Smart X-ray beam position monitor system using artificial-intelligence methods for the Advanced Photon Source insertion-device beamlines

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At the Advanced Photon Source (APS), each insertion-device (ID) beamline front end has two X-ray beam position monitors (XBPMs) to monitor the X-ray beam position for both vertical and horizontal directions. Performance challenges for a conventional photoemission-type XBPM during operations are contamination of the signal from the neighbouring bending-magnet sources and the sensitivity of the XBPM to the insertion-device gap variations. Problems are exacerbated because users change the ID gap during their operations, and hence the percentage level of the contamination in the front-end XBPM signals varies. A smart XBPM system with a high-speed digital signal processor has been built at the Advanced Photon Source for the ID beamline front ends. The new version of the software, which uses an artificial-intelligence method, provides a self-learning and self-calibration capability to the smart XBPM system. The structure of and recent test results with the system are presented in this paper.

Keywords: XBPMs; artificial intelligence; Advanced Photon Source; insertion-device beamlines.

1. Introduction

At the Advanced Photon Source, each insertion-device beamline front end has two XBPMs to monitor the X-ray beam position for both vertical and horizontal directions. Both the first and second XBPM are located upstream of the user photon shutter so that they are functional whether the user shutter is open or closed. The XBPMs measure photo-electrons generated by the sensory blades and deduce the beam position by comparison of the relative signals from the blades. Analytical and experimental results proved that CVD diamond is a good choice for the APS high-heat-load XBPM blade material because of its superior thermophysical properties (Shu *et al.*, 1992). The major advantage of the XBPM is its high positioning sensitivity. Besides that, compared with the particle beam position monitors in the storage ring, the front-end XBPMs have much higher sensitivity to the X-ray beam angular motion simply because they are located far away from the source.

A design challenge for a conventional photoemission-type XBPM for an ID beamline is the bending-magnet contamination of the signal and the sensitivity of the XBPM to the ID gap variations. Work at synchrotron radiation laboratories has shown that contamination signals caused by the bending-magnet (BM) emitted radiation become a major problem (Warwick, 1995). Problems are exacerbated for the XBPM when the IDs operate with different magnet gaps, because the percentage level of the contamination will be variable.

Since 1994, efforts have been made to design and develop a digital signal processor (DSP) based smart XBPM system for APS ID beamline front ends (Shu & Kuzay, 1996a). In this paper, we present the recent progress in the development of the APS smart XBPM system, including the software structure, which uses an artificial-intelligence method and provides a self-learning and self-calibration capability to the XBPM system. Test results with this novel smart system are also presented.
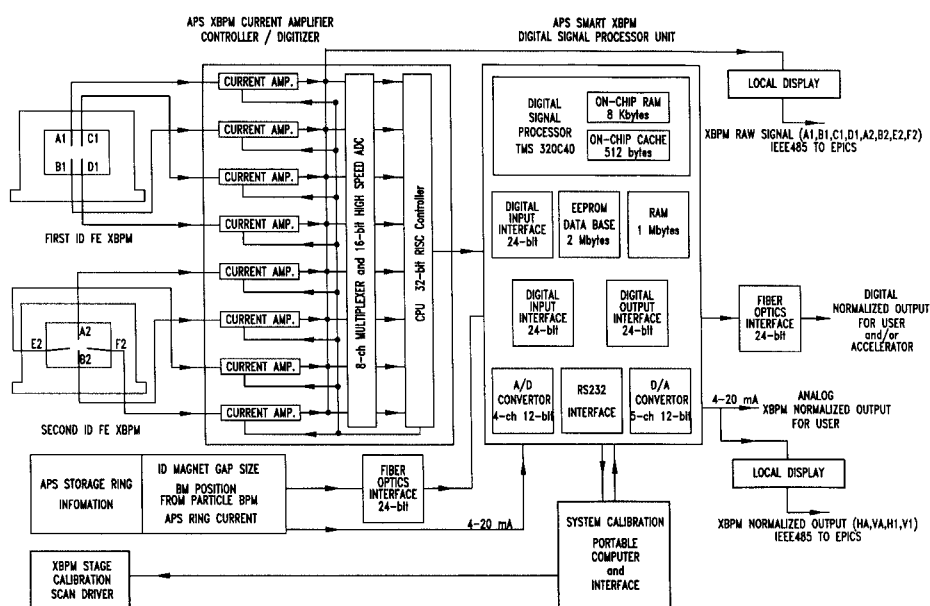

Figure 1
Schematic of the APS ID front-end smart XBPM system hardware configuration.

