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DE-COHERENCE STUDY OF BETATRON OSCILLATION FOR THE BEAM SHAPE MANIPULATION *

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Abstract

De-coherence of vertical betatron oscillation in a electron storage ring was measured. A beam is deflected by a fast kicker and the phase spread was measured at the timing of integer times the synchrotron oscillation period. Dual sweep streak camera recorded vertical and longitudinal profiles for 6 turns, which gave the phase spread of the sliced bunch.

INTRODUCTION

In some proposals for synchrotron radiation storage rings, a temporal spatial structure in a bunch would be used to emit short X-ray pulse or coherent THz radiation. Our proposal uses chromatic betatron phase shift to produce temporal spatial wavy structure [1]. The first step is to deflect a bunch and produce vertical coherent betatron oscillation. After a half of the synchrotron oscillation period ($T_S/2$), a finite chromaticity produces a 'betatron phase tilt', that is a difference between the bunch head and the bunch tail. This makes a vertical position difference in the bunch [2,3]. After one synchrotron oscillation period, the phase tilt disappears. However, when the chromaticity is modulated with synchrotron oscillation frequency, the phase tilt is accumulated with many oscillations and produces a large phase tilt. For this technique of bunch shape manipulation, it is important to reduce unwanted de-coherence of betatron motion, which would break the intended spatial structure.

At NewSUBARU we kicked the beam using a vertical fast kicker and observed how the coherence was broken. Here 'de-coherence' means a betatron phase spread. In the measurements explained in this report the chromaticity is not modulated.

LINEAR EQUATIONS

In the following analytical calculations we will ignore higher order and non-linear contributions as well as the negligible effect of radiation damping.

The chromatic betatron phase shift $\Delta\psi_y$ is given by

$$\Delta\psi_y = \int (2\pi\xi_y / T_{REV})\varepsilon dt . \quad (1)$$

Her ξ_y is the chromaticity, ε is the energy displacement and T_{REV} is the revolution period. The synchrotron oscillation of ε and the time displacement τ are expressed by the following equations

$$\varepsilon = \varepsilon_0 \cos\omega_S t + (\omega_S/\alpha_P)\tau_0 \sin\omega_S t , \quad (2a)$$

$$\tau = \tau_0 \cos\omega_S t - (\alpha_P/\omega_S)\varepsilon_0 \sin\omega_S t . \quad (2b)$$

Here α_P is the momentum compaction factor, $\omega_S=2\pi/T_s$ is the angular synchrotron oscillation frequency, and ε_0 and τ_0 are the initial parameters.

The betatron phase shift of a particle is obtained by substituting Eq. (2a) into Eq. (1). When we use ε and τ as the beam parameters instead of ε_0 and τ_0, the result is written as

$$\Delta\psi_y = \frac{2\pi}{T_{REV}}\xi_y\left[\frac{\varepsilon}{\omega_S}\sin\omega_S t + \frac{\tau}{\alpha_P}(\cos\omega_S t - 1)\right]. \quad (3)$$

This shows that at $t=n\pi/\omega_S$, where n is an integer, the shift is independent of ε and is proportional to τ. Using the natural energy spread σ_ε the variance of the betatron phase shift produced by the energy spread is given by

$$\sigma_{\psi E} = (T_S/T_{REV})\left|\xi_y \sin\omega_S t\right|\sigma_\varepsilon \quad (4)$$

MEASUREMENTS

Non-Achromatic Lattice of NewSUBARU

We used the non-achromatic lattice designed to use the AC sextupole magnet, although that magnet was not excited in the following measurements. The parameters of the ring with non-achromatic mode are listed in Table 1. Twiss parameters of the lattice was reported at the previous conference [4].

Table 1: Basic Parameters of NewSUBARU

Injection Energy	0.976 GeV
Circumference: L_0	117.8 m
Revolution Frequency: T_{REV}	2525 kHz
Natural Emittance (This measurement)	80 nm
Natural Energy Spread: σ_ε	0.047%
Synchrotron oscillation Period: $T_s=2\pi/\omega_S$	167 μs
Radiation Damping Time: τ_L / τ_Y	12 ms / 24 ms

Parameter Adjustment

In order to minimize the disturbance of the H/V coupling, we adjusted the skew quadrupole families in the ring. The vertical dispersion was reduced to rms=8.4 and the estimated coupling constant was 0.1%.

The amplitude dependent tune shift was the other harmful factor. However, the vertical amplitude dependence could not be serious because of the small vertical beam size. The possible problem was only a horizontal amplitude dependent vertical tune shift. The one octupole family (4 magnets) was optimized for the coherence.

