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REAL-TIME SYNCHRONIZED CALIBRATION AND COMPUTING SYSTEM WITH EPICS BASED DISTRIBUTED CONTROLS IN THE TPS XBPM SYSTEM

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Abstract

In synchrotron facilities, X-ray beam position monitor (XBPM) is an important detector for photon beam position monitoring and must be calibrated to ensure reliability and precision. However, light source operating conditions, such as beam orbit, injection and insertion device parameters, etc., can influence the sensitivity and specific weighting of photoemission current from the XBPM diamond blades. In the Taiwan Photon Source (TPS), Experimental Physics and Industrial Control System (EPICS) was utilized to implant an automatic calibration process. By using EPICS, we can ensure a seamless integration between the different front ends (FEs) and direct all data stream into a centralized server, creating a distributed XBPM calibration system. The XBPM performance indicators are analyzed to evaluate the validity of calibration parameters by input/ output controller (IOC) in each FE computing system. This paper will discuss the benefits of implanting this distributed control system into a working environment such as the TPS.

INTRODUCTION

The XBPM is obviously a standardized diagnostic sensor for orbit feedback or beam alignment [1, 2]. However, due to the blade-type design and the measurement object being a photon beam, calibration must be done more frequently than for other commercial sensors such as temperature or pressure sensors, etc. Many studies have shown that the accuracy of an XBPM is greatly affected by the conditions of synchrotron radiation operation [3, 4]. According to these studies, we define the XBPM as a time-varying system with varying responses to different light source conditions. In order to prove this concept and optimize the performance of XBPMs, we describe in this study the development of an XBPM dedicated control system. Considering of the TPS is composed of 48 segments, each with a FE. This generates a large system control issue and a real-time synchronized XBPM calibration process to perform rapid and remote scanning becomes desirable. This system is required to determine all XBPM coefficient calibrations and data analysis. The XBPM system should be able to provide high precision and reliable beam position information for a number of applications which is the main purpose to develop this control system.

THE XBPM SCANNING CONTROL SYSTEM

The XBPM scanning control system consists of a two-dimensional translation stage to move the XBPM along the X and Y-axis. The signals from the four-diamond blades transmit photoemission current signals by standard 50-ohm coaxial cables to the data acquisition Libera photon controller which calculates the X and Y positions to be published as process variables (PVs) by the EPICS on the TPS instrument control intranet [5]. The control software which is programmed with the LabVIEW object-oriented software will be described in this section.

Programming Method

Considering program flexibility, the architecture utilizes the queue message handler (QMH) structure which is composed of event-triggered producer-consumer, state machine and functional global variables (FGV). The advantages are easy maintenance and readability as well as high expandability and supporting multiplex executions. Parameters, which need to be matched with corresponding states, are triggered by the event handling loop and are passed to the "Message Handling Loop" by the queue method for physical actions.

After the XBPM calibration process in the QMH architecture is completed, the authenticity and independence of data transfer requires that all instruments and devices, which are used in this process, must be classified and encapsulated. Each instrument must follow the required rules in three steps: open (initialize), configuration, read/write and close. Encapsulating the motor control parameters of the translation stage into an object and its reference, established during the "Open" process, is transferred by the shift register in the main program architecture. Thereafter, the reference from the shift register is updated when activating the "Read/Write" status. In order to make the calibration process simpler, each axis is used separately. The axis control parameters of each axis are encapsulated in the cluster which can be regarded as a "Struct" in C++ and then placed in an array. When operating a specific axis, only an element in the array changes the parameters to make it more convenient to use, as shown in Fig. 1.

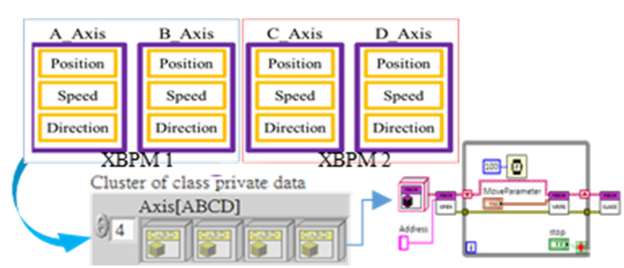

Figure 1: Encapsulating the axis control parameters in the clusters.

