Closed Orbit Measurement and Correction of the SRRC Storage Ring

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Abstract

The commissioning of the storage ring at Synchrotron Radiation Research Center have been successful and the residual closed orbit distortion was reduced to 0.23 and 0.13 mm rms in the horizontal and vertical plane, respectively. This paper describes the works related to the closed orbit at SRRC, ranging from the design tolerances of the magnetic field, alignment, correction scheme, orbit measurement methods to orbit correction methods. The performance of the beam position monitor system is described and the on-line orbit correction programs are discussed.

1. INTRODUCTION

The Synchrotron Radiation Research Center in Taiwan, the Republic of China, started the commissioning of its 1.3 GeV third generation low emittance storage ring in the early part of 1993. The first stored beam was achieved on April 13 and the closed orbit was measured on April 26 once the beam position measurement (BPM) system became operational. The closed orbit distortions (COD) were then corrected to less than 0.5 mm rms in both planes using the on-line orbit correction programs. We succeeded in storing beam current of more than 200 mA in August 1993 and the ceremony of the SRRC was held on October 16, 1993. Since then, the machine has been routinely scheduled for users' beam time for more than six months. The improvement of the machine performances was still on going. Up to now, the stored beam current exceeding 400 mA has been recorded and beam lifetime can be more than 6 hours at 200 mA.

Both position and angle of the source are very important parameters for the synchrotron light users. One would like to have these two values close to zero. Therefore, the closed orbit of the stored beam need to be corrected to the designed orbit if possible. From the users' point of view, both the beam orbit and the beam stability are the major concern at this stage in order to undertake dedicated synchrotron radiation experiments.

In this report, the performances of the COD measurements and corrections are given and the comparison between the measured orbit and the calculated one is described. The stability of the beam orbit is not emphasized in detail here.

2. ERROR SOURCES OF THE CLOSED ORBIT DISTORTIONS

The 1.3 GeV synchrotron radiation storage ring is a combined function triple bend achromat (TBA) type lattice with strong focusing magnets and chromaticity correction sextupole magnets as well.[1] The circumference is 120 meter long and the ring is six-fold symmetry. The natural emittance of the beam is 1.92 10^{-8} m-rad at 1.3 GeV. The designed betatron tunes are $\nu_x = 7.18$ and $\nu_z = 4.13$. Due to the strong focusing of the quadrupole magnets, the misalignment of the quadrupole magnets results in a substantial amount of the kick strength of the electron beam if it does not pass through the quadrupole magnet center. The overall amplification factor of the closed orbit distortions to errors can be expressed as[2]

$$\begin{aligned}<x_{co}>^2 &= (11.3)^2(\Delta x_{Q1})^2 + (26.0)^2(\Delta x_{Q2})^2 + (4.3)^2(\Delta x_{Q3})^2 \\ &\quad + (14.4)^2(\Delta x_{Q4})^2 + (3.4)^2(\Delta x_{BM1})^2 + (2.7)^2(\Delta x_{BM2})^2 \\ &\quad + (3.5)^2(\Delta BL/BL)^2 \\ <z_{co}>^2 &= (9.3)^2(\Delta z_{Q1})^2 + (16.0)^2(\Delta z_{Q2})^2 + (6.5)^2(\Delta z_{Q3})^2 \\ &\quad + (11.3)^2(\Delta z_{Q4})^2 + (5.3)^2(\Delta z_{BM1})^2 + (5.5)^2(\Delta z_{BM2})^2 \\ &\quad + (8.3)^2(\Delta\theta_{SBM1})^2 + (4.2)^2(\Delta\theta_{SBM2})^2.\end{aligned}$$

where Δx and Δz are the transverse alignment errors in magnets in units of meters, $\Delta BL/BL$ is the field error in the dipole magnets, $\Delta\theta_S$ is the rotation error of the dipole magnet along the beam path axis.

Note that the distortions caused by the rotation errors of the quadrupole magnets are negligible while the rotation errors of the quadrupole along S axis will cause the x-z emittance coupling. The rotation errors of the dipole along x and z axis contribute a small amount of orbit distortions. The misalignment of the sextupole magnets mainly generates x-z emittance coupling, reduce dynamic aperture and cause only a very small amount of orbit distortions. Obviously, Q2 magnets, which have large betatron function and field strength, give the largest contribution to the closed orbit distortion. If we assume that the rms transverse alignment errors are the same for all magnets, then one can express the rms orbit distortions as follow:

$$\begin{aligned}<x_{co}>^2 &= (32.1)^2(\Delta x_Q)^2 + (4.3)^2(\Delta x_{BM})^2 + (3.5)^2(\Delta BL/BL)^2 \\ <z_{co}>^2 &= (22.6)^2(\Delta z_Q)^2 + (7.6)^2(\Delta z_{BM})^2 + (9.3)^2(\Delta\theta_{SBM})^2\end{aligned}$$

To keep the values of COD without correction as reasonable small as possible, we set the specification of the integral dipole field errors of the bending magnets to be $|\Delta BL/BL|$ rms $\leq 10^{-3}$, the quadrupole magnet alignment errors to be less than 0.15 mm rms, and the rotation errors of the dipole magnets is 0.5 mrad rms. These criteria are technically accessible, although care has to be taken in the construction.

