

BUNCH LENGTH MEASUREMENT AT BUNCH BY BUNCH IN HARMONICS METHOD AT SHANGHAI SSRF STORAGE RING

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Abstract

Harmonics method in frequency domain is an effective and inexpensive bunch length measurement method. With advances in technology, it is possible to do bunch length measurement at bunch by bunch using electronic method. We design and make an electronic system to realize metering at bunch by bunch, and believe it has reasonable bunch length resolution. All selected harmonic signals will be mixed down to 500 MHz and digitized at bunch-by-bunch rate by a multi-channel DBPM processor. The primary beam experiment results will be presented and discussed in this paper.

INTRODUCTION

Shanghai Synchrotron Radiation Facility is the third synchrotron radiation light source in Shanghai China, which could produce broad rates of X-ray for lots of primary scientific research and other domains applications. To X-ray light source, high current, high brightness, favorable stability are not only advantages but demands of users, so lots of work are done to ensure them. Observe and measure the beam in real time can help the researcher analyze the storage ring operation status.

Streak-Camera Measurement can achieve bunch length measure at bunch-by-bunch and have reasonable resolution about 200 femtosecond, but it needs complicated optical structure and cannot be on-line device [1-3].

Harmonics method using electronic system can realize bunch-by-bunch beam length measurement and it is easy to construct and could be on-line device with Ethernet connected. Bunch length measure at bunch-by-bunch can test beam longitudinal movement such as synchronous oscillations and inspect some issues like the relationship between beam charge and length, which we cared and can't be found by mean bunch length measure.

In order to make up bunch-by-bunch measurement, high sampling rates and high resolution bits acquisition device with large memory capacity is necessary. In our experiment, we use oscilloscope and customized DBPM processor to acquire data. Due to time restrict and device debugging trouble, we take off-line algorithm process to deal with beam length relevant calculation.

MEASURE METHOD

Beam distribution in storage ring is approximately regarded as Gauss distribution: $G(\omega) = A \exp\left(-2\sigma^2/\omega^2\right)$.

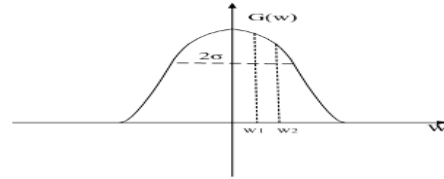


Figure 1: frequency distribution of beam in storage ring.

In figure 1, if we obtain two high harmonic signals of ω , we could figure out σ from down equation, which is called harmonics method [4].

$$\sigma = K \sqrt{\frac{2}{m_2^2 \omega_0^2 - m_1^2 \omega_0^2} \ln \frac{V(m_1 \omega_0)}{V(m_2 \omega_0)}} \quad (1)$$

In equation 1, ω_0 is the repetition frequency 499.68MHz of SSRF, m_i is higher harmonic orders. $V(m_i \omega_0)$ is signals' voltages metered of different frequencies and K is a coefficient while comparing two different frequencies. When bunch runs across not from the electrical centre of BPM monitor, there is an influence by the transverse deviation; and, for different frequencies, wave transfer coefficients across BPM monitor and analog front-end are diverse; both contribute to the coefficient K in the equation. K is a constant for two specified frequencies while the system is unchanged.

ELECTRONIC SYSTEM

A reasonable performance measurement system could make measure convenient and reliable. We have developed an electronic measure system to realize real-time beam signals acquisition, Fig. 2 is block diagram of measure system using oscilloscope to acquire data and Fig. 3 is object picture of analog front-end.

