AUTOMATIC CLOSED ORBIT ERROR CORRECTION SYSTEM OF A COMPACT STORAGE RING FOR SR LITHOGRAPHY

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Abstract

The system has been developed to correct SR position drift on an SR lithography beam line during long-term operations. An SR position monitor consisting of two photodiodes was arranged on the SR lithography beam line and the vertical SR positions were measured continuously. The closed orbit drift was corrected automatically using a dipole correction magnet. The SR position drift without any feedback corrections was about 2.5 mm at the SR position monitor over a year. SR position centering within 10 μm on the beam line was maintained for 6 months.

1 INTRODUCTION

The stability of the position of synchrotron radiation (SR) is one of the most critical parameters for x-ray lithography users. Pattern replication is sensitive to small changes in the SR intensity induced by the fraction drift of the electron beam. The permissible drift of SR position is within 20 μm on the photon beam position monitor (P-BPM) in our storage ring. Considering the distance from the beam source to the P-BPM (about 7.5 m), the electron beam must be stabilized within about 5 μm. The sources of disturbance affecting the beam stability are ground vibrations due to thermal stress, temperature changes of magnetic instruments and cooling water, power supply ripples, mechanical noises produced by the SR ring itself or other machines, and stray magnetic fields [1]. The compact storage rings for industrial uses are especially likely to be placed in an unfavorable environment. A beam position feedback system is essential, since it is difficult to suppress those disturbances within permissible ranges. It is difficult to correct the drift using the electron beam position data measured with electrostatic pick-up electrodes (E-BPMs). The absolute accuracy of E-BPMs is about 100 μm, and the resolution is about 10 μm, and the measured data is very susceptible to drifts induced by the mechanical movements of E-BPMs and their electronic drifts. And E-BPMs provide limited information about SR drift because they are commonly located on straight sections which are positioned up to several meters in front of or behind bending magnet [2].

A photon beam feedback system using P-BPMs was developed in order to stabilize the vertical SR drift at the X-ray stepper within 10 μm. A P-BPM based on a user beam line is not only a very economic and reliable on-line monitor for the local SR position and a long-term position fluctuation, but also suitable for a monitor of the feedback system. In the present paper, the feedback system and a result of the application for the compact storage ring for lithography are described.

2 METHOD

The SR position $Y_{SR,i}$ and its angle $Y'_{SR,i}$ at a position of a P-BPM are given by

$$Y_{SR,i} = y_{beam,i} + y'_{beam,i} d_i$$
$$Y'_{SR,i} = y'_{beam,i}, \qquad (1)$$

where $y_{beam,i}$ and $y'_{beam,i}$ are the source beam position and its angle, respectively, and d_i is the distance between the source beam and the position of the P-BPM, An SR feedback system ordinarily uses two P-BPMs situated in a beam line. The system can calculate $y_{beam,I}$ and $y'_{beam,i}$, and, can create locally beam bumps in angle and position that are of opposite sign and same amplitude as the beam perturbation with a set of four dipole correcter magnets [3]. However the mechanical movements of two P-BPMs induced by temperature changes produce calculation errors of $y'_{beam,i}$, and, the system may be incapable of making corrections with an accuracy of the order of a few microns.

Our feedback system is composed of one P-BPM situated near the stepper tool on the beam line, because achieving $Y_{SR,i}=0$ at the stepper is our main purpose. The SR position at a P-BPM position is calculated with the following simple equation,

$$Y_{SR,i} = Y0_{SR,i} + \sum_{m=1}^{N} c_{m,i} I_m \ , \qquad (2)$$

where $Y0_{SR,i}$, I_m, and $c_{m,i}$ are the SR position without any feedback actions, the current of a dipole correction magnet, and the coefficient, respectively, and the number of P-BPMs and of dipole correction magnets is N. The coefficient $c_{m,i}$ can be determined by calculation or measurement. The difference between measured coefficients and calculated ones is about 15% in our storage ring, and measured coefficients are used for the feedback system. The dipole correction kick currents are calculated by the former equation, when $Y_{SR,i}=0$ is substituted into the former equation and the value of I_m is found.

It is necessary to make a global feedback which corrects the closed-orbit errors of the entire ring circumference by referring to the E-BPMs before the SR feedback system operation. This is because the results of SR feedback without global feedback may produce large values of $y'_{beam,i}$, making the beam unstable. A conventional closed-orbit correction method, that is, the global harmonic correction system [4] is used in our SR ring.

