FREQUENCY MAPS AT PETRA III

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Abstract

PETRA III is a 3rd generation synchrotron radiation light source which started commissioning in April 2009. Recently, first frequency map measurements have been made using the turn-by-turn capabilities of the beam position monitors and horizontal as well as vertical kicker magnets. The results are in good agreement with expectations from tracking studies performed with SixTrack.

INTRODUCTION

Optimal performance of third generation light sources require a careful control of the linear and nonlinear parameters governing the dynamics of the circulating beam. Frequency map analysis as introduced by J. Laskar [1] has proven to be a valuable tool to investigate and optimize the performance of third generation synchrotron light sources [2, 3, 4, 5]. It provides information about global parameters like detuning coefficients and resonance structures of single particle dynamics which contribute to performance limitations of the machine.

PETRA III [6] is a 3rd generation synchrotron radiation light source which started commissioning in April 2009. In seven of the eight octants the lattice is based on a 72° FODO structure, while the 8th octant consists of 9 double bend achromat cells with dispersion free straight sections for the installation of up to 14 undulators. The emittance of the bare machine (without insertion devices) is 4.65 nm rad. Two of the long straight sections, one in the west and one in the north, accommodate in total 20 damping wigglers needed to achieve the design emittance of 1 nm rad.

Table 1: Main Parameters of PETRA III

Energy [GeV]	6.0
Circumference [m]	2303.952
Emittance Hor./Ver. [nmrad]	1.0/0.01
Hor. Tune Q_x	36.115
Ver. Tune Q_y	30.28
Hor. nat. Chromaticity ξ_x	-42.8
Ver. nat. Chromaticity ξ_y	-41.3

Based on tracking studies [7] a chromaticity correction scheme was chosen which relies on sextupoles installed only in the seven FODO octants. In principle, the arc FODO lattice allows two families of chromatic sextupoles per plane in PETRA III, but the optimization of detuning terms has shown that minimized sextupole strengths using only one family per plane are favorable in view of a maximal dynamic aperture. In addition to the nonlinearities introduced by the sextupoles the strong damping wigglers are intrinsic sources of octupole components. On top of the intrinsic nonlinearities multipole errors obtained from magnet measurements are added to the machine model. Their influence on the dynamic aperture was investigated in tracking studies in [8]. Here we report on first measurements using frequency map analysis at PETRA III made during commissioning in 2009 and compare the results with the numerical simulations.

PREREQUISITES

A prerequisite for the measurement of frequency maps in accelerators are 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 also 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. The kicker timing is adjusted to kick the beam at the peak of the half sine pulse to ensure optimal amplitude control. The maximum kick angle exceeds the physical aperture 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. For the measurement presented here a dedicated monitor for turn-by-turn measurements located at the end of the short straight section near the injection has been used. For future measurements the use of several (or possibly all) BPMs is planned to increase the resolution of the tune measurement. Due to the notorious problem of decoherence of kicked beam data the data acquisition has been limited to a typical value of 1024 turns. During commissioning 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 at a beam current of 5 mA. For the measurements reported here only single bunches of around 1.5 mA intensity have been used.

Using higher current multibunch fills are likely to provide enhanced resolution in future measurements.

MEASUREMENTS

The machine status at the time of data taking was as follows. All wigglers were installed and the linear optics correcting their (mainly) vertical focussing contribution was established. Several iterations of optics corrections were performed leaving an rms beta beating of $\sim 3\%$ in the horizontal and $\sim 2\%$ in the vertical plane. The sextupoles were slightly detuned to give a chromaticity slightly below the nominal value of $\xi_x = \xi_y = 0.5$ close to zero in order to minimize the decoherence of the data. 200 datapoints were recorded in ten series of 20 linearly spaced horizontal kicks with linearly increasing vertical amplitude. In both planes the limit of the available dynamic aperture has been reached so that the boundary could be determined according to the fractional beam loss (see below). The data acquisition time for the complete experiment was approximately 2 hours.

