OFF-MOMENTUM INJECTION INTO AN NON-AQCHROMATIC LATTICE

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Abstract

We are going to test a chromaticity modulation system in order to suppress the transverse beam instability at NewSUBARU. One AC sextupole magnet set at one of the long straight section would produce that modulation. For this purpose we tried an non-achromatic lattice to produce large dispersion at the long straight section. One of the problems of the lattice is an efficient injection into the ring. We calculated the beam trajectories in the ring to see if an off-momentum injection would help to improve the injection efficiency.

INTRODUCTION

The 1.5 GeV electron storage ring NewSUBARU [1] has been constructed in the SPring-8 site in 1998 for researches and developments on synchrotron radiation and its application. Then it is suitable to use the ring for a proof of new ideas and technologies. We will try the chromaticity modulation to suppress the transverse instability proposed by T. Nakamura [2]. Main parameters of NewSUBARU are listed in Table I. The ring is a racetrack type with the circumference of 119 m and has two 14 m long (LSS) and four 4 m long (SSS) straight sections. In the LSSs the 10.7 m long undulator (LU) and an optical klystron FEL (OK) have been installed.

Table I: Parameters of the NewSUBARU at 1.0 GeV, in the normal condition (achromatic lattice).

Injection energy	1.0 GeV
Circumference	118.731 m
Type of bending cell	modified DBA
Number of bending cells	6
RF frequency	499.956 MHz
Harmonic number	198
Revolution period	396 ns
momentum compaction factor α_P	0.0013
RF acceleration voltage V_{RF}	120 kV
Betatron tune ν_x / ν_y	6.30 / 2.23
Synchrotron osci. frequency f_S	6 kHz
Chromaticity ξ_x / ξ_y	3.2 / 5.8
Natural emittance	38 nm
Natural energy spread	0.047%
Damping time τ_E / τ_X	12ms /22 ms
Maximum stored beam current	500 mA

The chromaticity modulation with a synchrotron frequency (f_S) makes a betatron tune spread in a bunch, which produces Landau damping. At least one AC sextupole should be set at a dispersive section in NewSUBARU. Unfortunately NewSUBARU has no space for that AC component at the present dispersion sections. Therefore, we decided to make the bending cell non-achromatic and produce dispersion at the straight sections. One sextupole magnet will be set at one of the long straight sections, using a space at the downstream end of the long undulator. More information on this subject is given in the other article of this conference [3].

NON-ACHROMATIC LATTICE

The requirements for the non-achromatic lattice are;
(1) The absolute of the dispersion function (η) is larger than 0.5m.
(2) The momentum compaction factor (α_P) should be 10^{-3} or less.
(3) One can change lattice keeping the stored beam from the normal lattice.

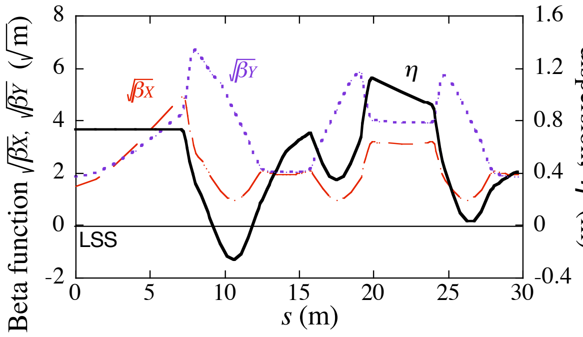


Figure 1: Beta functions and dispersion function of non-achromatic lattice in 1/4 of NewSUBARU. The solid, the dashed and the dotted lines show η, $\sqrt{\beta_X}$ and $\sqrt{\beta_Y}$, respectively. The left end is the half of the long straight section. The AC sextupole will be set at the location: s=5.87m in this figure.

Table II: Parameters of the NewSUBARU at 1.0 GeV, in the normal condition (achromatic lattice) and the non-achromatic condition.

Ring Parameters		
Lattice	achromatic	non-achr
Natural emittance (nm)	38	80
Parameters at AC sextupole		
dispersion η (m)	0	0.73
beta function β_x / β_Y (m)	22.7 / 11.8	17.3/13.3
Parameters at the injection point		
dispersion η (m)	0	1.10
dispersion angle η' (rad.)	0	0.05
beta function β_x / β_Y (m)	9.36/11.57	10.0/15.9
alpha function α_x / α_Y	-0.035/-0.14	-0.15/-0.19
horizontal beam size σ_X	0.6 mm	1.03 mm

Figure 1 shows the Twiss parameters (β_X and β_Y) and η of the non-achromatic lattice. The betatron tunes (ν_X and ν_Y) and α_P are the same as those of the normal (achromatic) lattice. The comparison of parameters of two lattices are given in Table II.

As the first step we succeeded to store the beam in that non-achromatic lattice. The measured tunes and chromaticities, of two betatron oscillations and the synchrotron oscillation were consistent with the calculation using a rough model.

