LONGITUDINAL BEAM DYNAMICS ON AN ELECTRON STORAGE RING WITH NEGATIVE MOMENTUM COMPACTION FACTOR

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Abstract

Longitudinal behavior of single bunch electron beam with both signs of negative and positive momentum compaction factors has been investigated on the UVSOR storage ring. Significant differences in the bunch lengthening and the increase of the energy spread with the beam current have been found between two operations.

1 INTRODUCTION

Study of the longitudinal single bunch dynamics of the electron beam circulating in a storage ring is significant for future development of a synchrotron light source and the storage ring free electron laser [1]. Particularly, the longitudinal single bunch instability, which is one of the beam characteristics on the circular accelerators, does not only spoil stability but also increase the energy spread and the bunch length of the beam [2].

The single bunch instability mainly originate from interaction between the electron bunch and the impedance of the environment such as sudden change of the vacuum chamber cross section, bellows, BPMs and etc. Base on a low Q resonator impedance model, Fang et. al. recently pointed out a possibility of which the threshold current for microwave instability would be high and the bunch lengthening would be not significant when a storage ring is operated with negative momentum compaction factor [3].

In this article, we report in our preliminary experimentally results of the single bunch behaviors when the storage ring is operated with negative and positive momentum compaction factors.

Table 1 Basic parameters of the UVSOR storage ring for negative α experiment.

Energy	E = 600 MeV
Circumference	C = 53.2 m
Bending radius	ρ = 2.2 m
Betatron tune	n_x = 3.16 (horizontal)
	n_y = 1.44 (vertical)
Momentum compaction factor α	
	|α| = 0.033
Harmonics	h = 16
RF frequency	f_{RF} = 90.107 MHz
RF voltage	V_{RF} = 46 kV
Energy spread	σ_E = 0.23 MeV
Natural Emittance	ε_0 = 230 π nm rad
	90 π nm rad (positive α)

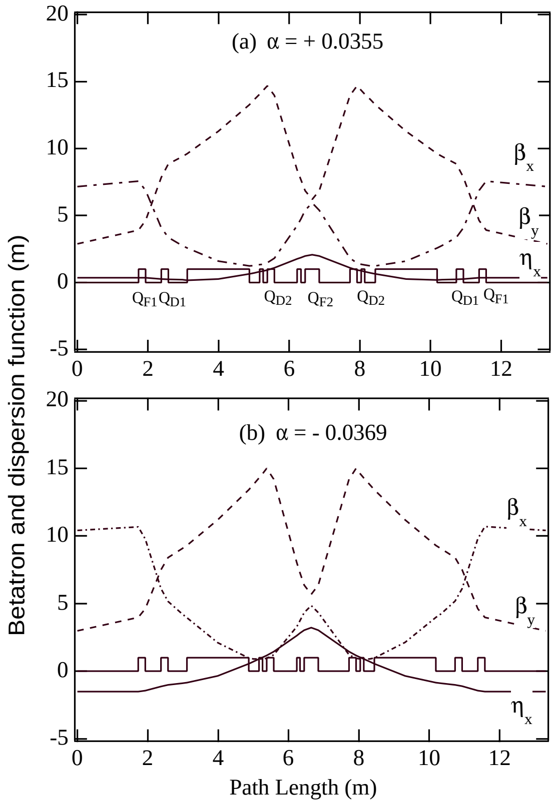

Fig. 1 Calculated Twiss parameters for one unit cell as positive α (a) and negative α (b) operation.

2 DEVELOPMENT OF LATTICE FOR BOTH POSITIVE AND NEGATIVE MOMENTUM COMPACTION FACTOR

Table 1 shows basic parameters of the UVSOR storage ring for the negative momentum compaction factor experiment. In the normal operation for users of synchrotron radiation (SR), a bit of positive dispersion remains in straight sections to minimize the effective emittance, and then the momentum compaction factor α is estimated to be + 0.035. For the experiment with negative α, we developed a new operating point, where α can be turned smoothly from positive to negative without change of the betatron tunes. This operating point has been also optimized to use of the helical optical klystron with small gap [4].

