SLAC-PUB-10359

Bunch length measurement and the beam spectra observation through high power RF waveguide system

T.Mimashi, H.Mizuno, N. Iida, KEK, Ibaraki Japan
B.Hong, SLAC, CA. U.S.A.
F.Tamura, JAERI, Ibaraki Japan

Abstract

A wide-band pick-up, which is mounted on the wall of waveguide between the klystron and the RF cavity, has been developed for measuring beam spectra in KEKB. The spectrum between 5 GHz and 20GHz is taken to calculate the bunch length. And the synchrotron oscillation is observed as the side band of revolution peak. The bunch length and synchrotron frequency are measured under the different momentum compaction factors α and different total RF voltages Vc. Measured bunch length is compared with the measurement of streak camera.

1 INTRODUCTION

The KEKB[1], an asymmetric electron-positron collider consists of a 3.5 GeV positron storage ring (LER) and an 8.0 GeV electron storage ring (HER). The bunch length is expected to affect the KEKB luminosity. And the accurate bunch length measurement [2] is very important to understand the intra-beam scattering effect in the stored electron (positron) beam. Beam spectrum monitor is installed to measure the bunch length and to observe longitudinal beam oscillation.[3][4]

2 BUNCH LENGTH MEASUREMENT PRINCIPAL

The bunch length measurement is based on the spectral analysis of the beam-induced signal in the RF cavity. When the Gaussian bunched beam pass through the RF cavity every ΔT sec, they produce signal at the time t,

$$f(t) = a \cdot \sum_{n=-\infty}^{\infty} e^{-\frac{(t-n\cdot\Delta T)^2}{2\cdot\sigma_t^2}} \quad -(1)$$

Where $\sigma_t = \sigma_z / C$, σ_z is the bunch length, C is the speed of light and a is the function of bunch current. Their frequency spectrum is given by the Fourier transform of equation (1).

$$F(\omega) = \frac{1}{\sqrt{2\cdot\pi}} \int_{-\infty}^{\infty} f(t)\cdot e^{j\cdot\omega\cdot t} dt$$

$$= \frac{a}{\sqrt{2\cdot\pi}} \sum_{n=-\infty}^{\infty} \int_{-\infty}^{\infty} e^{-\frac{(t-n\cdot\Delta T)^2}{2\cdot\sigma_t^2}} \cdot e^{j\cdot\omega\cdot t} dt \qquad -(2)$$

$$= \frac{a\cdot\sigma_t}{\sqrt{2\cdot\pi}} \cdot e^{-\frac{\omega^2\cdot\sigma_t^2}{2}} \sum_{n=-\infty}^{\infty} e^{j\cdot\omega\cdot n\cdot\Delta T}$$

The equation (2) indicates, the peaks appear every 1/ΔT, and the envelop of these peaks gives $\exp(-\omega^2 \cdot \sigma_t^2 / 2)$ distribution.

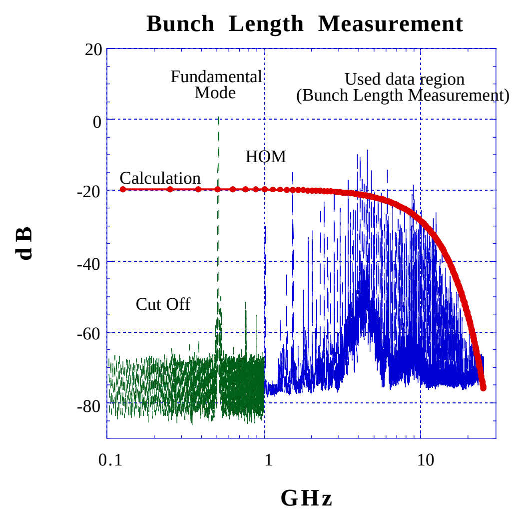

Figure. 1: Beam Spectrum measured at the KEKB LER through the high power RF waveguide system and the expected spectrum of the Gaussian beam.

Figure.1 shows the spectrum of the positron beam at KEKB LER. No frequency component can be observed below wave-guide cut off frequency. Then the fundamental mode appears at 508MHz. Between 508MHz and 5GHz, only higher order mode components of the fundamental frequency are observed. This is because the cavities absorb the signal of this region. Above 5GHz, the wavelength of the signal is much smaller than the size of wave-guide, so that almost all components pass through the wave-guide. Using the signal spectrum in this region, the bunch length is calculated.

An advantage of this method is the system can observe the wide-band beam spectrum from 5GHz to 40GHz. The distortion of the beam spectrum is much smaller than that of button electrode and cable system in this frequency region. This makes it possible to place the digitizer outside of tunnel and to observe the bunch length directly by looking at the longitudinal beam spectrum. And it is also possible to observe other beam oscillation such as synchrotron oscillation or other beam instability.

Work supported in part by the Department of Energy contract DE-AC03-76SF00515.
Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309
Presented at the 8th European Particle Accelerator Conference (EPAC 2002), 6/3/2002 - 6/7/2002, Paris, France

Another advantage is no special hardware except for small pickup is necessary to be installed. And this system can be used at other accelerators easily.

