# Measurement of Bunch Time-structure in KEK PF

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## Abstract

A photon counting system was installed in the Photon Factory storage ring at the KEK for precise measurement of the time-structure of bunches. Photons emitted in a bending section are detected with a microchannel-plate photomultiplier. The time interval between the output of the photomultiplier and the signal synchronized to the revolution frequency of the ring is converted to the pulse height. The distribution of the pulse height which corresponds to the time-structure of bunches in the ring is analyzed by a multichannel analyzer. In addition to the bunch length measurement, the single bunch impurity was also successfully measured since the system has an excellent dynamic range.

## 1 Introduction

The time-structure of bunches in an electron storage ring in the single-bunch-mode is interesting in two points of view. In the microscopic view, the length or the shape of bunch has great interest. The electromagnetic field induced in vacuum vessels of the ring by a bunch acts back to the bunch, changing its shape and length. By measuring bunch length as a function of the beam current, the coupling impedance of the vacuum chamber of the ring can be estimated.

In the macroscopic view, it is necessary to measure the single bunch impurity, which is the ratio of positrons in unwanted buckets to those in the main bucket, in order to improve the quality of time-resolved experiments[1].

There are several methods to measure the time-structure of bunches. We adopted a photon counting method. As the main error source of this method is the statistical one, an excellent resolution is obtainable when enough events are collected. This enables us to have much larger dynamic range compared with other methods such as a streak camera or photo-diode. The single bunch impurity cannot be measured quantitatively without the photon counting method[2].

We have installed a photon counting system in the beamline 21 in the Photon Factory of National Laboratory for High Energy Physics (KEK-PF) and measured the time and current dependence of the time-structure of bunches. The related parameters of the KEK-PF storage ring is listed in Table 1.

Table 1: Main Parameters of KEK-PF-Ring

| | | | |
|---|---|---|---|
| Energy | $E$ | 2.5 | GeV |
| Circumference | $C$ | 187.07 | m |
| Betatron tune | $\nu_x$ | 8.37 | |
| | $\nu_y$ | 3.39 | |
| Revolution frequency | $f_{rev}$ | 1.6 | MHz |
| Harmonic number | $h$ | 312 | |
| Radio frequency | $f_{rf}$ | 500 | MHz |
| Momentum compaction factor | $\alpha_p$ | 0.0157 | |
| Peak RF voltage | $V$ | 1.7 | MV |
| Radiation damping time | $\tau_x$ | 7.79 | ms |
| | $\tau_y$ | 7.82 | ms |
| | $\tau_e$ | 3.92 | ms |
| Synchrotron frequency | $f_s$ | 36 | kHz |
| Natural bunch length | $\sigma_z$ | 50 | ps |
| Touschek lifetime (1A) | $\tau_T$ | 2000 | s |

## 2 Experimental setup

Positrons circulating in the ring emit photons stochasticaly in a bending section. As the probability of the emission of photon is the same for all positrons in any RF-buckets, the time distribution of photons is proportional to that of the positrons.

The system is shown schematically in Fig. 1. Photons from the nearest bending section are led to a mirror chamber through a vacuum pipe. About 20% of the visible light are reflected by a mirror made of SiC. The mirror is cooled through a water-cooled Cu holder. The reflected light reaches a photomultiplier (PMT) through an ICF-70 view port, a Pb-acrylic glass of 22 mm thick, light reducing filters and a precise horizontal slit. The number of photons are reduced to the level of one photon detection per about hundred revolutions of a bunch. As it is necessary to use PMT with small transit time spread (TTS), we have chosen a microchannel-plate type PMT (Hamamatsu Photonics R2809U), TTS of which is about 55 ps.

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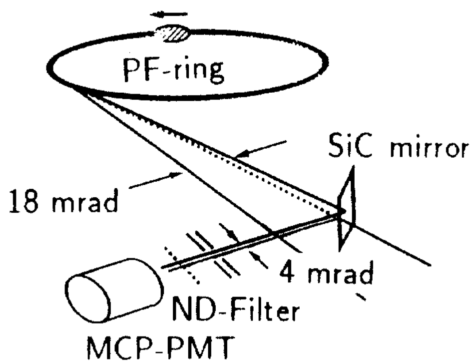


