EXPERIENCE OF QUASI-ISOCHRONUS OPERATION AT NEWSUBARU

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Abstract

quasi-isochronus operation is one of the operation modes of NewSUBARU, a 1.5 GeV VUV storage ring. NewSUBARU has six invert bending magnets to control the momentum compaction factor. The aim of this research is to explore the extreme reduction of electron bunch length by reducing the momentum compaction factor. We experimentally reduced the momentum compaction factor from 0.0014 down to less than 10^{-5}, keeping the beam in the ring. The second-order momentum compaction factor was adjusted to almost zero, while keeping the third-order momentum compaction factor positive. The ring was operated at 1.0 GeV. Using a streak camera, the shortest bunch length we observed was 4 ps FWHM.

1 INTRODUCTION

NewSUBARU [1] is a 1.5 GeV synchrotron radiation ring at the SPring-8 site. Laboratory of Advanced Science and Technology for Industry (LASTI) at the Himeji Institute of Technology is in charge of its operation, collaborating with SPring-8. A bending cell in the ring is a modified DBA with an 8^{O} invert bend between two 34^{O} normal bends. This facilitates the control of the linear momentum compaction factor (α_1) while keeping the cell achromatic and with only a small change of natural emittance.

The bunch length was measured with a streak camera as a function of α_1. The idea of bunch shortening is derived from a well-known expression that the equilibrium bunch length is proportional to $\sqrt{a_1}$. It was demonstrated in some facilities in 1990s [2]. Recently M. Abo-Bakur *et al.* reported that in BESSY the bunch length decreased to 1 ps (FWHM) according to the $\sqrt{\alpha_1}$ law, but with stored current of less than 1 μA per bunch [3]. On the other hand, Y. Shoji *et al.* theoretically predicted the intrinsic bunch-shortening limit came from longitudinal radiation excitation [4]. At NewSUBARU, that was 0.144 ps (FWHM) at 1.0 GeV. Approaching this limit is one of the goals of the bunch-shortening study. We report some experiences of quasi-isochronus operation at NewSUBARU up to the present.

2 EXPERIMENTS

We define the linear and non-linear momentum compaction factors (α_n) as

$$L=L_0(1+\alpha_1\delta+\alpha_2\delta^2+\alpha_3\delta^3+\ldots)\ . \qquad (1)$$

Here L is a circumference and δ is a relative energy displacement defined by $E=E_0(1+\delta)$. In this report symbols with suffix "$_0$" denote the values of the reference electron.

2.1 Control of α_1

We control α_1 by changing two quadrupole families at the dispersive sections as shown in Fig.1. The measurement of the synchrotron oscillation frequency f_S confirmed a shift of α_1. It is known that when we keep the RF acceleration voltage V_{RF} constant, $f_S^2 \propto \alpha_1$. The shift of f_S^2 to the α_1 of the lattice model is shown in Fig.2. Our linear lattice model had energy dependence and was not good enough for the accurate calculation of α_1. The α_1 was estimated at one set-point from two kinds of independent measurements [5]. We estimated α_1 at the other set from measured f_S assuming that $f_S^2 \propto \alpha_1$.

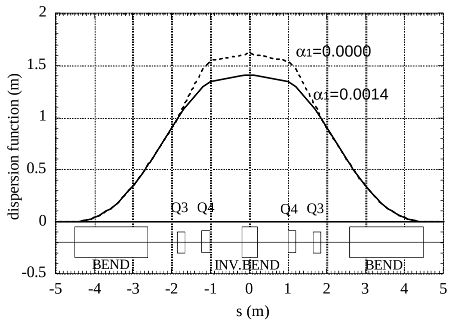

Figure 1: Calculations of dispersion function of NewSUBARU in one bending cell. The solid line is for α_1=0.0014 and the broken line for α_1=0.

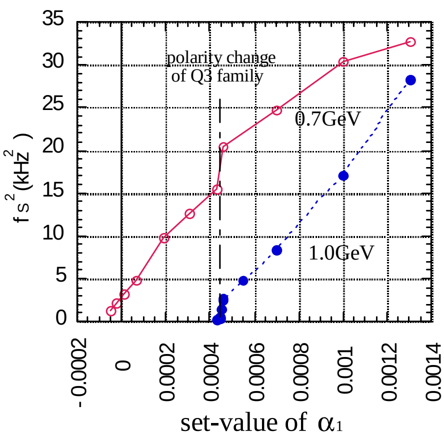

Figure 2: Measured f_S^2 vs. set value of α_1 (calculation using the present model). The solid line was measured at the stored energy of 0.7 GeV and the broken line at 1.0 GeV.

2.2 Control of α_2

The second order momentum compaction factor α_2 was controlled by changing one sextupole family SF at the dispersive section. The smallness of α_2 was confirmed by measuring f_S varying Δf_{RF}. Fig. 3 shows f_S vs. Δf_{RF} at α_1=7.5×10^{-6}.

