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UPGRADE OF BUNCH PHASE MONITOR AT SSRF STORAGE RING*

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Abstract

Beam instability is a serious problem for physics in beam diagnosis technology. With regard to the evaluation of longitudinal phase oscillations during the transient injection process, bunch-by-bunch phase measurement is a useful tool for studying the behavior of the refilled bunches. A new upgraded beam phase monitor system with 1.2GHz bandwidth PXI waveform digitizer has been developed at Shanghai synchrotron radiation source (SSRF). Bunch-by-bunch phase information, retrieved from button pickup signals, is calculated by the zero-crossing detection method with the best phase resolution of 0.4ps. The refilled bunches can be separated from the stored ones, and the longitudinal offset of each refilled bunch has been measured. Several groups of experiments have been performed to verify the repeatability of bunch-by-bunch phase measurement, and some results regarding refilled bunches will be discussed in this paper.

INTRODUCTION

Shanghai synchrotron radiation facility (SSRF) is a multi-bunch, high-current third generation light source, which consists of a 150MeV linac, a 3.5GeV booster and a 3.5GeV storage ring. The ring has a harmonic number and RF acceleration frequency of 720 and 499.654MHz, respectively. Its unique feature is almost constant bunch current with top-up operation, which will reduce the beam failure time during user's operation and prolong pulsed injection hardware lifetime [1]. With this filling pattern, more frequent beam injections were added and 500 bunches were stored with 2ns spacing. In this experiment, the total beam current is 180mA.

Although all bunches in a bunch train have almost the same intensity, bunch-by-bunch beam parameters not always have the same value. Moreover, every bunch is the basic unit of the beam physics research, and the motion information of every bunch will be largely approximate to its natural properties [2]. Therefore, a bunch-by-bunch diagnostic tool is useful for measuring three-dimensional position information and observing the beam instability of each bunch.

A bunch-by-bunch phase system has been developed at SSRF to improve the accuracy of phase measurement [3]. Base on the same method, BPM signals directly pick up from the button electrodes and recorded by a PXI waveform digitizer-based data acquisition system. Bunch-by-bunch phase measurement has been implemented by a new high-bandwidth waveform digitizer after Phase-II at SSRF. In addition, due to the increase of new insertion devices (IDs), the transient beam loading becomes an important problem for the study of longitudinal instability. When the dynamic instability occurs, the beam transverse position and longitudinal phase will be shifted, and the injection transient process is a typical beam unstable state. 5 Bunches were injected every 10 minutes.

BASIC IDEA

As a common diagnostic component in an electron storage ring, a four-button BPM pickup carries the information of transverse position, longitudinal phase and bunch charge. Assuming the bunch charge (Q_0) was in a Gaussian distribution at a bunch length σ, the time domain expression of a single bunch could be got with t_0, which is the phase difference relative to RF clock. The beam intensity is given by

$$I(t)=\frac{Q_0}{\sqrt{2\pi}\sigma}\exp\left(-\frac{(t-t_0)^2}{2\sigma^2}\right). \tag{1}$$

where, bunch-by-bunch charge monitoring has been implemented at SSRF [4].

The longitudinal phase is measured by a zero-crossing detection method, which has been introduced in Ref [3]. Four sampling points with equal time interval around the zero-crossing point will be fitting at the rising edge of the button pickup signal. The principle block diagram is shown in Fig.1.

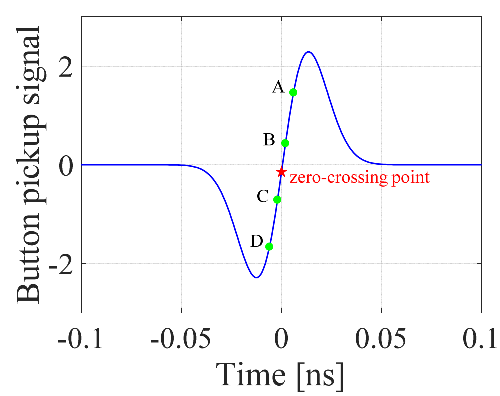

Figure 1: Principle block diagram of the zero-crossing detection method.

SYSTEM SETUP

In the new bunch phase monitor system, we adopted a new data acquisition device (ADQ14-4C digitizer from SP device) with ultra-high speed ADC. One of its main features is the high bandwidth (1.2GHz), which can ensure the integrity of the sampling signal. The other is the increased sample rate of each channel (1Gsps), which can improve the phase measurement resolution. However, the

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external clock of this waveform digitizer is only allowed to input 1GHz, equivalent to sampling two points each time of our 500MHz bunches. In this case, we need to select sampling points for each channel to ensure the four sampling points are in the correct order. On the other hand, the 2Hz external trigger is used for simultaneous sampling. In order to ensure that the starting point of the phase oscillation is about 500 turns during the injection transient process, the triggering delay of the timing system need to be adjusted. In general, bunch phase is usually detected from the phase difference between a beam pulse and a reference frequency signal. The advantage of this waveform digitizer is that every acquisition is taken place in the same location, which omits the input of the reference signal.

