Measurement of Beam Bunch Length at SOR-RING

Tadashi Koseki, Haruo Ohkuma*, Kenji Shinoe, Hirofumi Kudo,
Hiroyuki Takaki, Yukihide Kamiya
The Institute for Solid State Physics, The University of Tokyo, Tanashi, Tokyo 188 Japan

Yoshinori Hashimoto, Hitoshi Masuda, Masayuki Muto
The Institute for Nuclear Study, The University of Tokyo, Tanashi, Tokyo 188 Japan

Abstract

Recent measurement of beam bunch length at SOR-RING is reported. The experiment was carried out at the beam energies of 308 MeV and 380 MeV, and current dependent bunch lengthening was observed in both single- and multi-bunch operations. In addition, impurity measurement was performed in single-bunch operation and the population growth of satellite bunches was observed at 308 MeV but not at 380 MeV.

Introduction

SOR-RING, a 380-MeV electron storage ring dedicated to vacuum ultraviolet synchrotron radiation use, belongs to the Synchrotron Radiation Laboratory of the Institute for Solid State Physics(ISSP), the University of Tokyo. It is located in the site of the Institute for Nuclear Study(INS) of the University of Tokyo. Since the completion of construction in 1974, SOR-RING has been operating stably and its performance has been continuously improved. The present status of SOR-RING is given in these proceedings[1].

For a circular accelerator, the measurement of current dependent bunch lengthening is important for understanding single bunch phenomena. In an electron(positron) storage ring, bunch lengthening usually occurs as the beam current increases. At SOR-RING, some bunch length measurements were carried out in the early 1980's[2, 3]. In these measurements, the bunch lengthening was observed only in multi-bunch operation but not in single-bunch operation.

In this paper, we describe a recent measurement of bunch lengthening at SOR-RING. The measurement was carried out for multi-bunch and single-bunch operations at two different beam energies of 380 and 308 MeV. Contrary to the previous measurements[2, 3], The bunch lengthening was observed not only in multi-bunch but also in single-bunch operations. We also describe about impurity measurement of single bunch. The population increase of satellite bunches that follow the main bunch was first measured at SOR-RING.

Apparatus

A. SOR-RING

Electrons accelerated to 308 MeV by electron synchrotron(ES) of the INS are injected into SOR-RING at a repetition rate of 1Hz. In an usual operation for synchrotron radiation use, the injected electrons are accumulated to more than 200 mA and then accelerated up to 380 MeV. The main parameters of SOR-RING are summarized in Table 1.

* Present address: The institute of Physical and Chemical Research (RIKEN), Wako, Saitama 351-01 Japan.

Table 1: Main parameters of SOR-RING.

Energy	E	308-380 MeV
Circumference	C	7.4 m
Averaged radius	R	2.77 m
Bending radius	ρ	1.1 m
RF frequency	f_{RF}	120.83 MHz
Harmonic number	h	7
Revolution frequency	f_{rev}	17.3 MHz
Energy spread	σ_ϵ	3.0 $\times 10^{-4}$
Momentum compaction	α	0.636
RF voltage	V_{RF}	22 kV (typical)
Synchrotron frequency	f_s	123 kHz (at 308MeV) 110 kHz (at 380MeV)
Natural bunch length	σ_0	246 ps (at 308MeV) 274 ps (at 380MeV)

B. The system of bunch length measurement

The longitudinal density distribution of an electron bunch was found by measuring the time structure of synchrotron radiation. The synchrotron radiation emitted from a bending magnet was brought outside through a quartz window and detected by a fast photomultiplier tube(PMT)(Hamamatsu Photonics, R1564U) that has a double-stage micro-channel plate. The thickness of neutral density filters(attenuation by 1/10 - 1/100) and the bore size(25 - 200 $\mu m\phi$) of the pinhole mounted in front of the PMT were adjusted to keep the counting rate of the PMT less than a few kcps.

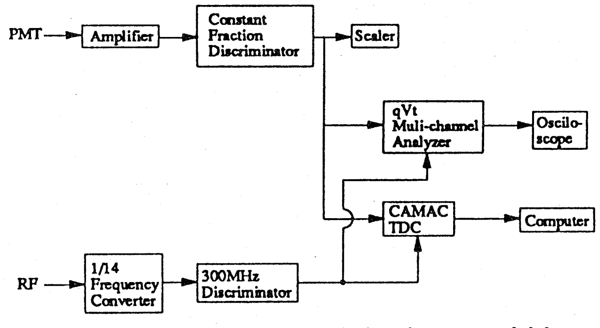

Figure 1: Schematic diagram of the data acquisition system.

A schematic diagram of the data acquisition system is shown in Fig. 1. Signal from the PMT was sent to the amplifier and constant-fraction discriminator, and then fed to a CAMAC Time-to-Digital converter(TDC). The signal was used as the start signal for time interval measurement. The stop signal was sent from the frequency converter by which the RF frequency was converted with the ratio of 1/14. The events counted by TDC were accumulated on a personal computer. The qVt system(LeCroy, 3001 multi-channel analyzer) was also used to monitor the bunch length when data acquisition was in progress.