Figure 1: The photon counting system

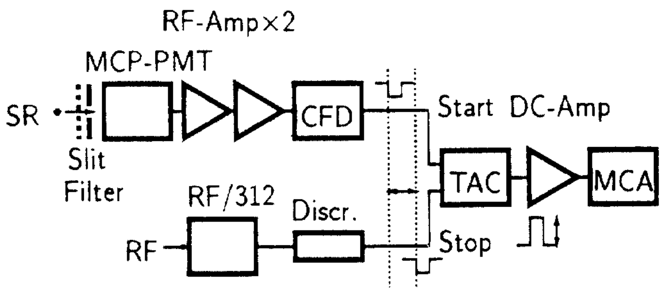


Figure 2: The block diagram of the electronics. MCP-PMT: Microchannel plate-type photomultiplier, CFD: Constant fraction discriminator, TAC: Time to amplitude converter, MCA: Mulitichannel analyzer, RF/312: Trigger signal synchronized to revolution frequency.

The block diagram of the electronics is shown in Fig. 2. Pulses from the PMT is amplified with a wideband amplifiers, the total gain and the bandwidth of which are 49 dB and ~ 1 GHz respectively, and amplified signals are shaped with a constant fraction discriminator (CFD, Ortec 582). The RF from the acceleration system is divided by 312 that is the harmonic number of the PF ring in order to obtain the signal synchronized to the revolution of a bunch. A time to amplitude converter (TAC, Ortec 467) generates pulses the height of which is proportional to time interval between the shaped signal from the CFD and the synchronized signal. The outputs from the TAC are amplified by a DC-amplifier with a gain of ~ 14 dB and the distribution of pulse heights are analyzed with a MCA (multichannel analyzer, EG&G 7800). The typical counting rate was about 20 kHz and the dead-time was about 30% at a beam current of 20 mA.

# 3 Results

Figure 3 shows an example of time-structure of the bunch in log scale at a circulating current of 10 mA. The abscissa shows the MCA channels correspond to time interval. In this figure, time flows from the right to the left, *i.e.*, the bunch on the left follows that on the right, and one channel corresponds to 5.05 ps. At least three bunches are clearly recognizable. The forth peak may be due to the internal reflection in the PMT. The ratio of positron number in the

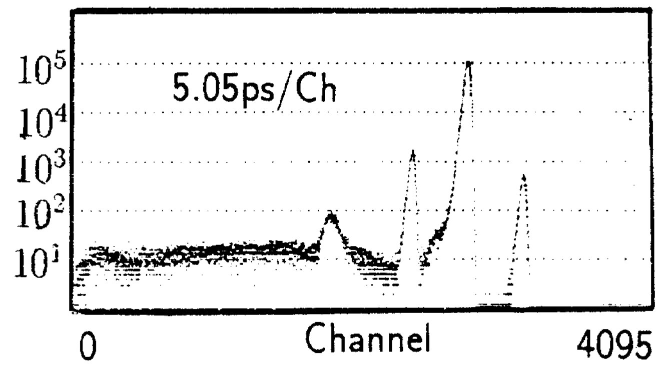


Figure 3: Time-structure of the bunch in log scale.

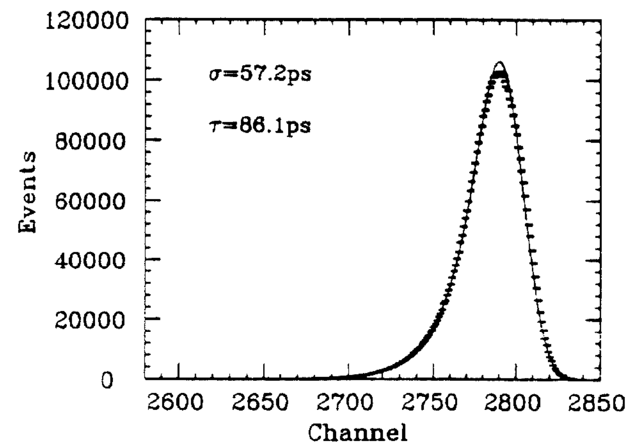


Figure 4: The shape of the main bunch in linear scale. The beam current was 10 mA.

second bunch to that in the main bunch is about 1 %.

Figure 4 shows the shape of the main bunch in linear scale at the beam current of 10 mA. The shape has an appreciable asymmetry. However, the current dependence of the asymmetry is not noticeable, as described in the next section. Therefore, the cause of the asymmetry seems not to be the wake field induced by the beam but to be the TTS in the PMT.

