PAUL SCHERRER INSTITUT

SWISS LIGHT SOURCE SLS

SLS-TME-TA-2002-0207
9th August 2002

Measurement and Correction of Imperfections in the SLS Storage Ring

M. Böge, A. Streun, V. Schlott

Paul Scherrer Institut, CH-5232 Villigen PSI, Switzerland

Abstract

Based on precise average beta function measurements with errors of $\approx$ 1 % for the locations of the 174 quadrupoles an SVD based beta beat correction has been applied using the individually powered quadrupoles as correctors. Residual horizontal and vertical beta beats of 4 and 3 % have been measured after correction. Beam based alignment techniques have been applied to determine BPM centers with respect to adjacent quadrupoles.

Presented at the 8th European Particle Accelerator Conference (EPAC'02)
3-7 June 2002, La Villette-Paris, France

MEASUREMENT AND CORRECTION OF IMPERFECTIONS IN THE SLS STORAGE RING

M. Böge, A. Streun, V. Schlott, PSI, Villigen, Switzerland

Abstract

Based on precise average beta function measurements with errors of ≈ 1 % for the locations of the 174 quadrupoles an SVD based beta beat correction has been applied using the individually powered quadrupoles as correctors. Residual horizontal and vertical beta beats of 4 and 3 % have been measured after correction. Beam based alignment techniques have been applied to determine BPM centers with respect to adjacent quadrupoles.

1 BETA CORRECTION

In order to optimize the performance of the SLS storage ring a good understanding of the linear optics is necessary. Whenever possible, known differences between the real machine and the underlying model should be minimized. For this reason, the 174 individually powered quadrupoles in SLS storage ring have been used as "beta function correctors".

1.1 Beta Function Measurement

An important ingredient for the successful compensation of the linear optical distortions is the precise measurement of the average beta functions at the location of the quadrupoles. The presented procedure makes use of the fact that a betatron tune change $\delta\nu$ is related to the perturbation $\delta k(s)$ of the focussing strength and the beta function $\beta(s)$ around the ring:

$$\delta\nu = -\frac{1}{4\pi}\oint \beta(s)\delta k(s)ds.$$

Thus a change in the strength $\delta k(s_q)$ of quadrupole q allows the average beta function $\bar{\beta}(s_q)$ at position s_q to be measured, by observing $\delta\nu$ as a function of $\delta k(s_q)$. The error of this measurement defines the limit for the correction of the linear optics perturbations. Thus a sophisticated procedure has been implemented which takes into account known magnetic hysteresis effects and restores the betatron tunes rather than the original quadrupole currents. In addition, the quadrupoles are measured "magnet family" wise in order to minimize the residual optical perturbations. In order to increase the precision further, the tune is observed for 5 different currents. The beta functions are then derived from a least square fit. As a result average measurement errors of $\approx \pm 1$ % have been achieved.

1.2 Beta Correction Algorithm

The information about the horizontal and vertical beta beat $\delta\beta_i$ at the position of the ith quadrupole caused by a strength perturbation δk_j of the jth quadrupole is contained in the (2*174)x174 sensitivity matrix $\mathbf{S}$:

$$\mathbf{S}_{ij} = \frac{\delta\beta_i}{\delta k_j}$$

which can be derived from the model. A Singular Value Decomposition (SVD) technique is then used to "invert" $\mathbf{S}$ and determine the δk_j as a function of the $\delta\beta_i$. Feeding $-\delta k_j$ into the "beta function correctors" restores the ideal optics within the error of the beta measurement if the quadrupoles are the only source of the optics perturbation.

