Development and application of the new BPM system data processing program at Hefei light source

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Abstract A data processing program has been applied for the new beam position monitor (BPM) system of the storage ring at Hefei Light Source (HLS). The new BPM system in the upgrade project will be equipped with Libera Brilliance BPM processors to replace the old Bergoz MX-BPM processors. The embedded Linux system on Libera has completed some important work, including instrument status check，data acquisition, position calculation, EPICS IOC data release，and so on. A new EPICS record type has been developed to recalculate the beam position with log-ratio method. The property of the new position data was analyzed in the time and frequency domain. The results show that the rms value of beam position measurement resolution can be up to submicron. Preliminary studies have been carried out on the measurement of the tune and the beam lifetime with this new BPM system.

Key words BPM, EPICS IOC, Libera Brilliance, Log-ratio method

1 Introduction

The beam position is one of the important parameters of the accelerators. An upgrade project of HLS is in progress to improve the beam quality and obtain a beam current with lower emittance and higher intensity. It is required that the resolution of the new BPM system must be at the macron level for the beam position measurement.

Libera instruments produced by Instrumentation Technologies (IT) of Slovenia is widely used in the accelerators around the world, such as Diamond Light Source, SSRF, BEPC II, KEK, etc [1-4]. The Libera Brilliance is a new generation digital beam position processor instrument and 16 sets will be installed on the new storage ring BPM system to replace the existing processor equipments. The FPGA in Libera Brilliance is able to acquire the four electrode signals and calculate the beam position by difference/sum ratio method. A run-time database based on EPICS IOC is used to release results in the embedded GNU/Linux system running on the Single Board Computer (SBC).

A soft IOC is developed to receive necessary data and calculate beam position with log-ratio method. The features of the position are studied in time and frequency domain, including standard deviation, minimal and maximal position, FFT (Fast Fourier Transform), peak search, digital band pass filter, signal correlation, etc. All the operations are done on an industrial personal computer (IPC). Client program in the LAN can get the results conveniently with a third-party plug-ins, such as CaLab and MCA, etc. At the same time, the BPM data also can be used in beam physics studies, such as measurement of tune, beam current , life time, beam position feedback and phase space measurement, etc.

2 Main functions in the libera Brilliance

The software in the Libera Brilliance mainly consists of the two components: embedded FPGA program and SBC software based on a standard Linux kernel 2.6. The EPICS server, real-time I/O control and remote interface can communicate with the FPGA through the CSPI (Control System Programming Interface) layer and GNU/Linux kernel drivers conveniently. The

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Received date: 2012-06-25

EPICS client and other user programs can be connected to the system by Ethernet easily.

Commonly the Linux shell command is used directly in Libera server to acquire and save data from Libera FPGA, which is basic but discontinuous in time scale. A better way is to use an EPICS IOC to supply a real-time database. It can provide continuous data for a long time, which is necessary for many studies.

The data sampled with ADCs are processed in four identical channels. Each channel consists of a digital down converter (DDC), additional filtering, decimation and position calculation by difference/sum ratio method in the FPGA program, difference/sum ratio formula is:

$$\begin{cases} X = K_{\Delta/\Sigma,x} \dfrac{(V_A+V_D)-(V_B+V_C)}{V_A+V_B+V_C+V_D} - X_{\text{offset}} \\ Y = K_{\Delta/\Sigma,y} \dfrac{(V_A+V_B)-(V_C+V_D)}{V_A+V_B+V_C+V_D} - X_{\text{offset}} \end{cases} \tag{1}$$

Button signals and position results were transported into the EPICS IOC for releasing. Other client programs in the LAN could get and save the data for off-line analysis. There are several main data paths in use:

ADC raw data: ADC rate buffer contains raw amplitudes from BPM. ADC raw data is directly acquired from ADCs at ADC sampling frequency (about 117 MHz) on trigger.

Turn-by-Turn (TBT) and First turn (FT) data: TBT data (4.533 MHz) is filled continuously into circular buffer on the SBC. It is useful to study the beam position and related parameters in a large time scale. Data can be acquired on demand or on trigger. Acquisition of first turns must be done on trigger. TBT acquisition returns amplitudes or raw data.

Fast Acquisition (FA) data: FA data is continuous data at approximately 10 kHz for fast feedback calculation and for interlock calculation.

Slow Acquisition (SA) data: SA data is a stream with high precision derived from FA data at rate 10 Hz (Figs.1−4). It is defined by software filtering and decimation, which is useful for closed orbit beam position studies.

