FILLING PATTERN MEASUREMENT FOR THE TAIWAN LIGHT SOURCE

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Abstract

Filling pattern affects various operation performance of a synchrotron light source. Keeping a good filling pattern will improve beam stability. Measurement of the filling pattern is therefore essential in real-time during routine operation. As a result, a dedicated filling pattern measurement system has been implemented for Taiwan Light Source (TLS) for the future possible filling control or feedback. Measurement of the population distribution amount bunches in multi-bunch operation mode and purity of an isolated bunch by using time correlated single photon counting method are addressed. Related efforts are also summarized in this report.

INTRODUCTION

The filling pattern of the storage ring drastically affects the operation performance [1,2,3,4]. Control of the filling pattern has become one of serious considerations for a modern light source. There are many techniques to measure filling pattern in the synchrotron light source. Oscilloscope or fast digitizer with sampling rate at the bunch crossing rate or much larger than the bunch cross frequency can be used to observe signal from fast current transformer, sum signal of pickups or photo-detector of synchrotron light [1,2,3,4,5]. The approach to using single photon counting to measure single bunch purity is also widely used with practical dynamic range 10^6~10^7. To achieve more than 10^7 dynamic range [6], fast light shutter featured with the photon counting technique have been demonstrated to exceed 10^9~10^{10} dynamic range. Recently, great advances in the time-corrected single photon counting (TCSPC), for which the system adopts modern field programmable gate array (FPGA), create a novel design and make high counting rate can be possible. Multi-bunch measurement by the TCSPC system is also feasible [7,8,9]. There are two system setups required for routine measurement of the filling pattern at TLS. Continuous improvement is on-going.

FILLING PATTERN MEASUREMENT BY BPM SUM SIGNAL

A most simple and reliable approach with adequate dynamic range is to observe the sum signal of four button electrodes from a beam position monitor (BPM). The signal captured by the oscilloscope or fast digitizer is further analyzed to obtain the bunch current of each individual electron bunch. Accuracy is adequate for most of the applications.

Intensity of the sum signal from four button electrodes is proportional to the population of each bunch. Further processing of the observed signal is related to the bunch current. A dedicated filling pattern measurement system was set up as shown in Fig. 1 to satisfy the bunch current measurement requirements and possible filling pattern control in the future. The sum signal of BPM buttons is digitized by an Agilent 54832D 1 GHz oscilloscope, operated in an equivalent sampling mode with adequate average to improve the signal’s quality. The filling pattern server computer is connected to this oscilloscope via an Agilent E5810A LAN/GPIB gateway. The oscilloscope is trigger by the ring clock to define the bucket address. Analysis of the captured waveform can extract the relative intensities of all bunches. The raw bunches intensity data normalized by the precision averaged beam current read from DC current transformer (DCCT) is then used to obtain bunch-by-bunch current. Average about 16 or 32 traces can achieve better than 1% measurement accuracy within one second.

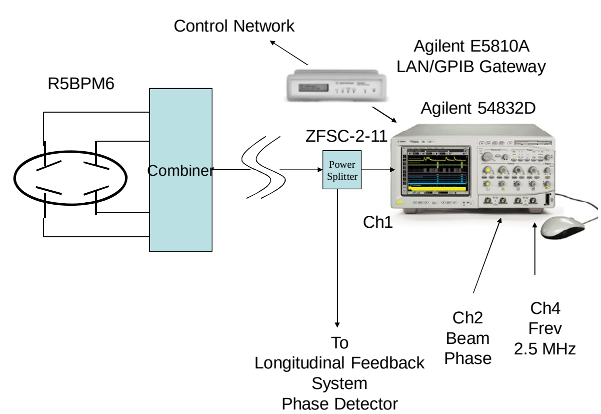

Figure 1: Pickups based bunch current measurement system.

Figure 2 shows the typical filling pattern with the stored beam current of 302 mA in a snapshot taken during top-up operation. This bunch current measurement has accuracy better than one percent. The 16 nsec structure and bunch current variation are associated with the present injection scheme. A short bunch train of about 30 bunches is used to fill the storage ring at this moment, and the bucket jump 8 bunches for each injection. This process is repeated during the top-up operation scenario, which results in bunch current variations per 16 nsec. Despite this fact, the filling pattern can be maintained within 5% during several days of continuous top-up operation. The consecutive bunch current in decay mode operation can be seen in Fig. 3. It can be used to study lifetime related effects of individual bunches.

