MECHANICAL DESIGN OF X-RAY BEAM POSITION MONITORS WITH INDIVIDUAL ACTUATORS FOR SPRING-8 FRONT ENDS

Hideki Aoyagi [1], Sunao Takahashi[1] and Hideo Kitamura [1,2]
[1] SPring-8 / JASRI, 1-1-1 Kouto, Mikazuki-cho, Sayo-gun, Hyogo 679-5198, Japan
[2] SPring-8 / RIKEN, 1-1-1 Kouto, Mikazuki-cho, Sayo-gun, Hyogo 679-5148, Japan

Abstract

X-ray beam position monitors (XBPMs) with individual actuators for driving detector heads have been developed for the SPring-8 front ends of insertion device beamlines. The XBPMs have four detector heads, which resemble blades in shape, in order to measure horizontal and vertical beam positions. Beam profiles vary drastically when gaps of insertion devices are changed. Ideally, each detector head must be driven to match with the beam profile. However, detector heads of a usual XBPM are fixed on a water-cooled copper holder. We have developed a four-blade-drive style XBPM, which is equipped with four individual actuators for driving detector heads in radial direction, and a vertical-blade-drive style XBPM, which is equipped with two detector heads in vertical direction. These XBPMS have been routinely utilized for daily beam diagnostics.

1 Introduction

In the SPring-8 storage ring, the energy of the electron beam is 8 GeV and the beam current is 100 mA. The majority of insertion devices are in-vacuum X-ray undulators [1]. The maximum power density is about 500 kW/mrad2 and the maximum total power is about 13 kW, typically. Stable handling of such a large emitted power and accurate position monitoring of very narrow synchrotron radiation beam are major challenges in the field of front end engineering.

The typical SPring-8 front end is defined as the part of photon beamline between a back end of a photon beam port of the storage ring and a beryllium (Be) window assembly installed just after the shielding wall [2]. The photon beam from the insertion device or the bending magnet is guided to the optics hatches through the front end components. In the front end there are various components, whose roles are (1) handling the high heat load, (2) monitoring the photon beam position, (3) protecting the ultra high vacuum of the storage ring, and (4) shielding the radiation for human safety.

1.1 Concepts of X-ray Beam Position Monitor

An X-ray beam position monitor (XBPM) is an important tool for beam stabilization in the third-generation synchrotron light facility. The directivity of the high brilliant radiation from in-vacuum X-ray undulator in SPring-8 is very high, for example, 5 ~ 20 μrad [1]. Each XBPM is installed at about 20 m distant from the light source point in the front end for the insertion device (ID) beamline, so the monitors need to be designed to have a resolution of micron order and to withstand the power density of over 1 kW/mm2. We have successfully designed and prepared XBPMs to diagnose X-ray beam position with high resolutions and good stabilities under the severe heat load conditions.

CVD diamond blades have been used as detector heads that operate in photoemission mode [3], because CVD diamond has excellent thermal properties. Diamond has the maximum thermal conductivity in materials as well as relatively low absorption coefficient against hard X-ray. CVD diamond blades are superior to metal blades, such as tungsten blades. Four CVD diamond blades are mounted on a blade holder, which is made of water-cooled Cu block. The blades are parallel to the beam axis to reduce the heat load. The photon beam passes among the blades without blocking the beam centre. Only the small portion of the beam halo is blocked. The beam positions of both the horizontal and vertical