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Scanning Control Program

A Galil motion controller with eight axis control ports and TCP protocol is utilized to control the XBPM translation stages. For controller protection, an error code can interrupt the entire program, if another command is executed by the program while another command is executing concurrently. To avoid this error to occur, the Flag function, which is embedded in the controller, is used to determine the progress of the execution. With the Flag function, control of program sequences is achievable. In other words, the axis control execution command and the Flag detection can be regarded as a set of features as Fig. 2 shows.

However, while executing the program in praxis, it can cause blocking issues if both these functions merge into the same sub-function during programming, resulting in an inability to interrupt the movement immediately during an emergency. Due to this reason, the execution command and Flag reading have to be separated in the program. Using an iteration loop in the main program to update the Flag, makes program modifications more flexible for insertions of new functional actions. The motor parameters and data required for the entire scanning process are sequentially filled into an "Enqueue" function, as shown in Fig. 3. Finally, the sequential control is achieved by the first-in-first-out (FIFO) concept.

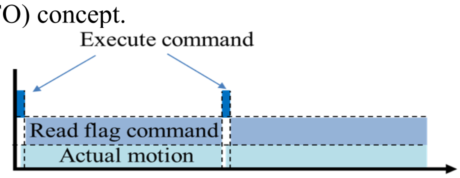

Figure 2: Axis control execution with Flag detection.

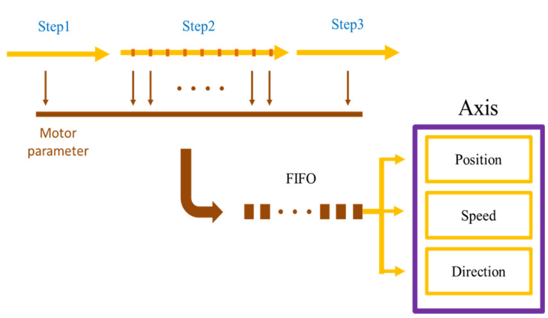

Figure 3: Control program in FIFO structure.

Intranet Construction

The XBPM scanning system is based on the Galil motion controller, the Libera photon, a machine protection interlock system, input/ output controller (IOC) and control server/client in each FE. The communication between instruments is based on EPICS protocol while a central PC controls each IOC by execution process variables (PV). For large distributed control system developments, EPICS, which is an open source software tool, provides a useful solution to publish variables between instruments. The EPICS protocol uses the Channel Access (CA) protocol to transfer variables between the CA client (CAC) and CA server (CAS) in the same network field by TCP/IP based protocols. In this study, we define the central PC as the CAC and the IOC in each FE as the CAS [6].

A CAS usually contains multiple PVs, which represents a value in the server and are important objects of the CA protocol. The CA protocol in the EPICS system can be read, written, and subscribed using CAC. In this distributed scanning control system, we installed a CAS in each FE IOC to monitor the executing PV from CAC on the EPICS network, i.e. the pub/sub method is practiced by CA monitor function in each FE server, and there is one central control client which is engaged to publish the execution PVs to each CAS (as shown in Fig. 4) as well as all FE XBPM status indicators for user monitors.

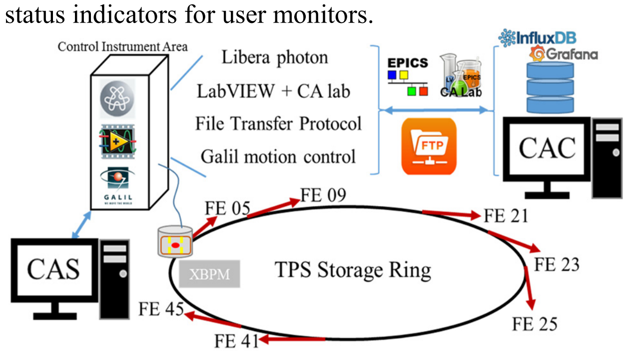

Figure 4: Distributed control system design for auto XBPM calibration.

