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BUNCH PURITY MEASUREMENT FOR SSRF*

B.Gao, L.W.Lai†, X.Q.Liu, S.S.Cao, Y.B.Leng

Shanghai Advanced Research Institute, Chinese Academy of Sciences, Shanghai, China

Abstract

SSRF is currently working on the beam line phase-II project, which has moved toward laser/X-ray pump-probe experiments. To quantify the bunch filling pattern and purity of the timing bunch, high precision beam charge measurement is necessary. Therefore, a bunch purity monitor based on the time-correlated single-photon counting techniques has been installed. A series of tests to evaluate the system have been carried out, according to these results, it is able to predict the system performance. The system has exceptionally good time resolution (a few pico seconds) and high dynamic range (more than seven orders of magnitude).

INTRODUCTION

Shanghai synchrotron radiation facility (SSRF) is a third-generation synchrotron radiation light source. It has completed a lot of research work in the 11 years since its establishment. The ongoing SSRF beamline phase-II project, the main construction content includes the construction of 16 beam lines and experimental stations, experimental auxiliary systems, light source performance expansion, etc. The project focuses on major scientific and technical issues in the fields of energy, environment, materials, condensed matter physics, earth sciences, chemistry and life sciences, with the goal of greatly improving the overall experimental capabilities of SSRF. It also has a lot of technology goals. To realize the third-generation synchrotron radiation light source experimental technology with near-limit resolution (time/space/energy/momentum), realize the innovative combination of photon energy regions and ultra-long station hall experimental technology, and realize online/offline comprehensive experimental capabilities [1].

At SSRF storage ring 720 RF buckets are available be populated with electrons. At the primary operational mode, 200 buckets are left empty, only 520 bunches in 4 bunch trains are injected to the storage ring. During the construction of the SSRF beamline phase-II project, the requirements for time-resolved experiments and special time structure filling modes are proposed. In order to meet this requirement, SSRF will be operated in hybrid mode. In the future, one of the buckets in the dark place will be populated with the timing bunch.

For the time-resolved experiment, in the detection window, there expects no other interference except for the synchronization light emitted by the probe bunch, that is, it is necessary to ensure that there are no electrons in the buckets around the timing bunch. These experiments typically require the pattern to be as exact as possible, with ideally no electrons in unwanted bucket/bunch positions: a typical ratio of 10^5 :1 between wanted/unwanted populations is desired this ratio often being referred to as the bunch purity [2]. However, in actual operation after the bunch is excited from the electron gun, due to acceleration errors during acceleration, part of the electrons will be captured by the RF buckets adjacent to the timing bunch, resulting in poor bunch purity; In addition, due to the effect of intra-beam scattering, there will also has a small amount of electrons in the adjacent buckets. Therefore, the users want to get more accurate bunch pattern, the purity measurement concept is born from this. Therefore, the injector and X-Y kicker magnets must be optimized to eliminate unwanted charges. At this time, the measurement of the bunch pattern provides a very important basis.

Historically, a dedicated BPM was used to monitor the filling pattern at SSRF and other light sources [3-6]. Although the beam charge monitor based on the BPM provides a rough monitoring of the bunch pattern, the resolution can reach to 0.02% (average measurement), this method is far from the requirement of purity measurement. Therefore, a more precise system is needed to measure the bunch purity of the timing bunch.

A bunch purity measurement system based on the photomultiplier tube and time-correlated single photon counter has been established at SSRF. This article introduces the construction of this system, the verification and optimization of system performance, and the related beam experiment results.

TIME-CORRELATED SINGLE PHOTON COUNTING

Time-correlated single photon counting (TCSPC) has the advantages of good time resolution, high sensitivity, high measurement accuracy, and large dynamic range. Photon counting technology is a digital technology that measures discrete photon pulses [7 ,8]. The intensity of the detected photocurrent is lower than the thermal noise level (10^{-14}W) of the photodetector itself at room temperature. It is difficult to use the usual DC detection method Extract it out. The photon counting method takes advantage of the natural discrete characteristics of the photon detector's output electrical signals under weak light irradiation, and uses pulse discrimination technology and digital counting technology to identify and extract extremely weak signals. The photomultiplier tube (PMT) outputs a fluctuating direct current when the input light intensity is relatively strong, and when the light is weak, the output photocurrent is no longer continuous, and when the input light is extremely

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† lailongwei@zjlab.org.cn

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weak, it will output discrete pulses. The output pulse of the multiplier tube can be identified and extracted by the single photon counter.

For the bunch purity measurement, the TCSPC techniques are common used in storage rings [2] [9-11]. The photon arrival time is measured relative to a clock pulse which is synchronized to the bunch revolution frequency via the storage ring RF system. The TCSPC system gives a histogram of the longitudinal distribution of the beam in the storage ring.

