickers, a vertical pulsed kicker designed for diagnostics purposes, and horizontal and vertical feedback kickers which can be driven in continuous mode with a frequency up to 62.5MHz. The pulsed injection kickers have a half-wave sinus pulse form with approx. 10 µs duration, and thus affect a bunch during two turns. During the measurements, the voltages of one horizontal and one vertical kicker are scanned on a mesh. During a beam loss or significant current drop, the beam in PETRA is refilled. The most significant overhead in the measurement is associated with changing the kicker voltages, which results in measurement times of a few hrs for a 100 point dataset. From the dataset, dynamic aperture, frequency maps, and linear optics can be extracted. Both on and off-momentum mesurements were performed. A significant problem is presented by choosing the right kicker voltage configuration. With the setup necessary for injection or probing the dynamic aperture, clean dependency of the kick on the applied voltage was not possible for small kicks which are necessary for linear optics determination. To simultaniously operate in large and small kick angle regimes, hardware setup might be revisited.

The Libera Brilliance BPM system can provide up to approx. 60000-turn data. To improve resolution, a moving averaged filter (MAF) can be used on the BPMs. Unfortunately, BPM firmware has to be changed every time such a filter is used, so it is not compatible with routine operation and was not used for most of the measurements shown here. To minimize the effect of the kicker pulse shape, all multiturn measurements were performed with one or a few (up to 5) bunches. The total current in such mode is limited to approx 5 to 10 mA. This affects negatively the BPM resolution, as compared to the more uniform fill pattern with higher current wich can be employed during orbit response measurements. Moreover, the optics change due to impedances at high bunch charge makes any measurement with such fill patterns (more than 1 mA per bunch) not directly related to, say, the most standard operation mode with about 0.1 mA per bunch.

LINEAR OPTICS FROM KICKED BEAM RESPONSE

Standard optics measurement and correction at PETRA is performed with LOCO [6]. A typical result of beta beating measurement is shown in Fig. 1. The linear optics can be extracted from the multiturn data in several ways, e.g. with the 3-BPM method as described in [2]. The phase difference between adjacent BPMs at PETRA is shown in Fig. 2. Some phase differences are close to $\pi/2$, which makes the 3-BPM method sensitive to errors. So, for PETRA a 10^{-3} error of betatron phase determination from multiturn data already leads to unacceptably large errors in Twiss parameter reconstruction (tens of %). More advanced methods based on data from N BPMs should be explored further (see e.g. [7]). Moreover, as described before, the measurement is limited by low accuracy of injection kickers at low voltage and by the unavailability of MAF filter on all BPMs during routine measurements. With all these effects combined, the 3-BPM method leads to beta beating estimate in the tens of percent range, which is contrary to the measurements

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with LOCO. Using multiturn data for optics extraction was possible for kick amplitudes of around 2 mm (see Fig. 3). At these amplitudes, the beam decoherence is already prominent and affects the measurement. Moreover, the optics for such amplitudes cannot be directly compared to the nominal linear model. Optics determination based on the maximum amplitude in the Fourier spectrum of the BPM signal suffers from the same problem, so we conclude that measures are to be taken if linear optics determination based on multiturn data is to be used routinely (routine usage of MAF filters, kicker calibration with both high and low voltage, maximum possible beam current). For large amplitudes the tune signals are clean (see Figs. 4, 5).

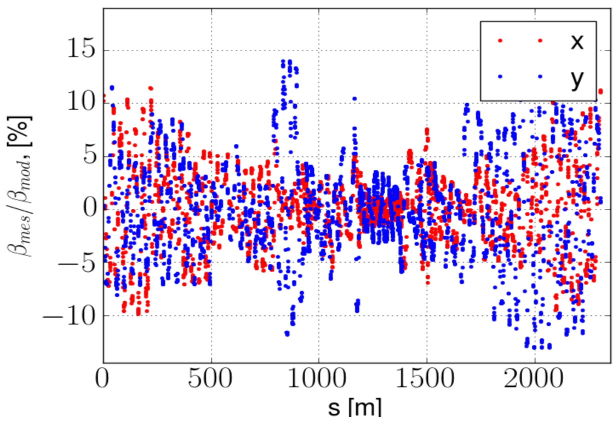

Figure 1: Beta beating measured with LOCO.