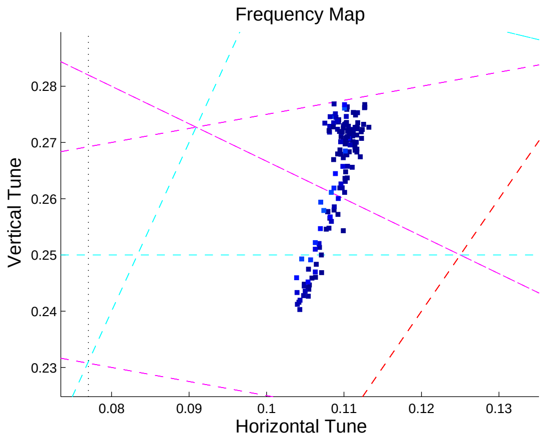

Figure 1: First experimental frequency map performed for PETRA III after installation of all damping wigglers. The color code indicates partial beam loss according to dark blue for no beam loss to light blue.

The result of the frequency analysis is shown in figure 1. Using a single bunch and only one BPM a limited resolution is expected. In addition, insufficient tune stability at the early stage of commissioning introduces further noise into the measurement. Nevertheless, some key features of the particle dynamics are still visible. As in the computed frequency map shown in figure 2 the expected dominant effect is the strong variation of the vertical tune with horizontal amplitude.

A large $\Delta\nu_{yx}$ detuning cross term is typical for FODO lattices. The value for the coefficient expected from a fit to the tracking data shown in figure 3 is approximately -2100. The variation of the vertical (horizontal) tune with vertical (horizontal) amplitude is typically one order of magnitude smaller.

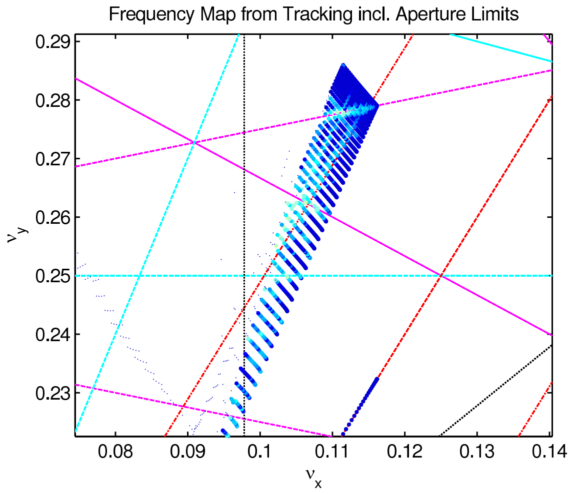

Figure 2: Frequency map for PETRA III with wigglers created with SixTrack. Measured multipole errors and aperture limits are included.

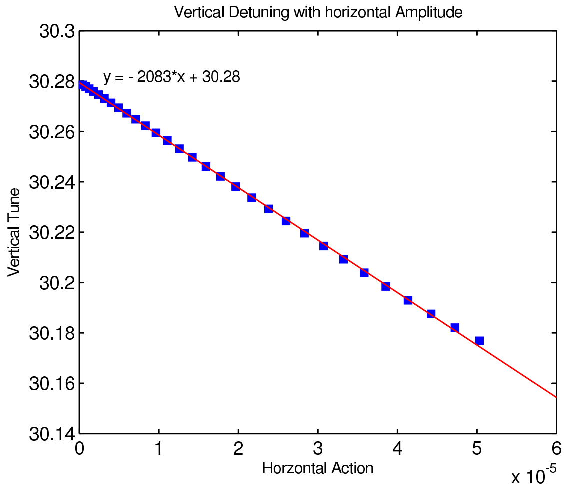

Figure 3: Detuning of the vertical tune with horizontal amplitude derived from tracking with SixTrack.

A fit to the experimental data gives a value of -2445 for $\Delta\nu_{yx}$ which is in reasonable agreement with the expected value. Although the machine features strong damping wigglers the detuning with amplitude is still dominated by the chromatic sextupoles ($\Delta\nu_{yx} = -2400$ for the bare machine without wigglers).

