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FILLING PATTERN MEASUREMENT SYSTEM UPGRADE IN SSRF*

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Abstract

Filling pattern affects various operation performance of a synchrotron light source. A new diagnostic beam charge monitor (BCM) with high bandwidth multi-channels digitizer was developed to perform bunch-by-bunch charge measurement and record filling pattern for SSRF storage ring. Signals picked up from button electrodes were sampled synchronously with RF frequency, and IQ (In-phase and Quadrature phase) sampling method was employed for noise-filtering and phase independence calibration. Layout and evaluation experiment of the system are presented in this paper.

INTRODUCTION

In Shanghai Synchrotron Radiation Facility (SSRF), for offering high-brightness synchrotron radiation light, the beam current is usually around 260mA. About 500 bunches are being stored with 2ns bucket spacing in the storage ring, where the harmonic number is 720 and the RF frequency is 499.654MHz.

Since 2011, the injection mode has been upgraded from decay mode to top-up mode, 6 ejecting bunches to fill different buckets at each injection cycle, aiming to achieve uniform filling. For better operation performance, all filled bunches were grouped as 4 bunch-trains, about 55 buckets spaced for each in normal operation mode, and user-defined filling pattern was also allowed in machine study. In the planned SSRF phase-II project, a new hybrid filling pattern mode with a single 20mA bunch will be added in normal operation state choice.

The first BCM system for monitoring filling pattern was developed in 2008 [1], which employed an 8Gs/s sampling rate digitizer to sample the BPM sum signal of 4 button electrodes, and using a waveform-reconstruction algorithm to calculate the charge of each bunch. But this device (including its backup) had been broken in 2017 and discontinued several years before. So a new type BCM system with a more commonly used equipment ADQ14-4AC has been developed. The same device were also used for BYB transverse position and phase measurement [2, 3]. Our work mainly refers to introducing the BCM system, and reporting on the measurement test and beam lifetime measurement.

SYSTEM OVERVIEW

General Idea

For filling pattern measurement, bunch pulses signals from FCT or sum signal from BPM could be sampled using RF frequency synchronized sampling rate. Data is proportional to bunch charge, but the sample phase would be varied each time the digitizer starts. For phase independence measurement, IQ sampling method was introduced.

This method was usually used to direct process high-frequency signals, which allow to measure the amplitude and the phase of beam signals with a reference signal [4]. BPM sum signal is usually broaden by band-pass filter to sine-like distribution, as shown in Fig. 1.

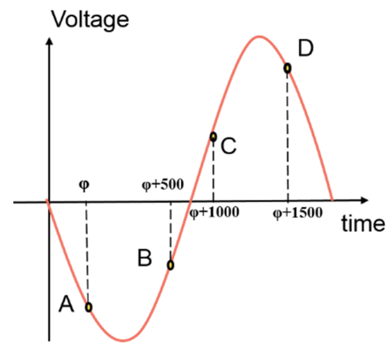

Figure 1: Principle of the phase calculation.

4 samples with 90° phrase difference were picked up and could be expressed as:

$$x_a(t) = A\sin(\omega t+\varphi) \quad x_c(t) = -A\sin(\omega t+\varphi)$$
$$x_b(t) = A\cos(\omega t+\varphi) \quad x_d(t) = -A\cos(\omega t+\varphi) \tag{1}$$

The I and Q signals are defined as:

$$A_I = \frac{x_a(t)-x_c(t)}{2} = A\sin(\omega t+\varphi_a) \tag{2}$$

$$A_Q = \frac{x_b(t)-x_d(t)}{2} = A\cos(\omega t+\varphi) \tag{3}$$

The bunch charge could be expressed in Eq. (4):

$$A = \sqrt{A_I^2 + A_Q^2} = \sqrt{\left(\frac{x_a - x_c}{2}\right)^2 + \left(\frac{x_b - x_d}{2}\right)^2} \tag{4}$$

The calculated result A in Eq. (4) is a phase independent variable proportion to bunch charge, so proportion factor is constant and only need to be calibrated once. Sampling noise introduced by digitizer would be counteracted by subtraction in Eq. (2) and Eq. (3).

Hardware

The BCM system consists of four BPM pickups, front-end, and a data digitizer/processor. Figure 2 shows its block diagram.

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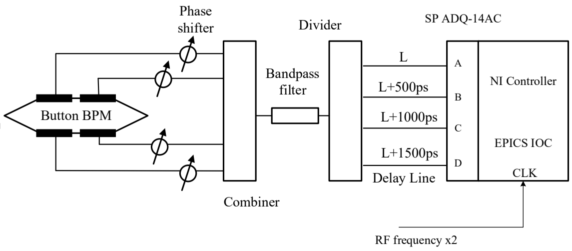

Figure 2: diagram of the bunch-by-bunch phase measurement system.

BPM sum signal is combined in a power combiner (4 to 1, BW 1-1000 MHz) from 4 button electrodes and adjusted by phrase shifters. Then it is spited into 4 equal signals by a power divider. Calibrated delay lines were used to generate 90°Phase differences from divider output and send to digitizer. To satisfy bunch-by-bunch charge measurement, SP-ADQ14-4AC board (14-bit, 4 channel, RF synchronized clock, 2 Hz system trigger, 350 MHz bandwidth) is adopted as digitizer, and sampled data is processed and calculated in NI controller based EPICS IOC.

BUNCH TEST AND EVALUATION

Bunch test was scheduled in the accelerator machine study, so single bunch could be injected in storage ring, and acquired by BCM, which could be used to evaluate the multi-bunch effect and data validity of the new built BCM system. This is shown in Fig. 3.