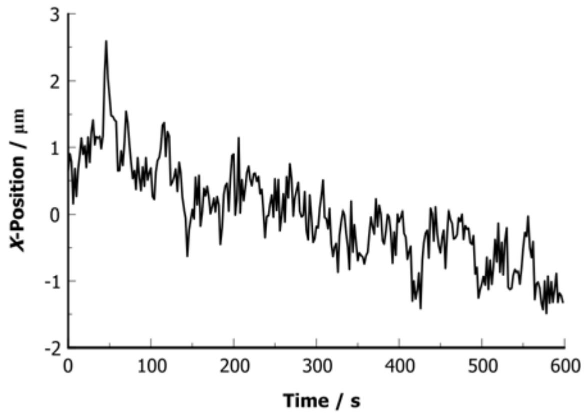

Fig.1 SA horizontal beam position.

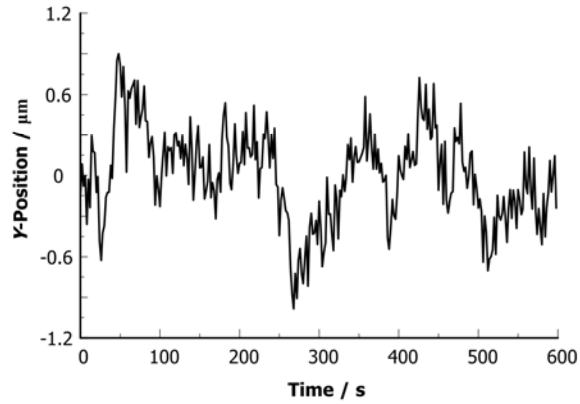

Fig.2 SA vertical beam position.

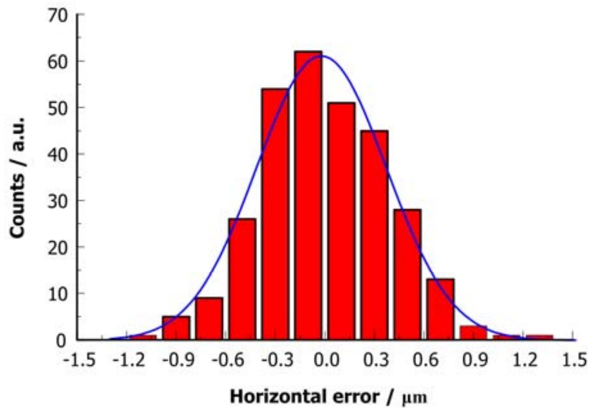

Fig.3 SA horizontal beam position error distribution when rms is 0.39 m.

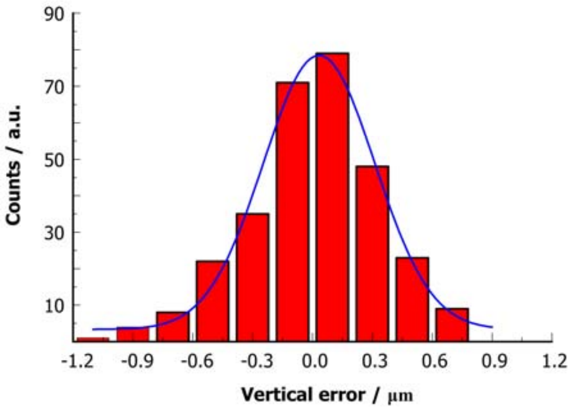

Fig.4 SA vertical beam position error distribution when rms is 0.33 μm.

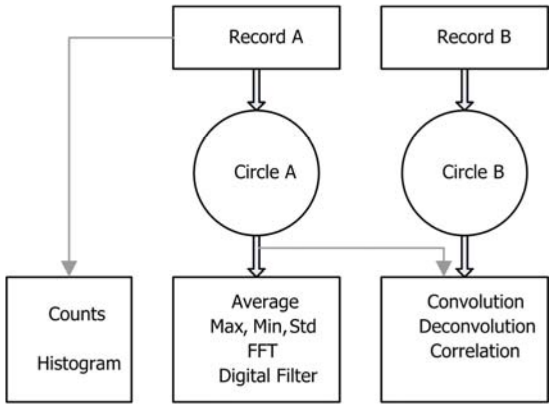

Fig. 5 New record type block diagram.

3 Program development in the IPC

A soft IOC is used to get button signals and achieve needed calculations for all Libera instruments in an IPC.