2. System hardware configuration

The APS smart XBPM system hardware configuration is depicted in Fig. 1. It includes the following.

(i) A pair of photoelectron emission-style beam position monitors using CVD diamond blades for the undulator beamline front ends.

(ii) A set of photoelectron current amplifiers with an eight-channel digitizer and auto-ranging controller (Meng, 1995).

(iii) A digital signal processor unit with an EEPROM database and input/output communication interfaces (Wu, 1996).

(iv) A system calibration controller with motor driver and encoder interface for XBPM calibration processes.

The XBPM in the front end is supported by a precision supporting unit, which consists of stepping-motor-driven vertical, horizontal, and rotational stages for XBPM calibration use.

The heart of the smart system is the DSP unit, which is equipped with a high-speed digital signal processor, TMS320c40 from Texas Instruments Inc. The TMS320c40 is a floating-point processor designed specifically for digital parallel processing and real-time embedded applications. The key features of the TMS320c40 device, especially those to be used in this system, are its high-performance DSP CPU with 40 ns instruction cycle times and 40/32 bit single-cycle floating-point/integer multiplier for high performance in computationally intensive algorithms (Texas Instruments Inc., 1993). We have added 2 Mbyte EEPROM and 1 Mbyte RAM as external memory on the unit. Besides the three 24 bit digital parallel input/output interfaces and one RS232 serial port, we have also mounted a four-channel 12 bit A/D converter and a five-channel 12 bit D/A converter on the unit to provide the capability for a 4–20 mA current-loop analog interface.

3. Database preparation

During the beamline and front-end commissioning activities, the final fine-tuning of the storage ring and/or final adjustment of the front-end components is attempted. Based on the measurement data for the beam position in two locations in experiment stations with a pair of transmitting XBPMs (Shu & Kuzay, 1996b), and in comparison with the data from the front-end XBPMs, a new zero position is set after the synchrotron radiation beam commissioning. Fig. 2 shows a typical setup for the beamline front-end commissioning and XBPM database preparation.

Once the zero point of the beam-position coordinate system has been determined, the XBPM calibration unit, which includes a portable computer-based data acquisition system with interfaces to drive the XBPM stages in the beamline front end, launches a two-dimensional (vertical and horizontal) data-mapping scan for each XBPM. The mapping scan covers a 1.2×1.2 mm cross-sectional area for each XBPM with ten different undulator gap settings from 11 to 30 mm. During the mapping scan, the photo-emission raw signals from each blade are recorded and labelled in a database. This database contains the calibration information about the XBPM local sensitivities (Kv, Kh) and local offset values (Sv, Sh) with different gap sizes and different vertical and horizontal beam positions within the mapping range.
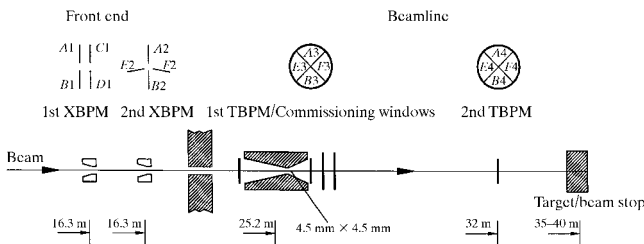
4. Software using artificial-intelligence methods

