CIRCUMFERENCE AND COD CONTROL ALGORITHM OF NEWSUBARU

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Abstract

We renewed a closed orbit correction program for NewSUBARU. We use a new horizontal orbit correction algorithm with a circumference control. A response matrix in the program is calculated using the correct equation of the response in an electron storage ring. It made the correction process faster and more stable. It also eliminated an interference with the control program of RF frequency.

INTRODUCTION

NewSUBARU [1,2] is a 1.5 GeV synchrotron radiation ring at the SPring-8 site. Laboratory of Advanced Science and Technology for Industry (LASTI) at the University of Hyogo is in charge of its operation, collaborating with SPring-8. The beam is injected from the SPring-8 linac with 1.0 GeV of electron energy. A bending cell in the ring is a modified DBA with an 8° invert bend between two 34° normal bends. This facilitates the control of the linear momentum compaction factor (α_P) while keeping the cell achromatic and with only a small change of the natural emittance.

The followings are historical improvements of the correction program of horizontal closed orbit distortion (COD) at NewSUBARU.

In 1998, at the early stage of the machine commissioning, a primitive program including a graphic user interface made by H. Tanaka of SPring-8 was used. It used the subroutine "MIKADO" [3] and selected the best set of correctors. The response matrix was calculated from the ring model. The COD measurement program and the RF frequency (f_{RF}) control were separated from the correction program.

In 2000 a serious effect of hidden COD [4] was recognized, which is a horizontal orbit distortion exists at between the BPMs (Beam Position Monitors). An inappropriate setting of f_{RF} produced the hidden COD. Before the engagement of a new steering parameters, we manually checked them so that not to change f_{RF} much. An adjustment of f_{RF} was required to obtain the appropriate change of the steering parameters. Then we had to adjust alternatively f_{RF} and the steering magnets. This correction process reduced the change of the hidden COD but did not eliminate its long-term drift.

In 2002, A. Ando and H. Fukuda combined the COD correction and COD measurement programs. It had a function to control f_{RF} and preceded the above correction process automatically. On the other hand, two different programs, COD correction and RF control, changes f_{RF}. This was an unwanted interference.

In 2003 the RF synchronized injection from the SPring-8 linac started [5]. It required a small long-term drift of the RF frequency. We added a new function, which changed the circumference, in other wards the hidden COD, using steering magnets without changing the beam position at BPMs. It kept the f_{RF} in a region of 499955500±300 Hz.

The correction program had two problems when we activated it continuously during the top-up operation. One problem was the so many iterations for a correction, which requires many times of measurements. This was bad because we could not inject the beam during the COD measurement. Another problem was that the horizontal COD became larger for a short period through the correction process. This article explains the new correction program, which solved the above problems. The key was a correct equation to calculate the response matrix.

RESPONSE MATRIX

Equation in a Introductory Text Book

In this article we use the commonly used curvilinear coordinate system, x, y and s, and the conventional beta function $\beta(s)$ and the betatron phase $\psi(s)$.

In any of introductory textbooks on synchrotron optics a response of COD to a thin dipole deflection is given by

$$x(s) = \frac{\sqrt{\beta(s)\beta(s_S)}}{2\sin\pi\nu}\theta_S\cos\left(\pi\nu - \left|\psi(s)-\psi(s_S)\right|\right). \quad (1)$$

Here s_S and θ_S are the s and the angle of the deflection. The ν is the betatron tune. A replacement of x by y in the equation gives a correct response in vertical direction. However in horizontal direction of a real machine, Eq. (1) is not correct because of the automatic acceleration by an RF system. The correct horizontal COD response is given by

$$x(s) = [\frac{\sqrt{\beta(s)\beta(s_S)}}{2\sin\pi\nu}\cos\left(\pi\nu - \left|\psi(s)-\psi(s_S)\right|\right) + c\,\eta(s)]\theta_S. \quad (2)$$

Here $\eta(s)$ is the dispersion function and c is a constant of s, which depends on a synchrotron. In most synchrotrons $c\approx 0$ is a good approximation.

Realistic Equation for a Hadron Synchrotron

An RF system of hadron synchrotron has a feedback system, which confines the energy displacement. Normally an averaged signal of horizontal displacement at some locations is feedback to f_{RF} in order that

$$\sum_{i=1}^{n} x(s_n) = 0. \quad (3)$$

Here n is a number of monitors for the feedback and s_i are their locations. Therefore c is given by

$$c = -\frac{\sum_{i=1}^{n} \frac{\sqrt{\beta(s_i)\beta(s_S)}}{2\sin \pi\nu} \cos\left(\pi\nu - \left|\psi(s_i) - \psi(s_S)\right|\right)}{\sum_{i=1}^{n} \eta(s_i)} \quad (4)$$