OFF-MOMENTUM INJECTION

In the normal achromatic lattice, a fine parameter adjustment is required for a good injection. The height of the injection pulse bump is adjusted with an accuracy of 0.5mm for the injection efficiency as good as 80-100%. The beam injection into the non-achromatic lattice is expected to be more difficult than that into the achromatic lattice, because the circulating beam size is expected to be 1.7 times larger.

Beam Injection System of NewSUBARU

The layout of the injection system of NewSUBARU is shown in Figure 2. Four pulsed bump magnets produce the injection bump. The pulse septum is an out-of vacuum type, with the septum thickness of 3mm. The pulse shapes of the bump and the septum are shown in Figures 3 and 4.

The septum wall position, on the side of the circulating beam, is 21mm from the duct centre. In order to separate the beam from the septum by $4\sigma_X$, the height of the closed injection bump should be less than 17mm.

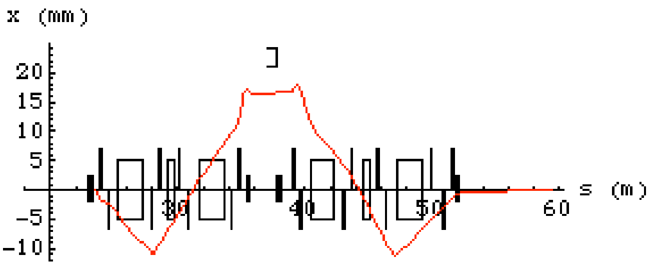


Figure 2: Closed injection bump of NewSUBARU. The height at the injection point is 16mm. Four small squares indicate the locations of four pulse bump magnets. The top clear box shows the location and the thickness of the septum. The stored beam goes from the left to the right.

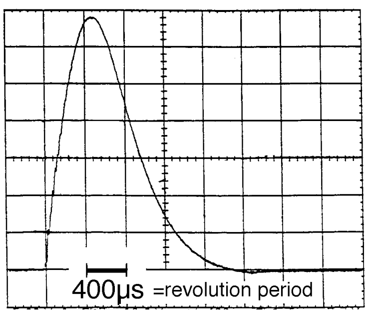
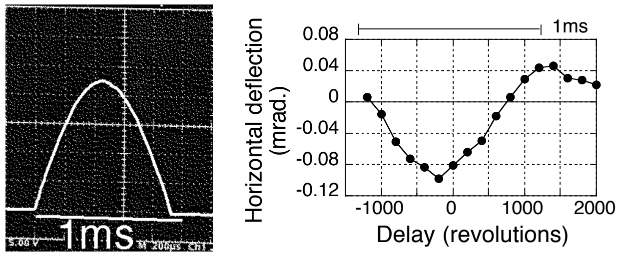


Figure 3: Pulse shape of the injection bump. Beam feels the bump field for 5~6 revolutions.



(a) (b)

Figure 4: (a) Pulse shape of the injection septum; 1ms width half sine and (b) deflection of the stored beam by the stray field of the septum [5].

Preliminary Test of On-momentum Injection

We have had tried the on-momentum injection into the non-achromatic lattice. The injection efficiency was measured for different pulse bump height (Figure 5). The injection bump was closed in the calculation but was not in the real machine, because of the stray field of the septum and the other non-linear element. At the best setting, the calculated bump height of 32mm, we could inject only 54% of the injected beam.

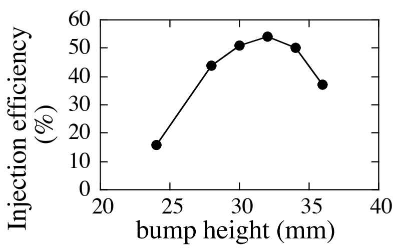


Figure 5: Injection bump height vs. injection efficiency. The bump height is the calculation based on the simple linear model.

Off-Momentum Injection -Calculation

We calculated the beam orbit of the injected beam in a linear lattice, which meant that all sextupoles were turned off. The assumed closed pulse bump height was 16mm at the injection point. The results are shown in Figure 6. In the calculation the ring has enough acceptance for the injected beam. However the model was too much simplified and the realistic machine has a complicated non-linear field. Still we could not identified the source of that big difference between the model and the real machine. There were many possible sources of errors.

The calculation indicated the critical point through the first revolution at s=46 m. The orbit excursion was -18.1mm. However if we inject the beam with 0.5% higher energy, the orbit excursion at this point was improved to -16.2mm. Figure 7 shows the orbit around this point. Here I should say that this off-momentum injection is no more than one of possible free parameters of the injection.