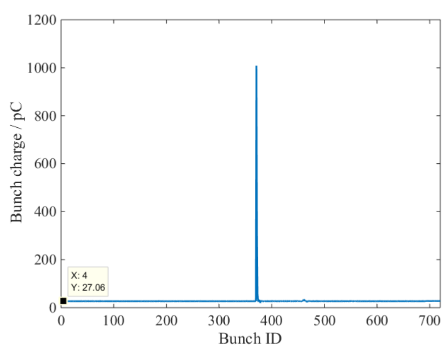

Figure 3: Single bunch mode in storage ring.

Single bunch mode acquired by BCM showed that the effect of individual bunch charge to others appeared after 90 buckets, and less than 0.5% charge of the bunch, which could be negligible for calculation.

In the multi-bunch test, storage ring ran in TopUp mode, about 500 bunches at 180mA grouped as 4 bunch-trains was used to fill the storage ring, so the filling pattern is similar to the normal operation. And the bucket jump 6 bunches for each injection. The filling pattern and individual bunch charge variation were showed in Fig. 4 and Fig. 5.

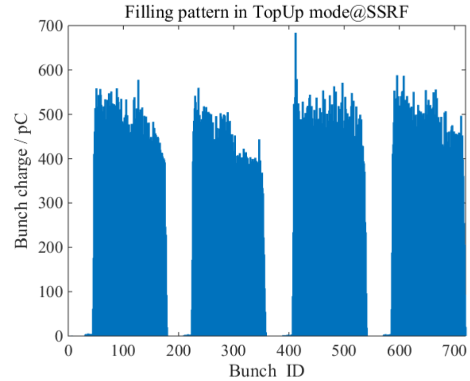

Figure 4: Measured Filling pattern of a snapshot during top-up operation.

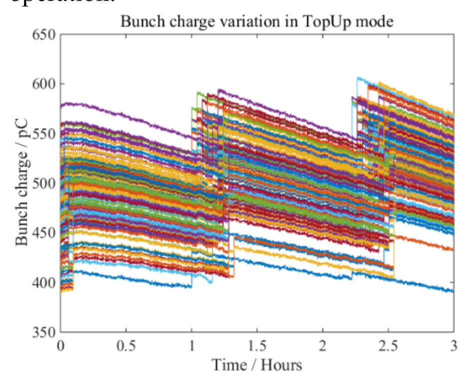

Figure 5: Individual bunch charge variation in 3 hours during TopUp.

For evaluating the resolution and bunch lifetime measurement, we have also curved the individual bunch decay formula Eq. (5) by least-square method and showed in Fig. 6.

$$I(t) = I_0 \exp(-t/\tau) \quad (5)$$

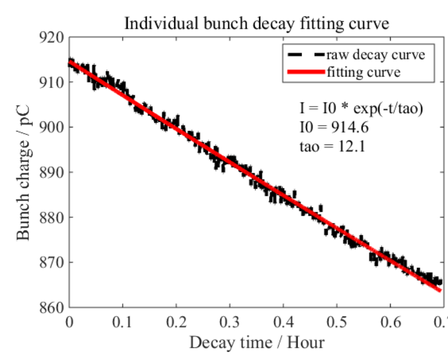

Figure 6: Individual bunch decay fitting curve.

And using the raw data from BCM and fitting curve showed in Figure 6, the resolution could be evaluated. For 600~1100pC bunch charge, the resolution is better than 0.2%

LIFETIME MEASUREMENT

Evaluation test shows that the performance of BCM system is not only satisfied top-up operation requirement but also good enough for individual bunch lifetime measuring.

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So a dedicated beam experiment has been set up to demonstrate the BCM performance for lifetime measurement. The calculation has to choose the decay part of bunches during TopUp period showed in Fig. 5. Using the beam lifetime in Eq. (5) we got bunch lifetime distribution in Fig 7.

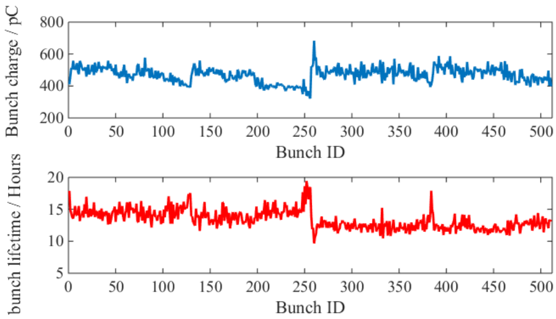

Figure 7: bunch lifetime distribution compared with bunch charge.

And the dependency between bunch charge and lifetime was charted in Figure 8

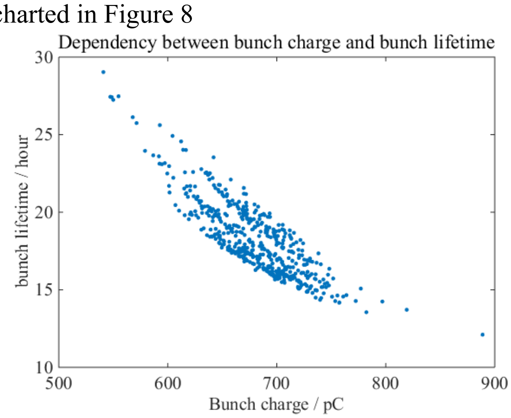

Figure 8: Dependency between bunch charge and lifetime.

CONCLUSTION

The new BCM system based IQ sampling method has been implemented in the SSRF storage ring. Bunch charge resolution is better than 0.2% in normal operation mode. Charge measurement accuracy is good enough to calculate individual bunch lifetime. All requirements of top-up operation and machine study have been met.

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