Calculated Twiss parameters of the lattice at positive and negative α operation are shown in Fig. 1a and 1b, respectively. At the positive α lattice, the dispersion function is positive in the bending magnet. On the other hand, at the negative α lattice, the dispersion function alters from negative to positive in the bend and a large negative dispersion function makes the integral of the dispersion in the arc negative.

3 MEASUREMENT OF BUNCH LENGTHENING

A dual-sweep streak camera is a powerful tool to observe the electron distribution in the bunch and its variation in a certain time range [5]. Since a slow-sweep axis can be expanded up to 100 ms from the one turn period, we can only observe the collective longitudinal oscillation with the synchrotron frequency of about 15 kHz (see Table 1) but also detect instabilities of which the electron distribution is slowly varied.

Current dependent bunch lengthening has been measured up to ~100 mA with the single-bunch mode for the almost same absolute values of the positive and the negative momentum compaction factors (|α| = 0.03). RMS bunch lengths were deduced from spectra averaged over many turns in the two-dimensional dual-sweep images of SR from a bending magnet. Figure 2 shows variations of the bunch length at a wide rang of the single bunch current. For the case of positive α, the bunch lengthens monotonously, which is in agreement with our previous measurement.

Basically the bunch lengthening is dominated by potential-well distortion and microwave instability due to the broad band impedance of the beam chamber. For the case of the positive α, the bunch lengthening due to potential-well distortion caused by the inductive impedance is theoretically evaluated by Laclare as a function of the beam currents as

$$\left(\frac{\sigma_b}{\sigma_{b0}}\right)^3 - \left(\frac{\sigma_b}{\sigma_{b0}}\right) = \frac{e\alpha I[Z/n]_{eff}}{\sqrt{2\pi}\nu_s^2 E}\left(\frac{R}{\sigma_{b0}}\right)^3 \qquad (1)$$

where σ_b is the bunch length at the current I and σ_{b0}, α, ν_s and R are the natural bunch length, the momentum compaction factor, the synchrotron tune and the mean radius of the ring, respectively [6]. The effective coupling inductive impedance $[Z/n]_{eff}$ is here normalized to the revolution frequency. A solid line in Fig. 2 is a fit with eq. (1) to the bunch lengths in the positive α operation below 50 mA, and the effective coupling impedance of 1.3Ω was obtained. Although it is not clear, one can see a discontinuity point around 60 mA.

The bunch lengthening with the negative α was drastically changed. As one can see, the bunch shortening was observed up to ~15 mA and then the bunch lengthening with the current.

The bunch shortening can be simply explained assuming the wake field generated by an inductive (L) impedance as $Vwake = -L(dI/dt)$. Since the synchronous phase of the beam with the negative α is the opposite side

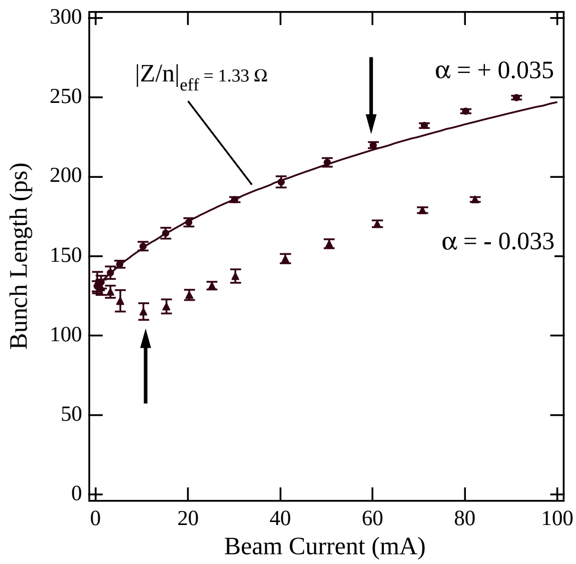

Fig. 2 Measured bunch lengths plotted as a function of the beam current.

of the slope of the accelerating RF field, a combined field with the RF field and wake filed become steep if the other is gently-sloping.