directions (X, Y) can be calculated from the current signal ratio of four blades using the correction factor (Ax, Ay).
On the other hand, the ID gap dependence of XBPM readouts is still a severe problem. The radiations from fringing fields of bending magnets at the upstream and downstream of IDs are piled up on the radiation from the ID itself. So, the accurate measurements of photon beam positions are affected by changing gaps of IDs. This problem is common to synchrotron radiation facilities in the world.
Therefore, we have proposed and demonstrated the new type of XBPMs based on the new principle using a CVD diamond disk as a detector head [4]. This monitor works in photoconduction mode and has high sensitivity to hard X-ray. This monitor is designed to reduce background radiations from bending magnets, which disturb the measurements of beam position. Originally, the diamond detector head was mounted in normal to the beam axis. However, the diamond disk still suffers severe heat load when it is used at front ends at SPring-8. So we propose to place the diamond detector head in parallel to the beam axis in order to reduce heat load and to increase design flexibility about sensitivity to X-rays. The details of this monitor operated in photoconduction mode are mentioned elsewhere [5].
The profiles of photon beam from the IDs are changed in shapes and in intensities drastically when the ID gaps are changed. Moreover, the beam profiles from figure-8 undulators are asymmetric [6]. Ideally, each detector head must be driven to match with the beam profile. Therefore individual actuators of detector heads are needed. Detector heads of a conventional XBPM are fixed on a single water-cooled copper holder. So we have developed a four-blade-drive style XBPM, which is equipped with four individual actuators for driving detector heads in a radial direction. We have also developed a vertical-blade-drive style XBPM, which is equipped with two detector heads in a vertical direction. Unique feature of this type is mechanical structure of changing distance between detector heads using a single stepping motor. Either of the two styles is equipped with common blade clams, which can be exchanged without difficulty, so that they can be operated either in photoemission mode or in photoconduction mode.
Mechanical designs of the four-blade-drive style XBPM and the vertical-blade-drive style XBPM and their performances are described in this paper.

2.1 Basic structure of photoemission type XBPMs

The majority of XBPMs in the SPring-8 front ends is a fixed-blade style, which is operated in photoemission mode. Four detector heads are fixed on a water-cooled copper holder as shown in Figure 1. The way of clamping on the single holder has been adopted in the other synchrotron radiation facility all over the world. In SPring-8 the heat load is extremely high, so the detector head, which resemble blades in shape, are designed to reduce heat load. The size of blades is 60×22×0.3 mm. The blades are clamped in large areas to have a good heat contact against the holder. The other feature is compactness in order to suppress vibration resulting from the cooling water flow. Moreover the cooling pipe is attached in an atmosphere side in order to prevent the vacuum leak accident. Photograph of the fixed-blade style XBPM installed at the front end is shown in Figure 2.

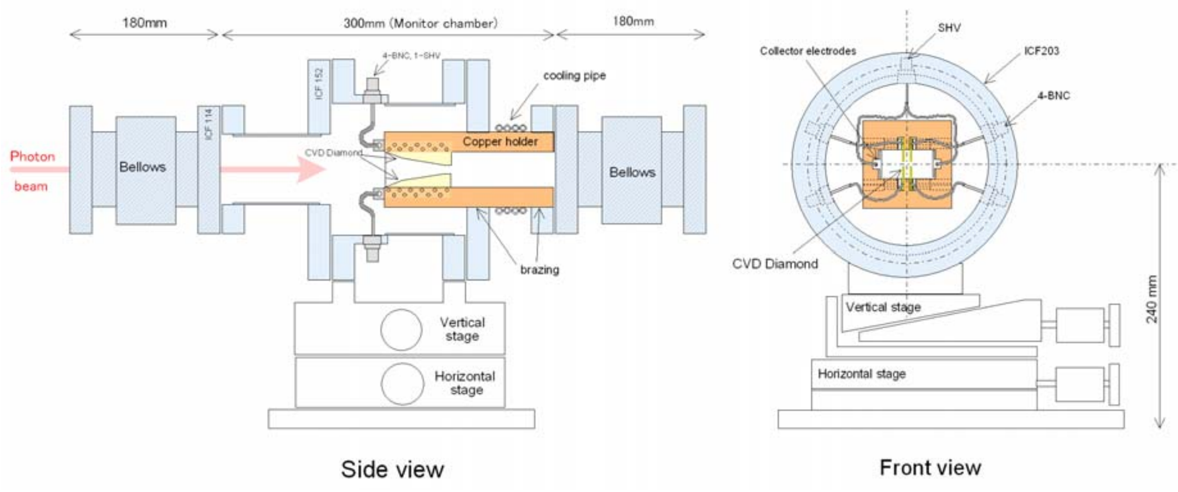


Figure 1. Schematic view of a fixed-blade style XBPM.