The so-called soft IOC is an EPICS IOC record whose value is only from command operation or other records but not hardware. The soft IOC can run on any computer in the LAN with good portability.

The log-ratio method was used to recalculate the beam position with the button signal data in the buffer, which has a higher sensitivity and greater linear range than the difference/sum ratio method. The recalculation formula is:

$$\begin{cases} X = K_{\log,x} \log\left(\dfrac{V_\mathrm{A}+V_\mathrm{D}}{V_\mathrm{B}+V_\mathrm{C}}\right) - X_\mathrm{offset} \\ Y = K_{\log,y} \log\left(\dfrac{V_\mathrm{A}+V_\mathrm{B}}{V_\mathrm{C}+V_\mathrm{D}}\right) - X_\mathrm{offset} \end{cases} \tag{2}$$

3.1 New record type

In order to achieve beam position recalculation and relative analysis in the time and frequency domain, a new EPICS record type has been developed (Fig.5). This record type is based on the synApps calc module of APS[5]. In order to achieve above goals, the needed migration algorithms include FFT, convolution and deconvolution, correlation and digital band pass filter. The updated record type with good versatility and scalability can be used by standard EPICS IOC programs.

3.2 Database

There are two main database files created with VDCT (visual database configuration tool).

Data1.db defined some important environment variables and made several basic calculations for data in different mode, such as ADCCW, TBT, PM, SA. Each position record had six input records, including signals from 4 buttons, gain coefficient and position offset.

Data2.db finished analysis in the time and frequency domain. The size of data is too large from Libera *via* CA (Channel Access) protocol. Delay and shift operations were used to reshape each button signal's data to an appropriate sub array. The sub arrays were stored in the two circle buffers for further processing. A serial of calculations were done in respective record to study the time and frequency domain features.

In order to increase the versatility, several macros were used in the database template files. With specific configuration file, special data in selected Libera could be analyzed with corresponding macro when loading database in the start-up script of the soft IOC.

During the early debugging, it is important to save the change of special parameters. Some important parameters, such as the gain coefficient and position offset, were saved and restored with an auto save module in the IOC. The parameters were loaded from stored files when the IOC started. A new file would be created if there were no stored file. And the changed values could be written into the stored files as a backup file.

3.3 Display

EDM (EPICS display manager) is a simple and convenient tool to create and edit display content for instrument debugging under GNU/Linux. The EDM panels are used to set parameters during running and show important machine status and results. As needed for the soft IOC, all functions were integrated into a single interface and each module could be opened as an independent subroutine.

Fig.6 showed the raw waveform of vertical position, the spectrum and the statistics results. 1024 circles data was stored and updated in the buffer for analysis. The interested statistics parameters can be changed easily.

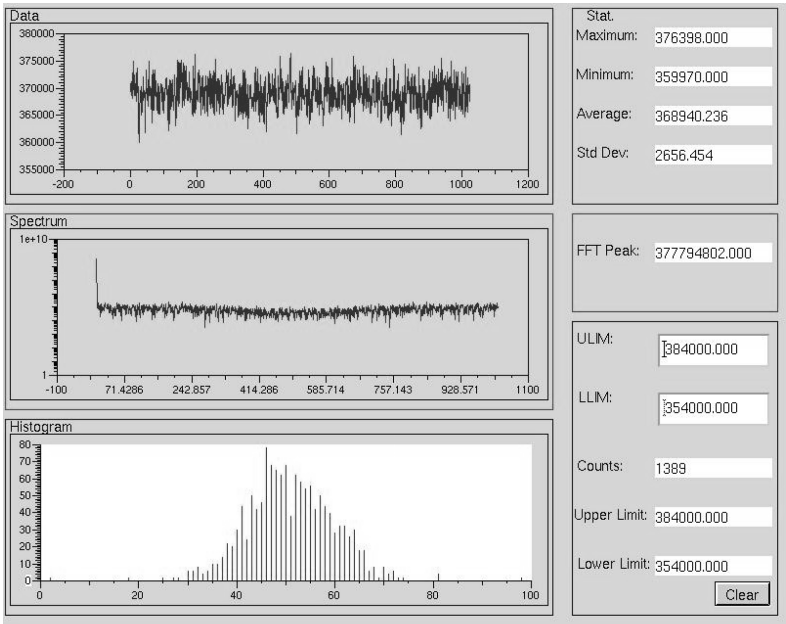

Fig. 6 EDM panel for statistics results.