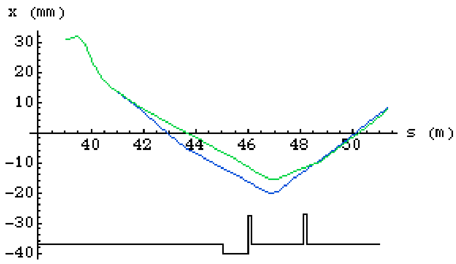


Figure 7: Orbit excursion of the injected beam at the first revolution. The blue line (below) shows the orbit of on-momentum injection. The green line (above) shows the orbit of off-momentum injection by +0.5%. The line on the base shows the physical acceptance. The injection point is s=38m.

STRAY FIELD OF THE PULSE SEPTUM

When we inject the beam into the dispersion section of a quasi-isochronous ring, a stray field of the septum would excite the longitudinal exciation. The change of the cod $x(s)$ by the dipole deflection θ_S is given by [4]

$$x(s) = \left[\frac{\sqrt{\beta(s)\beta(s_S)}}{2\sin\pi\nu}\cos\left(\pi\nu - \left|\psi(s)-\psi(s_S)\right|\right) + c\,\eta(s)\right]\theta_S \tag{1}$$

Here $c\theta_S$ is the shift of the equilibrium energy. The constant c is given by

$$c = -\eta(s_S)/(\alpha_P L_0). \tag{2}$$

In this article we call a ring “quasi-isochronous” when the second term is comparable or even larger in the bracket [ ] of Eq. (1). For example, the non-achromatic lattice of NewSUBARU is “quasi-isochronous” but SPring-8 SR is not, although its α_p is much smaller than that of NewSUBARU.

In our case the stray field of the pulse septum changes not only the COD but also the beam energy. The induced energy displacement of the stored beam is shown in Fig. 8. The energy displacement was comparable to the natural energy spread. We are going to reduce this stray field by adding insulation duct in this summer shut down. The new duct would eliminate the eddy-current field component [5].

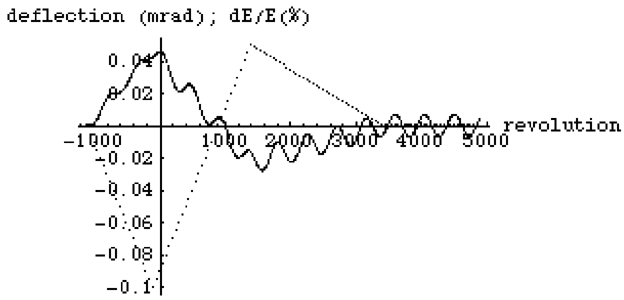


Figure 8: Simulation result of the energy displacement (waving line) induced by the defection by the stray field of the septum (dotted line). The horizontal axis is the number of revolutions, where the injection point is 0.

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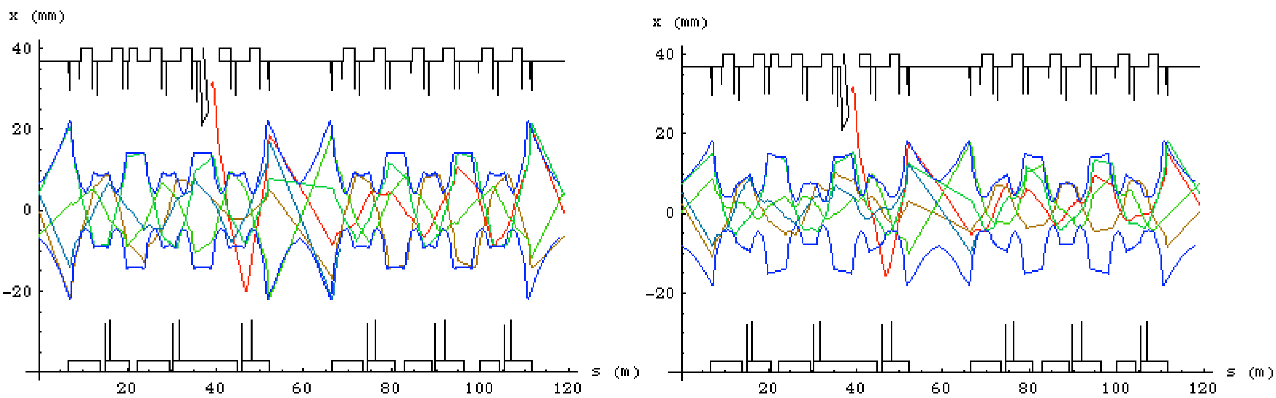

(a) on-momentum injection. (b) off-momentum injection by +0.5%

Figure 6: Orbit excursion of the injected beam in cases of (a) on-momentum injection and (b) off-momentum injection. The injection point (the exit of the pulse septum) is at s=38m. The red, brown, light green, dark green and dark blue lines are the orbits at the 1-st, the 2-nd, the 3-rd, the 4-th and the 5-th turn after the injection, respectively, during which the pulse bump field was active. The two blue lines show the envelope of the orbit excursion after the 5th turn, which include the spread by the synchrotron oscillation but we ignored the radiation damping. The black lines on the top and the bottom show the physical acceptance of the ring.