MEASUERMENT OF THE BEAM BUNCH LENGTH IN THE COMPACT SUPERCONDUCTING STORAGE RING "AURORA" USING AN AVALANCHE PHOTODIODE

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Abstract

The beam bunch length in the compact superconducting storage ring AURORA at Ritsumeikan University was measured using the avalanche photodiode. The radiation beam from the bending magnet was detected by the avalanche photodiode and a frequency spectrum was recorded using a spectrum analyzer. To compare the bunch length obtained by the present method, the bunch length was measured by streak camera. The bunch lengths that determined by the present method agree with the streak camera method.

INTRODUCTION

The beam bunch length in an electron storage ring is an important parameter for beam dynamics and there are several methods for its measurement. The most frequently adopted is the one employing a streak camera in which an instantaneous image is taken of the bunch running in the electron orbit. We present in this paper an alternative method, in which the frequency spectrum of radiation emitted from the storage ring is measured using an avalanche photodiode and the bunch length is derived by Fourier transformation of the frequency spectrum. It has been shown that the method yields the value in substantial agreement with that measured using the streak camera.

EXPERIMENTAL PROCEDURES

Measurement was made at the compact electron storage ring AURORA at the Synchrotron Radiation Center at Ritsumeikan University. Details in the structure and performance of AURORA are found in [1,2]. Figure 1 shows schematically the layout of the measurement system constructed at the beam extraction port BL-9 [3,4]. The first mirror that is made of beryllium and cooled by water reflects the visible SR lights. The quartz window seals in vacuum of storage ring and passes the lights. The radiation detector employed was an avalanche photodiode module APDM (MATSUSADA R263VF), the sizes of the detector being 55 mm (Width) ×45 mm (Height) × 90 mm (Depth). Since the avalanche photodiode is a detector with a very quick response, it is possible to measure the frequency structure of the intensity of radiation. Signals from the detector were transferred to a spectrum analyzer (HP E4403B) and analyzed. To compare the bunch length obtained by the present method with that by the conventional method, the streak camera (HAMAMATSU C1370-01) was placed behind the movable mirror and the radiation beam was accepted with the mirror out of position.

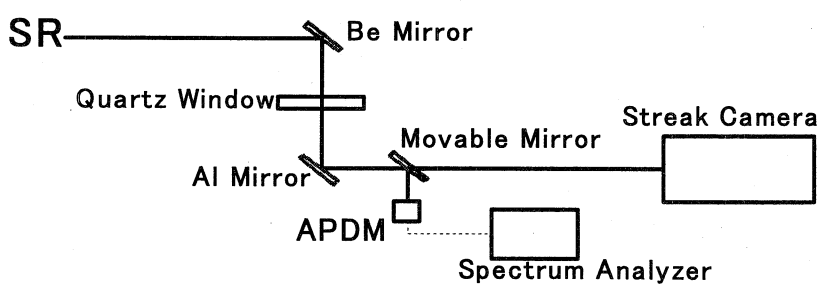

Figure 1: Layout of the bunch length measurement system at BL-9.

EXPERIMENTAL RESULTS

Bunch length determination

Figure 2 shows the frequency spectrum measured at a stored beam energy E of 575 MeV and a gap voltage V_g of 100 kV. The fundamental frequency f_{rf} is 190.86 MHz that is RF frequency of AURORA. It can be seen that the spectrum contains higher harmonics up to the sixth order in addition to the fundamental one and their amplitude decreases with increasing order. Harmonics higher than the seventh order could not be recorded due to the cut-off frequency 1200 MHz of the present measurement system. If the bunch were so short that it could be regarded as a point, a series of harmonics up to infinite order would be seen with the same amplitude. The spectrum was recorded at various gap voltages.

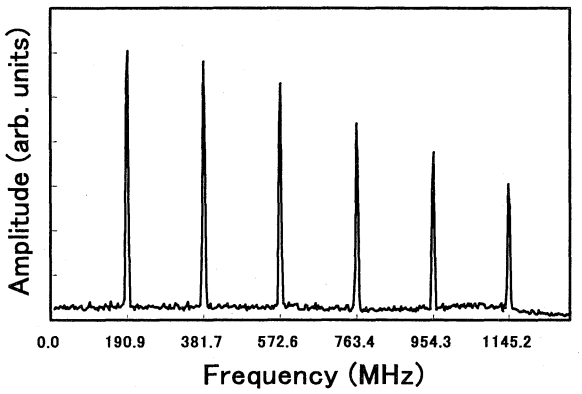

Figure 2: Frequency spectrum with fundamental frequency of 190.86 MHz.