In the operating mode, the DSP unit gets the XBPM signal raw data from the pre-amplifier/digitizer through one of the digital parallel ports and groups them into an input buffer array. Then the DSP calculates the data under the control of a signal normalization program. For the current undulator gap-size information from the real-time input, this program searches a previously prepared database from an EEPROM. After a step-by-step convergence process, the final beam position data (a pair for the beam positions at the first XBPM location and a pair for the beam
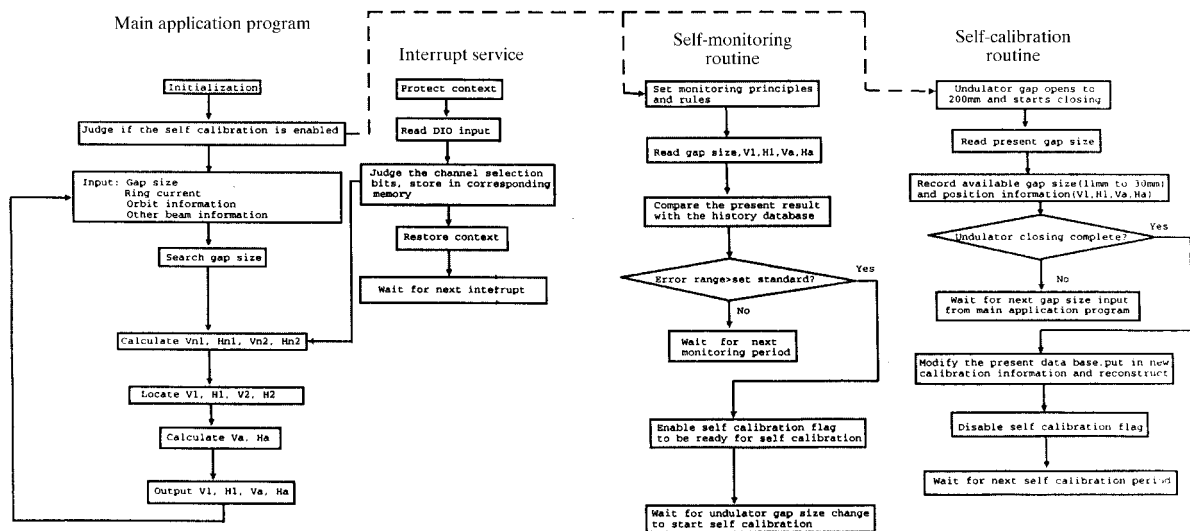

Figure 2
Schematic of the set-up for beamline front-end commissioning and XBPM database preparation.

Figure 3
Block diagram of the smart XBPM system software structure.

Table 1
Apparent X-ray beam position and angle measurements with and without the smart XBPM system, for varying undulator gaps from 11 to 30 mm while the particle beam position is stable.

XBPM readout	Without smart system	With smart system
1st XBPM vertical position (μm)	700	12
1st XBPM horizontal position (μm)	300	30
2nd XBPM vertical position (μm)	325	19
2nd XBPM horizontal position (μm)	2400	42
Vertical angular measurement (μrad)	275	6
Horizontal angular measurement (μrad)	600	8

angular displacement) are resolved and transmitted to a signal output buffer. There are two types of output data format available for users: 24 bit digital parallel output and 4–20 mA current loop for analog output. Both digital and analog output will keep the final beam position signal with a DC 100 Hz bandwidth.

Fig. 3 shows the smart XBPM system software structure, which consists of four major parts.

(*a*) An interrupt service program for XBPM raw data and undulator gap size input.

(*b*) A program with step-by-step convergence process for signal resolving and normalization output.

(*c*) A self-monitoring program with a historical dynamic database.

(*d*) A self-learning and self-calibration routine for second-order correction.