Different orbit correction schemes were searched and the effectiveness of the orbit correction were compared. [3] The simulated orbit before correction with RACETRACK for 20 machines were about 6 mm rms and the maximum distortions were about 15 mm in both planes which were in consistent with results from Eq. 2.[4] With several iterations of the corrections using "most effective method" and "beam bump method", one could reduce COD to less than 0.15 mm rms in both planes. The maximum corrector strength was less than 1 mrad. To enable the first turn steering in the commissioning phase, we designed maximum corrector strength to be larger than 1.5 mrad. Finally, a total of 47 BPMs for the position measurement in both planes and 24 horizontal and 30 vertical correctors were used. To save space, 24 correctors are combined with sextupole magnets as trim coils. Fig. 1 shows the layout of position of the correctors and monitors as well as the main magnets of the SRRC storage ring. The dynamic aperture of the single particle with corrected orbit is almost the same as that of original lattice without errors.

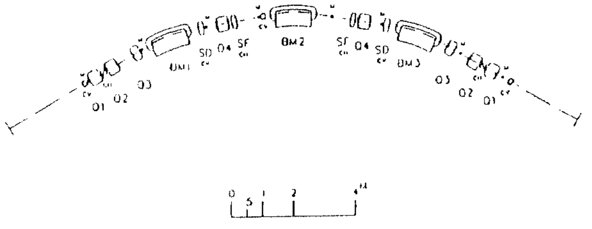

Figure 1. Layout of one period of the SRRC storage ring

In SRRC the magnetic field quality of all the manufactured dipole magnets were measured using Hall probe and the dipole field errors at 1.3 GeV electron beam settings were $|\Delta BL/BL| = 4.0\ 10^{-4}$ rms. The survey and alignment of the ring magnets were carefully performed. The position deviation of each magnet with respect to the ideal orbit was measured. The position deviation of the dipole and quadrupole magnets in both horizontal and vertical planes are shown in Fig 2. The results demonstrated that the alignment work has been well performed and reached the tolerance requirement. With the measured field errors and alignment errors, we simulated the COD using accelerator design codes RACETRACK and MAD. [5] The alignment errors of the dipole, quadrupole, and sextupole magnets together with the dipole fields errors were taken into account in the simulation.

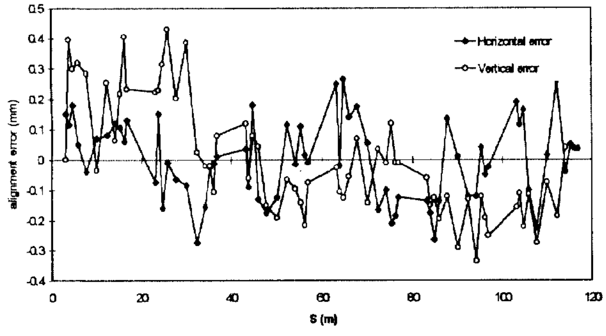

Figure 2. Measured transverse misalignment errors in the dipole and quadrupole magnets.

3. BEAM POSITION MEASUREMENT SYSTEM

Forty-seven BPMs were made of four button-type electrodes skewly mounted on the vacuum chamber. The mechanical and electrical calibration of each set, including nonlinear fittings, from bench measurements were carefully done. These BPM system have high dynamic range, from 0.2 mA to 600 mA. The button signals are sequentially selected by solid state switches (RF multiplexer) and sent to IF module, which is tuned at 500 MHz (200th harmonic of the revolution frequency). The signals then read into Intelligent Local Controllers (ILC) sequentially and beam positions are calculated in ILCs. It takes about 30 ms in the time being to get one complete COD measurement of the ring and the COD data are updated to the dynamic database in the process computers at 10 Hz. Detail description can be found in reference [6].

4. CLOSED ORBIT CORRECTION

The measured COD is displayed on the screen . The orbit correction application program is one of the machine parameter application programs (MPAP). [7] The modeling of the machine from MPAP can be examined. For example, the calculated betatron tunes are compared with the measured ones. Another way to verify of the validity of the model is to apply one corrector and check the difference of the simulated and measured orbit change. It was found that the linear model was quite satisfactory. The tune difference between the simulated and measured ones was about 0.001~ 0.005 in both planes. Note that the working point of the machine was set to $\nu_x = 7.24$, $\nu_z=4.08$ for both efficient injection and longer lifetime. The difference of the orbit change is shown in Fig 3. There existed 60 and 180 Hz noise in the button signal and hence the maxium beam position fluctuation could be 100 μm. No averaging was taken in the COD measurement and the consistency between simulated and calculated orbit responses are good. The measured tranfer matrix routinely used as database will be tried next.