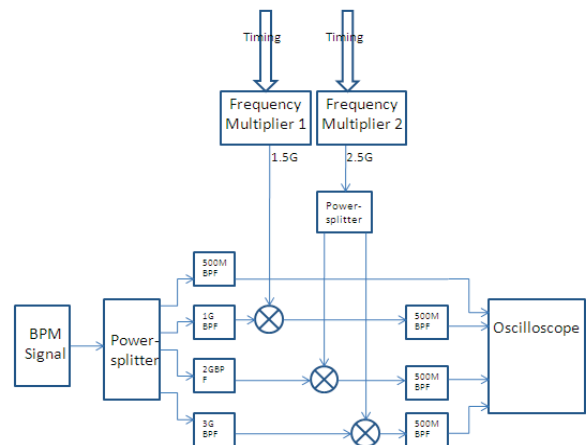


Figure 2: block diagram of oscilloscope measure system.

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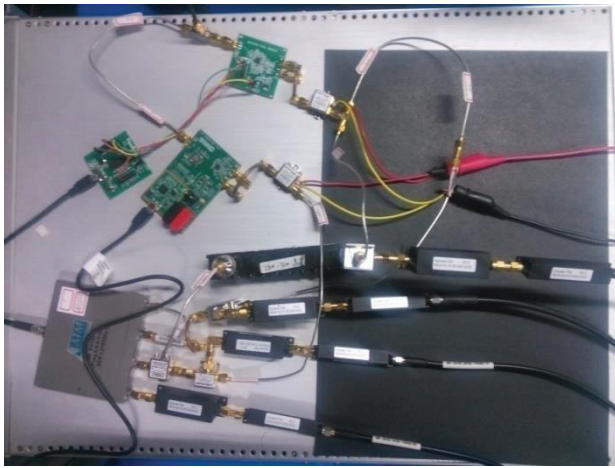


Figure 3: picture of analog front-end.

Source signals come from butter BPM detector installed upon linear vacuum pipe at SSRF. We take one channel of butter detector because transverse deviation will not affect beam length computing. A 4 way 0 degree power splitter divides signal into four channels and each channel will pass through a corresponding band pass filter. Central frequencies of these filter are 0.5G 1G 2G and 3G, and their bandwidth is above 250MHz but smaller than 500MHz in which we obtain signals in each specified frequencies and eliminate other spectrum band.

Filtered signals would be down converted to intermediate frequency about 500M respectively, and after that be filtered again by a band pass filter before oscilloscope data acquisition. This filter is customized from WI corporation. It consists of a high pass filter and a low pass filter, its band is from 350M to 650M. Its restrain performance outside pass band is advanced and is about 50dB, which can depress down other high order harmonics reliably.

Multiple channels data acquisition in our experiment have an inevitable problem, which is your all signal source must come from one system so their phases can be locked. In SSRF, there exist timing signals, which is the circular rate of storage ring. And with frequency multiplier we use it to produce 1.5G and 2.5G clock signal which serve as the mixer local terminal. This frequency multiplier is integral times device EVAL-ADF4351 from ADI corporation. Its reference frequency is 250MHz at most and output frequency range is from 35MHz to 4400MHz. In experiments test, frequency accuracy of this device could be 1kilo hertz and we find different channels of signals can be locked definitely.

When we use DBPM processor to acquire data, the structure of analog front-end is little different from oscilloscope. Figure 4 is its block diagram.

DBPM processor is DSP-c6655-C6-10 of Wuhan Linjiu corporation and its sampling rate is 500M at most, that is, acquire one data per bunch. Before acquisition, we add low noise amplifier to magnify signals to match ADCs range and we adjust signals phases via phase shifter in order to catch wave maximum value. We need an-

other timing block to produce 500MHz block signal for DBPM processor synchronous acquisition.

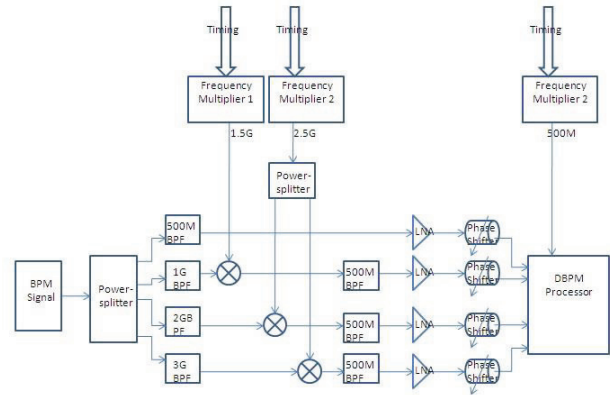


Figure 4: block diagram of DBPM processor system.