4 MEASUREMENT OF ENERGY SPREAD

Radiation spectrum from the optical klystron is very sensitive to the beam energy spread. A modulation factor, which indicates degree of interference between two radiation from undulators separated by a dispersive section, defined as, $f_{mod} = (s_+ - s_-)/(s_+ + s_-)$, where s_+ and s_- are the maximum and the minimum intensities of a jagged-structure spectrum, respectively. Complete interference in both spatial and frequency domains makes $f_{mod} = 1$. An actual modulation factor may be separated into two terms as $f_{mod} = f_\varepsilon \bullet f_\gamma$, where f_ε and f_γ are the modulation factors originated from the emittance and the energy spread, respectively. The analytical formula of f_γ is written as

$$f_\gamma = \exp\left[-8\pi^2 \left(N_u + N_d\right)^2 \left(\frac{\sigma_E}{E}\right)^2\right], \qquad (2)$$

where N_u and N_d are the period number of one undulator and the interference order of the radiation.

We chose a resonant wavelength of 355 nm to measure the modulation factor, and at the wavelength was 130. Results of the measurement of the energy spread are plotted as a function of the beam current in Fig. 3. Absolute values were normalized to calculated one at the very low beam current. One can apparently notice the threshold beam current around 50 mA and 15 mA exits for the increase of the energy spread in the positive and negative a operation, respectively, which correspond with the discontinuity seen in data of the bunch length measurement (Fig 2.) These

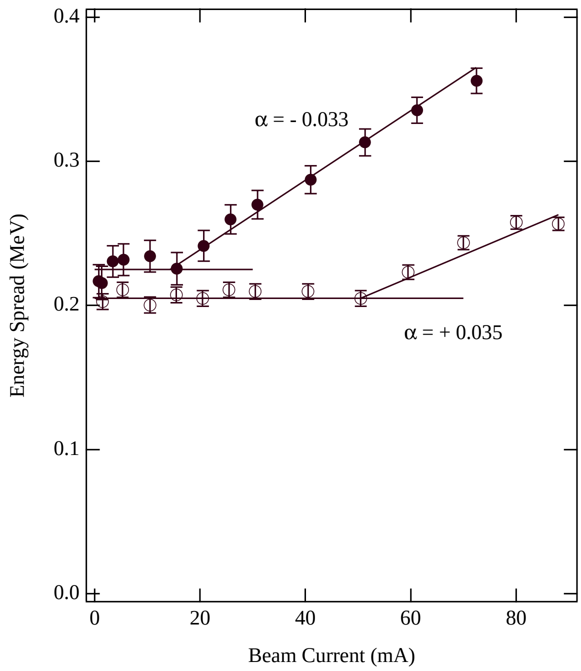

Fig. 3 Beam current dependence of the energy spread derived from the modulation factor of radiation spectra from the optical klystron. Lines are guided by eyes.

points can be considered as onsets of the microwave instability. As seen in the figure, the growth rate of the microwave instability in the negative a operation is faster than in the positive one, which may be interpreted by the higher peak current coming from the bunch shortening effects due to the inductive impedance.

5 SUMMARY

The bunch length and the energy spread were measured as a function of the beam current for the positive and negative momentum compaction factor. In the positive α operation, the bunch was lengthened monotonously with beam current. However at the very high current the microwave instability was occurred, which is confirmed by the measurement of the energy spread. The bunch shortening was observed in the negative α operation below the threshold current for the microwave instability. Once the microwave instability was occurred, the energy spread grew rapidly with the beam current. The averaged bunch length with the negative α is shorter than that with the positive α at the wide range of the beam current. Nevertheless the negative α operation has no advantage because of the lower threshold current of microwave instability. As far as the UVSOR ring, the suggestion of Fang et. al. is not realized. Probably the impedance model of the low Q resonator employed in their article is not suitable for the UVSOR ring.

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