When α_2 was not small enough for a small α_1 there existed a two stable buckets in one RF period. A beam in one bucket was transferred to another bucket by changing f_{RF} as shown in Fig. 4.

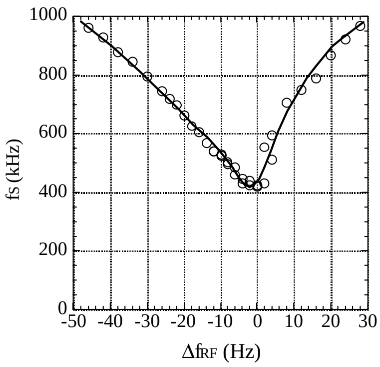

Figure 3: Synchrotron oscillation frequency (f_S) vs. the shift of RF frequency (Δf_{RF}). Circles are measured and the line is a calculated assuming that the circumference is proportional to the function: $1+7.5\times10^{-6}\delta+0.9\delta^3-180\delta^4+1000\delta^5+6.4\times10^6\delta^6-6\times10^{-8}\delta^7$. During this measurement the RF acceleration voltage (V_{RF}) was set at 114 kV.

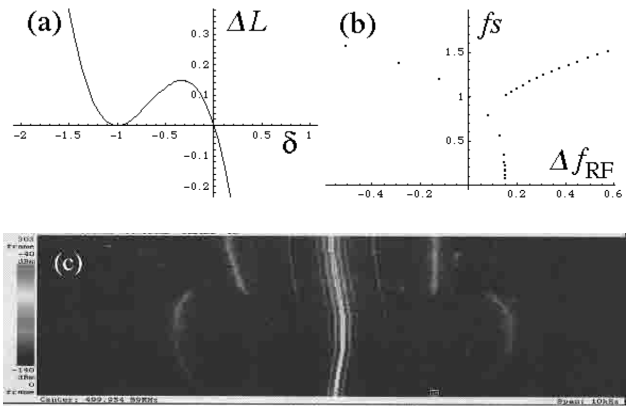

Figure 4: Beam transfer from one bucket to another bucket. (a) shows a relation between ΔL (vertical axis) and δ (horizontal axis). The units are relative. (b) shows the expected shift of f_S to Δf_{RF} in the case of (a). (c) is the time evolution of FFT spectrum. The vertical axis is time flowing from the top to the bottom. The horizontal axis is the frequency with full span of 10kHz. The centre line is the f_{RF} and the side lines are side bands corresponding to f_S. We observed a jump of f_S expected from the calculation schematically shown in (b).

Terms of higher order than α_2 were not controlled because the ring has no element to control them. The α_3 was always positive. This finite positive α_3 was essential to keep the beam inside the ring aperture especially when the ring parameter was moving. The smaller the α_1, the larger the energy displacement is, and the positive α_3 reduced the energy displacement for a mismatch of the RF frequency (f_{RF}) to the ring circumference. Although a beam storage with smaller α_1 value was not difficult, the synchrotron oscillation was no longer linear. At α_1=7.5×10^{-6}an energy displacement of 0.048%, which is a standard deviation of a natural energy spread, increases the magnitude of α by about 10% because of the finite higher-order terms.

2.3 Bunch length Measurement

For the bunch length measurements the streak camera (Hamamatsu C6860) was used in synchro-scan mode. The set up of the camera was explained in the other article [6]. The fast sweep frequency was 83.3 MHz, 1/6 of the RF frequency (500 MHz). The measured bunch shape was an accumulation of signals emitted for 1.0 second. The harmonic number of the ring was 198=6×33. We filled the ring with 33 bunch trains of five filled and one unfilled buckets in succession.

We reduced α_1, keeping the V_{RF} constant, to ensure that the theoretically expected bunch length was proportional to f_S. The stored beam current was about 1μA per bunch with stored energy of 1.0 GeV. Fig.5 shows the measured bunch length with respect to the measured f_S. The bunch length agreed with theoretical calculation in the range of α_1=1.2×10^{-3} ~ 2.0×10^{-4}. Fig.6 shows the observed bunch shape at α_1=2.2×10^{-5}, which was fitted with Gaussian distribution. However at very small α_1, the measured length was greater than the calculated one. As yet, we have not reached any conclusion about why this occurred.

We also observed a dependence on V_{RF}, keeping α_1 constant, as shown in Fig.7. The bunch length was longer at the highest V_{RF}.