There are several algorithms available to reduce COD globally or locally. For instance, the harmonic method, the brute-force most effective method, the least square minimization method, the singular value decomposition method, and the bump method, etc. We usually used the constrained MICADO method and combined with three-bump method.[8] The rf frequency was tuned to the value in which no modulation of the COD arised due to dispersion function. This rf setting was also matched to the good injection condition.

Fig. 4 depicts the results of the simulated COD due to errors, the measured COD without correction, and the optimal COD. It was found that the uncorrected orbit from measurement were in agreement with the calculated ones. The measured uncorrected orbit was 2.83 mm rms in the horizontal plane and 3.38 mm rms in the vertical plane. The lowest residual COD we could obtain up to now was 0.23 mm rms in the horizontal plane and 0.13 mm rms in the vertical plane. The reason why we had poorer orbit in the horizontal plane could be attributed to the difficulty of the calibration and sensitivity to the current-dependent position reading change. It is expected that after the improvement of BPM system, including the noise reduction, the attenuation of front end signal and the correctness of the offset values, the residual COD will be reduced. Some misbehaved BPMs were removed from the correction data. The maximum corrector strength is 0.43 mrad which is much less than the designed requirement.

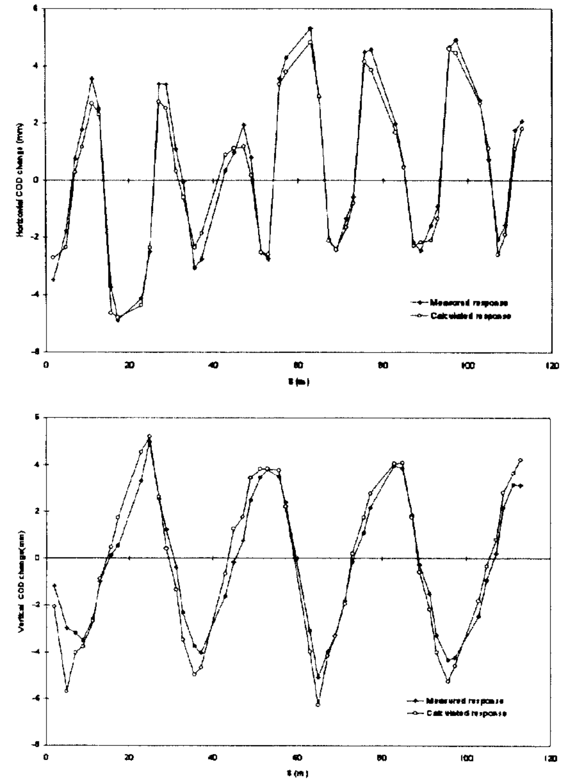

Figure 3. Measured and simulated orbit changes in both planes

Since September 1993, three high resolution VUV photon beamlines have been commissioned. The orbit has been adjusted to satisfy users' requirements. Up to now, the stability of the orbit is our main task. It was found that coherent betatron oscillations were excited with small empty gap of bunch train and with larger beam current. To suppress these oscillations we increased the chromaticities to positive values and these values were different from fill to fill due to different pattern of bunch train. These higher and varied sextupole settings not only decreased the beam lifetime due to reduced dynamic aperture but also changed the orbit a little bit. Slight adjustment of mirrors of the photon beamlines from fill to fill was needed.

5. ACKNOWLEDGMENT

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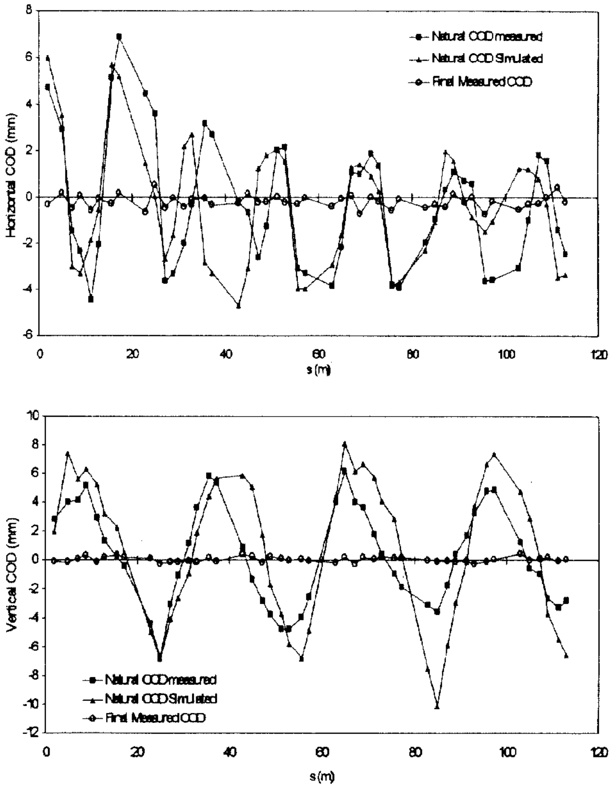

Figure 4. Measured and simulated COD before correction as well as the optimal residual COD in both planes

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