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Chromaticity Related Non-Linearity

The other harmful non-linear effect is the non-linear α_P and ξ_y. We define their higher order parameters as

$$\Delta L / L_0 = \alpha_P \varepsilon + \alpha_{P1} \varepsilon^2 + \alpha_{P2} \varepsilon^3 + \ldots \quad (5)$$

$$\Delta \nu_y = \xi_{y0} \varepsilon + \xi_{y1} \varepsilon^2 + \xi_{y2} \varepsilon^3 + \ldots \quad (6)$$

The non-symmetry of chromaticity and synchrotron oscillation for $\varepsilon>0$ and $\varepsilon<0$ would reduce the cancellation of the phase shift at $t=n\pi/\omega_S$. However in our case the synchrotron oscillation amplitude dependent synchrotron tune shift was more harmful. These non-linearity produces synchrotron amplitude dependent phase shift.

These non-linearities were controlled by the adjustment of the linear parameter because NewSUBARU does not have enough non-linear control knob. At NewSUBARU, a linear momentum compaction factor was effective.

Table 2 shows the ring parameters for two non-achromatic lattices. The normal non-achromatic lattice was our selection because it had much smaller non-linear parameters. The measurement of the rf frequency (f_{RF}) dependence of the synchrotron oscillation frequency $f_S=\omega_S/2\pi$ and the sub-integer betatron oscillation frequency $f_y=(\nu_y\text{-}2)/T_{REV}$ gave the non-linear parameters. Figure 1 shows the data and the results of the analysis, non-linear parameters, are listed in Table 2.

Table 2: Summary of Styles

Non-Achromatic Lattice		Normal	Small α_P
Momentum Compaction Factor :	α_P	0.00144	0.00096
	α_{P1}	0.021	-0.046
	α_{P2}	4.8	6.6
Vertical tune:	ν_{y0}	2.197	2.197
Vertical chromaticity :	ξ_{y0}	1.80	1.80
	ξ_{y1}	-1.4	-96
	ξ_{y2}	-2400	7800
RF Voltage for f_S=6 kHz		96.7 kV	138.6 kV

According to the simulation using the measured parameters, the contributions of non-linear rf acceleration field and that of non-linear α_p to the amplitude dependent synchrotron tune cancels out with each other.

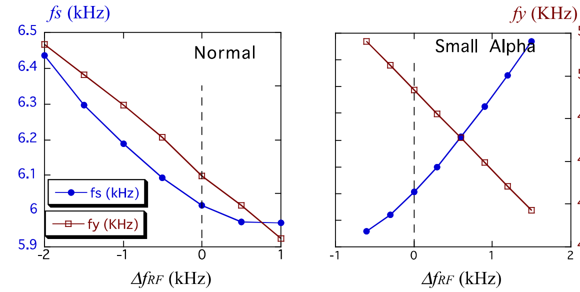

Figure 1: RF frequency dependence of synchrotron oscillation frequency (f_S) and betatron oscillation frequency (f_y) for two non-achromatic lattice.

Measurements Using Streak Camera

We measured $\Delta\psi_y$ using the dual-sweep streak camera. The longitudinal and the vertical profiles for successive 6 turns were recorded in one camera frame.

The profiles were sliced from the bunch head to the bunch tail. The time gate width for one slice was 18 ps. The vertical profiles of 7 slices were analyzed to obtain the betatron oscillation phase and its spread. The analysis took place for each single shot because the results showed a shot-by-shot tune variation of $\Delta\nu_y\approx0.000010$.

The pulse width of the vertical kicker [5] was 0.25 µs, which was a little bit longer than T_{REV}. The maximum Courant Snyder Invariant of the vertical oscillation was 0.2 µm rad. The ring buckets were filled with two bunch trains and one target bunch. The bunch trains were necessary for the synchrotron oscillation feedback system. Only the one target bunch is on the phase recorded in the frame of the streak camera.

Figure 2 shows the results of the measurement through 3 synchrotron oscillation periods from the deflection. The

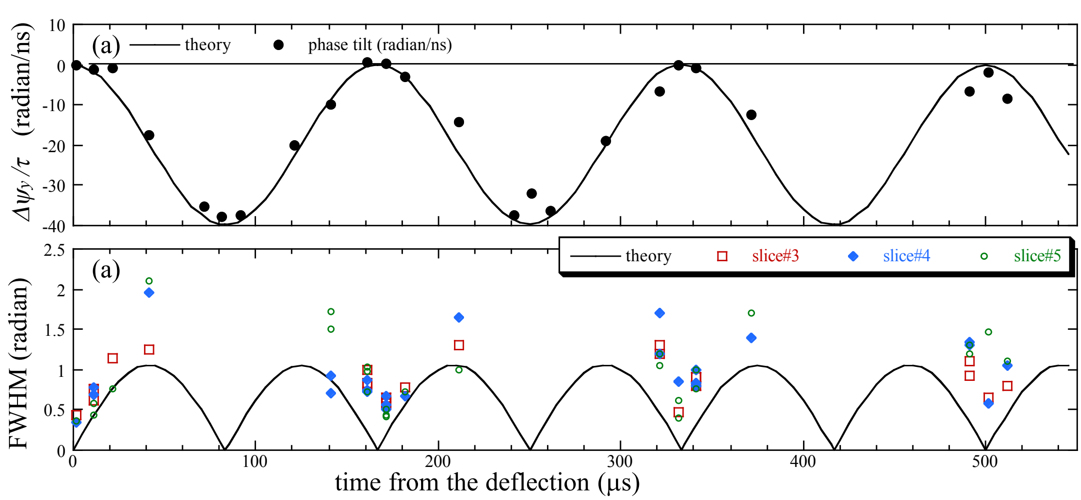

Figure 2: Oscillation of the (a) phase tilt and the (b) phase spread.

