Measurement of Bunch Time-structure in KEK PF

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Abstract

The time-structure of the bunches in the KEK-PF storage ring under the single bunch condition was measured by means of a photon counting system installed in beamline 21. When the jitter in the electronic system is negligible, the response of the whole system is finally determined by a transit time spread (TTS) of a photomultiplier (PMT). The TTS of the PMT was measured with a picosecond pulse laser system, pulse width of which was about 7 ps in FWHM. A current dependence of the longitudinal bunch shape was observed with the improved system and was found the increase of the asymmetry with the increase of the current.

1 Introduction

In a positron (electron) storage ring, the longitudinal bunch shape has a Gaussian distribution standard deviation of which is determined by the radiation damping and the quantum radiation excitation if the interaction between bunches and the vacuum chamber is negligible at a low current. However, when the beam current becomes large and the interaction increases, the longitudinal bunch shape deviates from the ideal or natural bunch shape. As one of the features of this effect, the bunch lengthening is widely investigated not only theoretically but also experimentally[1]. Furthermore, it is also predicted that the longitudinal shape is deformed from the Gaussian distribution[2].

We have installed a single photon counting system in beamline 21 in the KEK-PF. An excellent dynamic range is obtained when enough events are collected and high time resolution is achieved because the timing at which event occurs can be detected precisely with a fast photomultiplier and a constant fraction discriminator. A large dynamic range of the system gives us precise measurement of the single bunch impurity which is defined as a ratio of electron number in unwanted bunches to that in the main bunch.

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Table 1: Main Parameters of KEK-PF-Ring

Energy	E	2.5	GeV
Circumference	C	187.07	m
Betatron tune	ν_x	8.37	
	ν_y	3.39	
Revolution frequency	f_{rev}	1.6	MHz
Harmonic number	h	312	
Radio frequency	f_{rf}	500	MHz
Momentum compaction factor	α_p	0.0157	
Radiation damping time	τ_x	7.79	ms
	τ_y	7.82	ms
	τ_e	3.92	ms

Measured data do not show the longitudinal shape but convolutions of the response function of the system to the bunch shape. Therefore, if the response function is determined, we will be able to reconstruct the original bunch shape by the deconvolution. We have measured the response function of the system using a picosecond pulse laser system‡. The determination of time response and its improvement are shown in Sec. 3. With a new electronic system, the bunch shape was measured as a function of beam current. The change of the shape of the bunch is discussed in Sec. 4. Related parameters of the KEK-PF storage ring is listed in Table 1.

2 Experimental Setup

The experimental setup has been described in refs.[3, 4] in detail, therefore only a brief outline is shown here. The system is shown schematically in Fig. 1. Photons from the nearest bending section (BM21) are led to a mirror chamber through a vacuum pipe and are reflected by a mirror made of SiC. The reflected visible light reaches a microchannel-plate type photomultiplier (MCP-PMT, Hamamatsu R2980U) through an ICF-70 view port, a Pb-acrylic glass of 22 mm thickness, light reducing filters and a precise horizontal slit. The intensity of photons is reduced to the level of one photon detection per about a hundred

‡The picosecond pulse laser system, Faculty of Integrated Arts and Science, Hiroshima University

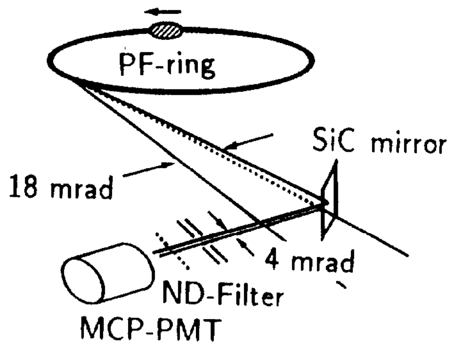

Figure 1: The photon counting system

revolutions of a bunch.

Pulses from PMT are amplified by two wideband amplifiers, then shaped by a constant fraction discriminator (CFD) and led to a time to amplitude converter (TAC). The time intervals between the shaped signal from the CFD and the synchronized signal to the bunch are converted to the pulse heights by the TAC. The outputs from the TAC are amplified with a DC-amplifier and the distribution of pulse heights is analyzed with a multichannel analyzer (MCA).

