Development of the bunch-by-bunch beam current acquisition system at SSRF

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Abstract In this paper, we report the development of a bunch-by-bunch beam current acquisition system. Through a waveform- reconstruction algorithm, the system realizes high equivalent sampling rate with a relatively low inherent rate. Based on the EPICS environment, information communication with other systems can be achieved. Preliminary test results in commissioning the SSRF storage ring show that the system can reconstruct the beam waveform of single bunch, providing a convenient and reliable method for the top-up operation in the future.

Key words EPICS, Top-up operation, Waveform-reconstruction, Shanghai Synchrotron Radiation Facility (SSRF)

1 Introduction

In order to provide users with stable beam, the Shanghai Synchrotron Radiation Facility (SSRF) in operation adopts top-up injection, a key technique to achieve high performance of a light source. With this technique, the synchrotron has one injection in several minutes, ensuring continuous lights for the users. On the premise that the charge of each beam bunch must be under precise control and the beam current shall not decay over time, staying in a constant level of better than 1%. Therefore, the way to realize high-precision measurement of beam bunch is of great importance to the quality of top-up injection.

2 Requirement analysis

At SSRF the beam current is measured with mainly DCCT (DC current transducer) and oscillograph. The DCCT measures average beam current, but it is not capable of measuring the charge of an individual bunch. An oscillograph measures the bunch charge. However, most oscillographs nowadays are under Windows operation system, resulting in unsatisfactory stability and flexibility in programming. Like other control systems in SSRF, the bunch-by-bunch system is based on EPICS (Experimental Physics and Industrial Control system)[1]. As a distributed and open-source platform, EPICS provides a uniform operator interface, which greatly reduces programming workload of the users and avoids bottleneck in data transferring. Researchers in accelerator engineering usually focus on applications based on Linux or vxWorks. Therefore, should a technical problem occur in EPICS applications with a Linux operation system, one can have more reference information than with a Windows system. In addition, high-sampling oscillographs are generally of 8-bit resolution, which has disparity with dedicated data acquisition cards available.

Based on our evaluation and experiences in the Australian Light Source[2], we chose the data acquisition device from Agilent Technologies. High-speed digitization of the beam signal is accomplished using an Acqiris DC252 8GS/s CompactPCI card housed in a 6 U CompactPCI crate. With this device, it is convenient for us to install a proper operation system (e.g. Linux), develop the corresponding drive routines for the acquisition card and acquire the data. DC252 has a 10-bit resolution, 2 GHz bandwidth and transfers data at sustained rates up

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to 400 MB/s to embedded computer, which meets our present needs.

3 Design and realization of the system

3.1 Waveform-reconstruction algorithm

The RF of SSRF is about 500 MHz, with the shortest interval of 2 ns between two bunches, and the width of bunch pulse after the extension by signal transmission network is merely hundreds of ps. Therefore, even if the acquisition rate is up to 8 GS/s, with channel-combined mode of the acquisition card, one can hardly acquire adequate points to reconstruct the beam waveform.

On condition that the hardware is unable to meet the requirements, the only way to solve this problem is by software. The idea of this algorithm is that mapping sample values of each circle to the corresponding time of the first circle with a sorting algorithm, making use of the relationship that radio frequency is not in direct portion to sampling rate[3], as shown in Fig.1.

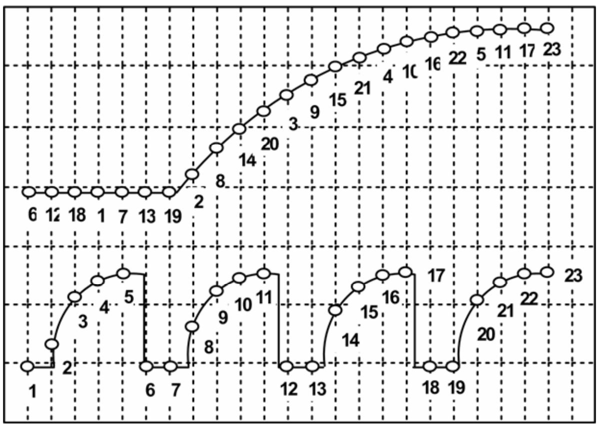

Fig.1 Sketch map of wave reconstruction.