BEAM EXPERIMENTS

In order to test and verify the electronic measure system, we design two beam experiments: one, bunch injection experiment; two, bunch length measurement with different bunch charges.

Bunch Injection Experiment

When bunch injection happens, bunch length and bunch charge should vibrate violently. We choose 500MHz and 3GHz as specified frequencies and calculate bunch length according to equation 1.

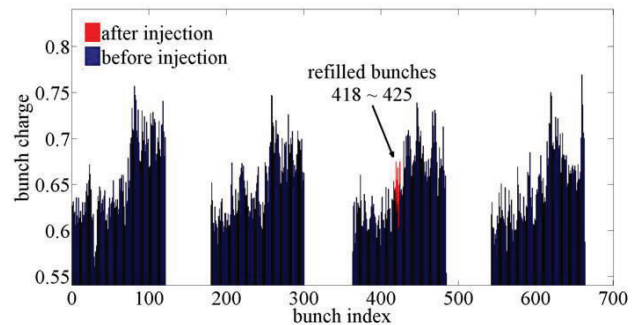


Figure 5: bunches filling mode.

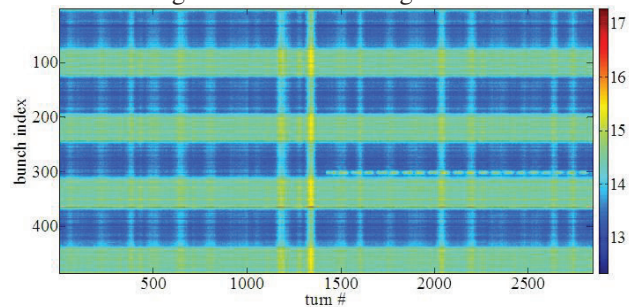


Figure 6: bunch length waterfall plot of all turns.

Figure 5 is bunch filling mode of used data, and we can see when bunch injection happens, refilled bunches charges become larger. Figure 6 displays different bunches length of different turns. Y-axis is exactly matched with Fig. 5. There exist some yellow bar which means

bunch length is bigger at that time. Another important item is the dotted line, which is bunch length regular variation array corresponding to these bunches and these turns.

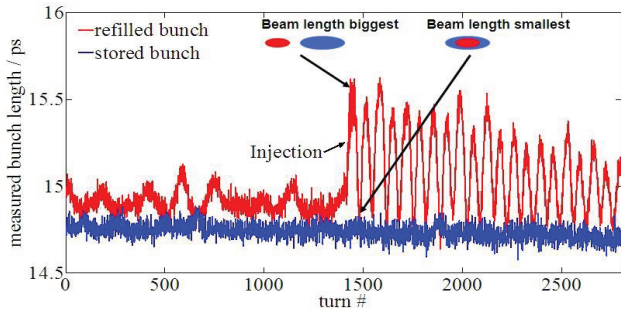


Figure 7: measured bunch length of different bunches.

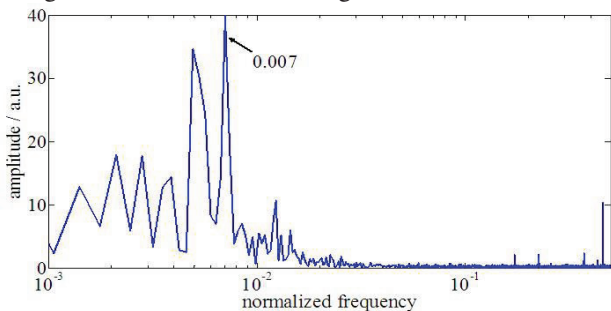


Figure 8: spectrum of refilled bunch length.

