BEAM DIAGNOSTICS USING VARIATIONS OF LOCAL MAGNETIC FIELDS

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At the 800 MeV low emittance electron storage ring BESSY we use the effect of field and gradient errors caused by closed orbit distortions in quadrupole and sextupole magnets to determine the beam position with respect to the center of these magnets. Their local fields are changed and the perturbed closed orbit or the tune shift is measured. From the measured effects of the field or gradient errors the horizontal and vertical beam position in the quadrupoles or the horizontal position in the sextupoles can be deduced. The experimental setup can be used also for the measurement of the local beta functions in the quadrupole magnets.

1 Beam Position Measurement

The ideal orbit in a storage ring coincides with the axes of the quadrupole and sextupole magnets. In reality, the closed orbit is different from the ideal orbit and the particle motion has to be considered in the magnetic field on the actual orbit. In case of a closed orbit distortion in a quadrupole magnet this field will contain a small additional dipole component (field error), h, proportional to the quadrupole strength, k, and to the distance, Δ, between the beam and the axis of the magnet: $h=k\cdot\Delta$. If the strength of the quadrupole is varied, the dipole term will change too. This field error perturbs the closed orbit all around the ring [1] and a beam position measurement can be used to calculate the beam position, Δ, inside the quadrupole magnet [2].

In case of a horizontal closed orbit distortion, Δ_x, in a sextupole magnet, the field expansion on the actual orbit contains a small additional quadrupole field component (gradient error), k, proportional to the sextupole strength, m, and proportional to Δ_x: $k=2\cdot m\cdot\Delta_x$. If we vary the strength of the sextupole, the tune shift associated with the variation of the gradient error can be used to determine the horizontal beam position, Δ_x, in the sextupole magnet.

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We apply both techniques to measure the position of the beam around the ring. At BESSY an additional power supply can be switched with a relay circuit to any of the 32 quadrupole or any of the 16 sextupole magnets of the storage ring. The design of our main power supplies allows one only to increase and not to decrease the individual magnet current.

Three optical imaging systems [3] are used to observe the small orbit perturbations from the field variations of the quadrupoles. The beam positions are measured with our random access camera [4] and two simple devices similar to the monitors used by Yu et al. [5]. These monitors are equipped with a lateral effect photodiode and the analog output signals of the device are proportional to the horizontal and vertical beam position. The accuracy of the measurement is increased by switching the additional quadrupole current on and off and averaging the position shifts of the beam. The measurement is under computer control. The observed closed orbit perturbations are compared to linear optic calculations to determine the position of the beam relative to the axis of the quadrupole magnet. The uncertainty of this calculation is comparatively large (± 0.5 mm), however, because of the poor theoretical modelling of the BESSY storage ring.

The determination of the horizontal beam position in the sextupole magnets is more accurate. In this case, only the beta functions in the sextupoles have to be taken from a theoretical optics calculation to estimate the beam position. The measurement is fully automated. The computer switches the additional power supply to the sextupole magnets and the tune is measured for 9 different current settings. We use a spectrum analyzer and tracking excitation to determine the tune. The beam is excited with strip lines and the response is detected with one pickup electrode. After the measurement, the computer performs a straight line fit to the tunes and, from the slope of this line, the horizontal beam position is determined with a typical uncertainty of only 0.1 mm or 10 percent if the offset of the beam in the sextupole is large.

2 Beta Function Measurement

The setup described above for the determination of the horizontal beam position in the sextupole magnets can be used immediately for the measurement of the beta function in the quadrupoles. The main effect of the additional quadrupole magnet current is a tune shift, ΔQ, proportional to the gradient error, k, and proportional to the beta function, β:

$\Delta Q = -1/4\pi \cdot k \cdot L \cdot \beta$, where L is the effective length of the quadrupole magnet. In an actual measurement, the computer switches the power supply to the quadrupoles, measures the tune shift, and determines the beta functions from the known magnet calibration. A complete measurement in all 32 quadrupole magnets takes about 2 h. The gradient error, k, has to be kept low enough in order not to distort the measured beta function too much. In our case, this distortion is always less than 2 percent and the estimated overall uncertainty of the measurement is around 2 percent if the beta functions are large ($\beta > 5$ m).