COMPUTING SYSTEM

Following a XBPM scan, a set of calibration coefficients are determined by CAS and inserted into the following equation [7]:

$$\begin{bmatrix}\Delta_x\\ \sum x\\ \Delta_y\\ \sum y\end{bmatrix}=\begin{bmatrix}a_{0x} & b_{0x} & c_{0x} & d_{0x}\\ a_{1x} & b_{1x} & c_{1x} & d_{1x}\\ a_{0y} & b_{0y} & c_{0y} & d_{0y}\\ a_{1y} & b_{1y} & c_{1y} & d_{1y}\end{bmatrix}\begin{bmatrix}VA\\ VB\\ VC\\ VD\end{bmatrix}=\begin{bmatrix}1 & \frac{-1}{G_x^B} & \frac{-1}{G_x^C} & \frac{1}{G_x^D}\\ 1 & \frac{1}{G_x^B} & \frac{1}{G_x^C} & \frac{1}{G_x^D}\\ 1 & \frac{1}{G_y^B} & \frac{-1}{G_y^C} & \frac{-1}{G_y^D}\\ 1 & \frac{1}{G_y^B} & \frac{1}{G_y^C} & \frac{1}{G_y^D}\end{bmatrix}\begin{bmatrix}VA\\ N^B V_{raw}^B\\ N^C V_{raw}^C\\ N^D V_{raw}^D\end{bmatrix}$$

where $\begin{bmatrix}1 & \frac{-1}{G_x^B} & \frac{-1}{G_x^C} & \frac{1}{G_x^D}\\ 1 & \frac{1}{G_x^B} & \frac{1}{G_x^C} & \frac{1}{G_x^D}\\ 1 & \frac{1}{G_y^B} & \frac{-1}{G_y^C} & \frac{-1}{G_y^D}\\ 1 & \frac{1}{G_y^B} & \frac{1}{G_y^C} & \frac{1}{G_y^D}\end{bmatrix}$ is a 4-by-4 normalizing coefficient matrix for the four blades and

$\begin{bmatrix}VA\\ N^B V_{raw}^B\\ N^C V_{raw}^C\\ N^D V_{raw}^D\end{bmatrix}$ is a 1-by-4 matrix for the four-blade input photo-emission currents after normalization.

The accuracy of the XBPM system depends on its calibration coefficients. Long-term standard deviations and the correlation analysis [8] are performance indicators of the XBPMs and are utilized to judge the validity of the calibration coefficients. Due to operating conditions of the light source, some parameters or external interference factors affect the photon beam response of the XBPMs. If the standard deviation exceeds 2σ or the slope of the correlation values continuously increases during one calibration cycle, the calibration coefficients may not be reliable anymore.

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We can utilize an XBPM re-calibration to distinguish between a problem with XBPM coefficients and light source operation. Since the computing functions consume much time and resources while analyzing all FE data on a single IOC, we propose to use an XBPM, Libera photon and EPICS IOC in each FE to construct a computing system. It is responsible for calculating the correction coefficient and analyzing the validity of the correction coefficient through long-term diagnostics and comparison followed by publishing the results on the CAC. The CACs create a monthly report to track performance and improve the reliability of the XBPM system.

To concentrate the large numerical data processes in one CAC causes high risk, complexity and data management loading issues. In order to avoid these disadvantages, the quasi-edge computing system is introduced for system stability enhancement, thus becoming a basic equipment in the TPS FE XBPM system.

EXPERIMENTAL RESULTS

Practical experience with this system, allowed us to gain some insight into the XBPM performance and data collections, which we will discuss in more detail in this paper.

Calibration Results

The main purpose of this control system development is to calibrate the XBPM system by a different calibration method compared to most synchrotron radiation facilities [9]. In addition to the *Kx* and *Ky* factor determination (as shown in Eqs. 1, 2), a calibration system is discussed in this study with a sensitivity normalizing feature for diamond blades through the computing. Following the establishment of the correction factor matrix for the blades and substituting this matrix into the Libera photon, the X and Y measurements of the beam position can be confirmed by the optimization of the decoupling effect, which represents the limits of the practicality of this system for XBPM calibration.

$$X = K_x \frac{\Delta_x}{\Sigma x} - x_0 \quad (1)$$

$$Y = K_x \frac{\Delta_y}{\Sigma y} - y_0 \quad (2)$$

Taking beamline TPS 25A as an example, we show the results before calibration in Fig. 5, where the X-axis is the scanning axis and the apparent displacement of the stationary axis Y exhibits a drifting issue. Results after calibration at a gap of 7 mm are shown in Fig. 6, where it can be observed that the drift of the stationary axis is effectively suppressed to less than 1 um.