Figure 7 is about measured bunch length of refilled bunch and stored bunch which abstracted from bunch length variation array in Fig. 6. Figure 8 is its spectrum. We can see when bunch injection happens, bunch length arise quickly, then its vibrating amplitude decreases regularly.

At the moment injection happens, injecting electron bunch is farthest from stored bunch and equivalent bunch length is biggest. Then injecting electron bunch goes into the centre of stored bunch, here equivalent bunch length is smallest. As the speed of injecting bunch is quicker still than stored bunch, injecting bunch passes away and equivalent bunch length become bigger again until the biggest. At the same time, the speed of this injecting bunch becomes slow due to synchronous damping. When its speed is smaller than stored bunch's, the distance between two bunches decreases and equivalent bunch length becomes smaller again. The vibrating goes like this and its magnitude becomes smaller and smaller until this two bunches fuse together.

If we do a Fourier transform and attain its frequency spectrum as Fig. 8. We find its highest peak is 0.007, which corresponds with the synchronous vibrating of SSRF exactly. Thus confirms our bunch length measurement system is constructed successfully.

Bunch Length Measure Experiments with Charge

There exists electron bunch collectivity instability because of tail field effects and other factors when elec-

tron bunches go through metal pipeline. Bunch size would be restricted and cannot increase infinitely. To study this, we design experiments and try to verify the relationship between bunch length and charge.

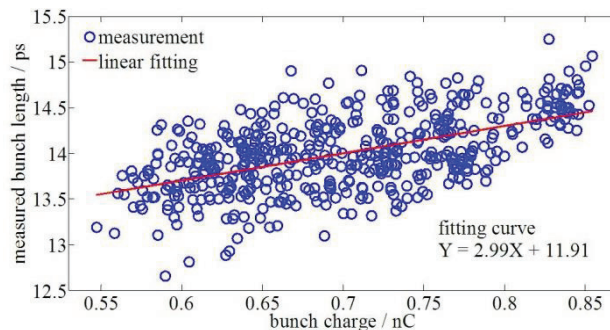


Figure 9: relationship between bunch length and charge.

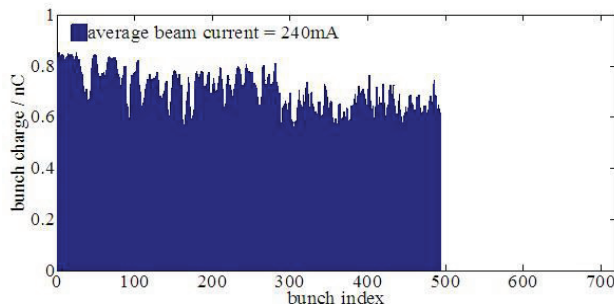


Figure 10: bunches filling mode of figure 9.

Figure 9 is a distribution map of bunch length and charge and Fig. 10 is bunches filling mode. Those data is acquired using our DBPM processor and we choose 500MHz and 3GHz as specified frequencies. From these measured data, there exists probably a linearity relationship between bunches length and their charges.

CONCLUSION

Harmonics method using electronic measurement system is an easy and effective way to measure bunch length. We designed construct an electronic system and design two experiments to test. Bunch injection experiment has affirmed the longitudinal synchronous vibrating. The second experiment obtains the relationship of bunch length and charge. Bunch length measurement at bunch-by-bunch is significant and in which we can detect other upscale accelerator physical phenomenon we cared which cannot be found by mean bunch length measure.

REFERENCE

- [1] Chen, J., et al. "Bunch length measurement with streak camera at SSRF storage ring." Proceedings of IBIC2013, Oxford, UK, p. 478.
- [2] Fisher, A. S., et al. "Streak-camera measurements of the PEP-II high-energy ring." AIP Conference Proceedings. IOP institute of physics publishing LTD, 1998.
- [3] Geitz, M. "Bunch length measurements." Proceedings of DIPAC. Vol. 99. 1999.
- [4] Guo, Z., et al. "Bunch lengthening study in BEPC." Proceedings of PAC95, Dallas TX (1995): 2955.