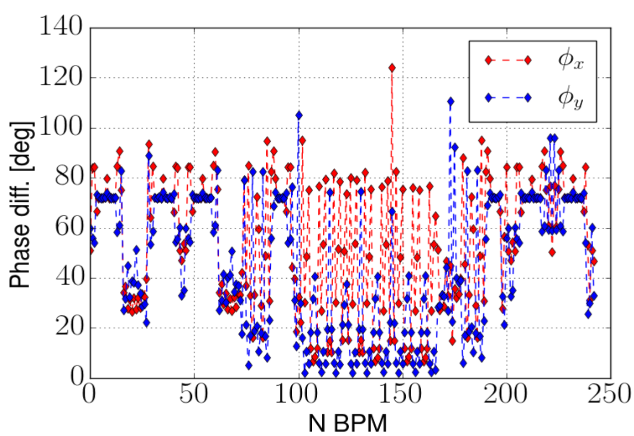

Figure 2: Phase differences between BPMs at PETRA.

For larger excitations (amplitudes 2 mm and more), signal-to-noise ratio in the tune spectrum becomes insignificant.

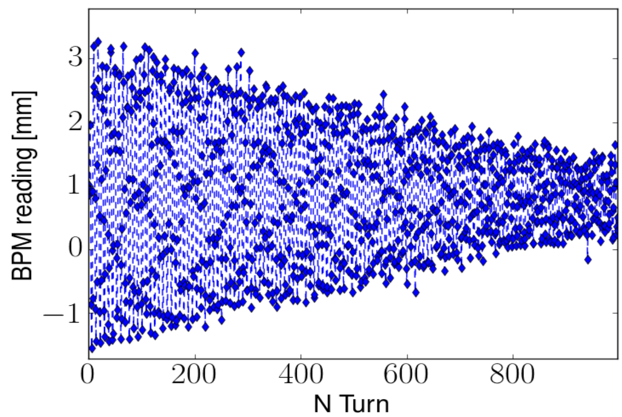

Figure 3: BPM signal, β_x=12 m at BPM location.

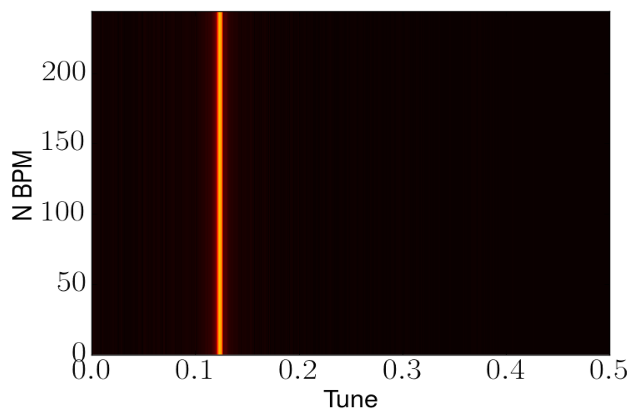

Figure 4: X spectrum, corresponding to horizontal excitation of 6 mm and vertical excitation of 3 mm.

LINEAR OPTICS FROM AC EXCITATION

A technique that allows to potentially overcome many of limitations described above consists in extracting the optics information from the multiturn response of the beam to a continuous (AC) excitation [8]. At PETRA III, first measurements were performed with a single bunch using the multi-bunch feedback system. The excitation frequencies were close to the tune (17 kHz in the horizontal and 40 kHz in the vertical plane). The excitation amplitudes had to be manually adjusted to provide enough response without loosing the beam. Especially in the vertical direction where the aperture is limited by the collimators protecting the insertion devices, finding such excitation regime turned out to be non-trivial. During a second measurement we further attempted to bring the conditions closer to nominal operation, so that a comparison with LOCO could be made. The measurement was performed with 5 bunches (positions 1,2,3,4,5 out of 960, separated by 8 ns). With the multibunch feedback off, we were unable to store more that 1 mA current per bunch. Furthermore, we kept feedbacks acting in the plane different to the excitation plane on to improve bunch stability. The results of these measurements however showed larger estimated errors (about 4% compared to about 2% for the first measurement). An example of error distribution analysis of the optics reconstruction from the first measurement is shown in Figs. 6 and 7 (for this analysis, following somewhat conservative assumptions were assumed: 300 µm rms sextupole alignment error, 500 µm rms quadrupole alignment

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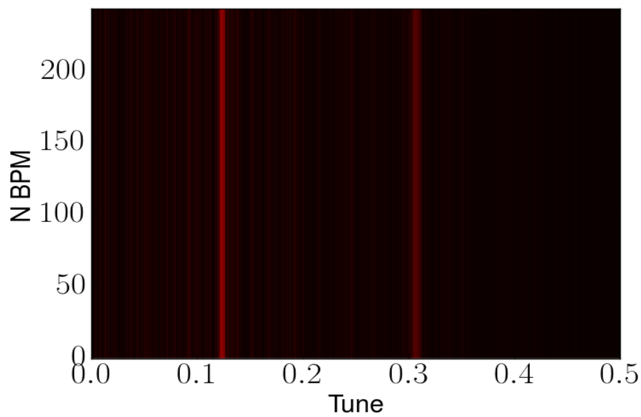

Figure 5: Y spectrum, corresponding to horizontal excitation of 6 mm and vertical excitation of 3 mm.

error, and 10^{-3} rms relative quadrupole strength error; in reality these values are better). Work is ongoing to improve the measurement resolution.