4 Experiments and data analysis

The data processing program introduced above has been tested on-line in the HLS BPM system successfully. There are some basic and important experimental results as following.

4.1 Tune measurement of injection

During the injection process, the beam is not stable. The tune can be calculated easily by spectrum analysis with TBT data. After collecting the TBT data for a long time, the change of tune during the injection can be measured.

Figure 7 showed the change of tune in the resonance diagram. In order to maintain the beam stability, the change should be as small as possible to avoid crossing some dangerous resonant lines. In this picture, the tune change is 0.0117 in horizontal direction and 0.0049 in vertical direction.

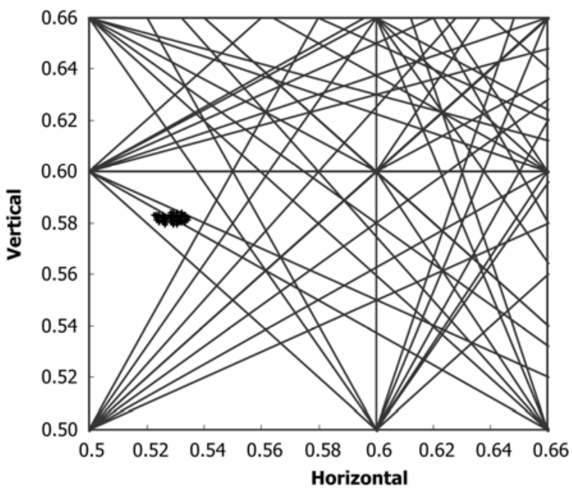

Fig.7 Change of tune during injection.

4.2 Tune measurement with white noise excitation

During the normal operation, the tune cannot be observed directly because the beam instability is suppressed. Usually an external excitation source is used to kick the beam to observe the tune[6]. A white noise signal derived from a FPGA board was chosen as the excitation source in this experiment. Fig.8 showed the block diagram.

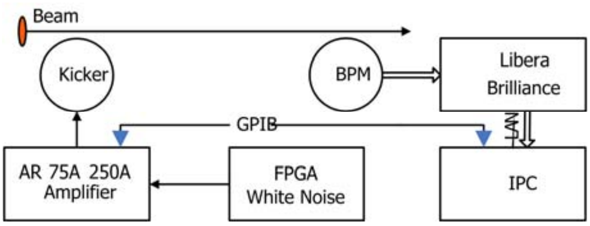

Fig.8 Block diagram of tune measurement with white noise.

The results of tune measurement are showed in Figs.9 and 10. The fractional of tune is 0.5479 in horizontal direction and 0.585 in vertical direction.

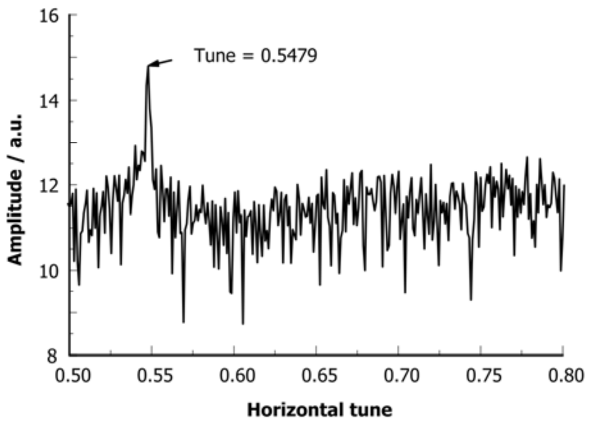

Fig.9 Horizontal tune.

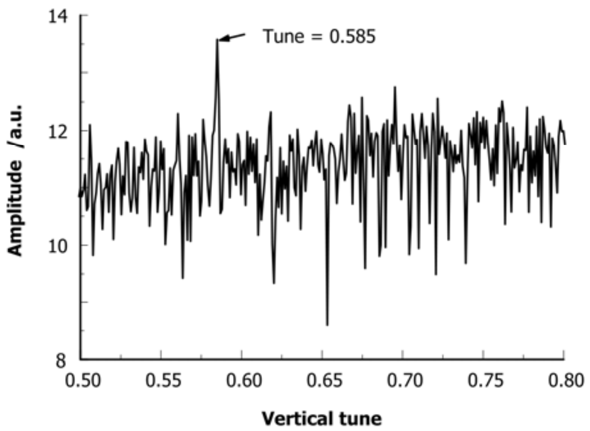

Fig.10 Vertical tune.

