CORRECTION OF THE LINEAR OPTICS AT PETRA III

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Abstract

PETRA III is a 6 GeV third generation light source located at DESY Hamburg. The former pre-accelerator of HERA has been converted in 2007/2008 into a high brilliance synchrotron light source with an emittance of 1 nm·rad. The commissioning of PETRA III started in 2009. PETRA III is like other third generation light sources very sensitive to errors of the linear optics. Gradient errors reduce the dynamic aperture, increase the emittance and change the beam size. The correction of the optics is based on orbit response matrix data which were analyzed both with the program LOCO and with a fit of the beta functions and phase functions at BPMs and corrector magnets. Initial results of the modeling of the machine and the correction of the linear optics functions will be presented.

INTRODUCTION

The layout of PETRA III consists of arcs connected by long and short straight sections and can be subdivided in eight octants (Fig. 1). Seven of the eight octants have a FODO lattice with 72° phase advance in the arcs. For the reconstruction the magnets of the octant ranging from NE to E were completely replaced by nine double bend achromat (DBA) cells to have space for insertion devices. Up to 14 undulators can deliver hard X-rays through beamlines to experimental stations. Damping wigglers with a total length of 80 m have been installed in the long straight sections N and W to achieve an emittance reduction of a factor of four to reach an emittance of 1 nm·rad.

Errors in the optics can lead to increased beam sizes, especially in chambers with small gaps like the undulator and wiggler chambers. Additionally they decrease the dynamic aperture of PETRA III. The correction of the linear optics is therefore a prerequisite for an appropriate injection efficiency and to achieve the intended small beam sizes at the undulators.

METHOD

The modelling of the linear optics uses the orbit response matrix (ORM) of N BPMs and M correctors defined as

$$\mathbf{C}_{ij} = \frac{\Delta x_i}{\Delta \theta_j} \quad , \tag{1}$$

where Δx_i is the orbit change at the beam position monitor (BPM) i and $\Delta\theta_j$ is the kick of a corrector magnet j. As the elements of this matrix depend on the twiss functions they can be used to model and correct the linear optics.

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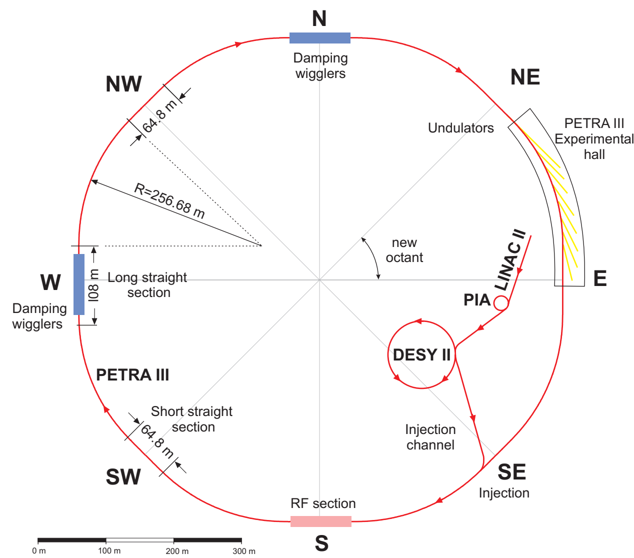

Figure 1: Schematic layout of PETRA III.

OPTICS MODELLING

Two different methods to model the optics have been used at PETRA III which will be briefly described now.

LOCO Fit

The LOCO method [1] minimizes the difference between the measured matrix $\mathbf{C}^{\text{meas}}$ and the model matrix $\mathbf{C}^{\text{mod}}$

$$\chi^2 = \sum_{i,j} \frac{(\mathbf{C}^{\text{mod}}_{ij}(\vec{p}) - \mathbf{C}^{\text{meas}}_{ij})^2}{\sigma_i^2} \tag{2}$$

by varying fit parameters $\vec{p}$ and taking into account the measured BPM noise σ_i. Fit parameters can be quadrupole gradient errors, BPM scaling factors and corrector scaling factors or other relevant parameters influencing the response matrix. Using the off-diagonal block matrices of the ORM skew quadrupole gradients errors, BPM couplings and tilts of corrector magnets can also be fitted. With a realistic model of the machine it is possible to compute focussing strength changes of quadrupoles to correct the optics.

For PETRA III the MATLAB version of LOCO has been used [2], which is based on the *Accelerator Toolbox* (AT) modelling code. Due to the large number of magnetic elements many fit parameters are necessary for an adequate model of PETRA III. In addition the large number of elements of $\mathbf{C}$ makes modelling using LOCO a rather tedious process.