The dynamic aperture expected from tracking studies is shown in figure 5. Injection efficiency for smooth machine operation requires 20 mm mrad of horizontal and 0.8 mm mrad of vertical acceptance. These limits are clearly exceeded as can be seen in the reconstruction of the dynamic aperture from the measured frequency map shown in figure 6 using 20% (blue) and 50% (red) beam loss as defining boundaries. The dynamic aperture reaches 27 mm mrad in the horizontal and 1.2 mm mrad the vertical plane. This

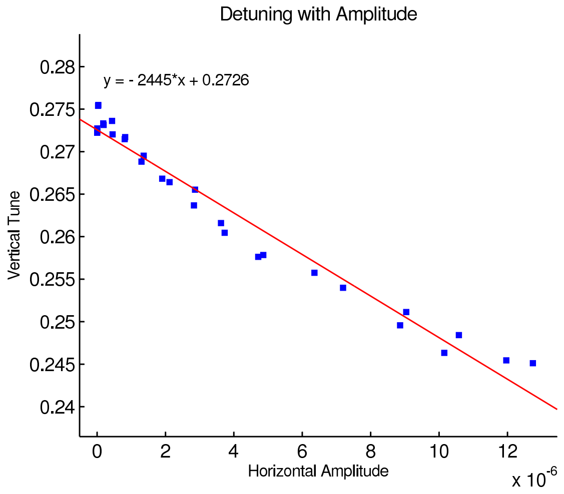

Figure 4: Detuning of the vertical tune with horizontal amplitude extracted from the experimental frequency map.

is in agreement with the good injection efficiency close to 100% even with closed wigglers.

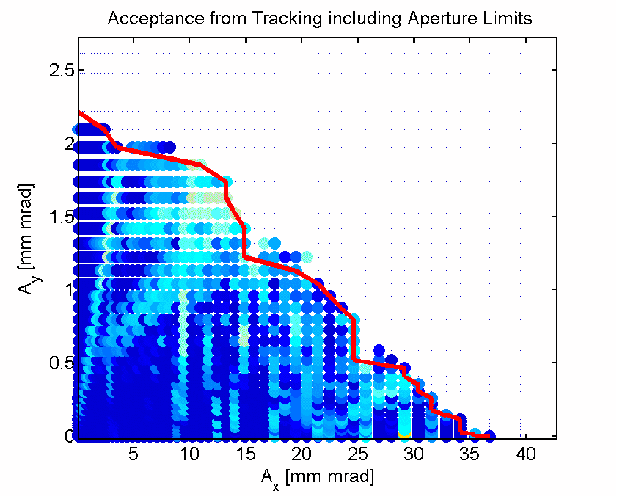

Figure 5: Acceptance determined from tracking with SixTrack.

CONCLUSIONS AND PERSPECTIVES

The first measurements using frequency analysis performed at PETRA III reveal a behavior in good agreement with expectations from numerical simulations. The detuning with amplitude exhibits the dominating cross term with the expected magnitude and the dynamic aperture exceeds the requirements set by injection efficiency. Improvement in the frequency resolution is needed in order to identify the limiting resonance structures. The investigation of off momentum dynamics is also planned in future experiments.

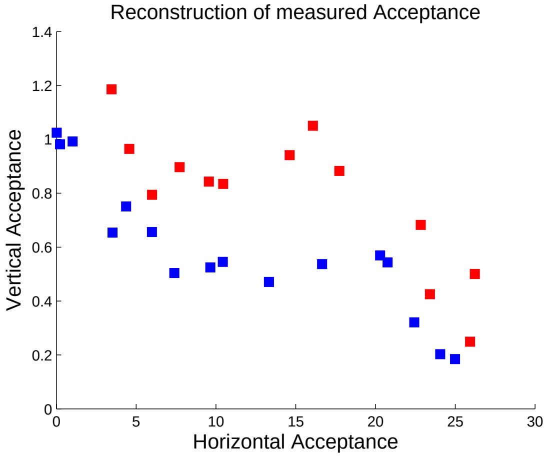

Figure 6: Dynamic aperture determined from the measured frequency map. Red squares correspond to 50% beam loss, blue squares correspond to 20% beam loss.

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