DATA ACQUISITION FOR SSRF RING BUNCH CHARGE MONITOR

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Abstract

Bunch charge uniformity control is very important for storage ring top-up operation. In order to monitor filling pattern and measure bunch charge precisely a PXI waveform digitizer based data acquisition system has been developed to retrieve bunch charge information from BPM pickup signals. Effective sampling rate is extended to 400GHz by waveform rebuilding technology, which overlays multi turns data into single turn with real time sampling rate of 8GHz. Online evaluation shows charge measurement accuracy is better than 0.5% with input range from 0.5nC to 12nC.

INTRODUCTION

Top-up operation mode is planed for SSRF storage ring to minimize the beam current dependence of machine parameters. The target is controlling the variation of bunch charges less than 10%. A precise bunch charge and filling pattern monitor is required for this purpose. Table 1 shows the basic specification.

Table 1: SSRF BCM Specifications

Parameter	Specification
Analoge bandwidth	>= 250MHz
Data updating rate	>= 1Hz
Bunch charge resolution	Better than 1%
Interface	EPICS CA

This measurement can be realized by direct sampling BPM pickup signal [1-3] or synchrotron radiation signal [4].

Due to simple configuration and good linearity Button BPM pickups and PXI waveform digitizer based solution has been adopted for SSRF storage ring. The developed instrument should provide full knowledge of the time domain structure of the beam, bunch-by-bunch, with a sub-nanosecond time resolution.

SYSTEM SETUP

Basic idea

Four-button type BPM pickup is common diagnostics component for electron storage ring, which carries not only beam position but also beam intensity information. Assuming bunch charge Q_0 is Gaussian distribution with bunch length σ.

$$q(t) = \frac{Q_0}{\sqrt{2\pi}\sigma} \exp(-\frac{t^2}{2\sigma^2}) \quad (1)$$

The peak value of four-button sum signal will be

$$V_{peak} = k(r,\theta) \cdot Z \cdot \sqrt{\frac{e}{2\pi}\frac{Q_0}{\sigma^2}} \quad (2)$$

In which k(r,θ) is a calibration factor determined by vacuum chamber cross section structure and beam position, Z is transfer impedance of measurement system, r and θ are beam position. For central beam with stable orbit, which is easily satisfied in SSRF, k(r,θ) can be treat as a constant k_0. Then we can define a scaling factor K_Q and rewrite equation (2) as

$$V_{peak} = K_Q \cdot Q_0$$
$$K_Q = k_0 \cdot Z \cdot \sqrt{\frac{e}{2\pi}\frac{1}{\sigma^2}} \quad (3)$$

Scaling factor is easy to be calibration with DCCT readings in single bunch mode. So bunch charge Q_0 can be derived by measuring peak value of sum signal.

Hardware

The bunch charge monitor hardware consists of beam pickups, RF front end, waveform digitizer, and a PXI IOC. Fig. 1 shows the block diagram of bunch charge monitor.

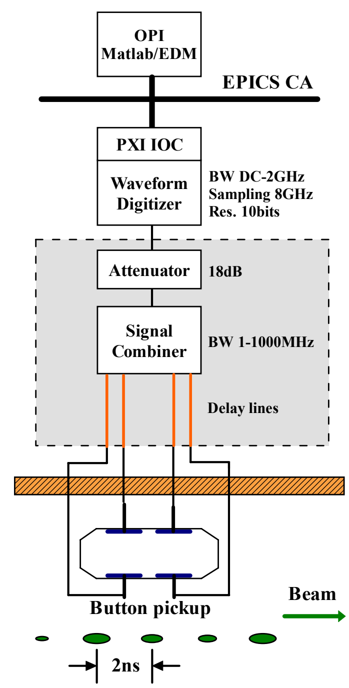

Figure 1: bunch charge monitor block diagram

Beam bunches are sensed by standard SSRF BPM buttons, 10 mm in diameter. Bunch signals from these buttons are connected to a filter/combiner/attenuator front-end chassis. This device consists of four delay coaxial cables, a power combiner (4 to 1, BW 1-1000MHz), and a fixed attenuator (18dB). Coaxial cables in the chassis are trimmed to eliminate time delay between signals. Power combiner produces position independent intensity signal. Attenuator adjusts output signal level to fit ADC input range. Waveform digitizer is acqiris DC252 with 2GHz analogue bandwidth, 8GHz sampling rate, 10bits resolution, and up to 1M samples data buffer. This module is triggered by "injection event" (2Hz) to take 576k samples (50 turns, 72μs) continuously. Multi turns digitized raw data will be sent to PXI CPU module, which is running a Linux EPICS IOCcore, to be rebuild to a single turn waveform.

