LONG TERM STABILITY OF THE BESSY II OPTICS AND RESULTING BETA BEAT CORRECTIONS*

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Abstract

Since many years response matrix measurements developed as a widely used and reliable means of understanding the optics of storage rings, and model calibration efforts. At BESSY II these measurements have been used from the very beginning in April 1998 [1]. Evaluation of the measurements taken during years of regular user operation reveal an extremely stable optics with relative changes in beta functions of $< 2\%$ per year. This high stability allows for precise determination of local gradients, gains of beam position monitors and individual corrector strength. It allows the detection of gradient errors f.e. due to hardware failures. It also provides reliable data to correct for unavoidable symmetry braking effects. It is shown that the relative beta beat of the machine can be reduced to few percent by individually powering the straight section quadrupoles. Influences of insertion devices can as well be measured and corrected for. Different optics are studied.

1 INTRODUCTION

BESSY II [2], a 3rd generation electron storage ring consists of an eightfold DBA lattice with alternating high and low beta sections for insertion devices. 81 horizontal correctors (including rf frequency) and 64 vertical correctors are used in the response matrix measurements [3, 4], The resulting orbit distortion is detected by 114 beam position monitors (BPM). The measurement is executed automatically and takes roughly one hour. From the data the impact of every steerer at each BPM is extracted, and arranged in a horizontal and a vertical matrix. Some 5-10 measurements are performed per year documenting the standard undisturbed user operation optics and are usually taken before and after shutdown periods and during machine shifts. Further measurements are taken at different energies, different optics or with insertion device gaps closed.

2 THE FITTING PROCEDURE

A model of the storage ring lattice is used to fit calculated response matrices to the measured matrices. The model consists of a regular, hard edge geometry of the storage ring magnets. The parameters varied during the fit are

- the quadrupole conversion factors, CF, i.e. the translation from the current in the quadrupole power supplies to gradients at the position of the beam, assuming that magnets fed by the same power supply create identical fields
- the individual BPM sensitivities (BPM gains) due to differences in electronics, vacuum chamber dimensions, large orbit offsets etc.
- the steering conversion factors, CF_S, i.e. the translation from the corrector currents to angular kicks on the beam.

While the achromatic quadrupoles are fitted as one family, individual conversion factors are assigned to the 8*2 rsp. 8*3 power supplies of the quadrupoles in the low (quadrupole doublet) rsp. high (quadrupole triplet) straight sections. The 42 quadrupole parameters are fitted by a SVD procedure, while the BPM gains and steerer conversions are iteratively adjusted. The quality of the fit is given by

$$\sigma_{x,y} = \sqrt{\frac{\Sigma_i \Sigma_j (S_{theory}[i][j] - S_{meas.}[i][j])}{i_{max} j_{max}}} \quad (1)$$

in units of $[mm/A]$. Coupling effects, magnet displacements and fringe field effects are neglected. Focussing due to orbit displacements in sextupoles will thus be attributed to nearby quadrupoles.

3 RESULTS FOR THE STANDARD USER OPTICS

The typical agreement between fitted and measured matrices is $\approx 35[\mu/A]$ horizontally and $\approx 11[\mu/A]$ vertically which is of the order of the measurement error. Thus, a $1mm$ orbit distortion will be predicted by the model to $4 - 5\mu$ absolute.

3.1 Quadrupole Conversion Factors

Up to now, all power supplies of the same family of straight section quadrupoles are run at equal setvalues, except for an insertion device gap dependend increment added to keep the tune constant during gap drives. The fitted CFs are given by

$$K[\frac{1}{m^2}] = PS_{setvalue}[A] \times \frac{0.2998}{E[GeV]} \times CF[\frac{T}{mA}] \quad (2)$$

with K being the K-value of the quadrupole and E the electron energy. Figure 1 shows the fitted quadrupole CFs for 18 measurements taken between January 2000 and March 2002. The differences in CF for members of the same family (i.e. hardware) of up to 1% clearly exceeds the spread of the measurements, which varies between 0.02 and 0.1% rms, depending on the power supply. These variations are caused by hardware differences in the magnets and/or power supplies, as well as by orbit offsets in the nearby sextupoles. The families with the largest fluctuations are Q5T