3 SYSTEM

Figure 1 shows the compact storage ring at Mitsubishi Electric and the basic ring parameters [5]. The ring is a racetrack-type consisting of two superconducting bending magnets with field indexes. Two beam lines are guided into a clean room, and X-ray steppers sit at the end of them. There are four E-BPMs and four horizontal and vertical dipole correction magnets at the exits of the bending magnets. There are in addition four vertical dipole correction magnets on the straight sections which are mainly used for the SR feedback system. The P-BPM is located 7.5 m from the source which has a size of roughly 0.4 mm σ_y, and a vertical of β_y=6 m.

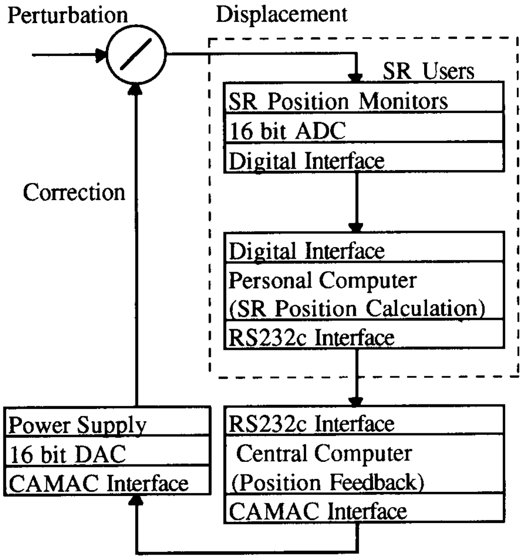

Figure 2: Block diagram of the SR feedback system (1).

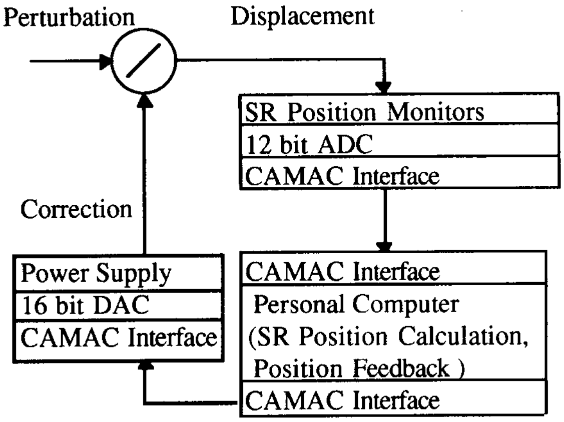

Figure 3: Block diagram of the SR feedback system (2).

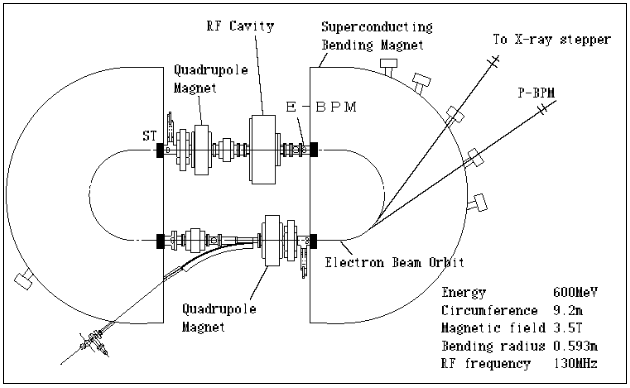

Figure 1: Schematic drawing of the compact storage ring.

Since the SR source points of the two beam lines using x-ray lithography are at a distance of 0.2 m apart, the number of the P-BPMs using the feedback system is one at present. The P-BPM consists of two photodiodes, and the SR positions are calculated by a function of $I_y = (I_u - I_d)/(I_u + I_d)$ as in the following equation;

$$Y = a_1 I_y^3 + a_2 I_y^2 + a_3 I_y \ , \tag{3}$$

where I_u and I_d are the upper and lower photocurrents. A positional calibration of the P-BPM was done by scanning the detector vertically through the SR beam while monitoring the currents I_u and I_d, and, a_1, a_2, and a_3 were determined. A block diagram of the SR position feedback system is shown in Figure 2. The photocurrents are amplified by an I-V convertor, and the data is tranferred to an ADC and a personal computer situated near the E-BPM. Then the SR position data is transferred through a RS232c interface to a central computer, and the correction kick values calculated by the computer are transffered through a CAMAC interface to a DAC, and the power supplies and magnets are finally applied to the electron beam. The measured feedback frequency of the system is about 3 Hz, the slow feedback speed is mainly due to the transfer speed through the RS232c interface.