Realistic Equation for an Electron Synchrotron

The horizontal displacement given by Eq. (1) changes also the circumference of the orbit. In electron synchrotron this change was cancelled out automatically by a shift of energy. In a linear system the change of the circumference by a horizontal displacement, ΔL_X, is given by

$$\Delta L_X = \int_0^{L_0} [x(s)/\rho(s)]ds \,. \quad (5)$$

Here $\rho(s)$ is the curvature of radius and L_0 is the circumference of the reference orbit. We substitute Eq. (1) into Eq. (5) and obtain

$$\Delta L_X = \eta(s_S)\theta_S \,. \quad (6)$$

On the other hand the circumference change by an energy displacement, ΔL_E, is approximated by

$$\Delta L_E = \alpha_P L_0 (\Delta E / E_0) \,. \quad (7)$$

Here α_P is the momentum compaction factor and $\Delta E/E_0$ is the relative energy displacement. The condition

$$\Delta L_X + \Delta L_E = 0 \quad (8)$$

should be satisfied when f_{RF} is not changed. Therefore c is given by

$$c = -\eta(s_S)/(\alpha_P L_0) \,. \quad (9)$$

This equation is not our original but not written in any introductory textbooks.

Response at NewSUBARU

The contribution of $c\eta$ is serious at NewSUBARU. Fig. 1 shows the calculated response to a change of steering magnet at the dispersion section. The difference between Eq. (1) and Eq. (2) are large.

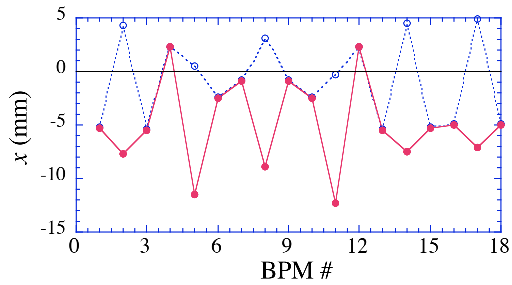

Figure 1; Example of a COD response to a thin dipole kick at the dispersion section. The blue dotted line is a calculated response using Eq. (1). The red solid line is a calculated response using Eq. (2) and Eq. (9). The assumed deflection was at near the BPM8 with strength of 1 mrad.

TEST OF THE PROGRAM

Steering and BPM System of NewSUBARU

Table I shows the main parameters of NewSUBARU. Fig. 2 shows the horizontal β and η of 1/4 of the ring. The ring has 18 horizontal steering magnets and 18 BPMs.

Table I Main parameters of NewSUBARU

Energy	0.5 - 1.5 GeV
Circumference	118.7m
RF frequency (f_{RF})	499.9555 MHz
Momentum compaction factor (α_P)	0.0013
Betatron tune (ν_X, ν_Y)	6.30, 2.23

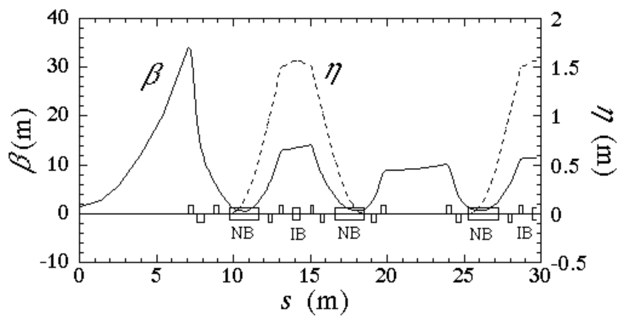

Fig.2 Horizontal beta function (β) and the dispersion function (η) of 1/4 of the ring.

COD Reduction by iterations

Fig. 3 shows the record of COD during the correction process using the old program. It took 29 times of COD measurement to reduce the rms (root mean square) down to less than 0.01mm. It alternatively adjusted f_{RF} and the steering magnets. One reason of such a large number of iterations was that the program applied only 75% of correction. The rms became larger at 8:31 (in Fig.3) after the engagement of the new steering parameters. The change of steering parameters changed the circumference and enlarged the COD. This COD was reduced by the successive adjustment of f_{RF} and the rms was reached to lower than 0.01mm. Suppose that we started a continuous correction from the COD at 8:30. The program would make 4 times larger COD for a short period to reach to a smaller COD. This was not acceptable during the user operation.

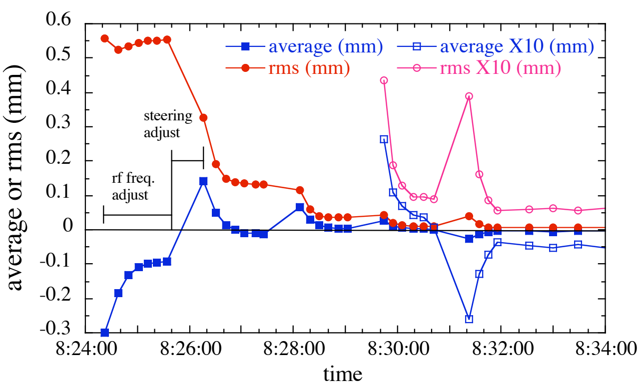

Figure 3; Improvement of the horizontal COD by iterations using the old correction process. The COD measurements took place at each point in the figure.