Assuming a Gaussian profile for the bunch, the amplitude of the n-th harmonics is expressed as

$$A_n = C\exp\left[-\frac{(n\cdot f_{rf})^2}{2(c/(2\pi\sigma_L))^2}\right], \qquad (1)$$

where σ_L is the standard deviation of the profile and taken here as the bunch length. c is the velocity of light. C is the quantity dependent on the stored beam current and the efficiency of APDM. σ_L was determined by fitting eq. (1) to the observed order dependence of the amplitude of the harmonics. The bunch length thus determined is plotted as a function of the gap voltage in Fig. 3. In the figure the bunch length determined using the streak camera is also plotted. Solid curve represents the calculated bunch length on the basis of the formula given by

$$\sigma_L^{calc} = c\cdot\left(\frac{\alpha}{\Omega_s}\right)\cdot\left(\frac{\sigma_\varepsilon}{E}\right), \qquad (2)$$

(σ_ε/E) is given by

$$\left(\frac{\sigma_\varepsilon}{E}\right)^2 = \frac{C_q\gamma^2}{J_s\rho}, \qquad (3)$$

where α is momentum compaction factor, C_q is a constant, J_s is dumping partition number, γ is ratio of total energy to rest energy and ρ is electron trajectory radius. Ω_s is synchrotron oscillation frequency given by

$$\Omega_s^2 = 2\pi f_{rf}^2\frac{eV_g\alpha\cos\phi_s}{hE_0}, \qquad (4)$$

where ϕ_s is synchronous phase angle.

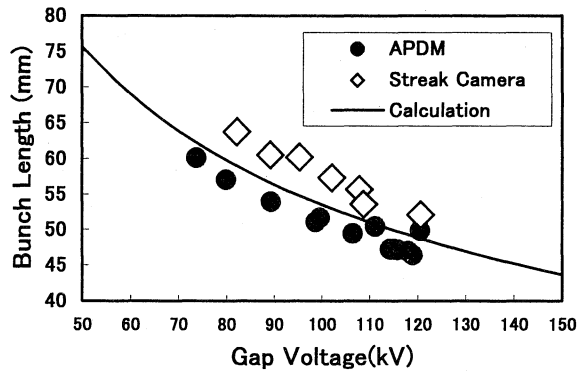

Figure 3: The gap voltage dependence of the bunch length. The curve is calculated one, squares and triangles represent experimental data.

It is seen that the bunch length determined using the avalanche photodiode is only a little smaller than the value from the streak camera method and almost in agreement with the calculated one, indicating the reliability of the present method. It is simpler and less expensive than the streak camera method and will have a wide range of application. The method developed here may be called a method of measurement in the Fourier space.

Bunch diagnostics

The method present here can be used to observe a change in the beam bunch length. Figure 4 shows the spectrum when the operation condition of the ring is modified to shorten the bunch length. Comparing with that shown in Fig. 2, the amplitude decrease of the harmonics with increasing order is less remarkable, in agreement with the result by the streak camera. The bunch length determined by fitting equation (1) is 33mm, while that determined by using streak camera is 36mm.

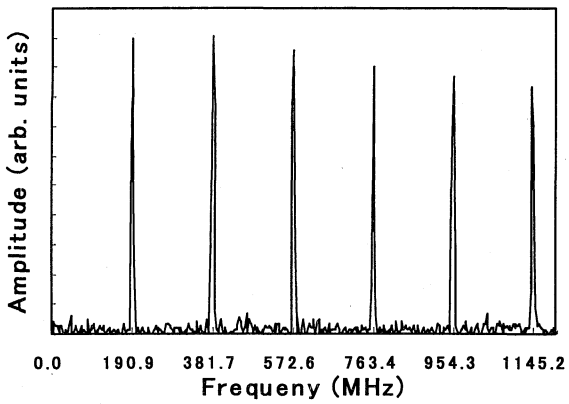

Figure 4: Frequency spectrum for the operation condition to shorten bunch length.

Figure 5 shows the spectrum under the operation condition to induce instability. Irregular dependence of the harmonics intensity on the order has appeared, suggesting that the bunch loses the Gaussian shape and changes into a twin form. This is also consistent with the bunch profile measured by the streak camera.

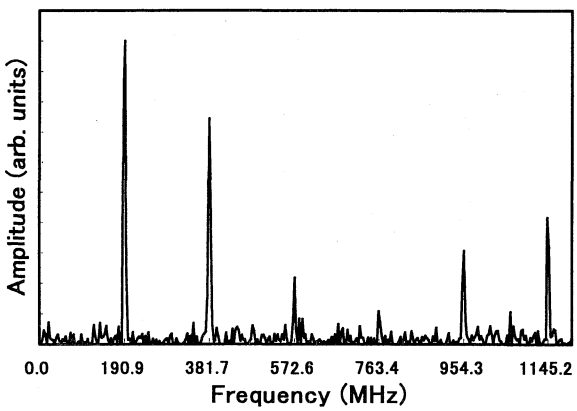

Figure 5: Frequency spectrum for the operation condition to induce instability.

ACKNOWLEDGMENT

We would like to thank Mr. H. Miyade and Dr. H. Tsutsui of Sumitomo Heavy Industry for useful discussion.

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