LAYOUT AND TIME-DOMAIN SIMULATION OF A LOCAL BEAM POSITION FEEDBACK SYSTEM FOR BESSY-II *

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Abstract

The general layout and hardware issues of a local position feedback system for BESSY-II, a 1.7 GeV synchrotron light source under construction at Berlin, are discussed. A time-domain simulation is used to explore the correction efficiency of the system.

1 INTRODUCTION

Time-dependent closed orbit distortions at a synchrotron radiation source increase the effective beam emittance seen by the experimenter. These distortions may be due to mechanical movements of optical elements, caused by ground vibrations or by vibrating machinery. Another possible source of closed orbit distortions is magnet power supply ripple at harmonics of 50 Hz.

BESSY-II is a 1.7 GeV synchrotron radiation source presently under construction at Berlin [1]. The required stability of the source point is given by a certain fraction of the source size, say 10%, or by the diffraction limit. Considering a vertical (horizontal) source size of the order of 10 (100) μm and a diffraction limit of 0.5 μm (for 10 keV radiation), the beam should be stable within 1 (10) μm vertically (horizontally).

Ground vibrations of the order of 1 μm displace the beam at the center of an insertion device (ID) by 20 μm rms, leading to a loss of beam quality, which can partly be recovered using an active feedback system.

The global closed orbit correction scheme of BESSY-II using correctors integrated in the sextupole magnets is limited to ∼1 Hz, whereas the sources of beam motion considered here demands a bandwidth of at least 100 Hz. For this purpose, local feedback systems are typically used [2], where four corrector magnets form a closed bump enclosing the ID region. This allows to independently control position and angle of the beam at the ID center.

A local feedback system may operate independently of the global system or the two may be combined [3]. In this paper, a purely local position feedback for BESSY-II is presented.

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2 CLOSED BUMP SCHEMES

A local closed bump is independent of the orbit outside of the bump and leaves it unchanged. With four correctors at positions labelled 1 to 4, the condition to be fulfilled reads:

$$M_{14}\vec{\phi}_1 + M_{24}\vec{\phi}_2 + M_{34}\vec{\phi}_3 + \vec{\phi}_4 = \vec{0}, \qquad (1)$$

where the vector $\vec{\phi}_i$ describes the kick produced by corrector i and M_{ij} is the transfer matrix between the correctors i and j. Using the equation

$$M_{10}\vec{\phi}_1 + M_{20}\vec{\phi}_2 = -\vec{z}_0, \qquad (2)$$

the kicks required to counteract a measured beam displacement $\vec{z}_0$ at the ID center (labelled 0) can be calculated.

2.1 4-Magnet Scheme

Figure 1 shows simulated distorted orbits over a length of 45 m covering three straight sections of BESSY-II. In figure 2, each of the three IDs is surrounded by two pairs of corrector magnets forming a closed bump. With no focussing elements within the bumps, the transfer matrices are particularly simple.

2.2 2-Magnet Scheme

Figure 3 shows a different closed bump scheme using only two magnets per straight section. Here, the closed bumps overlap each other, each extending from a corrector pair upstream of an ID to the pair upstream of the next ID. Only the upstream correctors are powered. The kick computed for each magnet is the sum of the two kicks computed for the two overlapping bumps seperately. For the ID region, this scheme has the same benefit as the 4-magnet bump, but the beam movement is also reduced elsewhere. Furthermore, the kicks produced by the magnets are on average smaller than in the 4-magnet scheme, because the kicks of the overlapping bumps partly cancel each other.

Installing four magnets per straight section allows to start with the traditional 4-magnet scheme and to switch to overlapping bumps at any time without hardware modification.

3 TIME-DOMAIN SIMULATION

The analysis of feedback loops is generally simplified if the time-dependent behavior of each component is transformed into the frequency domain using the Laplace transform (or Z-transform for the discrete-time signals). Some first insight

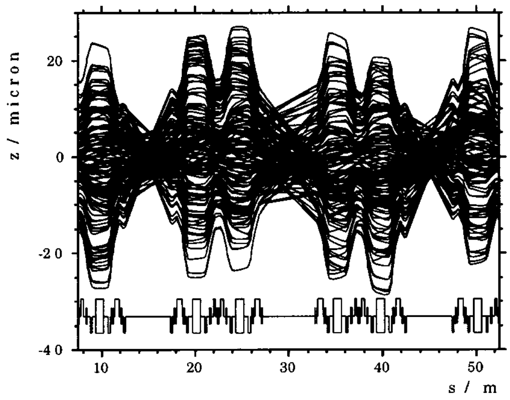

Figure 1: Simulated closed orbits without feedback.