3 MEASUREMENTS AT KEKB

The RF accelerating frequency of the KEKB is 508.887MHz and approximately 5120 buckets of particles are designed to be stored with 2nsec spacing. The beam spectra have been observed at both rings.

3.1 Set up

The wide-band pickups are mounted on the wall of wave-guide between klystron and the RF cavity in KEKB. The spectrum analyzer analyzes the signal extracted through the wide-band pick-up. Several kinds of pickups that should have flat frequency response at the region between 5 GHz and 40GHz, were investigated [5] using the MAFIA simulation code and Network-Analyzer test bench. Finally a strip line type pickup was chosen.(Figure 2) In order to avoid the coupling of the fundamental component, the strip line is installed parallel to the microwave propagating direction. In this installation, neither the electric field nor the magnetic field of TE10 mode is coupled.

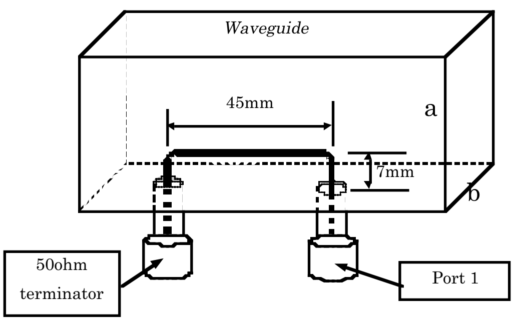

Figure 2: A strip line type pickup mounted on the wall of high power RF wave-guide system

3.2 Bunch length measurement

The electron (positron) beam is filled in every 3 or 4 buckets in 2002-year luminosity run. More than 1000 bunches are stored in each ring. The monitor measures an average bunch length of these bunches. When the positron beam is filled in every 4 buckets, peaks are observed every 127.22 MHz (=508.887/4 MHz) on the spectrum analyzer. Peaks between 5GHz and 20GHz are taken and used to calculate the bunch length. Figure 3 shows picked up peaks and expected beam spectrum of the several bunch length. Assuming Gaussian time profile of the beam, picked up data is fitted with two parameters, the bunch length and the bunch current. More than 100 points are used for fitting. As show in Figure 3, it seems enough sensitivity to determine the bunch length. Once the bunch length measurement is calibrated by the other measurement, such as streak camera, we can determine the transfer function of the cavity and waveguide system. The resolution of the bunch length measurement is about +-0.25 %. The bunch length calculated from spectrum analysis is compared with the streak camera measurement. (Figure 4)

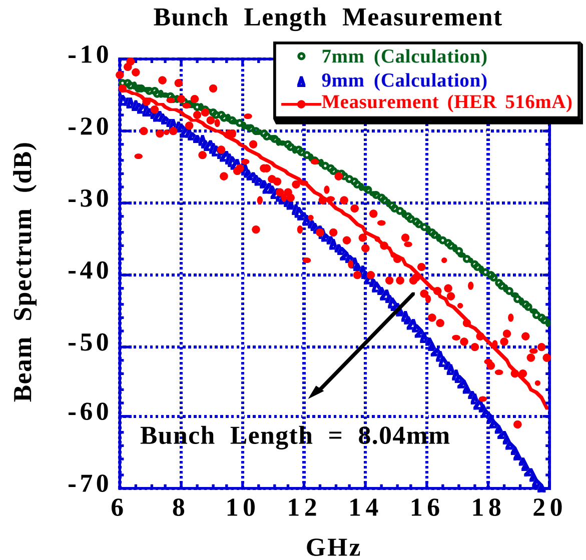

Figure 3: Frequency component picked up every 127MHz. And expected spectrum of several bunches length of the beam.

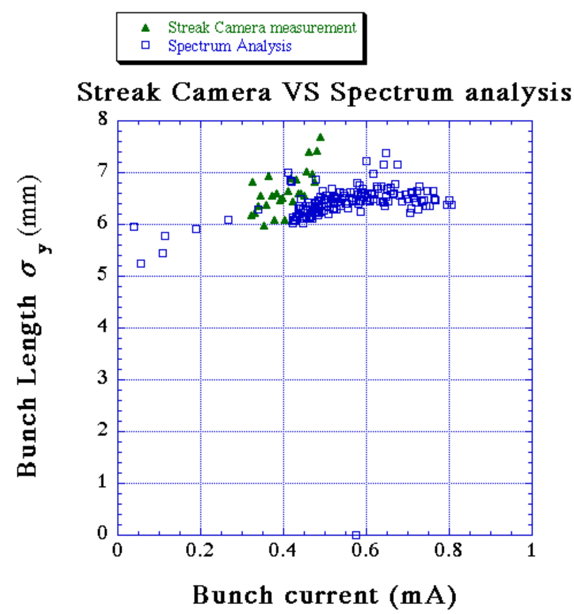

Figure 4: Comparison of the bunch length measurement by the streak camera and by the spectrum analysis

3.3 Synchrotron frequency measurement

The longitudinal coherent oscillation of the beam is also observed from the spectrum. The synchrotron frequency is observed as the side band of revolution peak. One of the peaks around 6GHz was picked up and zoomed up. Figure 5 shows the 2kHz synchrotron oscillation side band. And it also shows unknown beam oscillation around the 15 kHz. Thus when the instability occurs, this monitor would be very useful to observe the strength and frequency of the instability.