3 Time Response of the System

We determined the time response of the system using the picosecond pulse laser system. Figure 2 shows the measuring setup schematically. The laser pulse has the wavelength of about 800 nm, the pulse width of about 7 ps in FWHM and the repetition of about 80 MHz. As the wavelength is somewhat longer than the sensitive region of the PMT, we employed an optical doubler and a prism to select the wavelength of 400 nm only. About a third of the blue light are reflected by a half mirror and led to the PMT block. The straight light enters a pin-photodiode (HP 4203) and makes a stop signal to the TAC through a CFD. The mean counting rate of the PMT was tuned to be about 8 kHz.

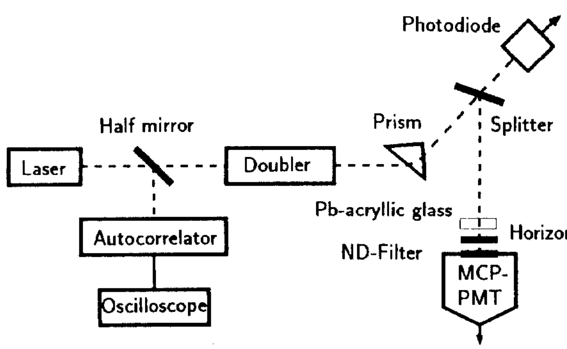

Figure 2: Time response measuring system with the picosecond pulse laser.

The obtained shape was far wider than the reported transit time spread (TTS) of the PMT. We found that the CFD (Ortec 582) limited the time response and it was exchanged for a faster CFD (Tennelec TC 454). The time response was greatly improved as shown in Fig. 3, the FWHM of which was about 28.18 ps. In order to determine the jitter of the photodiode, we set a same type photodiode instead of the PMT and made a same measurement. It was about 18 ps/$\sqrt{2}$ in FWHM, small enough compared with the whole resolution of 28 ps. The effect of the Pb-acrylic glass for radiation shield was measured and no evident change was seen. The result at the wavelength of 800 nm is almost the same as that at 400 nm.

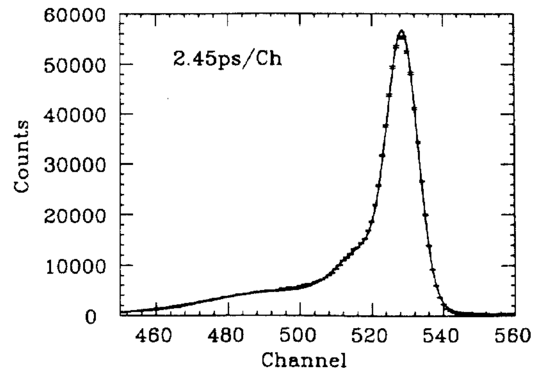

Figure 3: Time response of the system.

4 Bunch Shape

We express the response function of Fig. 3 with

$$g(x) = \sum_{i=1}^{3} a_i \exp\left(-\frac{(x-O_i)^2}{2\sigma_i^2}\right)$$

by the least square method using a computer code MINUIT. The fitted results are shown in solid curve in the figure. Assuming the Gaussian as the original bunch shape, we tried to deconvolute the experimental data by fitting with the equation

$$f(x) = \int_0^\infty \frac{A}{\sigma\sqrt{2\pi}} \exp\left(-\frac{(x-t-\mu)^2}{2\sigma^2}\right) g(t)dt \qquad (1)$$

where A, σ and μ are fitting parameters. Figure 4 (a, b) shows the result for I_b=9.5 mA and I_b=49 mA respectively, at the RF voltage of 1.3 MV. Time fries from right to left and statistical errors are also shown in the figure. The fits are not satisfactory as shown in the figure. The deviation of the fitted data from the observation is appreciable, especially around the peak. Judging from this fact, we conclude that the Gaussian bunch shape assumed in Eq. [1] is not adequate.