Signal processing

The ADC real time sampling rate of 8GHz is not good enough to determine the peak value from single shot measurements. So a waveform rebuilding technique so called equivalent sampling is used to increase time resolution. The beam is recorded for 50 turns. The samples are shifted through the bucket, due to the frequency difference between the sampling frequency (8 GS/s) and the accelerator RF (499.654MHz). An effective sampling rate of few hundreds GS/s (roughly 8GHz * 50 = 400GHz) is obtained by overlaying 50 successive revolutions. The real time value of accelerator RF is acquired via EPICS CA to calculate precise time axes for each sample. Compared with 10 hours lifetime the beam intensity drop during 50 turns can be ignored (2ppm).

Fig. 2 shows a typical example of signal reconstruction, which overlays data of 5 turns (10 turns apart) together.

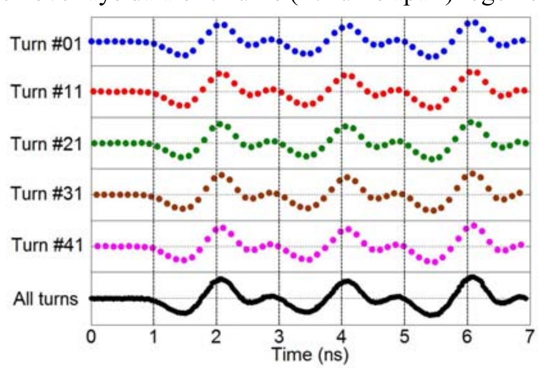

Figure 2: Example of equivalent sampling technique.

With time resolution increased data the peak of each bunch is easy to be determined by searching max value. In order to improve measurement accuracy 100 samples averaging around the peak is applied.

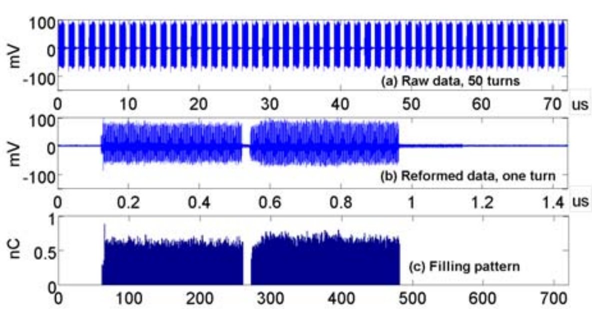

Figure 3: Typical filling pattern measurement.

Fig. 3 shows a typical measurement of filling pattern. Raw data of 50 turns is shown in (a). Rebuilt single turn data is shown in (b). Bunch charges distribution calculated from bunch signal waveform is shown in (c).

CALIBRATION AND EVALUATION

In order to calibrate the scaling factor KQ and evaluate the performance of BCM system several dedicated beam experiments have been carried out in the storage ring. A Bergoz NPCT and NI4070 digital voltage meter based DCCT is used as reference.

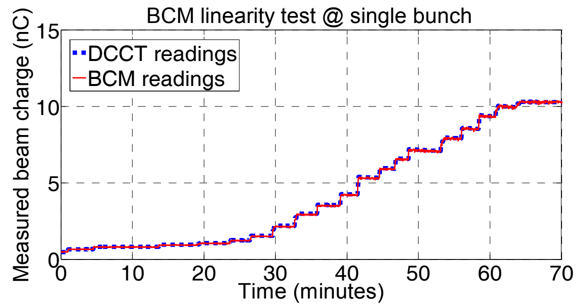

Figure 4: Beam experiment for calibration and performance evaluation

For calibration and linearity test beam current was added step by step from 0.2mA to 7mA with single bunch filling pattern. Fig. 4 shows recorded DCCT readings and BCM readings with in 70 minutes.

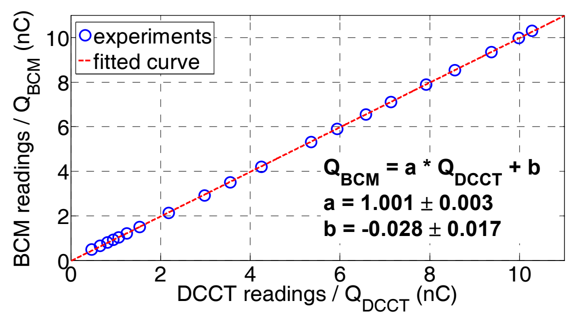

Figure 5: Linearity of BCM

Fig. 5 shows the analyze result of BCM linearity. In the full range the linearity is better than 0.5%.