Fig. 4 shows the record when we used the new program. The rms of COD reached to a level of saturation in 5 times measurements, although the program applied 75% correction. There was no drastic increase of COD. The saturation level of rms was the 0.01mm, which was larger than that of the old program.

No change of f_{RF} was required and the program was separated from the f_{RF} control.

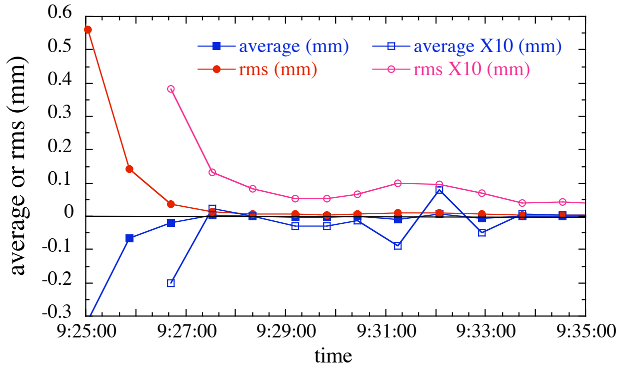

Fig.4 Improvement of the horizontal COD by iterations using the new correction program. No change of f_{RF} was required.

Saturation Level of the New Program

The reason of the larger saturation level of the new program was the poor setting resolution of the steering (correction) magnets. Table II shows parameters of the three types of the steering magnets. Fig. 5 shows the expected COD change by one control digital bit of the three types. In the correction process of Fig.3, the program used all of the 18 magnets. Then digitizing error made an horizontal COD of 0.01~0.02mm rms. In the old program this COD was reduced by the fine adjustment of f_{RF}. The resolution of f_{RF} was 1Hz, which made an adjustment of COD of 0.0010 mm rms.

Table II Parameters of three types of the horizontal steering magnet. The SSS, LSS IB are dispersion free Short Straight Section, dispersion free Long Straight Section, and dispersive Invert Bend section, respectively.

location	control bit	minimum		
		current	deflection	COD rms
SSS	12 bit	4.6 mA	0.61 μrad.	0.0039 mm
LSS	12 bit	1.5 mA	1.13 μrad	0.0023 mm
IB	12 bit	2.4 mA	0.78 μrad.	0.0046 mm

This saturation level was improved by reducing the number of steering magnets when COD was smaller than 0.02mm rms. Fig. 6 shows the reduction of the saturation level by reducing the number of correctors in MICADO. The saturation level with one corrector was about 0.004mm, which was smaller than the time drift at the present.

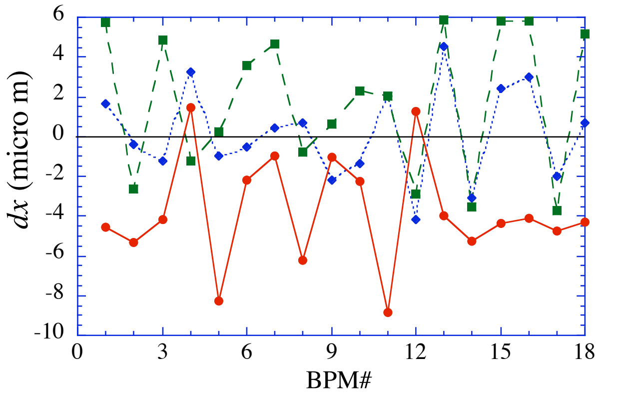

Fig.5 Expected COD change by the minimum changes of three types of horizontal steering magnets (correctors). The green broken line, the blue dotted line and the red solid lines are the responses to the magnets at SSS, LSS, and IB sections, respectively.

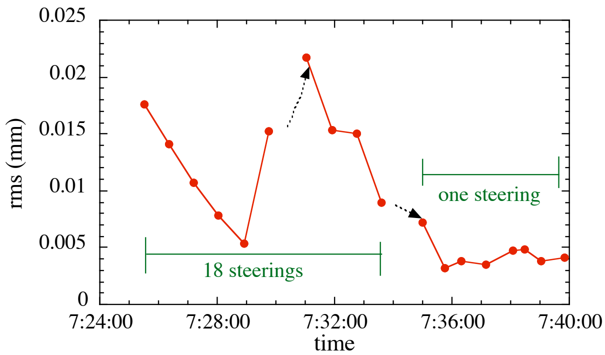

Fig.6 Change of the rms of the horizontal COD by iterations of correction. Until the time 7:34, 18 steering magnets were used to correct COD but after that one steering was selected and used. The shifts indicated by the black dotted arrows were a time drift of COD. During these periods the steering magnets were not changed.

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