BUNCH LENGTH MEASUREMENT BASED ON THE BEAM POSITION MONITOR

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Abstract

This paper summarizes the results of the study of a bunch length monitor based on the button BPM (Beam Position Monitor). The monitor consists of a BPM installed on the beam pipe and a spectrum analyzer. We use the button-BPM's button pickups as the electrodes to pick up the signal. The bunch length can be derived from the spectrum of the beam-induced signal got by the spectrum analyzer. We show the theoretical results and the simulations performed by CST

INTRODUCTION

The rms bunch length is one of the most important parameters in the electron accelerator used for Free Electron Laser (FEL). Direct measurement of the length of bunches of electrons with ≤1 ns, is very difficult, thus more elaborate techniques have been developed. The different techniques can be divided into two main areas, time domain methods and frequency domain methods [1-4].

The time domain methods reviewed are picosecond photoconductive detectors, streak camera, RF deflector, spectrometer and so on. The frequency domain methods described are coherent radiation, Martin Puplett interferometer, frequency spectrum analysis, electro-optic detection and so on.

We used streak camera to measure the bunch length formerly. For this method is costly, a new one is under development to substitute the former one. In this paper, the method which based on the BPM in the frequency domain is discussed. We use the BPM's button pickups as the electrodes. Similar work has been done at SLAC and CERN [1, 4].

THEORETICAL ANALYSIS

Single bunch

Beam bunches can have many shapes, we consider the Gaussian bunched beam in this paper.

Consider a Gaussian-shaped bunch containing N particles of charge e^- in a bunch of rms temporal length σ (in time units) and with a bunching period T. The instantaneous beam current of a single bunch is given by

$$I_b(t) = \frac{eN}{\sqrt{2\pi}\sigma}\exp\left[\frac{-t^2}{2\sigma^2}\right] \tag{1}$$

The qualitative analysis of the signal in time domain is as follow:

$$f(t) = \frac{1}{\sqrt{2\pi}\sigma}\exp\left[\frac{-t^2}{2\sigma^2}\right] \propto I_b = \frac{eN}{\sqrt{2\pi}\sigma}\exp\left[\frac{-t^2}{2\sigma^2}\right] \tag{2}$$

Its frequency spectrum is given by Fourier transform

$$F(\omega) = \int_{-\infty}^{\infty} f(t)e^{-j\omega t}dt \propto e^{-\frac{\sigma^2\omega^2}{2}} \tag{3}$$

This equation gives the expected distribution of the frequency spectrum.

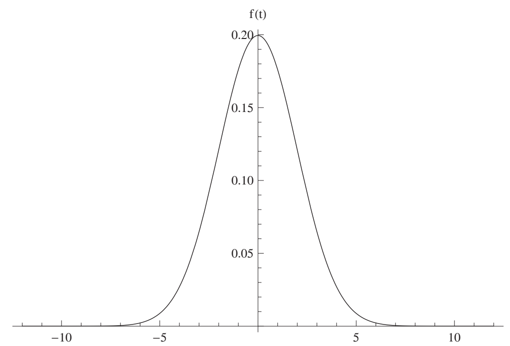

Figure 1: A single bunch of Gaussian-shaped distribution in time domain.

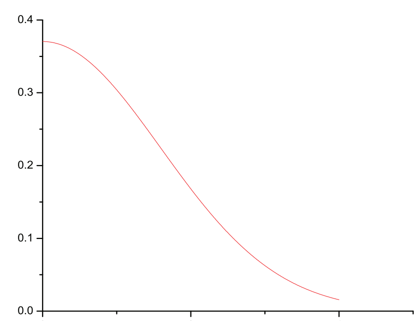

Figure 2: The Fourier transform of f(t).

Figure 1 is the distribution of Gaussian-shaped bunch f(t) in the time domain. Its frequency spectrum is given by the Fourier transform of equation (1). Figure 2 is the distribution in the frequency domain. Discretization of the frequency spectrum as showed in Figure 2, and performed Gaussian fitting then would yield σ which is the bunch length we want to measure.

Multibunch

In practice, it is difficult to get the signal of a single bunch. So we analyse the signal of multibunch and get the average length of multibunch instead of the length of a single bunch.

Considering a bunch train travelling at the center of the beam pipe, the intensity of the total current is given by:

$$I_{bm}(t) = \frac{eN}{\sqrt{2\pi}\sigma}\sum_{n=-\infty}^{\infty}\exp\left[\frac{-(t-nT)^2}{2\sigma^2}\right] \tag{4}$$

T is the bunching period. Its frequency spectrum is given by Fourier transform of Equation (4).