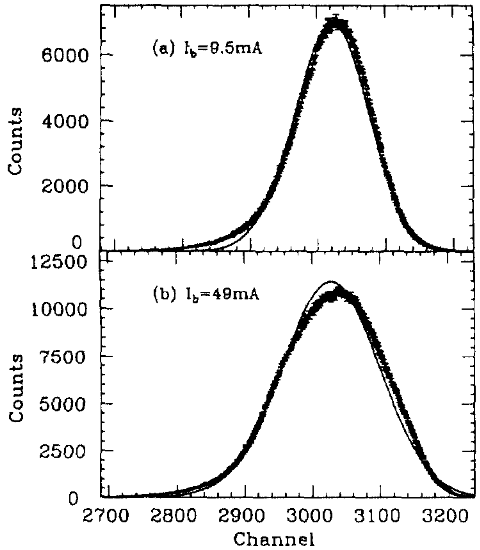

Figure 4: The shape of the main bunch and the calculated result assuming Gaussian distribution of the bunch at I_b=9.5 mA (a) and I_b=49 mA (b).

To express the asymmetry, we introduce a time dilatation factor τ and fit the experimental data with the equation

$$f'(x) = \int_0^\infty \frac{A'}{\tau\sigma\sqrt{2\pi}} \exp\left(-\frac{(x-t-\mu)^2}{2\sigma^2}\right) \exp(-\frac{t}{\tau})dt, \tag{2}$$

neglecting the response function of the system. This function has no theoretical base but fits very well as shown in Fig. 5. The fitted σ and τ are shown in Fig. 6. Using this

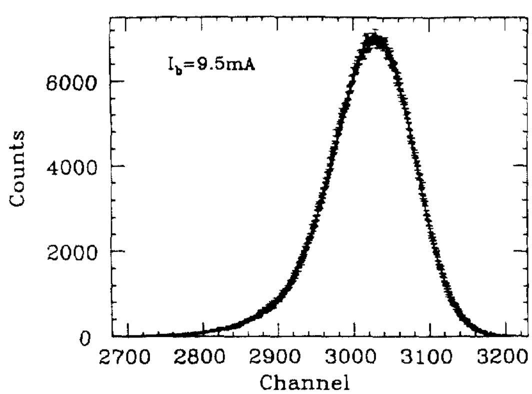

Figure 5: The fitted bunch shape.

σ, we fit the data by the potential well distortion formula (lower current side) and the microwave instability formula (higher current side). From the cross point of the two curves, we obtained the threshold current of microwave instability to be 27 mA. This fit becomes worse gradually above the threshold. We conclude that the behavior of the change in bunch shape varies above the threshold. More detailed experiment and analysis are necessary.

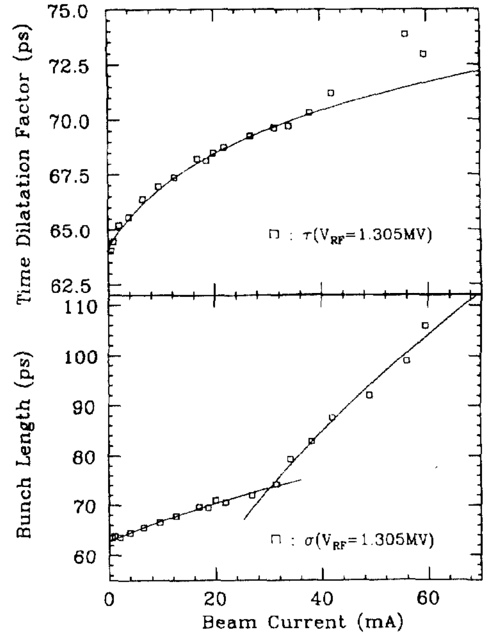

Figure 6: Current dependence of the bunch length σ (solid curve) and the time dilatation factor τ.

5 Summary

We have considerably improved the time response of the photon counting system installed at beamline 21 in the KEK-PF and determined the time response function of the system using the picosecond pulse laser system. With improved system, the change in the bunch shape as a function of the beam current has been measured. The longitudinal bunch shape is deformed when the beam current is high. Quantitative determination of the shape will be done in the near future.

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