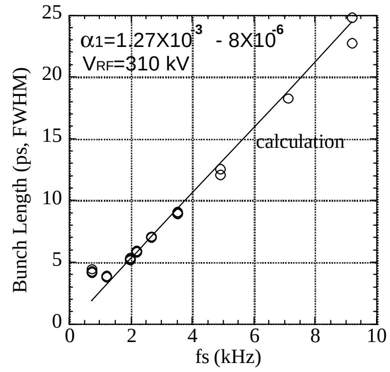

Figure 5: Bunch length vs. f_S. The circles are measured length and the line is a theoretical calculation. The RF acceleration voltage was kept constant (V_{RF}=310kV) while changing α_1.

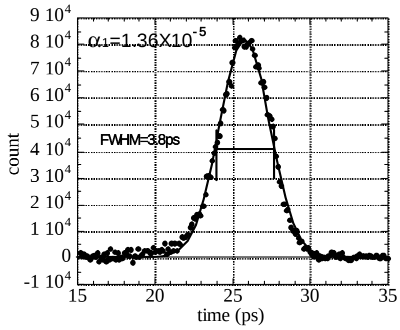

Figure 6: Measured bunch shape by the streak camera, including the resolution of the system. The line is a Gaussian distribution fitted to the data.

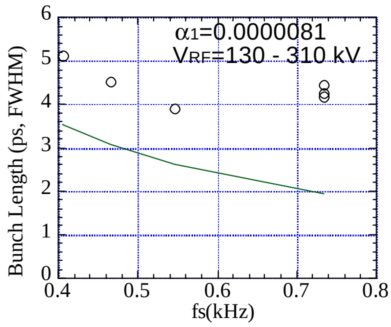

Figure 7: Bunch length vs. V_{RF}. The circles are measured length and the line is a theoretical calculation.

2.4 Synchrotron Oscillation Amplitude

Coherent movement of the beam was detected via the pickup electrode in the storage ring, and timing fluctuations appeared as side bands of f_{RF} in FFT spectrum. The coherent synchrotron oscillation amplitude in time axis (Δt_S) can be estimated from the peak ratio of side bands ($V[f_{RF}\pm f_S]$) to f_{RF} ($V[f_{RF}]$) as

$$\Delta t_S = (1/2\pi f_{RF})\,(V[f_{RF}\pm f_S]/V[f_{RF}]). \qquad (1)$$

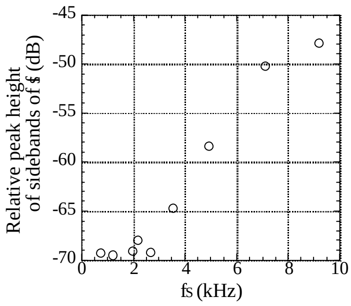

Figure 8: Relative peak height of the synchrotron oscillation sideband to the main f_{RF} peak in the FFT spectrum of beam signal.

Fig.8 shows the measured $V[f_{RF}\pm f_S]/V[f_{RF}]$ when we varied α_1. Two phase feedback loops of RF low level control reduced the RF phase noise at low frequency, which excited the synchrotron oscillation [7]. If the side bands were narrow, $V[f_{RF}\pm f_S]/V[f_{RF}]$=-70 dB means $\Delta\tau_S$=0.1 ps. However the synchrotron oscillation side band was broad at small α_1.

We observed a dependence of the synchrotron oscillation amplitude on Δf_{RF} as shown in Fig. 8. The effective bunch length was long for large synchrotron oscillation amplitude as shown in Fig.9.

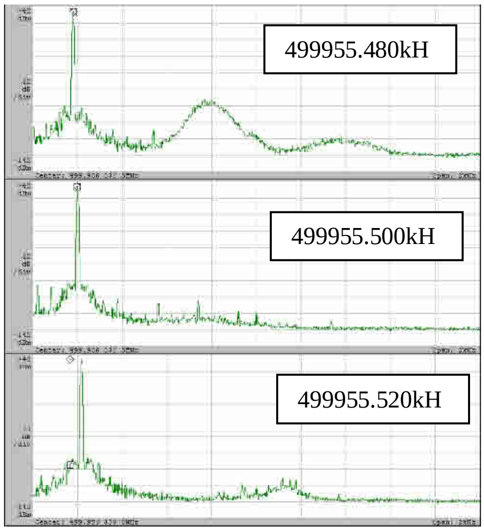

Figure 8: Dependence of the synchrotron oscillation amplitude on Δf_{RF}. The sharp peak at the left is f_{RF}.

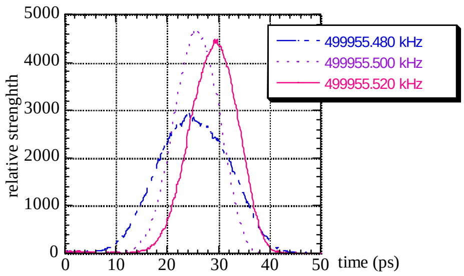

Figure 9: Measured bunch length for three cases of Fig.8.

3 ACKNOWLEDGMENTS

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4 REFERENCES

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