SYSTEM CONFIGURATION

Hardware

The TCSPC based bunch purity monitor was installed in the optics hunch of the SSRF diagnostic beamline. The whole hardware system includes: synchrotron radiation (SR) light extraction end, optical front end, photomultiplier tube, electronics front end, photon counter, etc.

The optics hutch of SSRF diagnostics beamline at about 17m from the source point, the wavelength of the extracted SR light is 532 nm ±5%. The purity measurement system is installed at the end of the beamline.

The front end includes: diaphragm, narrowband filter, and attenuator. The main purpose is to attenuate the synchronized light to be extremely weak to ensure that the PMT output signal is a pulse signal that can be recognized by the photon counter, the counting rate always be set to around 1 count per turn (1.44 µs). The beam current of SSRF is about 300 mA, the visible beam power is about 0.3mW or about 10^{15} photons/s. To reduce the counting rate, the power of SR light must be attenuated by 10 orders of magnitude.

The SR light will hit the PMT after being attenuated by the optical front end. The PMT of this system uses Hamamatsu's E3059-500 photomultiplier tube. The front end of its electronics is an amplifier.

The single photon counter uses the PicoHarp 300 (PicoQuant—http://www.pico-quant.com), bunch revolution frequency (694 kHz) signal generated by the storage ring timing system as its trigger signal. The interval between the photon reaching the detector and the trigger signal can be measured and counted. After a period of time (seconds or Minute level) to obtain the photon distribution curve, that is, the bunch charge distribution curve in the storage ring.

Schematic diagram of Bunch Purity Measurement System at SSRF is showed in Fig.1.

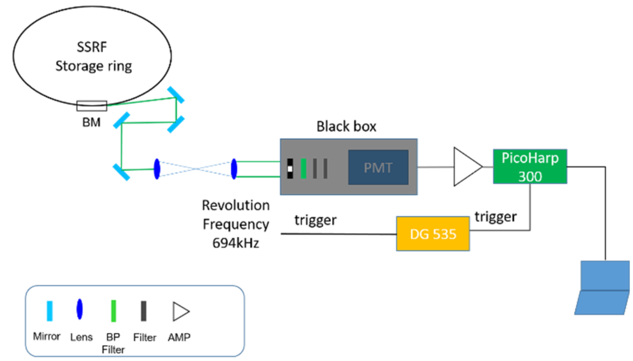

Figure 1: Schematic diagram of Bunch Purity Measurement System at SSRF.

A very important work in the single photon counting method based on time resolution is the removal of background light noise. Synchronous light needs to be attenuated to a single photon before entering the PMT. The presence of background light will directly affect the accuracy of purity measurement. Therefore, it is necessary to shield the background light. This system builds a black box on the optical platform to shield the background noise, as shown in the figure below in Figure 2.

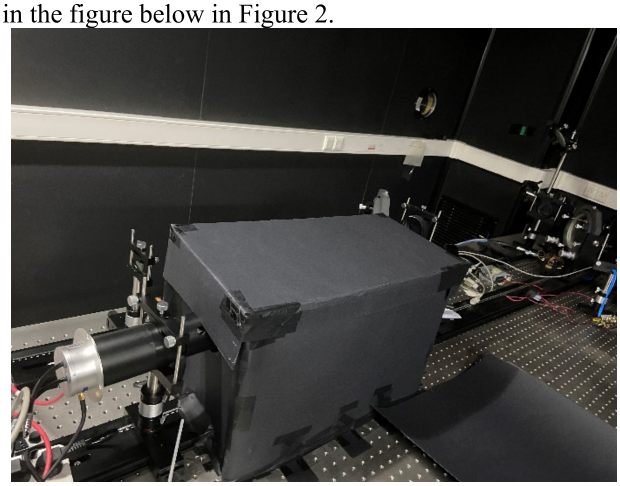

Figure 2: Black box to screen out the background light noise.

Software

The main function of the software is to set the photon counter parameters, data reading, data processing, and EPICS-based IOC and user interface.

The most important parameter setting of the photon counter is the time resolution. TCSPC system generates a histogram of binned arrival time measurements, the minimum binning window of "Pico-Harp 300" is 2ps and the maximum number of longitudinal binned windows in one trigger period is 65536. The trigger frequency of this system is 694 kHz (1.44 µs), so the time resolution of this system is set to 32 ps.

The data processing needs to extract the charge distribution. Since the longitudinal phase (arrival time) jitter of the SSRF under normal mode is a few ps, the bunch peak will be distributed in a single counting interval. Therefore the peak value extraction method is used to extract the charge

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of a single bunch. At the same time, in order to calibrate the beam charge, the system synchronously acquires the value of DCCT to realize the real-time calibration of the bunch charge.

In order to realize the connection with the main control network of the storage ring, the system builds an IOC based on EPICS, and builds a user interface control terminal in the control room, which can display the bunch charge distribution and purity data, as well as the configuration of system parameters, the interface is shown as Fig 3.