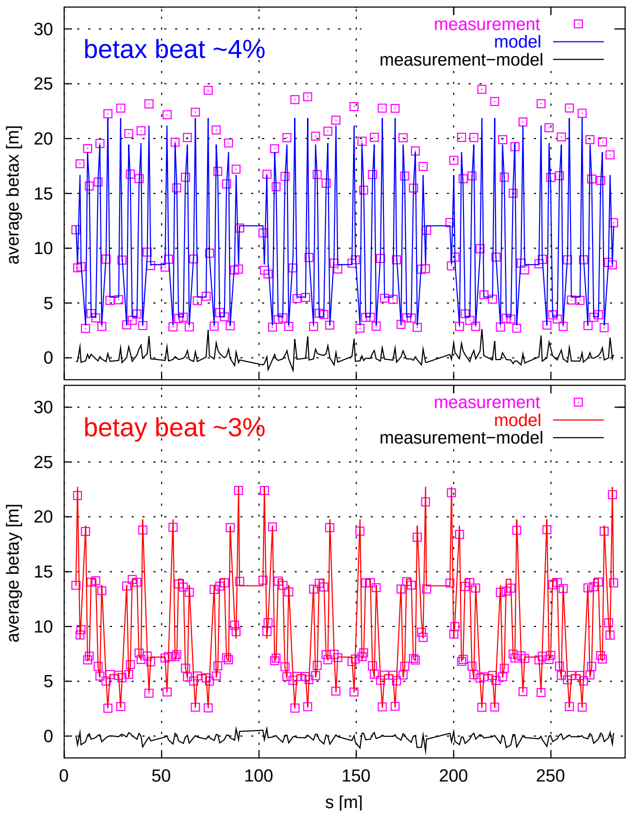

Figure 1: Measured average beta functions (squares) at the location of 174 quadrupoles in comparison to the model of the unperturbed optics (solid lines)

1.3 Beta Correction Results

Fig. 1 shows the result of a beta correction reducing the beta beat in the horizontal and vertical plane by a factor of 2 with remaining beats of ≈ 4 % and ≈ 3 %. The quadrupole strength variation $\delta k/k \approx$ 1.5e-3 with respect to the design strength k is consistent with magnet measurements [1].

2 BEAM-BASED-ALIGNMENT (BBA)

The BPM stations in the SLS storage ring are rigidly attached to the girders and serve as supports for the vacuum system. According to the specifications of the BPM support and the straightness rulers on the girders, the quadrupole-BPM offsets are known to within ± 50 μm [2]. The presented beam-based alignment technique allows to measure these offsets for the adjacent quadrupole-BPM combinations with μm precision. These offsets can be used to calibrate the mechanical positioning system (POMS) which monitors relative position changes of BPMs with respect to adjacent quadrupoles using linear encoders [3].

2.1 BBA Procedure

The applied method [4, 5] is based on the well known fact that if the strength of a single quadrupole q in the ring is changed, the resulting difference in the closed orbit $\Delta y(s)$ is proportional to the original offset y_q of the beam at q. The equation for the resulting difference orbit is:

$$\Delta y''(s) - (k(s) + \Delta k(s))\Delta y(s) = \Delta k(s) y_q(s).$$

The difference orbit is thus given by the closed orbit formula for a single kick, but calculated with the perturbed optics including $\Delta k(s)$. From the measured difference

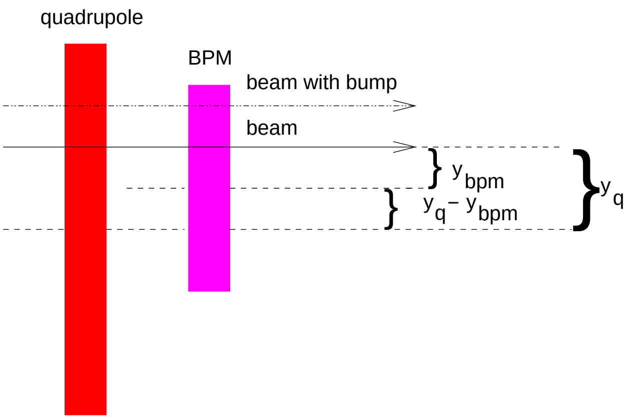

Figure 2: Illustration of the beam-based alignment technique applied to the quadrupoles with adjacent BPMs

orbit the kick and thus y_q can be easily determined and compared to the nominal orbit y_{bpm} in the BPM adjacent to the quadrupole, yielding the offset between BPM and quadrupole axis. The precision of the method is very much improved by taking difference orbit data for several local beam positions y_q varied with an orbit bump. The principle of the method is illustrated in Fig. 2. The error of the nominal position y_{bpm} for which the beam goes through the center of the quadrupole is then given by the resolution of the BPM system. In the SLS storage ring, a difference orbit with an amplitude of 5 μm can be clearly resolved [6]. This results in a resolution for the local kick of ≈ 0.25 μrad for quadrupoles at vertical beta values of 20 m. Since a change in quadrupole strength of $\Delta kl = 0.02$ m^{-1} causing a tune variation $\delta\nu = 0.03$, is possible without losing the beam, a minimum beam offset of $y_{q,min} = 15$ μm can be easily detected. Taking several data points by varying a local bump, the quadrupole-to-BPM alignment can be done with a precision of ≈ 5 μm. However some of the quadrupoles are at low beta values of 2.5 m which reduces the precision of the measurement to ≈ 40 μm.