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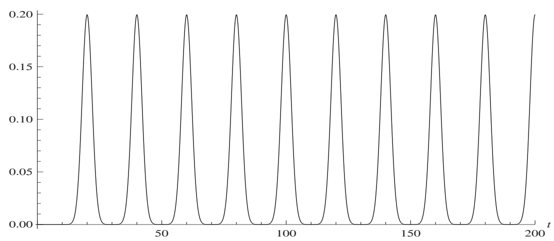

Figure 3: Multibunch of Gaussian distribution in the time domain.

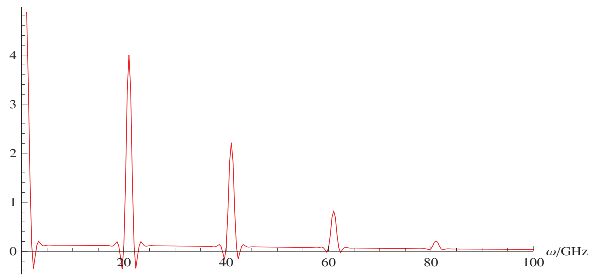

Figure 4: Spectrum of multibuch in frequency domain.

Figure 3 is the distribution of multibunch in the time domain. Figure 4 is the frequency spectrum of the multibunch. The analysis of the multibunch is similar to the single bunch as shown in the front of the paper. Find the peaks of the spectrum, the Gaussian fitting will yield the σ which is the average beam length of the multibunch we want to measure.

SIMULATION

To compare the analytical results with the numerical simulations, we have studied the signal of the button BPM performed by CST Particle Studio.

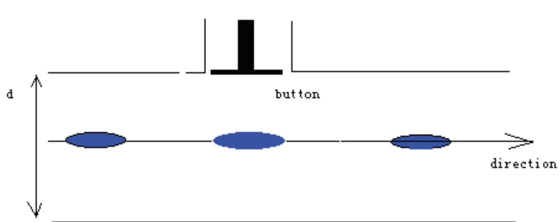

Figure 5: Sketch of the electrode.

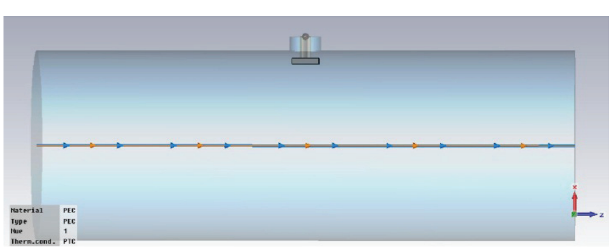

Figure 6: Model of the CST simulation.

The CST model is shown in Figure 5 and Figure 6 with the dimensions of the actual prototype and the system parameters shown in Table 1. It is only 1/4 of the structure of the button BPM pickups with magnetic boundary conditions on the symmetry planes. This model assuming a bunch train travelling at the center of the beam pipe, the signal excited by a bunch train pick-uped by the BPM button is shown in Figure 7.

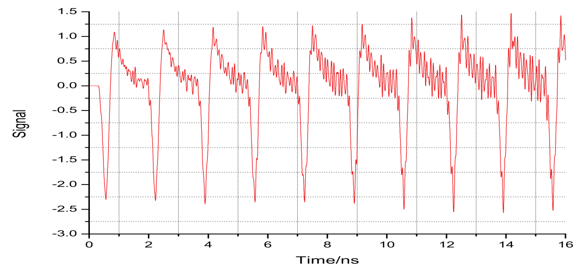

Figure 7: The signal of the button.

Using the FFT method to process the signal in time domain, the frequency spectrum can be got as shown in the Figure 8 as followed. Gaussian fitting, would yield the σ'=37.9 mm. This result is 26% larger than the σ in the simulation as shown in the Table 1. The spectral characteristic of the system would lead to the disturbance of the spectrum, then lead to the error of the measurement.

Table 1: Prototype dimensions and system parameters

d	35 mm
particle type	electron
σ(rms bunch length)	30mm (in length unit)
charge(abs)	1 nC
Bunch shap	Gaussian
Gamma of the beam	200
kinetic spread	1%

CONCLUSIONS

A new bunch length monitor based on the BPM has been described. These results confirm the potential application of the button beam position monitor as a bunch length monitor. The limitation is the performance of the monitor depends on the accuracy of the amplitude of the spectrum. So the key point is the design of the pickups and the analysis of the signal.

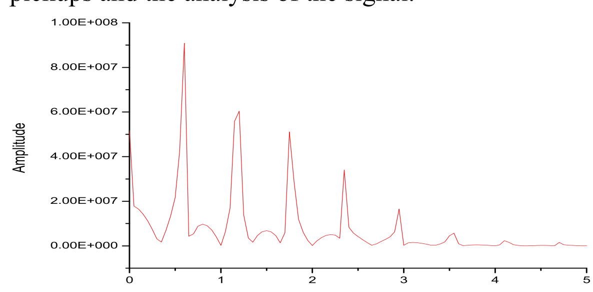

Figure 8: Spectrum of the signal.

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