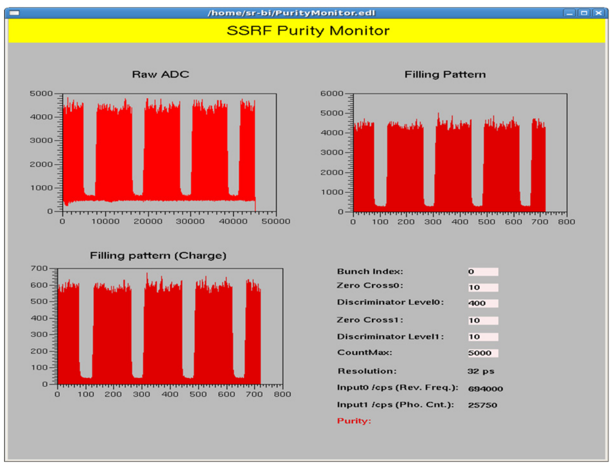

Figure 3: OPI of SSRF bunch purity measurement system.

SYSTEM PERFORMANCE EVALUATION

At present, the Shanghai Light Source has not been working in Hybrid mode, only 500 bunches distributed in 4 bunch trains. Bunch pattern measured by the purity monitor is showed in Fig 4.

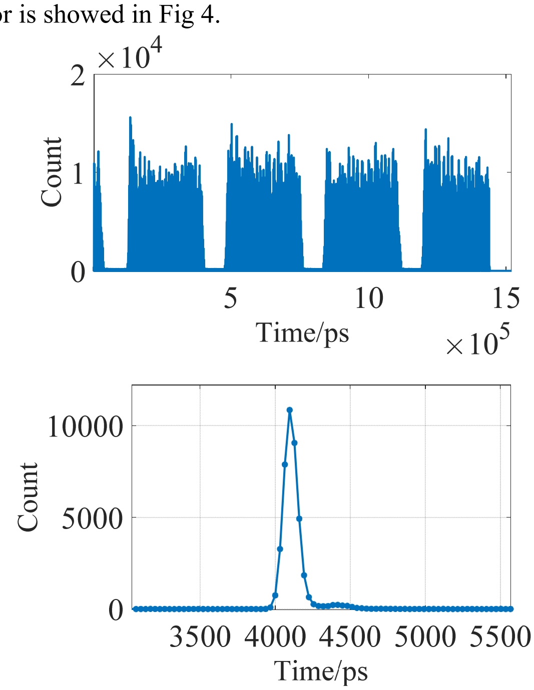

Figure 4: Bunch pattern measured by the SSRF bunch purity monitor at SSRF. Up: Filling pattern; Bottom: Charge distribution of a single bunch.

The SSRF bunch purification system has not been activated, hence the bunch purity cannot be guaranteed. Therefore, in order to evaluate the purity measurement resolution, this article applied for a special machine research time. Only two or three bunches were injected into the storage ring, so that electrons would not appear far away from the stored bunches. Bunch pattern (30 seconds accumulation) is showed in Fig.5.

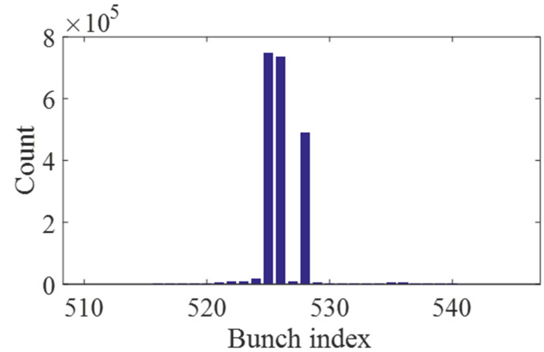

Figure 5: Bunch pattern from Bunch Purity Measurement System after only a few bunches have been injected into the storage ring.

Bunch purity is expressed by the ratio of the count of the highest bunch charge to the lowest count in the storage ring. After about 2 minutes of cumulative counting, the measured purity (ratio of wanted and unwanted populations) can reach $4*10^6$; after about 5 minutes of cumulative counting, the measured purity can reach $2*10^7$ level. According to this, time accumulation will make the purity measurement more accurate, and the data refresh time is a few minutes or even tens of seconds.

CONCLUSION

In this paper, the bunch purity measurement system is built based on the SSRF diagnostic line and time-correlated single photon counting technology. And through the performance evaluation experiment to complete the system performance evaluation. After evaluation, the time resolution of this system can reach to 32 ps; the bunch purity resolution can reach the order of 10^6 under the accumulation of 2 minutes, and the order of magnitude 10^7 under the accumulation of 5 minutes.

In the future, after the hybrid mode is realized, direct purity measurement will be achieved, and thanks to the time resolution bunch length measurement is planned to be studied based this new system.

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