2.2 BBA Results

In order to have a well defined tune variation ($\delta\nu = \pm 0.025$) during the beam-based alignment measurement, the previously measured average beta functions (see section 1.1) are used to determine the allowed change of quadrupole strength. A hysteresis correction restores the orbital tunes after each quadrupole variation cycle, in order to minimize the residual distortions of the linear optics.

Fig. 3 shows the result of a single vertical BPM offset

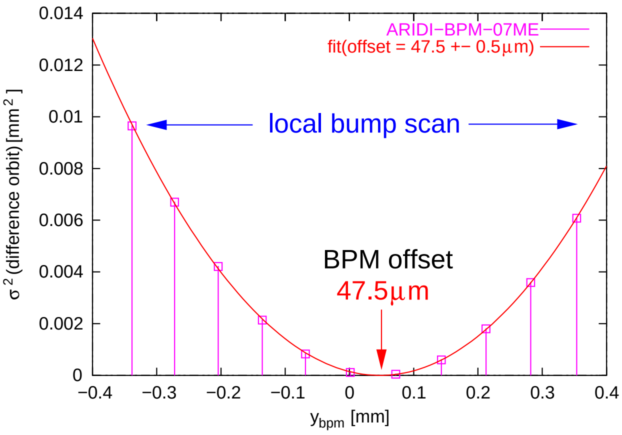

Figure 3: BBA data for BPM ARIDI-BPM-07ME showing a vertical BPM offset of 47.5 μm with respect to the adjacent quadrupole ARIMA-QMD-07 at a beta function of 18 m

measurement for ARIDI-BPM-07ME. After taking a reference orbit, the adjacent quadrupole ARIMA-QMD-07 is changed by $\Delta kl = 0.017$ m^{-1} followed by a variation of a local orbit bump of ± 0.4 mm. The square of the standard deviation of the difference orbit, excluding ARIDI-BPM-07ME, versus the BPM reading is fitted by a parabola. The difference between the minimum of the fit and the zero reading of the BPM determines the BPM offset. In this case the measurement reveals an offset of 47.5 μm within an error of ± 0.5 μm. Fig. 4 summarizes the result for 66 vertical BPM offsets with measurement error variations between < 1 μm and 50 μm. The offset distribution is fitted by a gaussian shifted by -0.11 mm with a standard deviation of 0.24 mm. Three BPMs show offsets larger than 0.5 mm.

The offsets have been fed into an SVD based global orbit correction code in order to determine the corresponding corrector pattern. These corrector predictions ("kick change") can be compared to the actual corrector settings

