BEAM INSTRUMENTATION SYSTEM OPTIMIZATION FOR TOP-UP OPERATION IN SSRF*

Y.B. Yan, Y.B. Leng#, W.M. Zhou, L.Y. Yu
SINAP, Shanghai, P.R. China

Abstract

In order to offer higher average brightness and more stable photon beam, top-up injection mode is scheduled for daily operation in SSRF. Several critical beam parameters, such as filling pattern, average current, beam lifetime and transfer efficiency, need to be measured precisely and reliably, and few interlock logics need to be added into machine protection system with top-up mode. Several hardware and software optimizations of beam instrumentation for this purpose will be introduced in this paper.

OVERVIEW

Shanghai Synchrotron Radiation Facility (SSRF) is a third generation light source, which located at Shanghai, P.R. China. Since December 2012, SSRF has operated in top-up mode for user experiments, which was a milestone of SSRF in facility performance improvements. The top-up injections are made continuously at the time interval of about 10 minutes. Each injection cycle takes about 10 seconds and the bunch change uniformity of the 500 bunch train is better than 95%.

For the top-up operation, several beam parameters, such as filling pattern, average current, beam lifetime and transfer efficiency, need to be measured precisely. Some extra interlock logics were added into machine protection system. This paper will introduce the details of hardware and software optimizations of beam instrumentation for the purpose above.

FILLING PATTERN

Bunch charge uniformity control is very important for the top-up operation. The quality mainly depends on the precision of bunch charge & filling pattern measurement. This measurement can be realized by direct sampling BPM pickup signal [1-3] or synchrotron radiation signal [4]. Due to easy configuration and good linearity button, BPM pickups and PXI waveform digitizer based solution have been adopted [5].

Hardware

The system consists of beam pickups, RF front end, waveform digitizer and PXI IOC. The raw pickup signals from four button BPMs are combined in the front end chassis, which is composed of four delay coaxial cables, a power combiner (BW1-1000MHz), and a fixed attenuator. The coaxial cables are used for compensating the delay of difference signals. The power combiner produces position independent intensity signal. The attenuator is used for adjusting the output signal level. The waveform digitizer is DC252 from Acqiris (Agilent Technologies Inc), with 2GHz analog bandwidth, 8GHz sampling rate and 10bits resolution.

The real-time sampling waveform of 50 turns can be recorded, but it is not good enough to determine the peak value of single shot. The samples are shifted through the buckets, due to the slight difference between the sampling frequency and the revolution frequency of accelerator. A kind of waveform rebuilding technique is used to increase the time resolution. The effective sampling rate can be extended to 400GHz, which overlays multi turns data into single turn.

Performance

In order to calibrate the scaling factor and evaluate the performance, several dedicated beam experiments were carried out in the storage ring. The data of DCCT was used as reference.

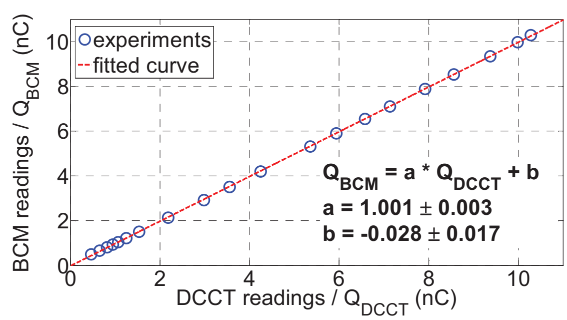

Figure 1: The linearity of beam charge measurement

The beam was injected step by step from 0.2mA to 7mA with single bunch filling pattern. In the full range the linearity is better than 0.5%.

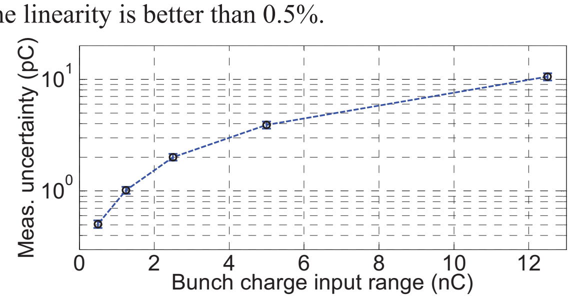

Figure 2: The dynamic range and charge resolution.