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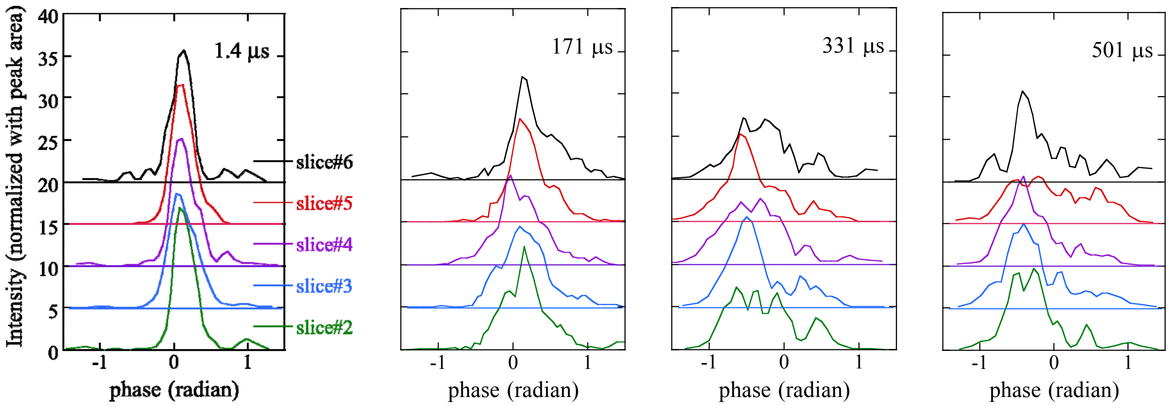

Figure 3: Phase spread profiles where the phase tilt disappears. 171µs≈T_S, 331µs≈2T_S, 501µs≈3T_S. The profiles of slice #1 and slice #7 are not shown because the intensity was too weak. The profiles at 1.4 µs≈0T_S are almost the resolution function. After many revolutions the profiles had a tail at higher phase side.

measured phase tilt ($\Delta\psi_y/\tau$) agreed well with the prediction calculated from Eq.(3). However, the phase spread was larger than that given by Eq.(4).

Figure 3 shows the beatatron phase profiles. The initial data at 1.4 µs shows the resolution function. The spread was growing with synchrotron oscillation. The spreading had a tail on the earlier phase (positive phase) side.

Bunch Charge Dependence

In the explained measurement the target bunch charge was 0.05 mA T_{REV}. When the target bunch charge was increased, while those of the bunch trains remained the same, the coherence was not the same. Figure 4 and 5 show the phase tilt for the two cases of bunch charge. The tilt did not goes to zero around t=3 T_S with higher single bunch charge than 0.2 mA T_{REV}. With higher charge the minimum tilt appeared at $t > nT_S$.

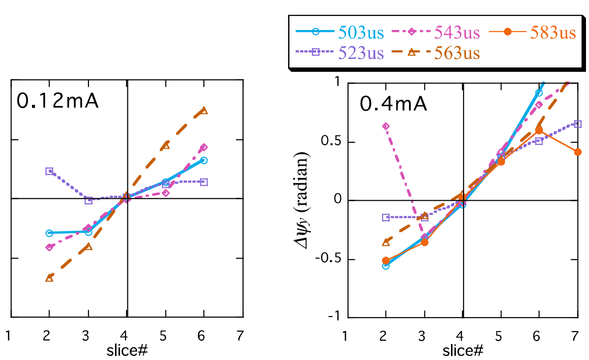

Figure 4: The phase tilt near t =3 T_S with high and low bunch charge. The labelled current times T_{REV} gives the single target bunch charge. One slice number corresponds to a time difference of 18 ps in a bunch.

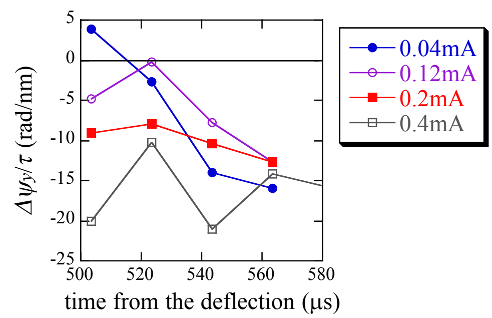

Figure 5: The phase tilt vs. time near t =3 T_S with different bunch charge. With higher single bunch charge than 0.2 mA T_{REV}, the phase tilt did not reach to zero.

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