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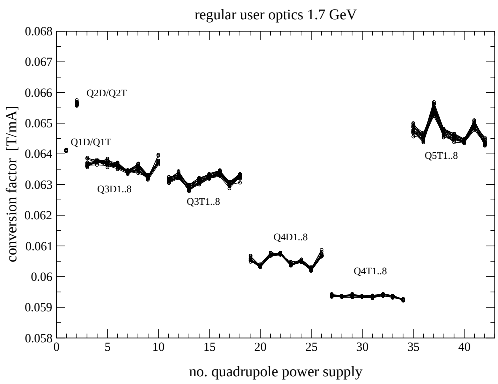

Figure 1: Fitted quadrupole conversion factors for measurements taken during more than two years, sorted by power supply families

and Q3T. Here the resulting CFs are correlated: the phase advance is too small to seperate between the two nearby defocussing gradients. The maximum deviation from average is less than 0.4% for the Q3T/Q5T power supplies and less than 0.2% for the others.

Measurements taken when the ring is run in an 16-fold symmetry, show equal average CFs for the power supplies of the Q3 and Q4 families, pointing towards substantiel effects caused by magnetic field overlap. The distance between magnets in BESSY II is $0.15m$, only. Also in the 16-fold symmetry the characteristic family patterns of the CFs persist.

Typically after shutdown periods when new equipment was installed, a new reference orbit is defined, in order to pin the goal orbit for the orbit correction to the center of the quadrupoles. These changes in the goal orbit are the mayor source for the spread between the measurements. Measurements taken at the same reference orbit agree to better than 0.1%.

Only 11 out of the 42 CFs change when the measurements are performed with reduced sextupole strength. These are locations in the ring where the orbit offsets in the sextupoles contribute significantly (0.4% of one quadrupole).

When the CFs are known, tunes, beta functions and all other optical parameters can be calculated. The resulting tunes differ in the order of a few kHz between the measurements, corresponding well to every day experience. The calculated beta functions show a beat (rel. deviation from symmetric betas) caused by the difference in local gradients of up to $\approx 13\%$ horizontally and 10% vertically ($\approx 0.6\% rms$)., Fig. 4-top. A typical beat pattern with a waist between 100m and 170m was confirmed by local beta function measurements. The waist is produced by the orbit offsets in the sextupole magnets. Measurements with reduced sextupole settings show a more homogenous beat distribution of comparable size.

Over the years the beta function vary by only few percent, often correlated with new reference orbits or small changes in setvalues, f.e. due to tune adjustments. For equal reference orbits, the maximum $\Delta\beta/\beta$ is around 2%.

3.2 BPM Gains

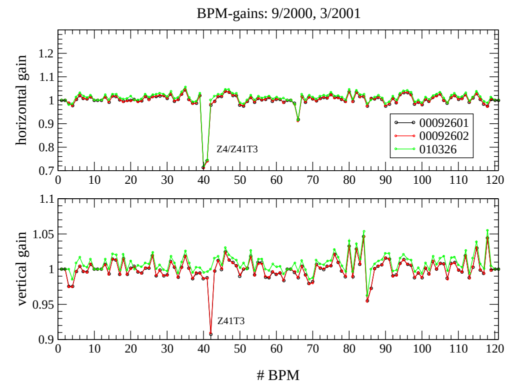

Figure 2: Resulting BPM gains for 3 typical measurements

Figure 2 shows the fitted gain factors for the BPMs. As expected, most BPMs show only few percent deviation from the average, and the reproducibility is high. Larger deviations correspond to modified vacuum chambers, or large orbit offsets as f.e. close to the a wave length shifter (BPM no. 40, 41).

3.3 Conversion Factors of the Correctors

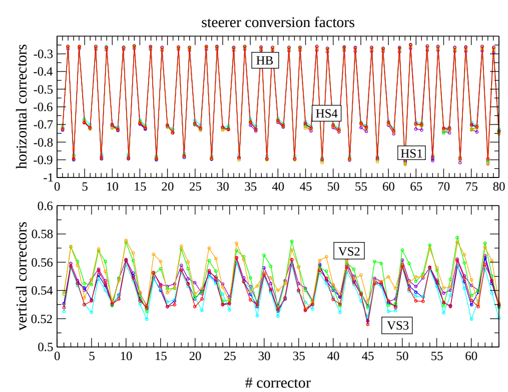

Figure 3: Fitted steerer conversion factors for horizontal (top) and vertical (bottom) correctors

The conversion factors for the corrector magnets are defined by

$$CF_S[mrad/A] = \frac{0.2998}{E[GeV]} \times \frac{B[T]l[m]}{I[A]} \times 10^3 \qquad (3)$$

All corrector coils in BESSY II are realized as additional windings on top of the sextupole or dipole magnets, and their impact depends strongly on the main magnets parameters and its location in the ring. The reproducibility of the field is on the percent level. Horizontal coils mounted on dipoles (HB) and sextupoles (HS1, HS4), have different length, resulting in different CF_S Fig. 3-top. Vertical correction coils mounted on S2 and S3 are mechanically identical, still the coils in S2 (well seperated from next magnets) act $\approx 5\%$ stronger than those in S3 (0.15m to next quadrupole) (Fig. 3-bottom).

