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BUNCH LENGTHENING OF THE NIJI-IV

M. Yokoyama, M. Kawai, K. Yamada*, N. Sei*, S. Hamada, S. Sugiyama*, H. Ohgaki*, T. Mikado*, T. Noguchi*, R. Suzuki*, M. Chiwaki*, T. Ohdaira* and T. Yamazaki*

Kawasaki Heavy Industries, Ltd. 118, Futatsuzuka, Noda, Chiba, 278, Japan
*Electrotechnical Laboratory, 1-1-4, Umezono, Tsukuba-shi, Ibaraki, 305, Japan

Abstract

The bunch length and the beam sizes in the single bunch operation on the storage ring NIJI-IV dedicated to FEL were measured and analyzed by using theories of the potential well distortion. The measured bunch length were in good agreement with the theoretical fitting curve with the longitudinal coupling impedance of 14 Ω, and the microwave instability was not found at beam current of below 8 mA. The measured beam sizes in the both directions were constant at below 8 mA. It was convinced from the measured bunch length and the horizontal beam size that the energy spread is not increased at the beam energy of 310MeV.

1. Introduction

The NIJI-IV is a compact storage ring dedicated to free-electron lasers (FELs). Lasings of FEL at 595 nm and 488 nm in the visible wavelength region and at 352 nm in the UV region were achieved up to 1994[1,2,3].

Generally, the potential well of the vacuum chamber occurs the bunch lengthening. On some storage rings, the microwave instability brings about the turbulence bunch lengthening with increase of energy spread above a threshold current. Since these effects decrease peak current and FEL gain, it is important that these effects are investigated.

In this paper, the beam current dependencies of the beam size and the bunch length are discussed taking into account the distortion of the potential well theoretically. The threshold current of the microwave instability was not found at the beam current of below 8mA. A longitudinal coupling impedance $|Z_{//}/n|$ obtained from the theoretical fitting curve of the distortion of the potential well was about 14 Ω. The large widening of the beam size measured was not found in both directions in the single bunch operation. The energy spread is not increased.

2. Theory of bunch lengthening

The bunch lengthening was studied by Hansen[4], Sacherar[5], Chao[6] and others. In single bunch operation, the coupled bunch instability does not occur, so only the potential well distortion should be taken into account as a cause of the bunch lengthening. Below a certain threshold current, the bunch lengthening due to the distortion of the potential well by the vacuum duct is given by

$$\left(\frac{\sigma_l}{\sigma_{l0}}\right)^3 - \left(\frac{\sigma_l}{\sigma_{l0}}\right) - \frac{I\alpha e|Z/n|}{\sqrt{2\pi}\nu_0 E}\left(\frac{R}{\sigma_{l0}}\right)^3 = 0 \qquad (1),$$

where E is the beam energy, σ_{l0} is the standard deviation of the natural bunch length, σ_l is the standard deviation of the bunch length, R is the average radius of the storage ring, e is the electron charge, $|Z/n|$ is the longitudinal coupled impedance, ν_0 is phase oscillation wave number α is momentum compaction factor[4]. The criterion of the threshold current I_{th} of the microwave instability is described by

$$I_{th} \geq \sqrt{2\pi}\frac{\sigma_l}{R}\frac{E\alpha}{|Z/n|e}\left(\frac{\sigma_E}{E}\right)^2 \qquad (2).$$

The energy spread σ_E increases above the threshold current as follows.

$$\left(\frac{\sigma_E}{\sigma_{E0}}\right) = \frac{1}{\sqrt{2}}\frac{\sigma_l}{\sigma_{l0}} \qquad (3),$$

where σ_{E0} is the energy spread determined from the radiation damping and the quantum excitation.

3. Measurement of bunch length

Time structure of the synchrotron radiation from an electron bunch at a bending section was observed by using a fast avalanched photodiode (ANTEL-270, rise time below 90 ps) and a sampling oscilloscope (HP-5490, sampling head 6740 with the frequency response of 50GHz). The bunch forms obtained with decrease of beam current were analyzed and their standard deviations were evaluated. Figure 1 shows the current dependence of bunch lengthening measured in the single bunch operation. The threshold of the bunch lengthening was not found in the measured beam current of below 8mA. The dash line