The system block diagram is shown in Fig2. Beam signal was divided into four components by a power splitter (1-1000MHz). Four samples with fixed time interval (150ps) for each bunch were fed into the 4 channels of the waveform digitizer. At the same time, a phase shifter was added after the synchronous clock to find the zero-crossing point. The biggest difference compared to the previous system is that the beam signal was picked up using one channel at this time. The reason for this is that the beam loading brings about a large signal reflection because of the increase of the IDs after Phase-II, and one channel can greatly reduce the influence of the reflected signal. However, the shortage of this operation is the introduction of transverse position effects.

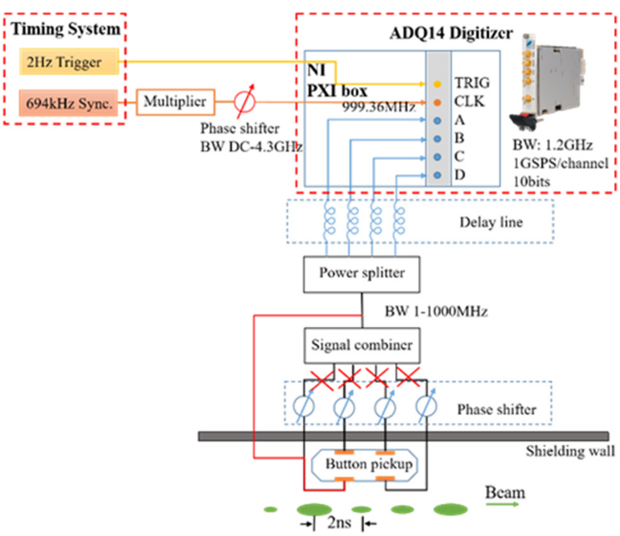

Figure 2: Hardware block diagram of the bunch phase monitor.

EXPERIMENTS

For Light Normal Mode

For verifying the repeatability of the bunch phase measurement of this system, several groups of experiments with the same conditions have been performed at SSRF. Bunch-by-bunch phase has been calculated by the zero-crossing detection method. As shown in Fig.3, bunch-by-bunch phase distribution of each group is almost similar.

Resolution, defined as the phase standard deviation between two bunches, is a very important parameter. Figure 4 shows the phase distribution of two adjacent bunches in different groups, all of which satisfy the linear relationship. Meanwhile, calculate bunch-by-bunch phase resolution between the fifth bunch and other bunches, as shown in Fig.5, the value is better than 0.4ps.

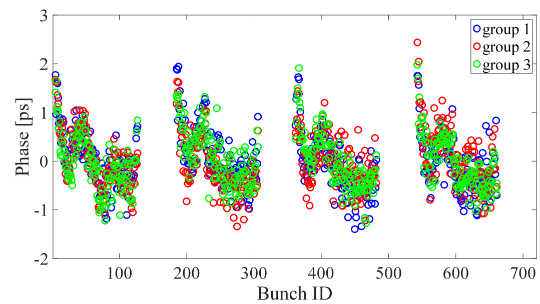

Figure 3: Repeatability of bunch-by-bunch phase measurement.

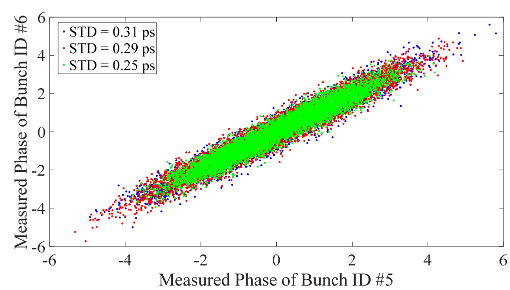

Figure 4: The phase distribution of two adjacent bunches in different groups.

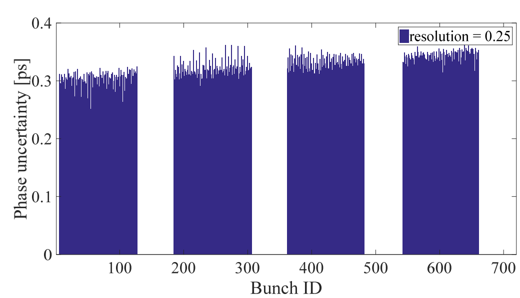

Figure 5: Phase measurement residuals using bunch #5 as reference.