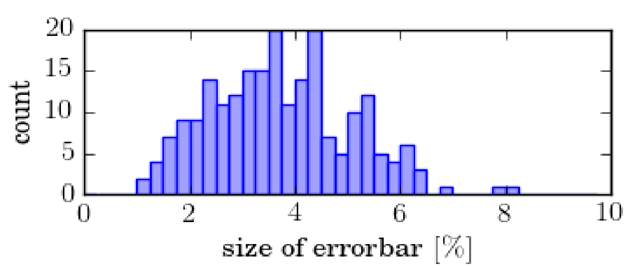

Figure 6: Error estimate in reconstruction of the horizontal optics with the AC dipole method.

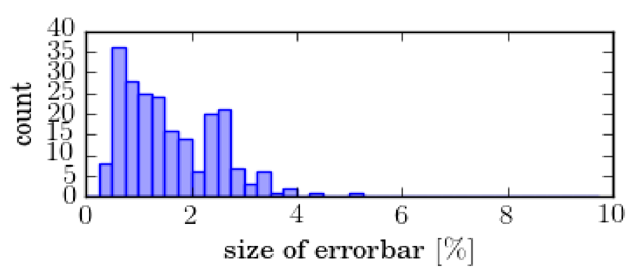

Figure 7: Error estimate in reconstruction of the vertical optics with the AC dipole method.

FREQUENCY MAPS

Frequency maps, i.e. the mappings from the 'actions' or 'amplitudes' of a (n-dimensional) dynamical system to its frequencies, play a prominent role in stability analysis. For an integrable Hamiltonian

$$H = H_0(I) \tag{1}$$

the non-degeneracy of the Jacobian

$$\left|\frac{\partial \omega}{\partial I}\right| = \left|\frac{\partial^2 H_0(I)}{\partial^2 I}\right| \neq 0 \tag{2}$$

is an essential condition for preservation of 'integrability' under the KAM theorem. In a more narrow sense the frequency map analysis was first applied in celestial mechanics [9] and could be used to characterize properties of nonlinear systems [10], [11]. The application of this technique to particle accelerators [12], [13] has two aspects: (a) presentation and interpretation of simulation (tracking) results via their frequency analysis and (b) nonlinear dynamics verification and identification of particle loss directions from experiments with excited beams. For PETRA, frequency map measurements were presented before [5]. The new measurements (see e.g. Fig. 8) are compatible with the old, albeit taken at a different working point. At PETRA III nonlinear dynamics does not play such a prominent role as at the new generation of storage rings based on MBA technology. As far as the frequency analysis is concerned, this manifests itself in a compact footprint with tune dependency on amplitude and energy deviation close to linear. For the PETRA upgrade (PETRA IV), the nonlinear dynamics verification via measuring the tune footprint will play a more important role.

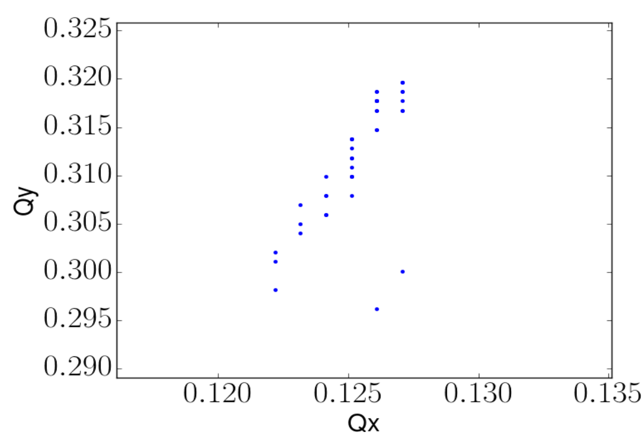

Figure 8: A measured frequency map at Petra III.

CONCLUSION AND OUTLOOK

Multiturn bunch measurement system is in operation at PETRA, but its potential for reliable diagnostics still has to be exploited, especially for the linear optics diagnostics. The problem of fill pattern and bunch current difference during multiturn measurements and normal operation has to be particularly addressed.

ACKNOWLEDGEMENTS

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