To prove the ID gap effect in the XBPM measurement, we used these results for comparison: While changing the ID gap by 7 mm, 11 mm and 15 mm, the results show that using the same calibration coefficients for 11 and 15mm as for 7 mm, the linearity decreases significantly as shown in Fig. 6. Scanning the axis gives linear results only when the gap is 7 mm, while keeping the XBPM calibration parameters, the results for 11 and 15 mm gaps become nonlinear. This is the main reason why we developed the distributed control system with computing feature. Using this system enables us to overcome the XBPM precision effect which is caused by variations of operating conditions.

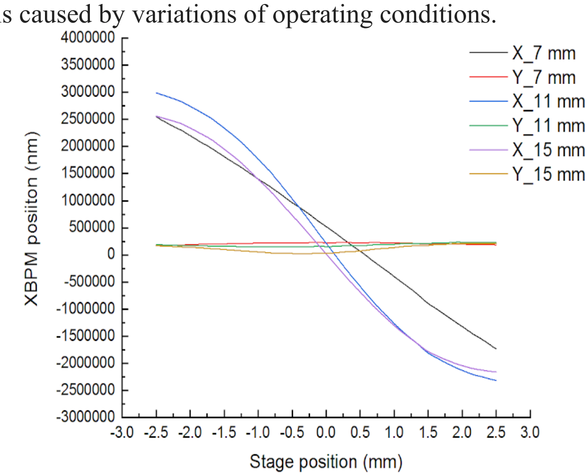

Figure 5: Scanning results before calibration.

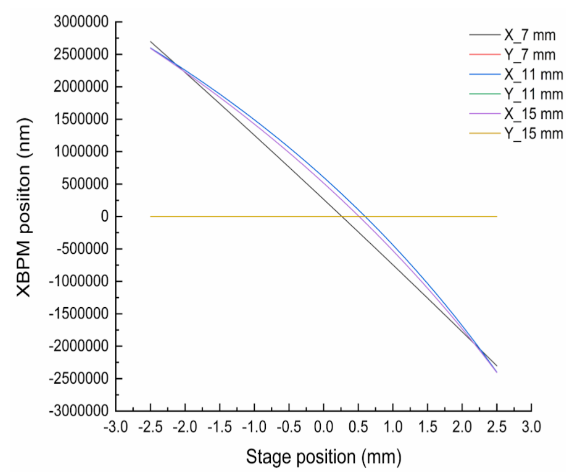

Figure 6: Scanning results after calibration.

Long Term Monitor Results

For a long term data record of Nov. 2018, the user beam time data are shown in Figs. 7-12. XBPM measurements can be continuously transferred through the quasi-edge computing of this system to determine the Pearson correlation coefficients (PCCs) and X/Y standard deviations. The PCC represents the effectivity of X/Y decoupling, where a normal XBPM is considered to be decoupled when a beam displacement in one axis does not affect the observed position in the other plane. A set of optimal calibration factors determined by a series of calibrations can be used to decouple the X/Y measurements with XBPMs. Comparing results before and after XBPM calibration, the PCC can be improved by over a factor of ten.

The STD is utilized to judge beam stability automatically every hour. If the current position has moved away from the STD by more than 2σ in the past hour, we have reached an alarm point to inform users and send a message to FE staffs' mobile devices by Line Chatbot. To observe the records in Figs. 7-12, the average STDs, except for injection and non-user time, is less than 5 um, proving a TPS operation with high orbit stability.

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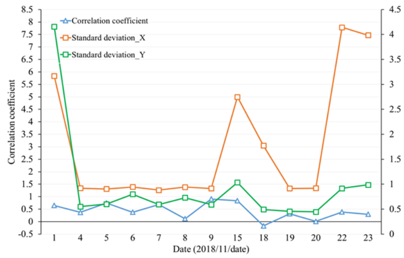

Figure 7: PCCS and STD for the TPS 05A.

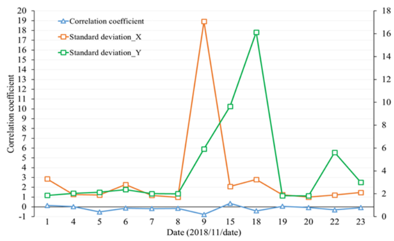

Figure 8: PCCS and STD for the TPS 09A.