Take an actual situation as an example. When RF of the storage ring is 499.654 MHz, one acquires 50 circles of beam current data at sampling rate of 8 GS/s. Given no measures taken, all data is supposed to be the sampling values of beam signal waveform in every 0.125 ns. On the consumption that the width of each beam pulse is 500 ps, one gets only four points to describe one pulse. However, by adopting the algorithm and calculating the moment of each sampling value after being mapped to the first cycle, 200 points will be obtained to describe the pulse and the reconstruction of beam waveform is relatively much easier with these points.

This algorithm improves the equivalent sampling rate of a given hardware, while there are certain prerequisites for this kind of application. Firstly, the signal repeatability should be good enough. Secondly, the sampling clock of acquisition card must be stable. Only if these two conditions are satisfied can the reconstructed waveform truly reflect the original signal.

As period of beam signal in a storage ring is determined by RF, which can be regarded as constant in one sampling process, the signal takes on stable periodicity. And the stability of sampling clock of data acquisition card is better than ± 2 ppm , which satisfies the requirement above.

Since approximately a million points need to be sorted and real-time result is requested, a dedicated sorting algorithm was developed to improve the computing efficiency in the implementation process of the waveform-reconstruction. This sorting algorithm is designed in consideration of the characteristics of the sampling time data. As shown in Fig.1, the data in one cycle are actually in the same order before and after sorting. Thus, a merging and sorting algorithm was adopted for n sets of orderly arrays (i.e. n circles of data). By merging the n sets of arrays, the n is smaller and smaller, and each set longer and longer. When n =1 and the length of this set becomes the total data to be sorted, this last array becomes an orderly one. In order to improve the computing efficiency, an array that gives out the number of points in each circle must be figured out in advance. Therefore, the number of sets is reduced from nearly a million to a hundred, which shortens the computing time from 20 ms to 10 ms (the average test result of ten times) when the sampling rate is 8 GS/s and the number of sample circles is 100.

As the reconstruction algorithm can result in unequal intervals of the acquisition and therefore affect the effects of the follow-up data processing, there is a need for analysis of the unequal degree. Table 1 lists the departure ratio of reconstructed time-axis data to the ideal equidistributed one under sampling rate of 8 GS/s. From this figure we can see that the departure ratio is better then one in a thousand in most cases, whose impact is weak enough to be ignored.

Table 1 Departure ratio of reconstructed time-axis to the ideal equidistributed one

Sample circles	RF Frequency / MHz				
	499.64	499.65	499.66	499.67	499.68
10	4.4×10^{-6}	2.3×10^{-6}	1.4×10^{-6}	3.6×10^{-6}	1.5×10^{-5}
30	3.7×10^{-5}	2.4×10^{-6}	8.9×10^{-6}	5.6×10^{-5}	1.5×10^{-4}
50	9.0×10^{-5}	3.4×10^{-6}	2.4×10^{-5}	1.8×10^{-4}	4.6×10^{-4}
80	2.2×10^{-4}	7.8×10^{-6}	5.9×10^{-5}	4.4×10^{-4}	1.1×10^{-3}

3.2 General design of the system

In order to realize the high-precision measurement of bunch-by-bunch beam current, we designed a system (Fig.2), with the data acquisition device from Agilent Technologies as the principle part[4]. The BPM is a four-pickup-button beam position monitor. After mix up of the signals from the BPM, a signal that reflects beam current information can be obtained. The mixed signal usually has large amplitude, and therefore must be attenuated before its transmission to next device. A precise adjustable attenuator is used to control the signal amplitude to appropriate extent. By completing the pretreatments, the data acquisition device is accessible by other subsystems *via* EPICS. The kernel of processing is done in the data acquisition device and after that the calculated result is accessible by other subsystems *via* EPICS.

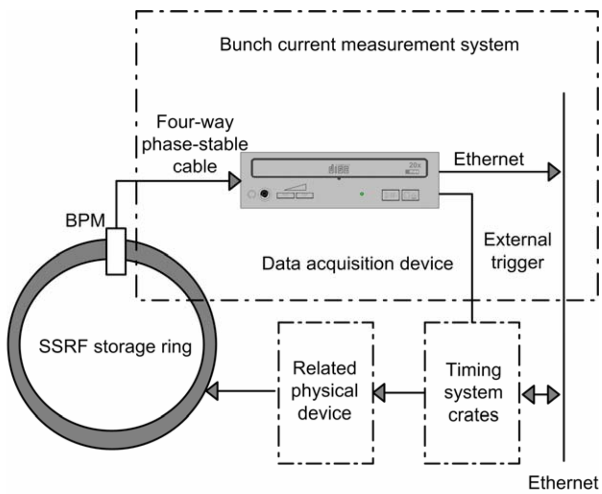

Fig.2 Principle diagram of beam current acquisition system at SSRF.