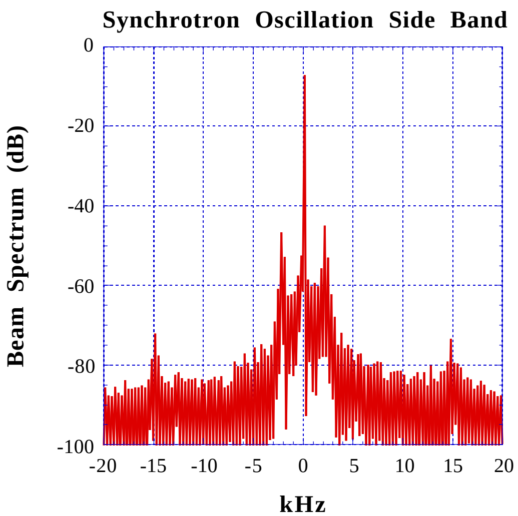

Figure 5: Synchrotron oscillation Side-band at KEKB LER

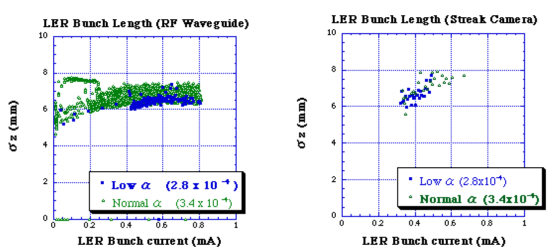

Figure 6: Bunch Length compaction factor dependence

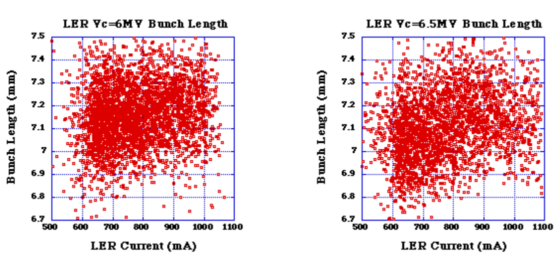

Figure 7: Synchrotron oscillation Side-band at KEKB LER

3.4 *Bunch length control*

At KEKB, the bunch length is controlled by the momentum compaction factor α and total RF voltage Vc. The beam-beam simulation indicates 10% decrease of the bunch length gives 10% increase of the luminosity. The bunch length is measured under different α optics and different Total Vc. The momentum compaction factor is decreased from 3.4e-4 to 2.8e-4, this 20% decrease of α is expected to decrease the bunch length 10%. Total Vc is increased from 6 MV to 6.5MV, it should decrease the bunch length 4 %. As shown in Figure 6 and Figure 7, the bunch length changed as we expected.

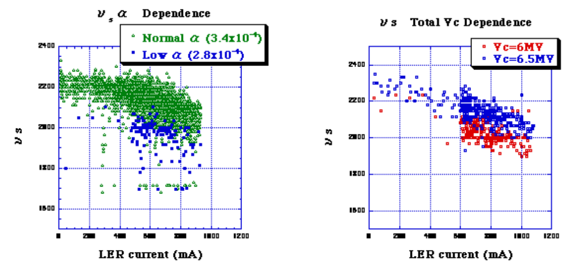

Figure 8: Total Vc and α dependence of Synchrotron frequency

Figure 8 shows the change of synchrotron frequency under these conditions. When we try to change α and Vc to decrease the bunch length respectively, the synchrotron frequency moves opposite direction. By using two method same time, it is possible to decrease the bunch length without changing the synchrotron frequency.

4 CONCLUSIONS

The longitudinal coherent motion of stored electron (positron) beam was observed through high power RF wave-guide system in KEKB. Strip line type of wide band pick-up is mounted on the wall of wave-guide. Using the 5GHz to 20GHz beam spectrum, an average bunch length was calculated. Synchrotron oscillation frequency also measured from the beam spectrum. The bunch length and synchrotron frequency are measured under the different momentum compaction factor and the different total RF voltage. They are consistent with the expectation.

REFERENCES

[1] S.Kurokawa et al, “KEKB B-Factory Design Report”, KEK Report 95-7, August 1995

[2] T.Ieiri, “Measurement of Bunch Length Based on Beam Spectrum in the KEKB”, EPAC2000, Viena, Austria, June 2000

[3] T.Mimashi et al, “Bunch length measurement and the beam signal observation through high power RF waveguide system”, submitted to HEACC2001, Tsukuba, Japan, March 2001

[4] M.Arinaga et al, “KEKB Beam Instrumentation systems”, submitted Nucl. Instrum. Methods.

[5] B.Hong et al, “A Wide-Band pick-up for measuring beam spectra in KEKB”, submitted to APAC2001, Beijing, China, September 2001