As shown in the figure above, the relative measurement uncertainty is better than 0.1%.

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# lengyongbin@sinap.ac.cn

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BEAM CURRENT AND LIFTTIME

The beam current and lifetime are key parameters for the circular accelerator. In the storage ring of SSRF, there are two high precision DC current monitors (DCCT), which are installed at Cell 15 and Cell 17.

Hardware

The NPCT175 (New Parameter Current Transformer) sensor from the Bergoz was selected as the monitor. The DAQ is based on the PXI platform, as its compatibility, stability, availability for various of IO boards and the CPU computing capability. The NI 4070 was selected, which is a 6½-digit PXI digital multimeter (DMM).

Current Interlock

For the safe top-up operation, the beam current is hard-interlocked, which is obtained via the comparison of the raw signal, as shown in Fig. 3.

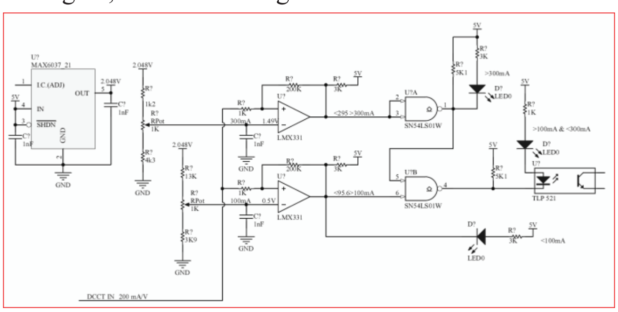

Figure 3: Beam current interlock module.

The enable signal will be output when the beam current is between 100mA and 300mA, and disable signal when the beam current is below 100mA or above 300mA. If the module is breakdown, the top-up mode can not be applied. Beside this hard-interlocked signal, the software signal is also interlocked, which is used for dual safety.

Software Optimization

To improve the reliability and stability of the whole system, some software optimizations were carried out [6-7], the platform transplant and redundancy architecture.

The old IOC was based on the Windows platform. The LabVIEW and EPICS shared memory IOCore were used, as shown in Fig. 4.

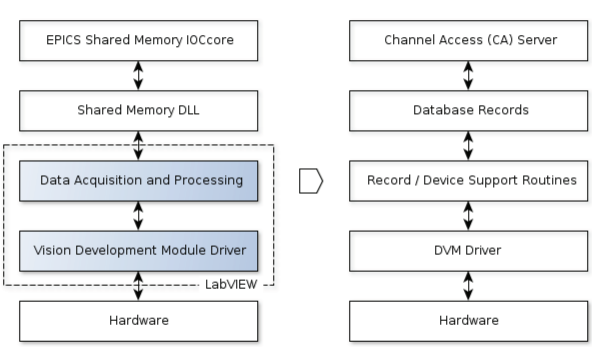

Figure 4: The block diagram of DCCT IOC.

A lot of problems were revealed gradually during the past several years, such as buffer overflow, core crashed, and the stability of operation system itself.

The new IOC is based on the Linux platform. The whole IOC program was written using the C++ language. The raw signal waveform from the DVM are acquired at 10kHz sampling rate, and the beam current is provided by averaging at 2Hz trigger frequency.

Redundancy

The redundancy architecture was designed mainly for the long-term operation stability, It is dual-system hot backup, and can also be used for other purposes, such as noise avoidance [8], online maintenance and so on. The architecture is shown in Fig. 5.

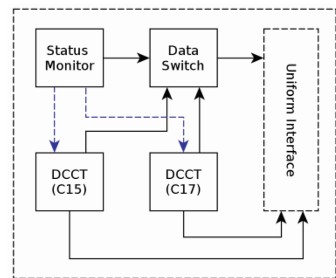

Figure 5: The DCCT redundancy architecture.

With the efforts above, the reliability and stability have been significantly improved. Up to now, there is no any failure occurs.