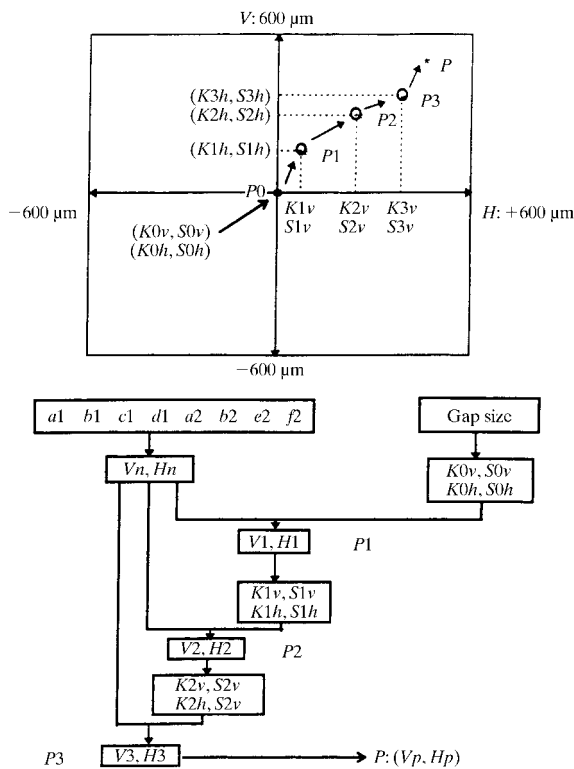The software has the capability to adapt itself to different environment conditions, not only to the undulator gap change, but also to the beam position or particle beam fill pattern conditions, which will collectively change the significance of the bending-magnet radiation 'contamination'. The self-monitoring program periodically records the smart XBPM output with the undulator gap setting and creates a historical dynamic database. Researching this historical performance database, the program determines if a second-order correction is necessary. If it is needed, a self-calibration process is launched, and the program records the smart XBPM output results for various undulator gaps, then creates a second-order correction table and puts it in use. This is a self-learning process, because the system updates and improves the existing database by itself as it detects changes in the environment

Fig. 4 shows the step-by-step convergence process searching for beam-position resolution. A typical searching process takes four steps and reaches a stable status as shown in Fig. 5.

5. Test results and conclusions

To date, three smart XBPM systems have been installed on APS ID front ends, and are operational. On-line preliminary tests began in August 1996. Fig. 6 shows a typical test result at the APS undulator beamline 1-ID front end. Table 1 shows the apparent X-ray beam position and angle measurements with and without the smart XBPM system, for varying undulator gaps from 11 to 30 mm while the particle beam position is stable.

The rest of the 20 ID front ends at the APS are expected to be furnished with smart XBPM systems within a year. Based on the experience from the prototype operation, we will determine the
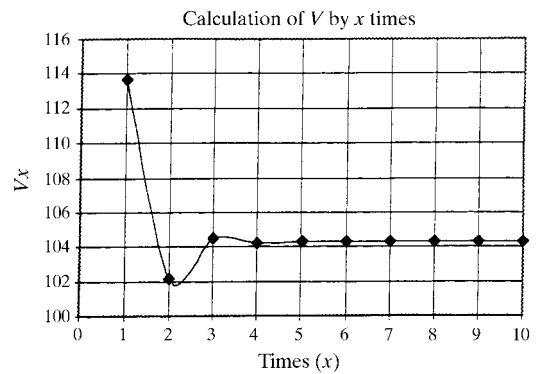

Figure 4
The step-by-step convergence process searching for beam position resolution. In this figure, *Knv* and *Knh* are the XBPM vertical and horizontal local sensitivities, and *Snv* and *Snh* are the XBPM local offset values for a linear approach.

Figure 5
A typical step-by-step convergence process takes four steps reaching a stable status.
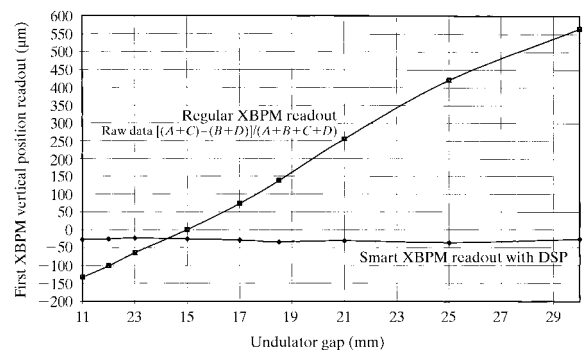

Figure 6
Test results at the APS undulator beamline 1-ID front end showing the apparent X-ray vertical beam position measurement at the front-end first XBPM with and without the DSP-based smart system, for varying undulator gaps from 11 to 30 mm.

time duration of the calibration period and optimize the database structure. Automatic calibration is necessary if the particle beam orbit changes frequently. If needed, the beam position at the neighboring bending-magnet front end may also be used as another database reference input.

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