3 Results

The measured horizontal closed orbit of the BESSY storage ring is shown in Fig.[1]. The measurement determines the orbit

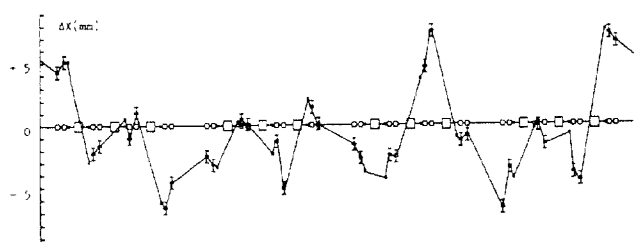

Figure 1: Result of the horizontal closed orbit measurement. The beam positions were determined by the measured effects on the beam from local field variations in quadrupole and sextupole magnets. The errors are large in the quadrupoles due to the poor theoretical modelling of the storage ring. The displayed orbit has been used successfully over the last couple of years in spite of the large rms deviation of about 4 mm. The magnet lattice of the ring is indicated - small rectangles are quadrupoles, large rectangles are bending magnets.

with respect to the centers of the quadrupole and sextupole magnets. This is the main advantage of the technique described above. We used this very time consuming measurement to find the actual positions of our horizontal pickup electrodes with respect to the axis of neighbouring quadrupoles or sextupoles. In the vertical plane the position of the pickup plates relative to the magnets can easily be determined with a theodolite. We routinely use the corrected results from the pickup monitors together with the horizontal beam position measurements in the sextupoles to determine the closed orbit.

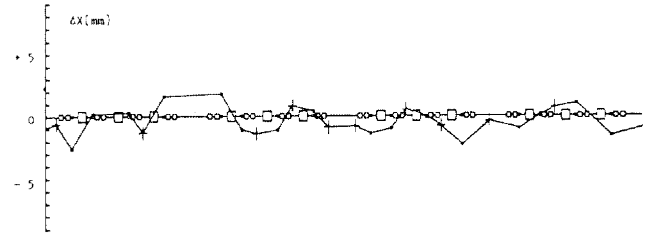

Figure 2: Horizontal orbit after a preliminary closed orbit correction in 1988. The rms deviation has been reduced to 1 mm. The beam positions were measured in the sextupoles (measurements are shown as squares) at low beam current (<1mA) and with pickup monitors (shown as crosses) at higher currents (>10mA).

Fig. [2] shows a recent measurement of the preliminarily corrected horizontal orbit. The rms deviation of the orbit has been reduced to 1 mm. Currently we are monitoring the horizontal orbit more frequently to investigate the long term stability of the position of the beam. In principle a more refined closed orbit correction is possible but makes sense only if the beam position is stable over long times.

In Fig. [3] the measured horizontal (left) and the vertical (right) betafunctions are shown. The line in the top is the result of the linear optics calculation. The sextupole magnets have been switched off for this measurement and in this case we find fair agreement between the measurement (shown as sqares) and the theoretical calculation. In the middle of Fig. [3] the same experimental results are used to display the beta beat, $\Delta\beta/\beta$. The beta beat is determined from the experimental results only. The BESSY storage ring lattice possesses a fourfold symmetry. Every superperiod is mirror symmetric with respect to the inner dipole. Therefore, for any quadrupole magnet there are 8 similar quadrupoles and the average of the measured 8 beta functions has been used to calculate the beta beat. The beta beat is less than 10 percent if the sextupoles are switched off but increases to 20 percent if the sextupoles are used for chromaticity compensation (Fig. [3] bottom). This large beta beat is caused by the remaining closed orbit distortion in the sextupole magnets. A simple estimate [6] for our case with a rms deviation of the orbit of 1 mm agrees with the observation.

In Fig. [4] the measured and calculated beta beats are shown for a 30 mm magnet gap of the BESSY multipole wiggler/undulator [7]. The four quadrupole magnets adjacent to the undulator have been powered individually with two additional power supplies to compensate the vertical and horizontal focussing properties of the insertion device. The experimental result is in fair agreement with the calculation. The beta beat is smaller than 10 percent in both planes but more pronounced in the horizontal plane.