3.3 EPICS-based software development

As the data acquisition card and PC card has been encapsulated into CompactPCI crate by the manufacturer, our only task was to develop the driver routines that enables the PC card to identify the acquisition card, exempting from the bothering hardware installation[5].

After installing the Linux system, bottom driver for the acquisition card (available to check whether installation is successful by command lsmod) and EPICS environment, we could start developing driver program (the device support module in EPICS) that meets our actual demand in a new IOC (Input/Output Controller), referring to the programmer's guide[6]. Fig.3 shows the driver structure of acquisition card. The following main functions were called in the programing:

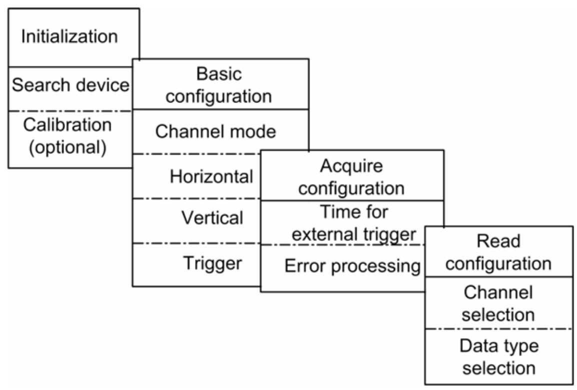

Fig.3 Driver structure of acquisition card.

(1) AcqrsD1_multiInstrAutoDefine(), automatically initializes all digitizers,
(2) AcqrsD1_InitWithOptions(), initializes an instrument with options,
(3) AcqrsD1_errorMessage(),translates an error code into a human readable form,
(4) AcqrsD1_configChannelCombination(), configures how many converters are to be used for which channels,
(5) AcqrsD1_configHorizontal(),
(6) AcqrsD1_configMemory(),
(7) AcqrsD1_configVertical(), is called twice in order to configure the vertical parameters of the signal channel and the external trigger respectively,
(8) AcqrsD1_configTrigClass(),

(9) AcqrsD1_configTrigSource(),
(10) AcqrsD1_acquire(), starts an acquisition,
(11) AcqrsD1_acqDone(), checks if the acquisition has terminated,
(12) AcqrsD1_forceTrig(), force a manual trigger,
(13) AcqrsD1_stopAcquisition().

The driver program was ported to EPICS IOC after debugging. The following records were added to the program: 1) corresponding records that needs adjusting on-line, 2) a sub-routine record to initialize the device and configure the settings of basic parameters, 3) waveform record to configure the acquisition mode and reading mode, 4) records that are acquired from IOCs in other systems in order to realize real-time waveform-reconstruction and charge-calibration. Fig.4 shows the structure of IOC, among which the records marked by the shadow have corresponding record supports.

The data processing part includes the elimination of singular points, waveform smoothing and discounting the effect of background noise. Finally, the processed data are sent to calculate the bunch-by-bunch beam current and charge.