The time resolution of the system(PMT and electronics) was estimated by the following method. The natural bunch length is inversely proportional to synchrotron frequency, f_s. The bunch length then becomes zero when f_s goes to the infinite. The measured bunch length, σ_m, may be written as $\sigma_m^2 = \sigma_b^2 + \sigma_r^2$. Here σ_b and σ_r are the intrinsic bunch length and time resolution of the system, respectively. In Fig. 2, the σ_m^2 is plotted to $1/f_s^2$. From the figure, time resolution of the present system, σ_r, is estimated as 107.5 ± 10.5 ps. In order to avoid the effect of beam instabilities, the resolution measurement was carried out at a low beam current of less than 500 μA.

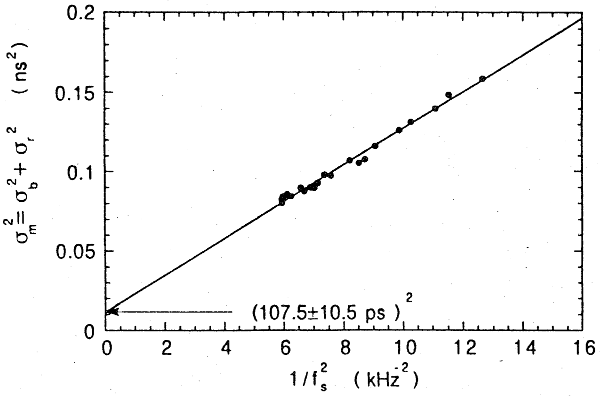

Figure 2: Estimated time resolution of the measurement system.

C. The system of single bunch formation

Since the RF frequency of SOR-RING is irrational to that of the injector, the ES* and single-bunch operation of the ES is presently not available, it is difficult to fill a single RF bucket of SOR-RING. So an RF-knockout method was used to produce a single bunch beam[4]. Just after the injection was finished, six bunches out of seven were shaken by the system in the transverse direction. In order to reduce the aperture limit, beam scrapers, copper rod of 10 mmϕ, were inserted close to the beam orbit.

Results and discussions

A. Bunch lengthening

There are two single-bunch effects which give rise to bunch lengthening. One is the potential-well distortion which is described by[5]:

$$(\frac{\sigma_b}{\sigma_0})^3 - (\frac{\sigma_b}{\sigma_0}) - \frac{\alpha e I_b |Z/n|}{\sqrt{2\pi} E \nu_s^2}(\frac{R}{\sigma_0})^3 = 0, \quad (1)$$

where $|Z/n|$ is the longitudinal effective impedance, ν_s the synchrotron tune, e the electron charge and I_b the beam current. The other is the microwave instability. The Chao-Gareyte scaling law above the threshold currents is written as[6]:

$$\sigma_b^a \propto \frac{\alpha I_b}{E \nu_s^2}, \quad (2)$$

* The RF frequency of the ES is 138 MHz.

where a is a scaling constant. When $|Z/n|$ has no frequency dependence, the threshold current, I_{thr}, is given by[7]:

$$I_{thr} = \frac{F'}{\sqrt{2\pi} e} \frac{\nu_s^2 E}{\alpha |Z/n|}(\frac{\sigma_0}{R})^3, \quad (3)$$

where F' is the bunch form factor, and for a gaussian distribution it is about 8.

In the present study, the bunch length was measured for four cases: (i) single-bunch at 380 MeV, (ii) single-bunch at 308 MeV, (iii) multi-bunch at 380 MeV, (iv) multi-bunch at 308 MeV. The RF voltage was fixed at 22.0 kV throughout the study.

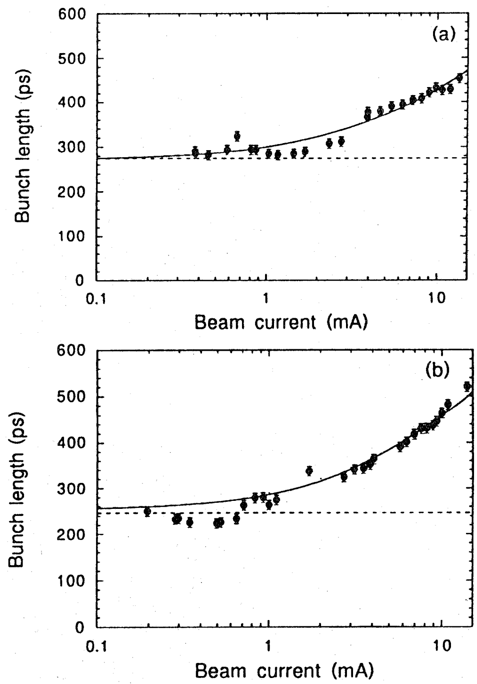

Figure 3: Beam current dependence of the bunch length in single-bunch operation : (a) at 380 MeV (b) at 308 MeV.

