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

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Abstract

A bunched beam produces longitudinal electric field in the RF cavity. The frequency spectrum of bunched beam is observed through the beam-induced signal in the RF cavity at KEKB ring. [1] The signal propagates to the klystron gallery through the waveguide and is extracted though the wide-band pick-up mounted on the wall of waveguide. The spectrum between 5 GHz and 20GHz is taken to calculate the bunch length. The strength of synchrotron oscillation and its frequency are also measured.

1 INTRODUCTION

The bunch length is expected to affect the KEKB luminosity. The detail observation of the current dependence of the bunch length and energy spread gives the information of the strength of the impedance.

Accurate bunch length measurement [2] is also very important to understand the intra-beam scattering effect in the stored electron beam. Beam spectrum monitor is installed to measure the bunch length and to observe longitudinal beam oscillation.

2 BUNCH LENGTH MEASUREMENT PRINCIPAL

The bunch length measurement is based on the spectral analysis of the beam-induced signal in the RF cavity. Suppose the Gaussian time profile is assumed, it produces a Gaussian frequency spectrum. 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.

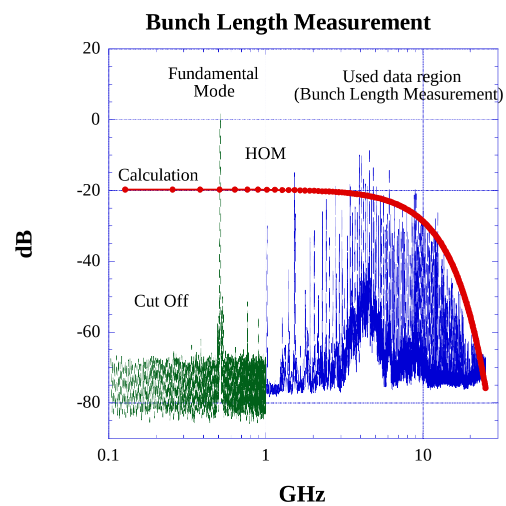


Figure. 1: Beam Spectrum measured at the KEKB Low Energy Ring (LER) through high power RF waveguide system and the spectrum of the Gaussian beam.

Figure.1 shows the beam spectrum of the positron beam at KEKB LER. Below wave-guide cut off frequency, no frequency component can be observed. 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.

There are two important advantages in this method. One is this system can observe the wide-band beam spectrum from 5GHz to 40GHz. The bare spectrum of the bunch is brought to the final observation station with only a few distortions above 5GHz, the distortion is much smaller than that of button electrode and cable system. This makes it possible to place the digitizer outside of tunnel, and to be easy to modify the read out system without access to the tunnel. Using this advantage, we can observe bunch length directly by looking at major component of the longitudinal beam spectrum. And it is also possible to observe other beam oscillation such as synchrotron oscillation or other beam instability.

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

3 MEASUREMENTS AT KEKB

The KEKB, an asymmetric electron-positron collider is now under operation. This collider consists of a 3.5 GeV positron storage ring (LER) and an 8.0 GeV electron storage ring (HER). The RF accelerating frequency is 508.887MHz and approximately 5120 buckets of particles are designed to be stored with 2nsec spacing. The observation of the beam spectra has been done with both the positron and electron ring.

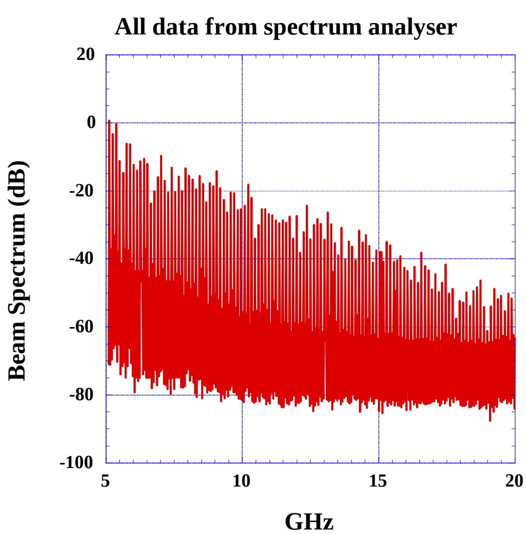
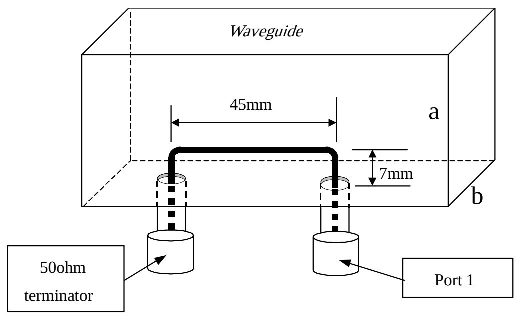


Figure 2: Observed beam spectrum of the KEKB High Energy Ring (HER) between 5GHz and 20GHz.