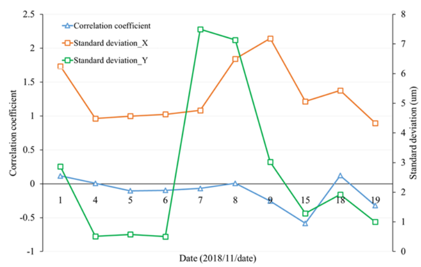

Figure 9: PCCS and STD for the TPS 21A.

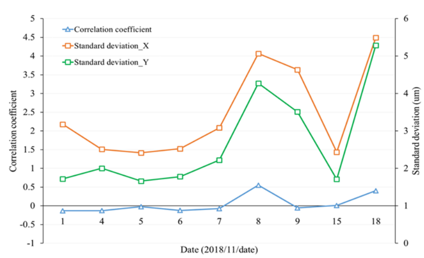

Figure 10: PCCS and STD for the TPS 23A.

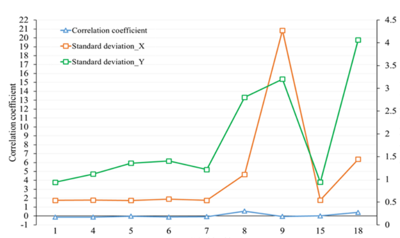

Figure 11: PCCS and STD for the TPS 25A.

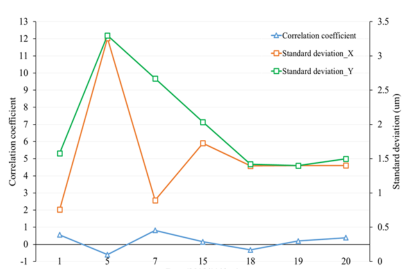

Figure 12: PCCS and STD for the TPS 45A.

CONCLUSIONS

Based on the results of this study, the XBPMs can be regarded as a time-varying system depending on operating conditions. The complexity of the XBPM system mainly comes from tolerances in the blade assembly, metal film coating quality and operating parameters of the synchrotron radiation source. The blade assembly is relatively fixed, but needs to be checked for long-term changes. The other causes change more frequently and, therefore, to be able to make high-precision measurements, the performance status of XBPMs must be monitored. However, after real-time re-calibrations, the beam position can be determined with high precision.

The calibration system is connected in series with the full TPS XBPM system and each XBPM is equipped with a computer control system. At parameter changes of the light source, an immediate calibration procedure can be performed without database requirement or any look-up table. This advantage will greatly enhance the utility of XBPMs in synchrotron radiation facilities. The accuracy of the XBPMs can be used as a basis for judging the stability of the light source and position record to the benefit of beamline users.

REFERENCES

[1] Smith, S. J. (2006). Front end x-ray beam position monitors at the Canadian Light Source (Doctoral dissertation, University of Saskatchewan).

[2] Carradine, J. A., & Linkups, F. R. (1998, December). Real-time orbit feedback at the APS. In AIP Conference Proceedings (Vol. 451, No. 1, pp. 125-144). AIP.

[3] Premask, J., Bogey, M., Schleicher, T., Scholtz, V., & Schmidt, T. (2004). The use of photon monitors at the Swiss Light Source.

[4] Holdback, K., Fakies, J., & Patman, W. B. (2001, May). Review of Emittance and Stability Monitoring Using Synchrotron Radiation Monitors. In DIPAC (Vol. 1, p. 16).

[5] Müller, R. (2014). Control Systems for Accelerators, Operational Tools. Synchrotron Light Sources and Free-Electron Lasers: Accelerator Physics, Instrumentation and Science Applications, 1-37.

[6] Russel, R. E., Ruthe, S., & Richter, D. (2014). Network distributed data acquisition, storage, and graphical live display software for a laser ion source at CERN (No. CERN-OPEN-2015-005).

[7] J. Y. Chuang, Y. Z. Lin, Y. C. Liu, D. Shu, …, J. Y. Yen (2019). Discussion and Improvement of Blade-Type XBPM Coupling Suppression by Compensating Calibration Coefficients. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, under review.

[8] Weichert, F., Bachmann, D., Radka, B., & Fissile, D. (2013). Analysis of the accuracy and robustness of the leap motion controller. Sensors, 13(5), 6380-6393.

[9] Dham Gaye, V. P., Lodhi, G. S., & Kane, S. R. (2011). Beam position measurements of Indus-2 using X-Ray beam position monitor. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 659(1), 525-527.