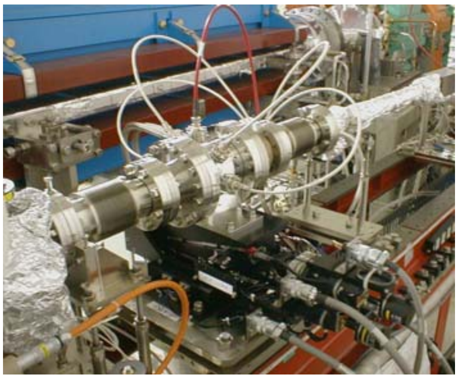


Figure 2. Photograph of a fixed-blade style XBPM

3.1 Performances of photoemission type XBPMs

The XBPMs that operate in photoemission mode have good performances. Typical resolutions in horizontal and vertical direction are about 1.0 µm and 0.5 µm, respectively. But ID gap dependence of XBPM readouts is the problem that cannot be conquered for the present. Figure 3 shows the example of the gap dependence. This data was acquired during user time. The gap dependences are about 300 µm at the gap of 9.6 ~ 50 mm, and about 100 µm at the gap of 9.6 ~ 25 mm. The displacement of 100 µm at 20 m from the ID, where XBPMs are placed, corresponds to the angle of 5 µrad. The data also shows that the behaviour of XBPM readouts does not change in a day or two, but does change drastically in a few weeks. This low reproducibility of the behaviour is due to the drift of the closed-orbit-distortion. During the user time, the periodical feed back of the storage ring runs all the time to stabilize the photon beam. After a long period, as the relative position of between the photon beam from the ID and the bending magnets change gradually, the total profiles of the photon beam are deformed.

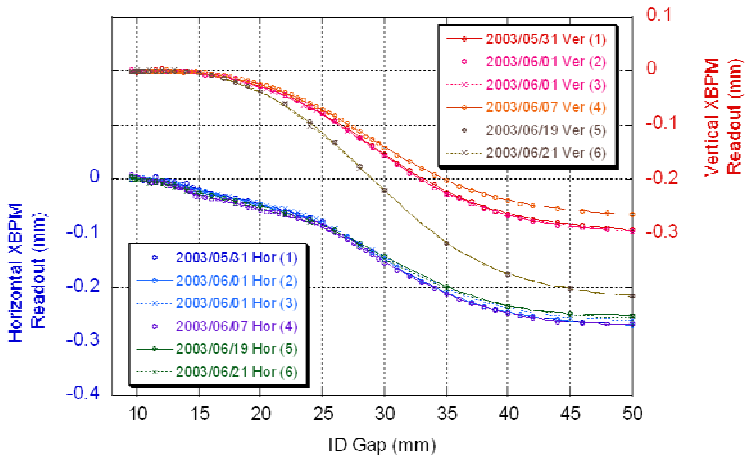


Figure 3. ID Gap dependence of a fixed blade style XBPM

If the XBPMs are used under the condition that the ID gaps are fixed, they show the excellent performances. The dependence on the ring current and the filling pattern of the storage ring are suppressed sufficiently. There are no problems in practical use. Figure 4 shows the results of the measurements that are carried out at some beamlines. Table 1 shows the statistics of the data. The standard deviations of the beam drifts are small enough, especially at the ring current from 50 ~ 100 mA. Under the condition of the ring current from 10 ~ 50 mA and the deferent filling pattern, the standard deviations are slightly high. This is because real beam drifts are included in these values. In fact, the beam orbit of the storage ring has fluctuations, so the performances of XBPMs are better than these values.