3.1 Set up

A wide-band pickups are mounted on the wall of wave-guide between klystron and the RF cavity both in KEKB Low Energy Ring (LER) and High Energy Ring (HER) to measure the spectrum of the stored beam. From obtained beam spectra, several important information such as bunch length, synchrotron oscillation frequency, is extracted. The induced signal in the RF cavity propagates in the wave-guide to the klystron gallery and is extracted through the wide-band pick-up. Then the spectrum analyzer analyzes the signal. Several kinds of pickup that they should have flat frequency response at the region between 5 GHz and 40GHz, was investigated [3] using the MAFIA simulation code and Network-Analyzer test bench. Finally a strip line type pickup was chosen. 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 3: A strip line type pickup mounted on the wall of



high power RF wave-guide system

3.2 Bunch Length measurement

At KEKB, the bunch length is controlled by the momentum compaction factor α and RF cavity voltage Vc. The designed natural bunch length in 2000 year operation is around 4-8mm.

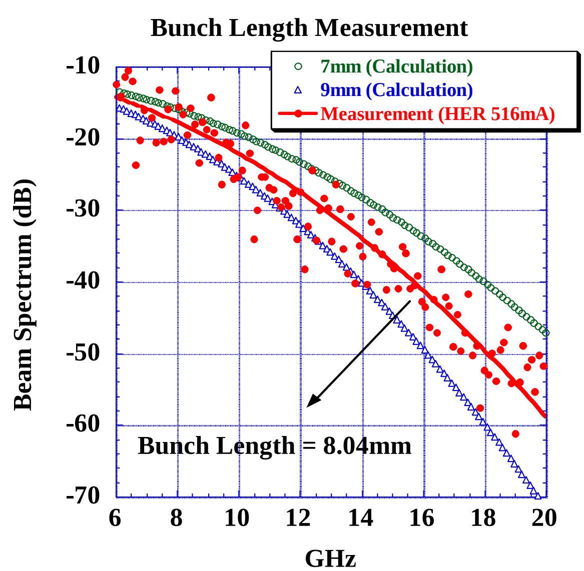


Figure 4: Frequency component picked up every 127MHz. And expected spectrum of several bunches length of the beam.

The positron and electron beam are filled in every 3 or 4 buckets in 2000 year luminosity run. More than 1000 bunches are stored in the ring. The monitor measures an average bunch length of these bunches. As we mentioned in the section 2.2, 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 picked up and used to calculate the bunch length. The system is designed to be able to observe the signal up to 40 GHz so that it can measure the shorter bunch length in future. Figure 2 shows beam spectrum between 5 and 20GHz. Figure. 4 shows picked up peaks and expected beam spectrum of the several bunch length.

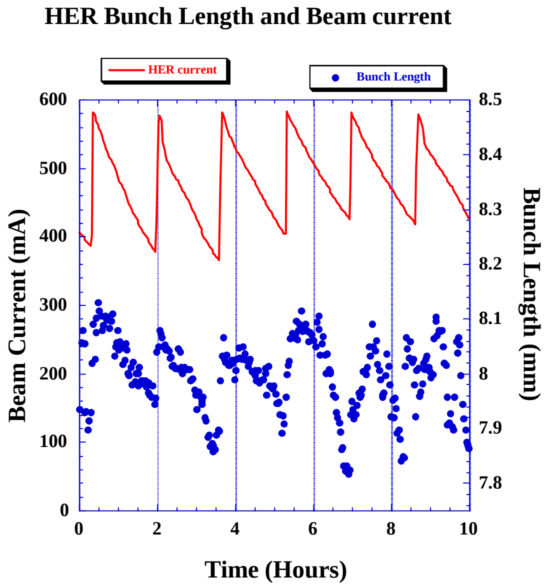


Figure 5: Total beam current and bunch length of the KEKB High Energy Ring.

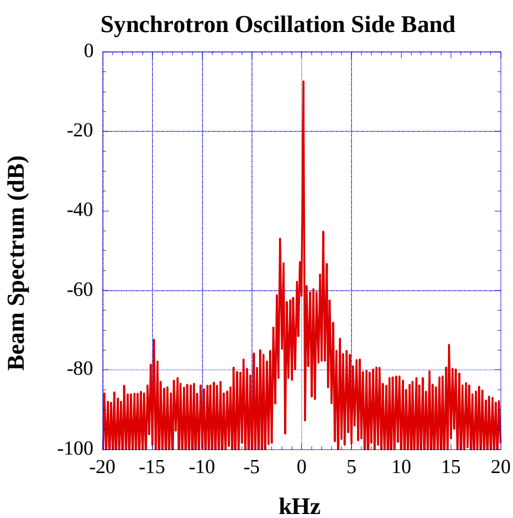


Figure. 6: Synchrotron oscillation Side-band at KEKB LER

Assuming Gaussian time profile of the beam, picked up data is fitted with two parameters, bunch length and bunch current. More than 100 points are used for fitting. As show in Figure. 4, it seems enough sensitivity to determine the bunch length. Although it is very difficult to measure transfer function of the cavity and waveguide system, once the bunch length measurement is calibrated by the other measurement, such as streak camera, we can determine the transfer function.

Figure.5 shows bunch length and total beam current of the KEKB HER. The resolution of the bunch length measurement is about +-0.25 %.

3.3 Synchrotron frequency measurement

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

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 between the klystron and the RF cavity. The frequency spectrum of bunched beam was measured. Using the 5GHz to 20GHz beam spectrum, the average bunch length was calculated. Synchrotron oscillation frequency also measured from beam spectrum.

REFERENCES

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

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