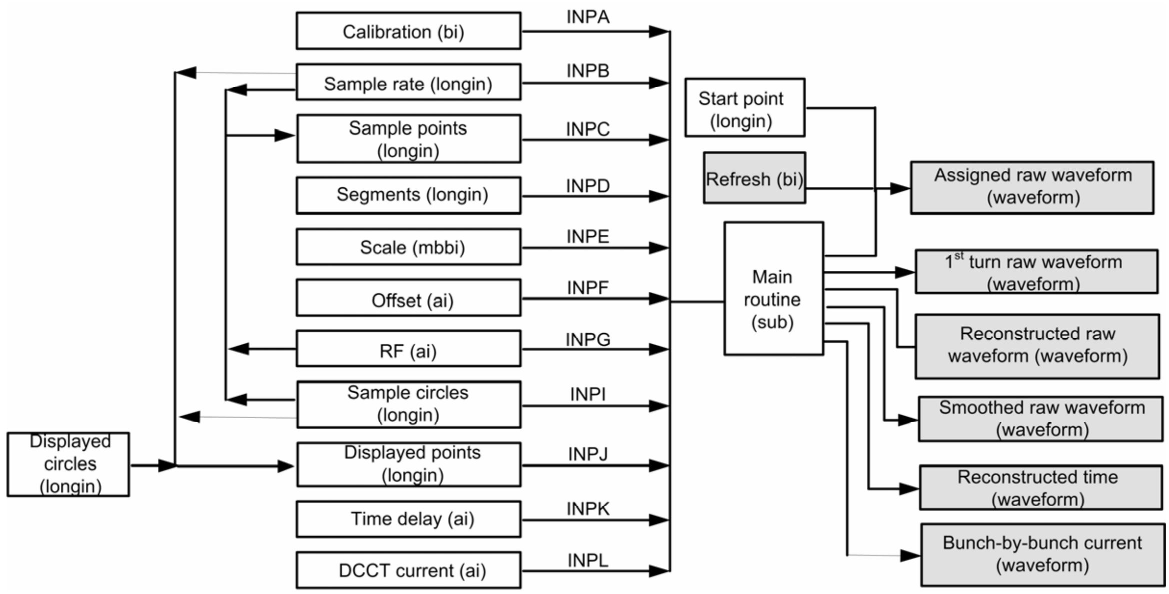

Fig.4 Record structure of IOC.

4 Application of the system

A preliminary test of this system done on the storage ring proved that expected result could be obtained.

Nine shots with a total beam current of 3.32 mA could be detected with a 20 dB attenuator (Fig.5), with the data acquisition in sampling rate of 8 GS/s and total sampling points of one million. The reconstructed waveform lasted 1.44 μs and the nine bunches were equidistantly distributed in the storage ring, with an interval of 0.144 μs between two bunches. Fig.6 shows the beam current waveform of Bunch 1 in Fig.5 detected by BPM. And the charges of Bunch 1–9 could be calculated as 0.55, 0.61, 0.56, 0.57, 0.58, 0.52, 0.54, 0.43 and 0.37, respectively using nc as a unit. The information is of help for top-up operation.

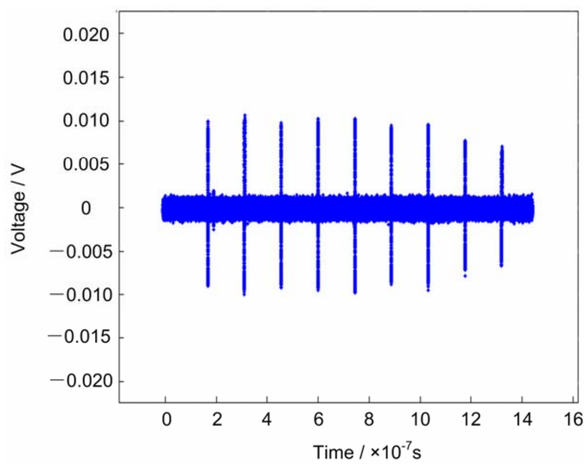

Fig.5 Beam bunch distribution in single turn at SSRF.

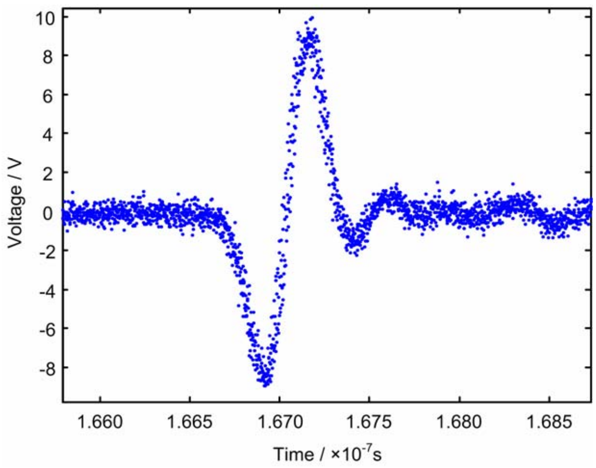

Fig.6 Reconstructed waveform of bunch 1 in Fig.5.

5 Conclusion

The test shows that this system and the beam current data attained by the above algorithm can well reflect the real waveform of bunch current and the system can run stably in a long time, which will satisfy the requirements of SSRF bunch-by-bunch current measurement in top-up injection mode in the future. And according to tests, the precision of this system can achieve 0.84%. As the system is operated on the Linux platform, all parameters in need can be adjusted on line according to the users' requirements. At the same time, other subsystem can access data in this system *via* CA (channel access), which makes the commissioning and operation of beam more convenient.

As a result of the flexibility of this system, we can develop other applications upon the driver layer in the future, such as the bunch-by-bunch life information, providing more measures of beam measurements during commissioning and operation in SSRF.

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