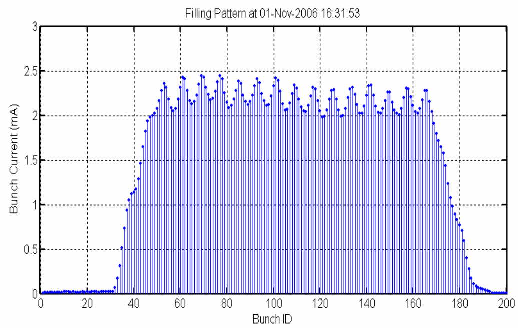

Figure 2: Measured bunch current of a snapshot during top-up operation. Total beam current is 302 mA.

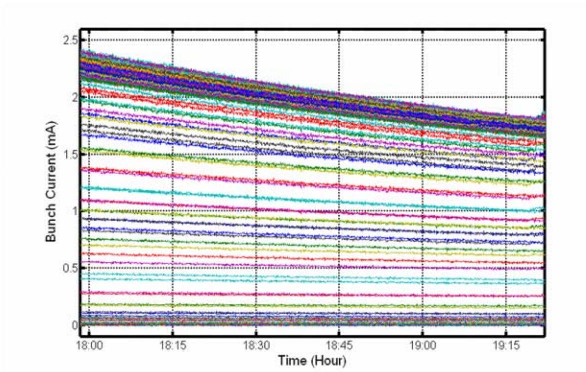

Figure 3: Bunch current decay during one hour period.

Due to the current hardware limitation, it is difficult to inject the storage ring by single bunch mode for top-up operation. The injector is also hard to produce the rectangular bunch train at this moment. The provisional approach is to adopt a short bunch train for the routine top-up injection and adjust the parameters of the injector to make it rectangular as close as possible. However, it slight varies from time by time. To keep a better filling pattern for the TLS operation, the current injection scheme is to inject the storage ring until the stored beam current reaches pre-define increased value and that each injection bucket address will jump by 16 nsec for the next injection. This is why the filling pattern has a 16 nsec cycle. This also can be observed on the beam spectrum. There is a proximate revolution harmonic peak near 62.5 MHz about the major multiple of the bunch cross frequency (500 MHz, 1 GHz, 1.5 GHz, … etc.). Whether it is good or not should need further study. The rising and the falling edges of the filling pattern is not so sharp but with gradually increase the bunch current from zero to the bunch current more than 2 mA per bunch. This will be a standard operation mode before further improvement.

Since the lifetime is dominated by the intra bunch scattering effect, lifetime of each bunch will differ from bunch to bunch due to its population distribution. Fig. 4 shows a typical bunch population distribution and its corresponding bunch lifetime. This can be understood that the lifetime is larger for the smaller bunch current, and the bunch lifetime is smaller for the larger bunch current due to Touschek effect. Fig. 5 shows bunch current corresponding to its bunch lifetime.

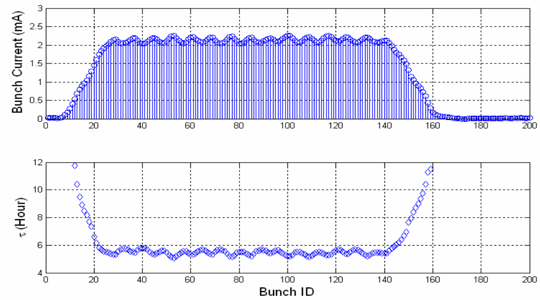

Figure 4: The above figure is shown the bunch population distribution at the instance for lifetime calculation. Distribution of the bunch lifetime is shown in the below figure.

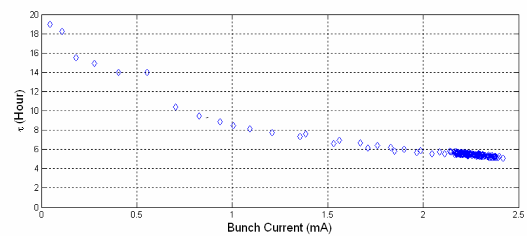

Figure 5: The bunch current population distribution at the instance for lifetime estimate.

FILLING PATTERN MEASUREMENT BY TCSPC

Another approach for multi-bunch filling pattern and the isolated bunch purity measurement is the time correlated single photon counting technique. New generation stand-alone FPGA time-to digital converter based photon counter (PicoHarp 300 [10]) for the time correlated single photon counting is adopted. The design of the PicoHarp 300 is different from conventional TCSPC systems where the tasks of the time-to-amplitude converter (TAC) and the analog-to-digital converter (ADC) are carried out by the so called time-to-digital converter (TDC). In brief, the strength of the design is to exploit the unprocessed independent arrival times as a continuous stream and permit uninterrupted data collection. The PicoQuant provides the Matlab scripts and firmware update for DLL support to acquire the data from PicoHarp300 via USB interface on Windows system.