Beta and Phase Function Fit

As an alternative to LOCO a fitting of the beta functions and phase functions at BPMs and correctors has been used for linear optics modelling at PETRA III [3, 4]. The method makes use of the dependence of elements of the ORM $\mathbf{C}$ on the beta functions β, phase function ϕ and the tune Q:

$$\mathbf{C}_{ij} = \frac{\sqrt{\beta_i \beta_j}}{\sin(\pi Q)} \cos(2\pi|\phi_i - \phi_j| - \pi Q) - \frac{D_i D_j}{\alpha_c\, C} \quad . \quad (3)$$

The second term takes into account the change of the energy due to the corrector kick, which depends on the dispersion function D, the momentum-compaction factor α_c and the circumference C. By minimizing

$$\chi^2 = \sum_{i,j} \frac{(\mathbf{C}_{ij}^{\mathrm{mod}}(\beta_i, \beta_j, \phi_i, \phi_j, Q) - \mathbf{C}_{ij}^{\mathrm{meas}})^2}{\sigma_i^2} \qquad (4)$$

the beta functions and phase functions at N BPMs and M correctors can be obtained. For χ^2-fitting the Levenberg-Marquardt method has been used in a MATLAB program.

Due to the small number of fit parameters $2(N+M)+1$ results for ϕ and β can be achieved in a short time. A disadvantage is that scaling errors of BPMs and correctors can't be distinguished from errors of the beta functions. The phase function can be used for optic corrections because it is not influenced by scaling errors. A correction of the optic can be determined by using the phase change due to quadrupole gradient changes.

ORM MEASUREMENTS

For orbit measurements 226 BPMs are available. They are equipped with the electronics *LIBERA Brilliance* manufactured by the company I-Tech. The resolution of the BPMs including orbit oscillations is around 1 μm for a 1 Hz data rate. To improve the accuracy of the measurement the non-linear position dependence of the four button signals from the beam position has been corrected. The computation is based on 2D-electrostatic calculations for different BPM geometries.

For orbit correction 196 horizontal resp. 187 vertical corrector magnets can be used. The nonlinear dependence of the corrector kick as a function of the current has been taken into account for the analysis. For the kick of the correctors 50 μrad has been chosen leading to a typical orbit deviation with an amplitude of 1 mm.

The ORM was measured by means of routines of the MATLAB Middle Layer (MML) [5]. The MML has been adapted to PETRA III and was interfaced to the control system using the TINE (Three-fold Integrated Network Environment) data protocol. Due to the large number of corrector magnets the measurement of the full matrix takes about 2 hours. The total number of matrix elements is 173 116.

OPTICS CORRECTION

For the optics measurement and correction the above described method of fitting the beta and phase functions has been used. In total 148 quadrupole power supplies are available for the correction. Each quadrupole in the new octant is connected to an individual power supply whereas the quadrupole currents in the seven FODO arcs cannot be adjusted separately.

The typical changes of the focussing strength were 0.5 %–1 % with some quadrupoles reaching 2 %. These changes are an order of magnitude larger than expected from the magnetic measurements. The reason might be orbit deviations in the sextupoles in the arcs producing additional gradient errors.

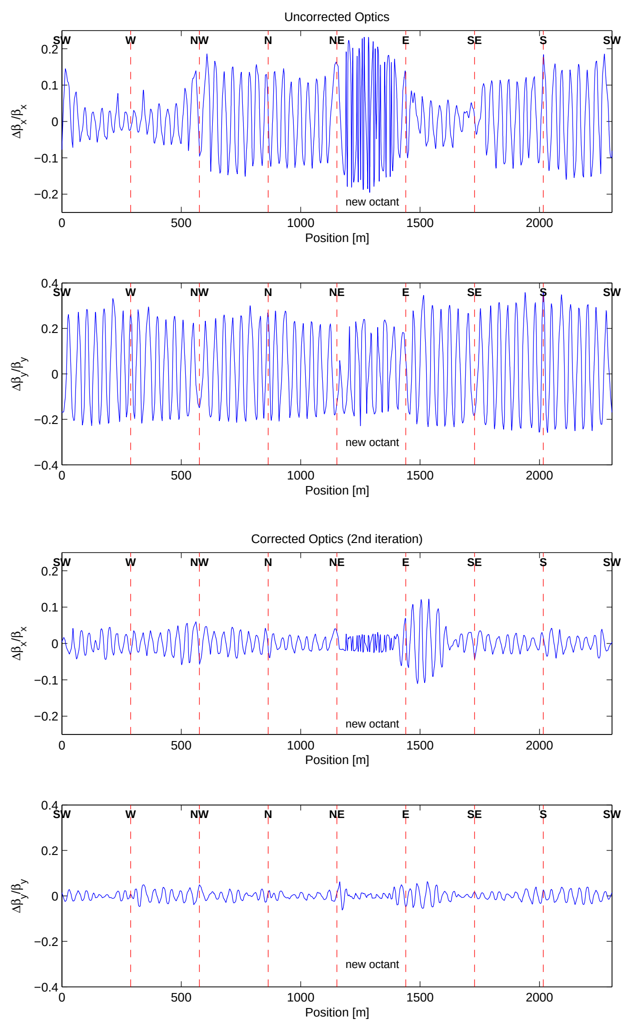

Figure 2: Beta beating before (top) and after correction (bottom).