Lifetime

The beam lifetime is the time interval after which the intensity of the beam has reached 1/e of its initial value. For the decay mode, a buffer of measured beam currents is kept and a least-squares fit is made [9]. The buffer is up to two minutes. For the top-up mode, the algorithm for lifetime calculations is adjusted with the rapid response time. Two pieces of the current data are buffered to find the slope of the beam current versus time. The first piece is fixed, which is selected after every injection cycle. The second piece is mobile, which is selected from the appointed current lower than the average value of the first pieces. In this case, the accuracy of lifetime calculation can be improved gradually.

The decay and top-up algorithm is switched according the operation mode. During the top-up mode, the lifetime is soft-interlocked. The threshold value is 10 hours.

Current Alarm

Beside the hard & soft interlocked signal, a dedicated alarm signal of beam current is introduced, which is used for the unpredictable failures during the top-up operation. It won't affect the mode, just providing the tacousto-optic alarm. There are two required conditions:

- ✧ The beam current is lower than the setting value.
- ✧ The machine is operated in top-up mode.

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TRANSFER EFFICIENCY

The high transfer efficiency is necessary for safety top-up operation. There are many methods for the efficiency calculation. For the storage ring, the injected current can be obtained from the DCCT or BPM. The feasibility of beam current measurement using BPM intensity signal was studied, including the method, the performance and the limitation [10]. For the injector, the ICT or BPM which should been calibrated, can be used.

During the daily operation of SSRF, the combination of DCCT on the storage ring and BPM on the LTB & BTS (Linac to Booster & Booster to Storage Ring transform line) are selected. Other options are also available and can be switched according to the actual demand. The block diagram of whole system is shown in Fig. 6.

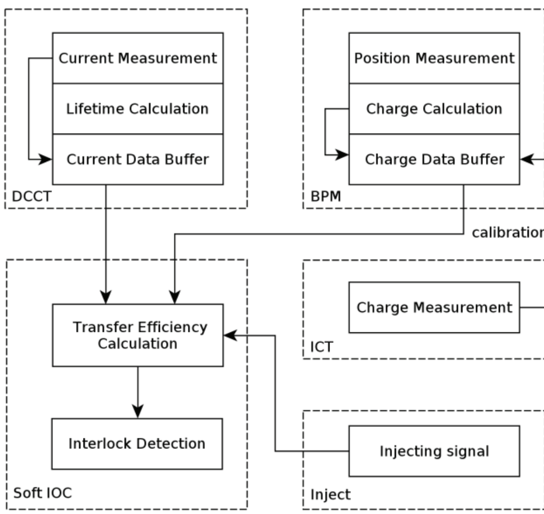

Figure 6: The block diagram of transfer efficiency measurement.

The system bases on soft IOC and Matlab is used as the background processing engine. They communicate via the shared memory interface, which is implemented as a dynamic linked library [11]. Matlab applications obtain raw data from shared memory, process, and store back the results, which can be accessed by EPICS CA clients.

The raw ADC signal of BPM on LTB is shown in Fig. 7.

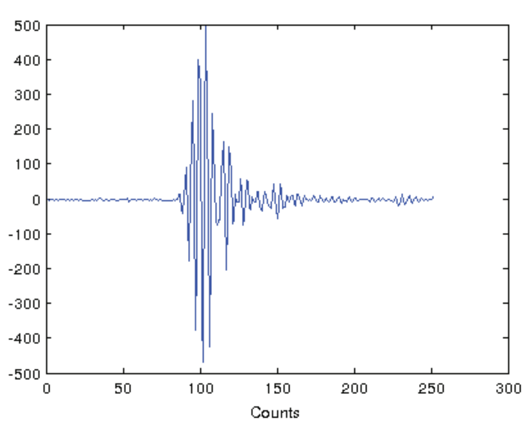

Figure 7: The BPM raw ADC signal.

Compared with the ICT monitor, the BPM signal has powerful anti-disturbing capability. Three methods can be used for the charge estimation, which are sum the square of BPM raw ADC data, the Hilbert transform or the frequency domain processing. In our case, the sum of squares is chosen, which should be calibrated via the neighbouring ICT.

CONCLUSION

After the hardware and software optimizations above, the stability of beam instrumentation have been improved significantly. The related beam parameters are measured precisely, and the necessary interlocks are implemented effectively, which play important roles during the top-up operation.

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