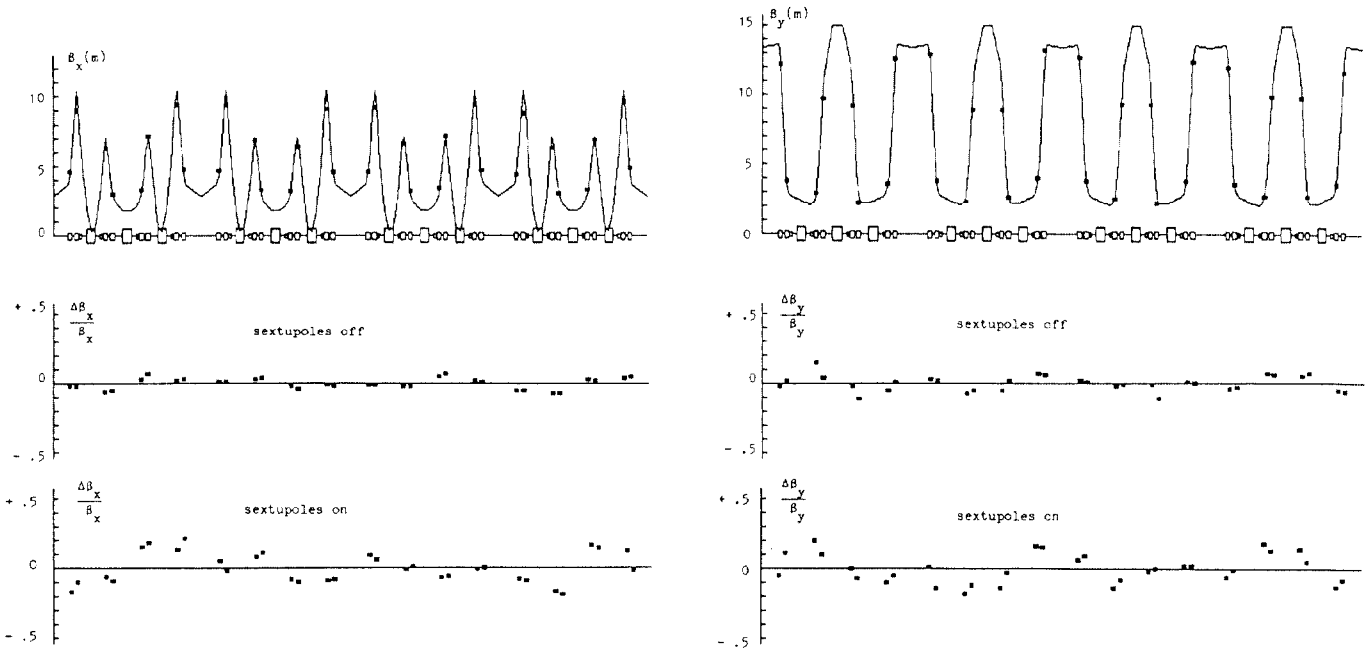

Figure 3: Top - measured and calculated beta functions for the low emittance optics METRO. The sextupoles have been switched off. Middle - measured beta beat without sextupoles. Bottom - measured beta beat with the sextupoles switched on. The chromaticity was compensated to positive values in both planes.

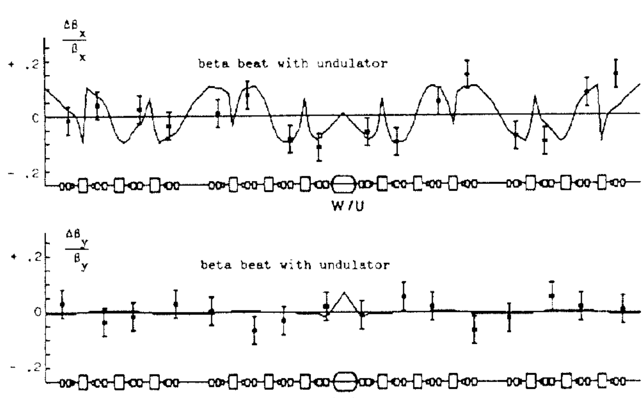

Figure 4: Measured and calculated beta beat for a 30 mm gap of the BESSY undulator. The tune shifts caused by the insertion device have been corrected for locally.

4 Conclusion

We have shown that the measurable effects caused by a variation of the local sextupole or quadrupole strength yield information on important beam parameters. The horizontal positions of the beam with respect to the center of the sextupole magnets are useful for a realistic estimate of the dynamic aperture by tracking studies. At BESSY the knowledge of the beam position in the sextupoles is essential for an effective horizontal closed orbit correction. The measured beam positions relative to the magnets can be used to correct the offset of pickup monitors. The unperturbed symmetry of storage rings of the third generation of synchrotron light sources is important for a large dynamical aperture. The measurement and the correction of the beta beat might become essential for these storage rings.

References

[1] M.Sands, SLAC-121, UC-28 (1970)

[2] R.Littauer, "Some Diagnostic Techniques Using Botton Pickup Electrodes" in Report of Machine Workshop on the 6-GeV Synchrotron Radiation Source, National Bureau of Standards, Gaithersburg, Maryland, March 1985, Apendix D-3

[3] F.P.Wolf and P.Kuske, "Synchrotron radiation diagnostics at BESSY", SPIE Vol.733 Soft X-Ray Optics and Technology (1986), p.92-95

[4] P.Kuske, K.Derikum, H.-G. Hoberg and H.Lehr, Proc. 1987 Particle Accelerator Conf., IEEE Catalog No.87CH2387-9, p.535

[5] L.H.Yu, R.J.Nawrocky and J.Galayda, IEEE Trans. Nucl Sci., NS-32,No.5(1985)3394

[6] A.Wrulich, "Tolerances for Sextupole Displacement Errors", DESY HERA 85-11, March 1985

[7] J.Pflüger et al. Nucl. Instr. and Meth. A266 (1988)120