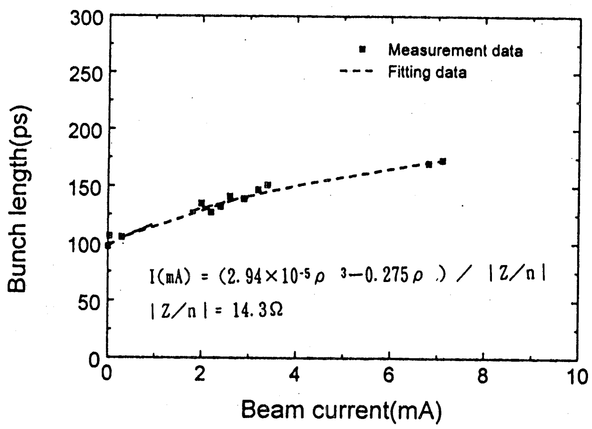

Fig. 1 The current dependence of the bunch length in the single bunch operation . The squares show measured values at the beam energy of 310MeV. The dash line shows calculated values of a equation in this figure and is obtained by fitting to EQ(1).

was a fitting curve by the EQ(1). The longitudinal coupling impedance $|Z_{//}/n|$ obtained from the fitting curve was about 14 Ω. A longitudinal coupling impedance $|Z_{//}/n|$ of a smooth vacuum duct with a finite conductivity σ_{con} is written by

$$\frac{Z_{//}}{n} = \frac{1-i}{b}\sqrt{\frac{R\beta Z_0}{2n\sigma_{con}}} + i\frac{Z_0}{\beta\gamma^2}\left(\frac{1}{4}+\ln\frac{b}{a}\right) \qquad (4),$$

where γ is the relativistic energy, β is the ratio of the electron velocity to the light velocity, Z_0 is the free space impedance 377 Ω, b is the radius of the vacuum duct cross section, a is radius of the transverse beam size, n is mode number[7]. The longitudinal impedance of the bellow is written by

$$\frac{Z_{//}}{n} = -i\beta Z_0 \ln\frac{b'}{b}\frac{total\ \ length\ \ the\ \ bellows}{circumference} \qquad (5),$$

where b' is outer radius of the bellows[7]. Generally, the longitudinal coupling impedance of smooth vacuum duct is much smaller than one of the bellows. On the NIJI–IV, if the all vacuum chambers except for the bellows are smooth, its impedance is below 1 Ω by EQ(4). The impedance of the bellows is about 2 Ω by EQ(5). The longitudinal impedance 14 Ω obtained from bunch lengthening measurement is much larger than the estimated one. In practice, the chambers with the screen monitor(screen monitor inputs and outputs owing to obtaining the position of the injection beam) are unsmooth and there are 6 screen monitors in the ring. It is not large compared with the values of the other rings, for example 20 Ω for the SRS[8], 30 Ω for SPEAR- I [9] and 40 Ω for SOR[10]. Under the observed current(below 8mA), turbulence bunch lengthening was not observed. The threshold current estimated by EQ(2) is about 18mA. The measured result is reasonable for the estimated value. This means that the energy spread is not increased under 8mA. It is important that the degradation factor f [1] of FEL gain is not decreased.

4. Measurement of the beam size

The beam size at the bending section was obtained from the synchrotron radiation through a focusing lens by a CCD(charged coupled device) camera. The focusing length, the length between the radiation point and the lens, and the length between the lens and the CCD camera are 0.5m, 1m and 1m, respectively. The beam profile with the same scale was displayed on the camera. It is convenient that the camera has linearity on the relation between the light intensity and the output signal. This relation was investigated by using the some neutral density filters and the synchrotron radiation from the bending section. The beam profile is kept for long time at low beam current of 0.1mA and can be used as a standard light source. Figure 2 shows the relation between the light intensity and the output signal. The output signal of the camera is proportional to the light intensity. Figure 3 shows examples of the light intensity in horizontal and vertical direction. The beam profiles in the both direction can be fitted by the Gaussian distribution. Figure 4 shows the relation between the beam current and the beam sizes σ_x and σ_y in both directions in the single bunch operation. The large widening of the beam size was not found in both directions. It means that the energy spread is not increased and the microwave instability does not occur at below 8mA. It is shown that the emittance growth due to the effect of the intrabeam scattering [11] also is very small. The emittance growth estimated from the theory of the intrabeam scattering is increase of a few percent at 8mA.