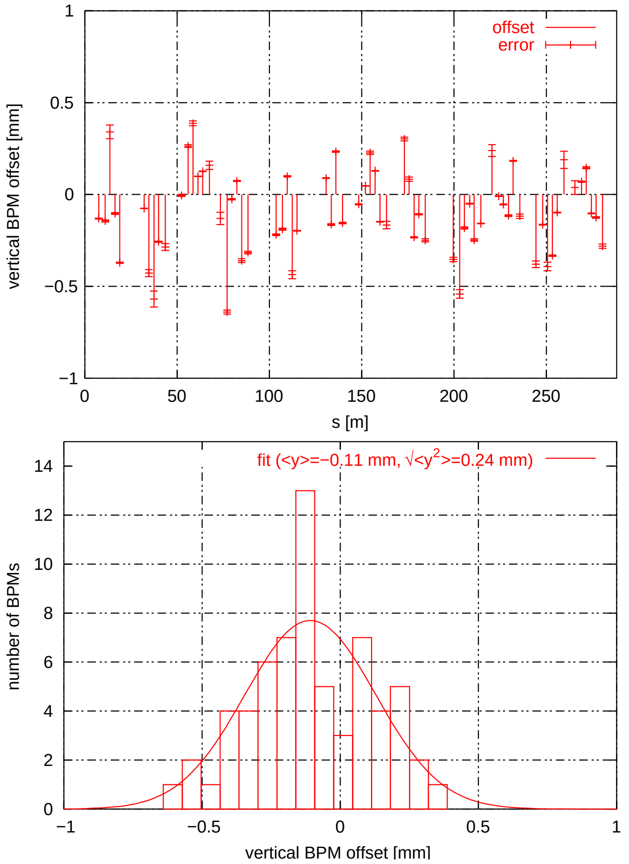

Figure 4: Vertical BPM offsets with respect to adjacent quadrupoles in the SLS storage ring. The offset distribution is fitted by a gaussian shifted by -0.11 mm with a standard deviation of 0.24 mm. The measurement error varies between < 1 μm and 50 μm.

("present kick") for a flat orbit. Fig. 5 depicts both patterns and their difference ("sum kick"). It can be seen that they are "anticorrelated" resulting in a 20 % reduction of the rms corrector kick from 0.15 mrad to 0.12 mrad. Furthermore the mean corrector kick of -0.014 mrad is removed.

The application of the vertical BBA data in the storage ring confirmed the expected rms kick reduction.

3 SUMMARY

The beta correction reduces the beta beat in the horizontal and vertical plane by a factor of 2 with remaining beats of ≈ 4 % and ≈ 3 %.

Several vertical BBA measurements have been carried out revealing BPM offset distributions with standard deviations of ≈ 0.3 mm and variations of ≈ 10 % over several months. Horizontal BBA measurements taking into account path length effects in the determination of the difference orbit have just been started. The "dynamic" beam-based alignment based on the modulation of quadrupole currents, at $<$10 Hz [7], observing the modulation frequency component in the resulting orbit [8] is planned.

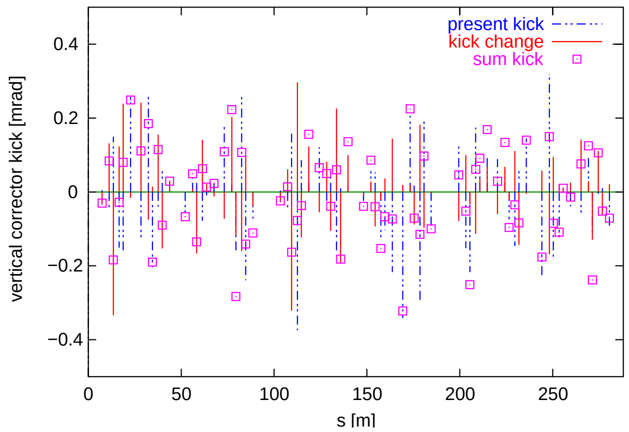

Figure 5: Comparison of actual corrector settings ("present kick") for a flat orbit and predictions for the correction of the vertical BPM offsets ("kick change") predicting an rms kick reduction by 20 %. The squares ("sum kick") denote the differences

4 REFERENCES

[1] B. Jakob et al., "Production and Measurement of the Magnets for Booster and Storage Ring", PSI Scientific Report 1999 Vol. VII, 2000.

[2] F. Q. Wei et al., "SLS Survey and Alignment in 2000", PSI Scientific Report 2000 Vol. VII, 2001.

[3] V. Schlott et al., "Dynamic Alignment at SLS", EPAC'00, Vienna 2000.

[4] P. Röjsel, "A Beam Position Measurement System Using Quadrupole Magnets Magnetic Centra as the Position Reference", Nucl. Instr. Meth., A343, 1994.

[5] R. Brinkmann, M. Böge, "Beam-Based Alignment and Polarization Optimization in the HERA Electron Ring", EPAC'94, London 1994.

[6] V. Schlott et al., "Commissioning of the SLS Digital BPM System", PAC'01, Chicago 2001.

[7] L. Tanner, F. Jenni, "Digitally Controlled SLS Magnet Power Supplies", PAC'01, Chicago 2001.

[8] R. Schmidt, "Misalignments from k-Modulation", 3rd Workshop on LEP Performance, CERN SL/93-19, 1993.