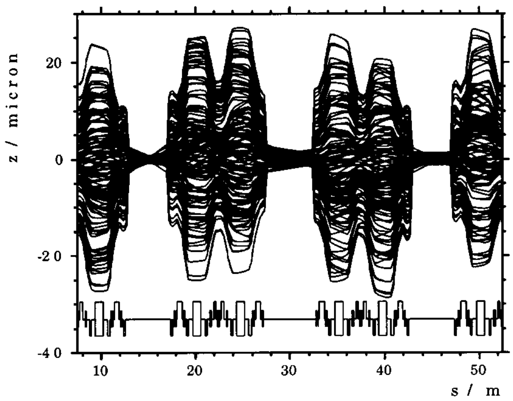

Figure 2: Simulated closed orbits with feedback using four magnets per straight section.

may also be obtained from a direct time-domain simulation, where the beam oscillation and the feedback system output are calculated in small time steps.

3.1 Assumptions

For BESSY-II, the beam oscillation was modelled considering a motion of the girders that support the quadrupole magnets. The spectrum of this motion was assumed to extend up to 100 Hz with a peak at 10 Hz. Furthermore, a 50 Hz ripple at all magnets of the global orbit correction scheme was added. Power supply ripple at the other magnets was neglected. The bending magnets, for example, have a common power source and should not produce oscillations in the dispersion-free ID region.

The beam position was sampled at both ends of the ID with 1 kHz and – after adding some noise – fed into a PID-controller which produced new settings for the corrector magnets with a time delay of 1 ms. It was assumed that the power supplies approach these values exponentially with a time constant of 2 ms.

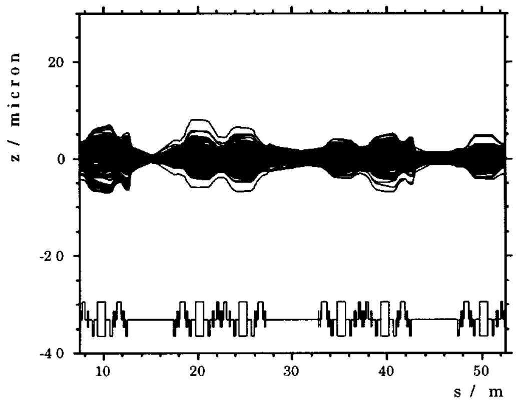

Figure 3: Simulated closed orbits with feedback using a scheme with two magnets per straight section.

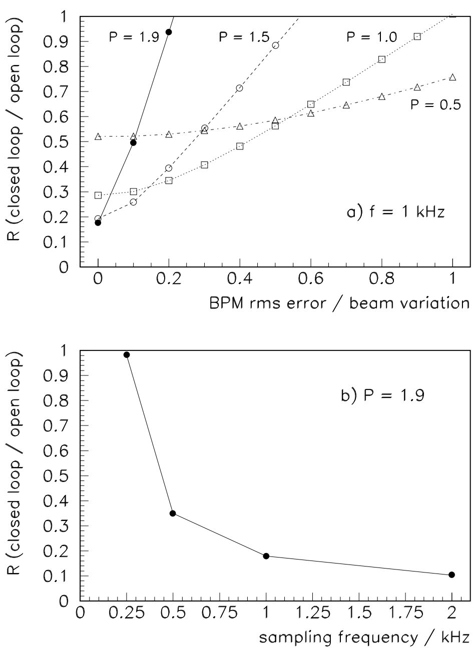

Figure 4: Feedback efficiency (defined in the text) as function of a) BPM error and b) sampling rate.

3.2 Results

To measure the efficiency of the system, the ratio R of the rms beam variation at the ID center with and without a closed feedback loop is defined. Applying proportional gain (P) only, a ratio of $R = 0.18$ is obtained. A non-zero integral (I) and derivative gain (D) does not improve the result significantly. The effect of noisy beam position readings is shown in figure 4a. Depending on the noise level, the proportional gain has to be reduced in order to obtain the optimum performance. The influence of the sampling rate on the efficiency is shown in figure 4b.