Figure 3 shows the beam current dependence of the bunch length in the cases of (i) and (ii). In the figure, the natural bunch length is shown by broken lines. At a low current, the measured bunch length well agrees with the natural bunch length. The experimental data were fitted for Eq. (1). The fitted results are shown as the solid curves in Fig. 3. From this fitting the effective impedances are estimated as 526 Ω(at 308 MeV) and 357 Ω(at 380 MeV). On the other hand, assuming that the bunch lengthening be caused by the microwave instability, from Fig. 3 (a) we may obtain ~ 2 mA as the threshold current of the instability, I_{thr}, at 380 MeV. Then the effective impedance calculated by Eq. (3) becomes more than 900 Ω. However the values of impedances estimated by Eqs. (1) and (3) are unreasonably large. Therefore, it suggests that the bunch lengthening of single-bunch observed at SOR-RING could not be explained by the potential-well distortion or the microwave instability.

Measured results for the multi-bunch (cases (iii) and (iv)) are shown in Fig. 4. The dotted line and the dashed line denote the natural bunch length at 380 and 308 MeV, respectively. The bunch lengthening in these cases are similar to those in single-bunch. The threshold currents have almost the same value for both single- and multi-bunch operations. In addition, synchrotron side bands were observed around the multiples of the revolution frequency in both single- and multi-bunch operations. The bunch lengthening occured almost at the same time when the synchrotron side bands appeared. Because of the small circumference of SOR-RING, even a single-bunch might be affected by a long-range wake-field, for example, the wake-field induced at the RF cavity.

Therefore the bunch lengthening in both single-bunch and multi-bunch at SOR-RING could be explained by a longitudinal coupled-bunch instability.

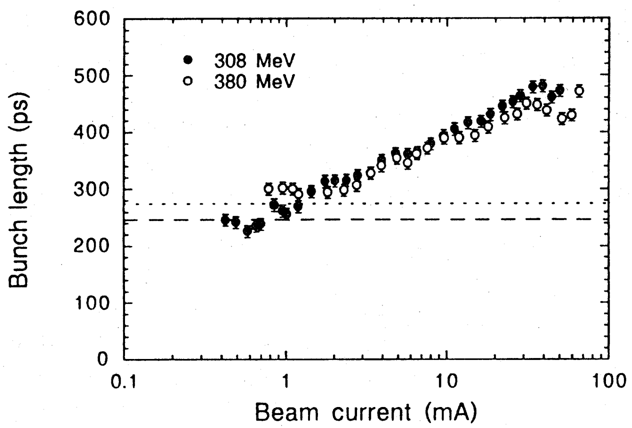

Figure 4: Beam current dependence of the bunch length in multi-bunch operation.

B. Impurity measurement

The increase in single-bunch impurity has been observed in several storage rings[8, 9]. In a low energy ring which has a beam energy less than a few GeV, the main source of this phenomenon is the Touschek effect, the electron-electron scattering effect in a bunch. Electrons which get a large longitudinal momentum by the scattering can be thrown out from the RF bucket and captured again in the following buckets through the radiation damping process[8].

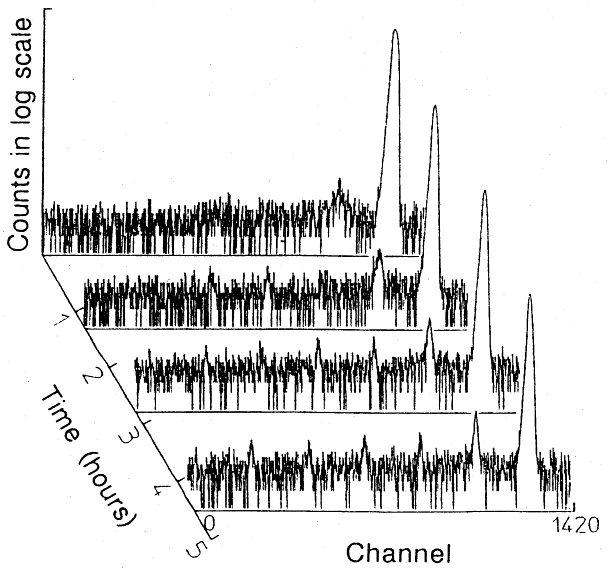

Figure 5: The time variation in the electron population at 308 MeV.

Figure 5 shows the time variation in the electron population measured at 308 MeV. In this figure, the maximum peak is the main bunch and the lower peaks are satellite bunches. Obviously, the number of electrons in the satellite bunches gradually increases with the time. At 380 MeV, however, this increase of impurity was not observed. It suggests that at 308 MeV the Touschek effect is the main source of beam loss but at 380 MeV some other process would be dominant one. In this connection, as described in ref. [1], the beam life time of multi-bunch operation at 380 MeV is mainly determined by scattering with residual gases rather than the Tousheck effect.

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