4 ACHIEVING SYMMETRY

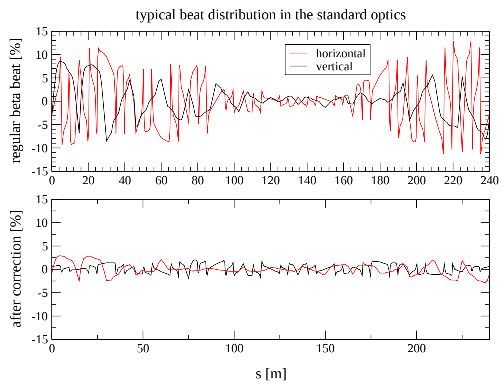

Figure 4: Beta beat before (top) and after beat correction

In order to locate the dominant effect causing the asymmetry in the machine, different sources where considered:

- large deviation of a single power supply's CF
- deviations of CFs associated with one straight section
- spread of CFs belonging to one family

The differences in the CFs of the Q4D family, cause almost 50% of the beat, as those are the magnets with the highest integrated strength. Single CFs or all CFs of a single straight sections did not show mayor contributions. The possibility to power the straight section quadrupoles individually has been used to test the results obtained by the response matrix measurements. The power supplies were set to yield equal impact rather than equal current. The additional currents varied from 0.1 to 2.0 A. The resulting beta beat measured in the machine was around 2% in both planes proving the possibility to fully restore symmetry of the beta functions Fig. 4-bottom.

Beamloss measurements performed for the symmetrized beta functions showed diminished particle losses compared to the uncompensated optics. Figure 5 displays a vertical tune scan between the half integer and integer resonances, where the dottet, lighter curves display the regular machine, and the stronger lines the symmetric machine. Especially the influence of the integer resonance (right side) could be suppressed by the corrected beat. Losses on other resonances were reduced by $20-50\%$. Alas, in the overall lifetime of the beam on the nominal working point these effects could not be seen.

5 OUTLOOK

It is planned to run the symmetric optics during user runs. Measurements at different energies (900MeV,

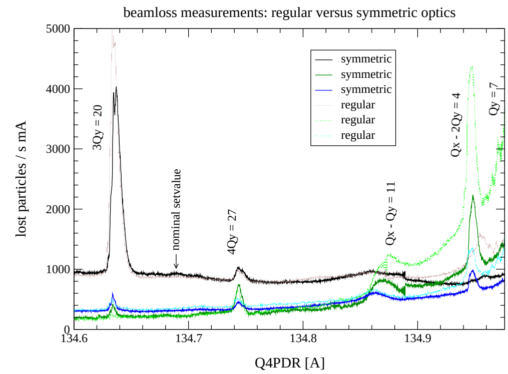

Figure 5: Particle losses for standard (solid line) and symmetry corrected (dotted, lighter colour) optics detected at different ring positions

1.9GeV) and for the recently developed low-alpha optics [5] have been performed, according sets of conversion factors have been determined and will be incorporated into the control system. As the evaluation of the measured response matrices associates all gradient errors, independent of their origin, to near quadrupoles, corrections of focussing effects due to insertion devices can as well be analysed and corrected for. It has been shown, that the beat caused by the 6T wavelength shifter can be cancelled with the same precision of $\approx 2\%$.

6 CONCLUSION

Using the response matrix technique, the BESSY II storage ring optics has been investigated. Comparing the data taken since 2000, a high degree of stability revealed. Beta functions vary less than a few percent over months. Changes in the CFs are mainly caused by the changes of the reference orbit. Associating all local gradients to nearby quadrupoles, opens the possibility for beat correction with the excisting local straight section power supplies, independent of the source. Betas with a beat as little as 2% can be realized and particle losses where reduced on resonances. Implementation in everyday user operation is planned.

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