The RMS-value of the horizontal beta beating $\Delta\beta/\beta$ has been reduced from 10% to 2.8% and the vertical beating from 18 % to 1.9% after two iterations of optic corrections (Fig. 2). Modelling the machine optics using LOCO gave almost the same results for $\Delta\beta/\beta$. Also the computed tunes of the model match with the measured tunes.

In the new octant $\Delta\beta/\beta$ is even lower, because all quadrupoles in that region have an individual power supply. In the arcs the optics cannot be corrected because the quadrupoles are not individually powered (e.g. in the octant E→SE).

BPM AND CORRECTOR SCALING FACTORS

The LOCO analysis of the scaling factors found out several problems with the BPMs: Some BPMs in the new octant had longitudinal positions shifted by several centimeters. The BPM positions have been corrected accordingly in the model. In addition two BPMs were interchanged.

Eight BPM types exist at PETRA III due to different chamber geometries. Most of the scaling factors are near the theoretical value (Fig. 3). One exception is the BPM type integrated in the undulator chamber with a significant deviation of $\pm 7\,\%$. 3D field simulations have been started to understand this discrepancy.

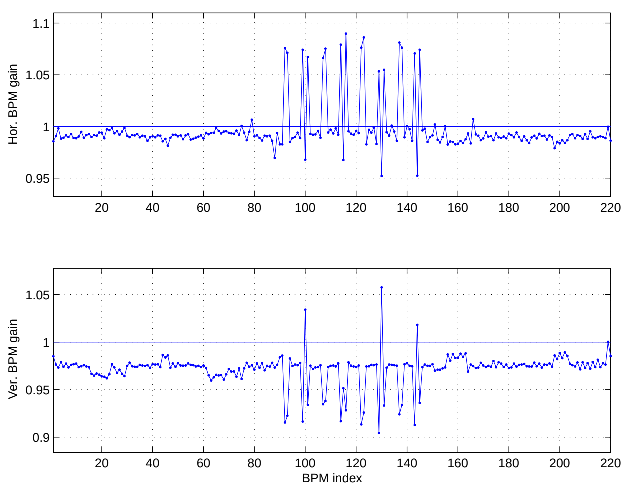

Figure 3: BPM scaling factors determined by LOCO.

The corrector system of PETRA III uses 10 different kinds of corrector magnets. Most of the correctors in the arcs are backleg windings on bending magnets or additional windings on sextupole magnets used as vertical correctors. In the straight sections and the new octant dipole corrector magnets have been installed.

The LOCO analysis also found out longitudinally shifted magnets in the new octant and three correctors with a wrong current calibration of the power supply. Most of the remaining systematic deviations of the corrector scaling factors shown in Fig. 4 in the horizontal plane are due to hysteresis effects of the magnets. An extreme example with a factor of ≈ 0.7 are four small dipole magnets used to separate the beam in the canted undulator cells. For one vertical corrector type used in the straight sections and deviating by $10\,\%$ a systematic error in the calibration seems to be likely.

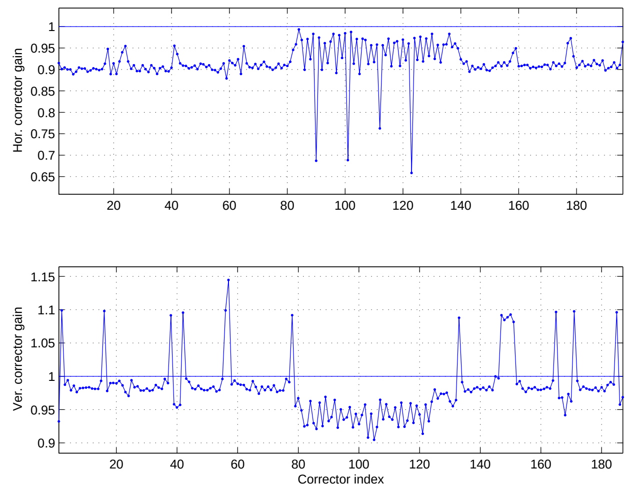

Figure 4: Corrector scaling factors determined by LOCO.

CONCLUSION AND OUTLOOK

By using the method of the analysis of the orbit response matrix the RMS beta beating of PETRA III has been corrected to a level of 2–3 % which is sufficient for the operation of the machine and the users of PETRA III. In the new octant the beating is even lower. In addition the ORM analysis using LOCO made it possible to compute scaling factors of BPMs and correctors. Several errors of BPMs and correctors have been detected by this method. The next step will be the identification of gradient error sources in the arcs and a better understanding of the coupling using the full response matrix to compensate it.

ACKNOWLEDGEMENTS

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