4.3 Beam current measurement

The relationship between the sum of the four buttons' signals and the beam current is approximately linear when the beam position and some other factors are not considered[7]. The beam current calibration coefficient for BPM can be calculated with the high-precision button signals and the DCCT (DC current transformer) value. Fig.11 shows good linear between the two variables.

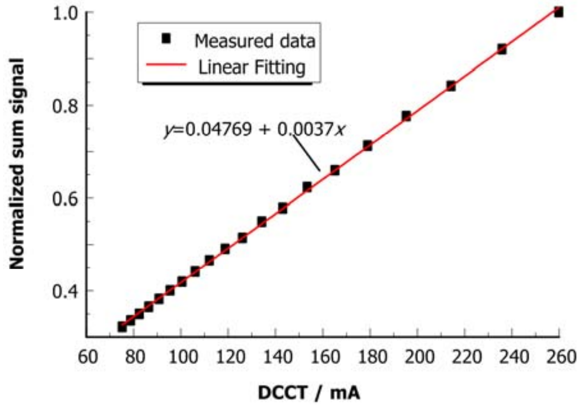

Fig.11 Sum signal *vs.* DCCT current.

4.4 Lifetime measurement

The beam DC current is exponential decay with time in the storage ring. The beam DC current can be expressed as $I_B(t)=I_{B0}e^{-t/\tau}$, where τ is the beam lifetime. So the lifetime can be estimated with the high-precision fitted sum signal. Fig.12 shows the lifetime calculated with sum signal and DCCT current. The two curves are similar and the difference is caused by the bunch lengthening effect[8].

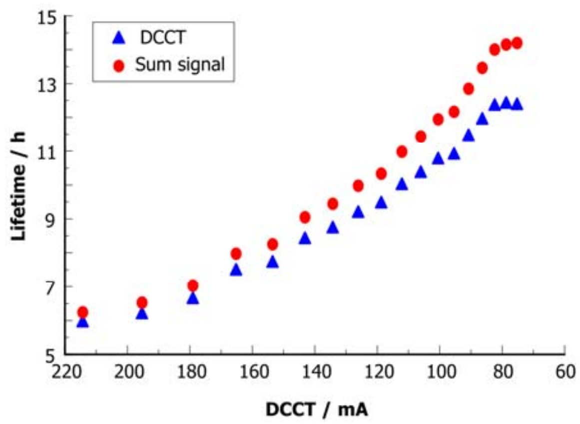

Fig.12 Beam lifetime.

5 Conclusion

The data processing soft IOC for the new BPM system has been running stably for a long time. The new EPICS record type shows good compatibility in use. The experimental results show a good performance and high precision on the storage ring. The rms value of beam position measurement is 0.39 μm in the horizontal direction and 0.33 μm in the vertical direction in ten minutes, which is qualified for the upgrade project. The fractional of tune is 0.5479 in horizontal direction and 0.585 in vertical direction for normal operation. More studies will be done with beam current calibration coefficient of BPM and beam lifetime measurement.

References

1 Abbott M, Rehm G, *et al.* The DIAMOND Light Source Control System Interface to the Libera Electron Beam Position Monitors. Proceedings of ICALEPCS2009, Kobe, Japan, 2009, 694−696.

2 Yan Y B, Leng Y B. Soft Ioc Application in SSRF Beam Diagnostics System. Proceedings of IPAC'10, Kyoto, Japan, 2010, 2707−2709.

3 Cao J S, Ma L, Ma H Z, *et al.* Application of Libera BPM at BEPC II for the early commissioning. Chin Phys C, 2008.3, **32(Suppl.):** 102-1-4.

4 Cheng W X, Obina T. Analysis of Transverse Beam Oscillation at Photon Factory. Proceedings of PAC07, Albuquerque, New Mexico, USA, 2007, 221−223.

5 Website of synApps which is a collection of software tools that help to create a control system for beamlines. http://www.aps.anl.gov/bcda/synApps/.

6 Cao Y, Sun B G, Lu P, *et al.* At Energy Sci Technol, 2008.5, **42:** 457−460.

7 Leng Y B, Yan Y B, Zhou W M, *et al.* High power laser and particle beams, 2010, **22:** 2973−2978.

8 Yang Y L, Ma T J, Sun B G, *et al.* HLS Bunch Current Measurement System. Sci China Phys, Mechanics & Astronomy, 2011, **54(Suppl.2):** s299−s312.