For Transient Injection Process

High current and stable beam are preferred to a light source, so the suppression of the oscillation due to the frequent injection get great attention. To evaluate the beam instability, a bunch-by-bunch phase monitor is used to study the behaviour of the injected bunches. From the filling patterns (as shown in Figure 6), the injected bunches can be found. Similarly, the phase resolution of different bunches was calculated, and the phase variation of the injected bunch can be also clearly observed in Fig.7.

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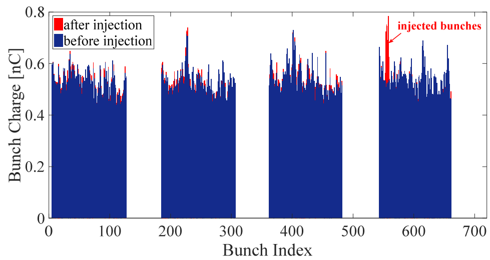

Figure 6: Filling patterns before and after an injection.

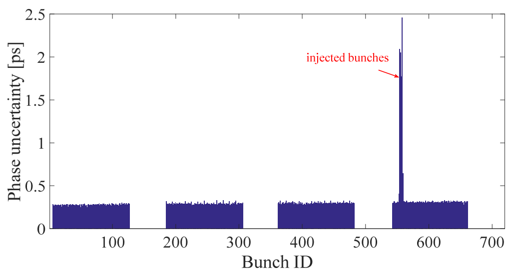

Figure 7: Bunches phase variation during injection.

To verify whether the longitudinal motion can be detected by this system, 500M samples of the raw data (about 3472 turns) were acquired during the injection process in the storage ring. The refilled bunch can be separated from the stored bunch, and the measured longitudinal phase oscillation in each turn of the 5 refilled bunches have been calculated (as shown in Fig.8). The phase oscillation frequency is similar and the maximum longitudinal offset of each refilled bunch is different. The frequency spectrum of refilled bunch and stored bunch is displayed separately in Fig.9, where we can see an apparent shift in the longitudinal synchrotron frequency.

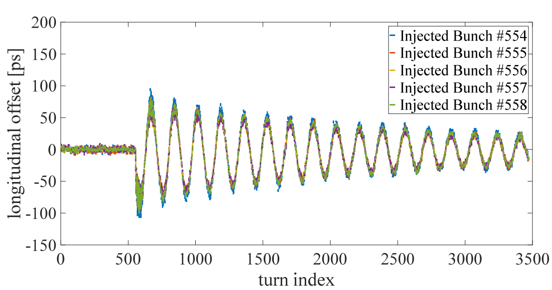

Figure 8: Measured longitudinal phase oscillation of refilled bunches.

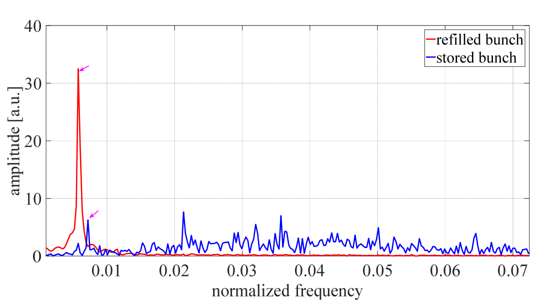

Figure 9: Phase spectrum of refilled bunch and stored bunch.

Furthermore, subtracted the noise signal by different low-pass filter, the behaviour of the stored bunch and the refilled bunch can be seen in Fig.10. The phase oscillation of the stored bunch (black line in Fig.10) is considered trivial, while the motion of the refilled one (red line in Fig.10) shows a horizontal symmetry attenuation oscillation, which is in accord with the real situation of the longitudinal motion of the accelerator.

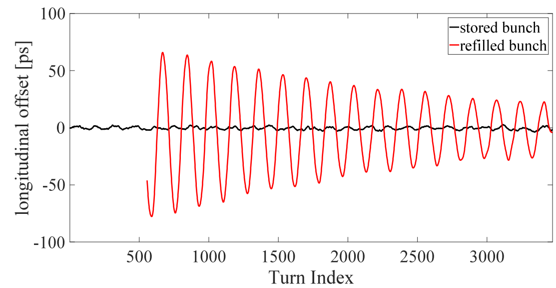

Figure 10: Stored bunch and refilled bunch after LP filtering.

CONCLUSIONS

The upgrade of bunch phase monitor has been implemented at SSRF. Bunch-by-bunch longitudinal phase was measured by zero-crossing detection method. The repeatability of bunch-by-bunch phase measurement has been verified and the phase resolution was improved to 0.4ps. The phase oscillation of the refilled bunch during the transient injection process was also studied. Refilled bunch can be separated from the stored bunch, and the oscillation attenuation is in accord with the real situation of the longitudinal motion of the accelerator.

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