A fast feedback system should be composed of one computer, the example is a system using a PC-controlled CAMAC interface system as shown in Figure 3. The system can be 100 Hz feedback frequency operation. The spectra of measured beam fluctuations has two peak at 2.4 Hz and 9.6 Hz in our storage ring, but the amplitudes are within 5 μm. The slow feedback system as the Figure 2 is used at present. The horizontal SR drift is not an unacceptably large for lithography, and feedback of the horizontal SR drift is not carried out.

4 APPLICATION

Figure 4 shows vertical closed orbit errors without and with corrections. The curved lines were calculated with the Fourier expansions of the measured data after the Courant-Synder conversions. The magnets were aligned twice, in 1993, and in 1995. The natural closed-orbit errors of the two cases agreed well. The reason is that the main source of the vertical closed orbit errors is the misalignments of the superconducting coils from magnetic shields around the coils, and the alignments were not done in 1995. The closed orbit error corrections were done by a conventional method, the global harmonic correction method. The closed orbit errors after the corrections are within $\Delta y = 0.1$ mm at the E-BPM positons and within $\Delta y = 0.3$ mm at the P-BPM position. The SR position drift at the P-BPM position without any feedback actions was about 2.5 mm within 6 months as shown in Figure 5. The temperature fluctuation is also shown in the figure. There is a lot of correlation between the SR position and temperature fluctuation. The SR positions were within 10 μm with the SR feedback system correction. The feedback system has worked well for 6 months without any problems.

Closed-orbit errors after the SR feedback system movement were simulated. Since the SR feedback was done with only the data of $Y_{SR,i}$, the closed-orbit errors of the entire ring circumference may be large values. The simulation was done as in the following steps; (1) practical misalignments were given to the magnets, and the closed-orbit errors were calculated, (2) the global harmonic closed-orbit correction was done, and (3) the SR feedback was done. Figure 6 shows the closed orbit errors at the maximum point of the entire ring circumference. The figure shows that closed-orbit errors after the SR feedback movement are not so large that the electron beam can be stable.

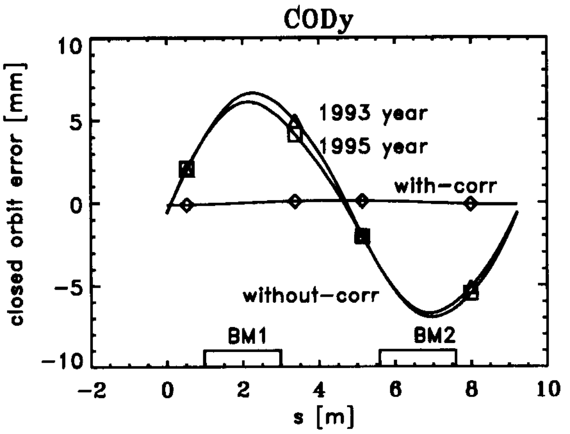

Figure 4: Vertical closed-orbit errors without and with corrections.

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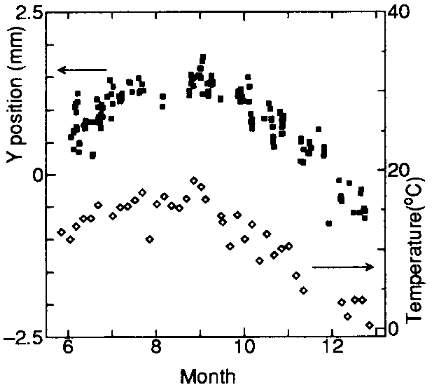

Figure 5: The SR position drift at the P-BPM position without any feedback corrections and the temperature fluctuation.

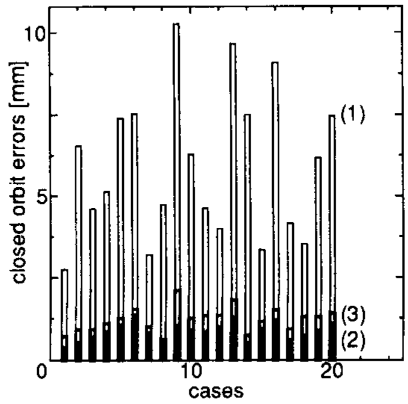

Figure 6: Closed-orbit errors at the maximum point of the entire ring circumference.