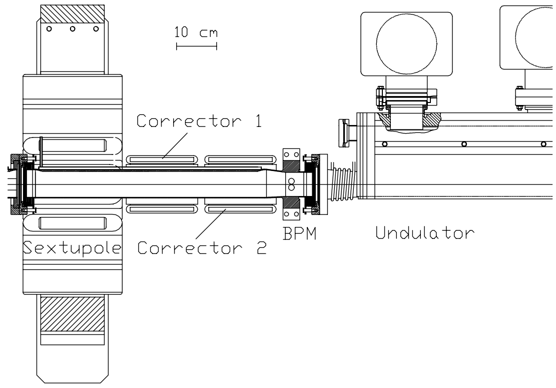

Figure 5: Two correctors between ID and sextupole.

4 HARDWARE ISSUES

Figure 5 shows a top view of the region between the upstream end of an ID in BESSY-II's high-β straight section and the next optical element, a sextupole magnet. A space of 0.5 m has to accomodate two corrector magnets, a beam position monitor (BPM), a bellow to absorb the thermal lengthening of the ID and a flange.

4.1 Magnets and Power Supplies

The correctors are window frame magnets with two horizontal and two vertical coils on a laminated or granulated yoke, designed under the following boundary conditions:

- Aperture given by beam pipe plus bakeout jackets.
- Total length of the pair of magnets limited to 0.4 m.
- Currents limited to 20 A.
- Bandwidth $\sim$ 100 Hz implying $L/R \sim 0.01$ s.

The current limit is given by the maximum current of a commercially available bipolar power supply with sufficient bandwidth [4]. The result of these design considerations is a corrector magnet capable of kicking a 2 GeV beam within $\pm$0.4 mrad. The corrector pair can produce a parallel displacement of the beam within ± 100 μm. The magnetic field and the effects of eddy currents, which were found to be negligible at 100 Hz, were simulated using MAFIA [5].

4.2 Beam Position Monitors

Two electron BPMs within the closed bump are required to measure position and angle of the beam. As shown in figure 4, their spatial resolution and readout frequency can seriously limit the performance of the feedback system. BPMs dedicated to this task should measure the beam position with 1 μm resolution and a frequency of 1 kHz or higher. Processing electronics with this capability [6] is currently tested at BESSY-I.

A feedback signal might also be derived from the photon beam produced by the undulator. Photoemission from thin tungsten blades surrounding the photon beam may be used for this purpose. Crosstalk between different blades and background radiation from dipole magnets are major problems of this technique. Promising experiments have been performed at BESSY-I, suppressing the dipole background by rejecting photo-electrons below an energy threshold given by the photon spectra and the photoemission characteristics [7].

4.3 The Feedback Controller

The feedback controller may be an electronic circuit (analog) or a computer using an appropriate algorithm (digital feedback). It is gererally felt that a digital feedback allows for more flexibility. To be compatible with the BESSY-II control system, the controller will be a MVME-162 CPU under VxWorks with analog I/O boards in a VME crate.

5 OUTLOOK

The individual components described above and a simplified version of a local feedback system are currently tested at BESSY-I. Here, three steering magnets with laminated yokes are used to form a closed bump which allows to control either the beam position or the angle. First results are described in [8].

The local position feedback system has to be operational in summer 1998, when the first ID is scheduled for installation at the BESSY-II storage ring.

6 REFERENCES

[1] D. Krämer, *Status of the Synchrotron Light Source BESSY-II*, this conference.

[2] J. N. Galayda, Y. Chung, R. O. Hettel, in: Synchrotron Radiation Sources - a Primer, ed. H. Winick (World Scientific 1994), and references therein.

[3] Y. Chung, *A Unified Approach to Global and Local Beam Position Feedback*, Proc. of the 3rd European Particle Accelerator Conference, London 1994, 1595.

[4] BOP 20-20M by KEPCO Inc., Flushing (NY).

[5] R. Klatt et al., *MAFIA - A Three-Dimensional Electromagnetic CAD System*, Proc. of the Linear Accelerator Conference 1986, SLAC-303 (1986) 276.

[6] J. D. Gilpatrick et al., *Experience with the Ground Test Accelerator Beam-Measurement Instrumentation*, BIW 1993, AIP Conference Proceedings 319 (1994), 154.

[7] K. Holldack et al., *Suppression of Dipole Background from Position Signals of Photon BPMs*, BESSY Jahresbericht 1995, 497.

[8] J. D. Gilpatrick, S. Khan, D. Krämer, *A State Variable Approach to the BESSY-II Local Beam-Position Feedback-System*, this conference.