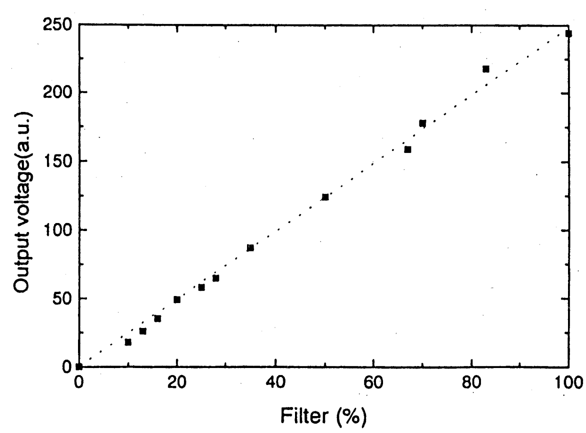

Fig. 2 Output voltage of the CCD versus Beam intensity

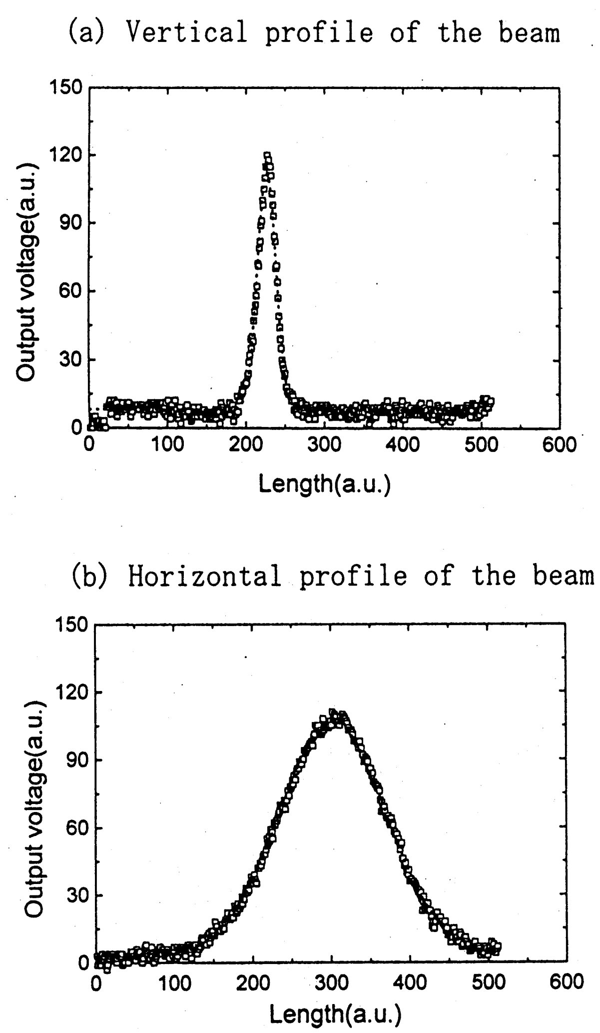

Fig. 3 Examples of the light intensity in horizontal (a) and vertical direction (b). The dot line in this figure is a fitting to the Gaussian distribution.

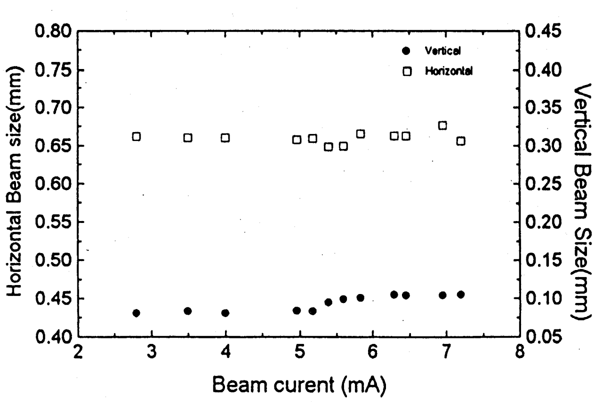

Fig. 4 The current dependence of the beam size at the bending section in the single bunch operation.

5. Conclusion

The bunch length and the beam sizes in the single bunch operation on the storage ring NIJI−IV dedicated to FEL were measured and analyzed by using theories of the potential well distortion. The threshold current was not found at the beam current of below 8mA and the microwave instability does not occur. The longitudinal coupling impedance $|Z_{//}/n|$ obtained from the theoretical fitting curve was about 14 Ω. The impedance of the bellows is about 2 Ω. The longitudinal impedance 14 Ω obtained from the measurement is much larger than the estimated one. It is considered that the difference of the impedance is due to the unsmooth chambers. The large widening of the beam size measured was not found in both directions in the single bunch operation. The energy spread is not increased and the microwave instability does not occur at below 8mA. The emittance growth due to the effect of the intrabeam scattering also was very small. The emittance growth estimated from the theory of the intrabeam scattering is increase of a few percent at 8mA.

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