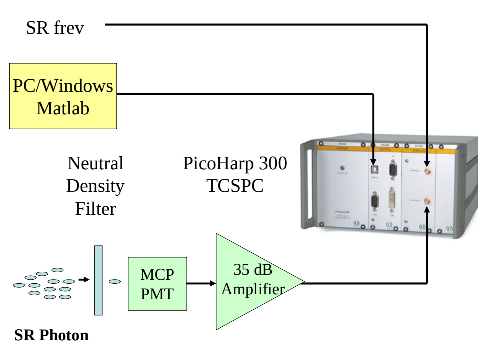

Figure 6: Setup of the time correlated single photon counting system.

The experimental setup is shown in Fig. 6. A Hamamatsu MCP-PMT R3809U-50 microchannel plate photomultiplier (MCP-PMT) is used to detect the synchrotron light. A neutral density filter is used to attenuate the incident light to provide a single photon event per revolution time. The revolution trigger is applied to the channel 0. The signal form MCP-PMT is amplifier by a 35 dB amplifier and fed into channel 1. Both signals play the roles of start and stop of the TDC.

The typical measurement result of multi-bunch filling pattern by TCSPC is shown in Fig. 7. The display is in linear scale to reveal its population distribution. The below figure shows many small bunched at the leading fridge of the filling pattern. The tailing fridge is the same. To have e better filling pattern, need further efforts to improve the injector. The display is also shown in log scale in Fig. 8 for four consecutive bunches. It is shown clearly that the dynamic range is about 10^3 in multi-bunch measurement. Since the machine is in routine top-up multi-bunch operation, it has no adequate window to test isolated bunch purity measurement. However, it is expected that the dynamic range will be more than the 10^6 similar with the results in reference [6,7].

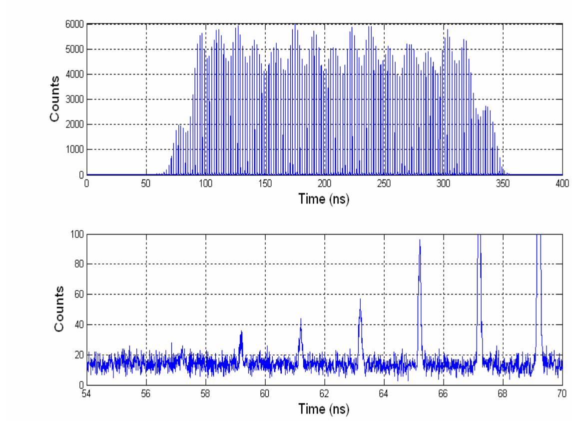

Figure 7: Filling pattern measured by the TCSPC. Vertical scale is in linear scale. The stored beam current is 301 mA. The above figure is the filling pattern of the whole ring, the below figure show very small bunches existed at the leading fridge of the major bunch train.

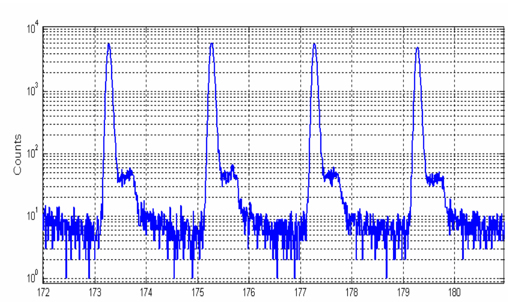

Figure 8: Filling pattern measured by the TCPCS. The vertical axis is in log scale.

FUTURE PLANS

Filling pattern measurement by the sum signal of the BPM button electrodes and synchrotron radiation by TCSPC system is implemented for routine filling pattern observation at the TLS. The oscilloscope is done by a GPIB interface. The preliminary test of the TCSPC system is underway, it is planned that integration with the EPICS environment in Windows or Linux system will be performed soon. All of efforts will directly contribute to the newly proposed 3 GeV synchrotron light source (Taiwan Photo Source, TPS). The baseline design of the filling pattern measurement include BPM sum signal observation system by LXI based EPICS oscilloscope and a dedicated TCSPC system accompany with MCP-PMT detector for visible light monitoring and X-ray APD for X-ray direct detection as auxiliary system. Both systems will support EPICS. It will be working at day one. X-ray APD detector will be also adopted. Top-up injection and filling pattern control infrastructure will be available soon after the TPS commissioning.

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