A preliminary result of the population versus time in the second bunch after injection is shown in Fig. 5. Though the systematic error due to analysis is uncertain, the increasing of population is clearly observed with this system. Detailed analysis is now under investigation.

# 4 Bunch Lengthening

We have tried to deconvolute the results by fitting them with the function

$$f(x) = \int_0^\infty \frac{a}{\tau\sqrt{2\pi}\sigma} \exp\left(-\frac{(x-h-\mu)^2}{2\sigma^2}\right) \exp\left(-\frac{h}{\tau}\right) dh$$

where the exponential and Gaussian functions show the TTS of the PMT and actual bunch shape respectively. The

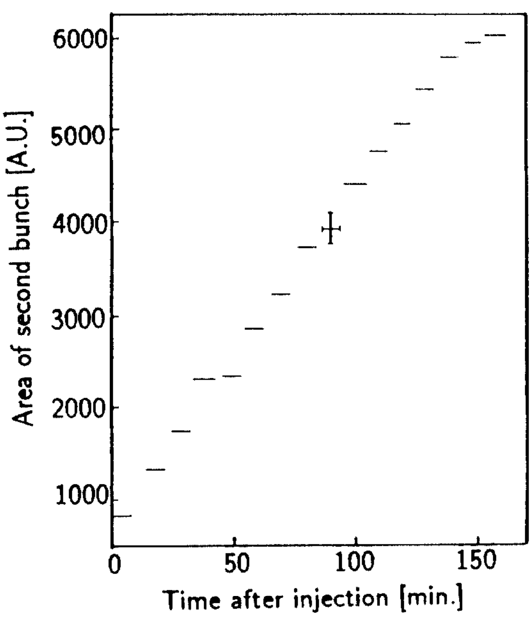


Figure 5: Increase in the population in the second bunch. The horizontal bars represent the time interval during each measurement.

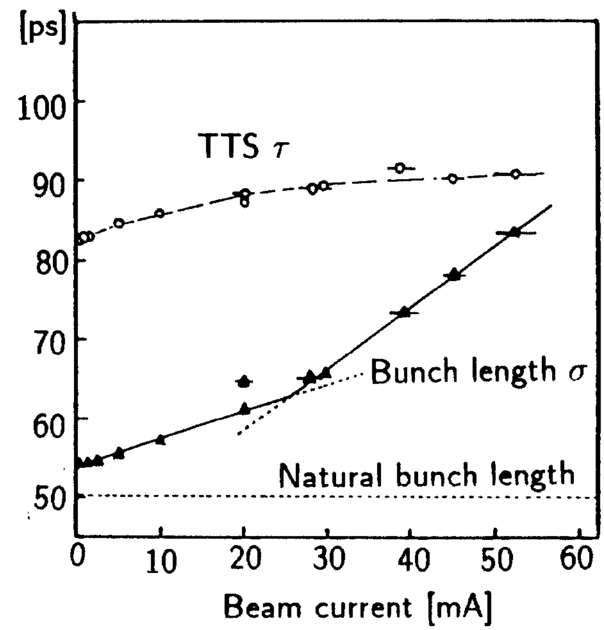


Figure 6: Current dependence of the bunch length $\sigma$ (solid curve) and TTS $\tau$ (dashed curve). The natural bunch length is drawn in dotted line. The horizontal bars mean the current variation during each measurement.

code MINUIT was adopted assuming the statistical error of $\sqrt{N+1}$, where $N$ is the event number. The fitted standard deviation ($\sigma$) and the "TTS" $\tau$ are plotted as a function of beam current in Fig. 6. The small change of $\tau$ shows this asymmetry does not come from the wake field. We have approximated the bunch lengthening data with two straight lines as shown in Fig. 6. The crossing point between two lines is near 25 mA and is consistent with other data independently obtained from a streak camera[3].

## 5 Summary

We have constructed a photon counting system at Beamline 21 in the KEK-PF. Though the background probably due to the multiple reflection in the photon beam pipe is not minimized enough, this system shows so large dynamic range as to measure the small change of the impurity quantitatively. With the method of deconvolution, the bunch lengthening is clearly obtained, which is consistent with the results from the streak camera.

We have a plan to use a focusing system to minimize the effect of the multiple reflection. The shape of TTS of the PMT will be measured by means of ultra-short-time laser.

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