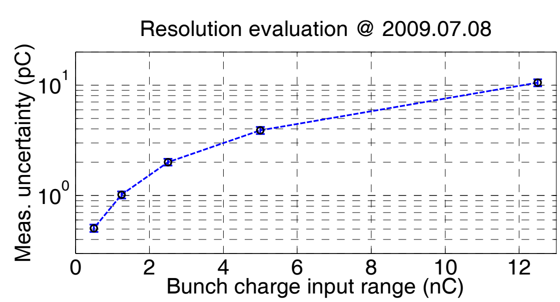

Figure 6: Input dynamic range and charge resolution

Fig.6 shows the charge input dynamic range and corresponding resolution of BCM. The input dynamic range is defined by digitizer voltage input range. For DC252 input range is [0.2, 0.5, 1, 2, 5] V selectable. It makes charge input range of BCM [0.5, 1.3, 2.5, 5, 12.5] nC selectable.

Evaluation result shows the relative measurement uncertainty is better than 0.1%. Charge input range can be extended by replacing fixed attenuator with adjustable attenuator.

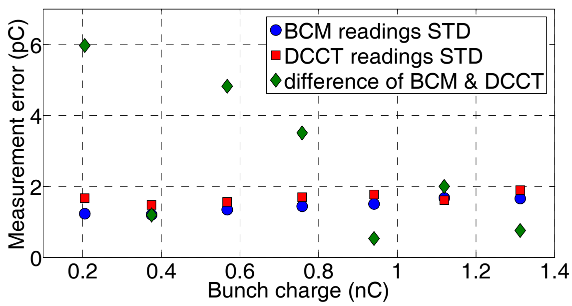

Figure 7: Accuracy evaluation result

Fig. 7 shows the accuracy evaluation result at 2.5nC input range. Measurement uncertainty is almost the same for both DCCT and BCM. The difference between DCCT readings and BCM readings is smaller than 0.5% of full range.

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. So a dedicated beam experiment has been set up to demonstrate the BCM performance for life time measurement. Filling pattern is designed as six bunches 100 ns apart shown in Fig. 8.

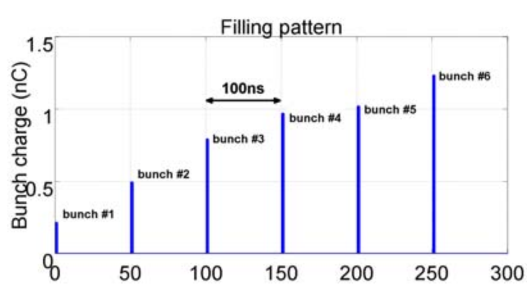

Figure 8: Beam experiment for lifetime measuring

Fig. 9 and Fig. 10 shows bunch charge decay and corresponding bunch lifetime.

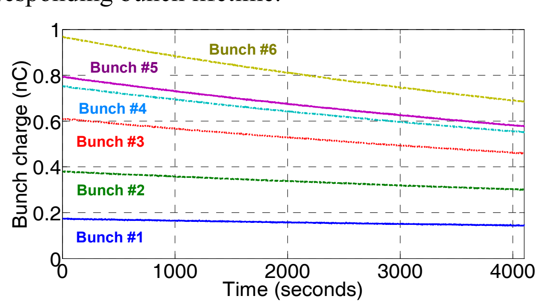

Figure 9: Bunch charge decay

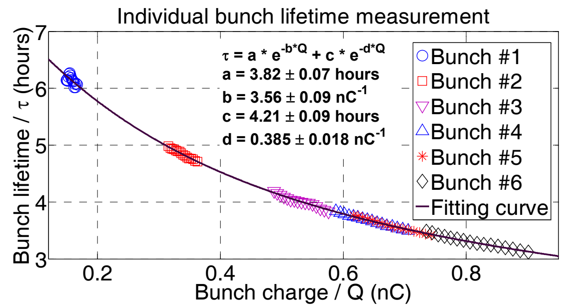

Figure 10: Bunch charge and corresponding lifetime

Lifetime analyze result shows that very small lifetime difference (0.08hrs) between bunch #4 & #5 can be identified easily in this experiment. The relationship of lifetime and bunch charge can be described by a double exponential function, which physical explanation is under study.

CONCLUSTION

BPM button pick and waveform digitizer based bunch charge monitor has been implemented in the SSRF storage ring. Bunch charge resolution is better than 0.5%. Linearity in the range from 0.2nC to 12nC is better than 0.5% using DCCT readings as reference. Charge measurement accuracy is good enough to calculate individual bunch lifetime. All requirements of top-up operation and machine study have been met.

ACKNOWLEDGEMENTS

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