Table 1: Statistics of ring current and filling pattern dependence

	Standard deviation of averages [μm]					
	at each Ring Current (10~100mA, 8 data points)		at each Ring Current (50~100mA, 6 data points)		at each Filling Pattern (5 data points)	
Beamline	Hor.	Ver.	Hor.	Ver.	Hor.	Ver.
BL10XU	3.8	6.5	0.8	0.5	2.4	0.9
BL11XU	3.1	4.4	2.1	1.5	0.8	2.6
BL13XU	0.6	1.0	0.5	0.8	4.8	2.1
BL20XU	1.4	2.3	0.8	2.2	2.7	0.5
BL24XU	0.9	2.6	0.6	0.8	2.0	1.8
BL29XU	8.2	1.8	2.3	0.5	5.4	0.5
BL35XU	1.5	5.3	0.6	1.2	1.7	0.5
BL37XU	4.2	5.7	0.9	0.9	0.9	2.0
BL39XU	8.1	13.5	0.7	1.2	5.9	0.4
BL40XU	2.8	5.4	0.6	0.8	0.5	0.6
BL41XU	5.7	4.1	1.5	0.5	1.3	2.6
BL46XU	3.0	2.5	1.4	0.2	1.0	0.9
BL47XU	1.2	0.5	1.2	0.3	8.4	0.5
Max.	0.6	0.5	0.5	0.2	0.5	0.4
Min.	8.2	13.5	2.3	2.2	8.4	2.6
Average	3.4	4.3	1.1	0.9	3.5	1.2

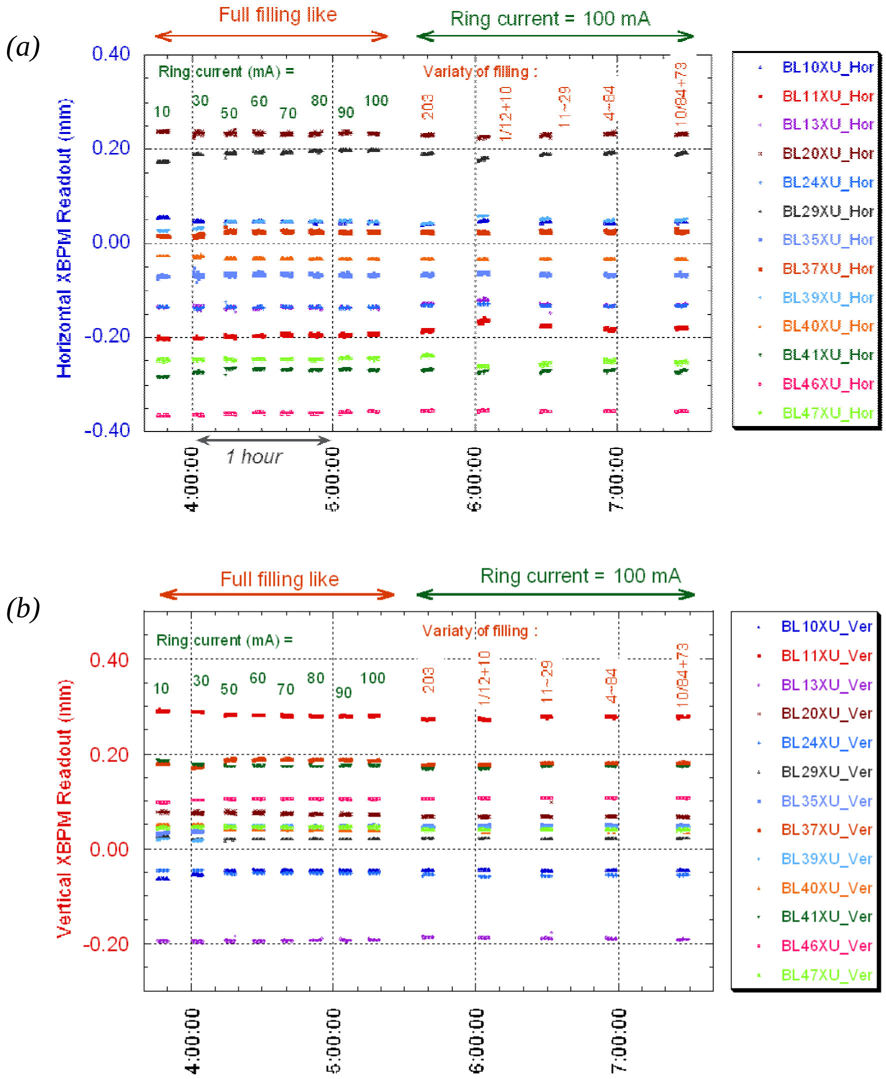


Figure 4. Ring current and filling pattern dependence of XBPMs in (a) horizontal and (b) vertical directions. All ID gaps are fix at the minimum. In the first half of the measurements, the beam was accumulated step by step. In the second half, beam injections and beam aborts are repeated for changing filling patterns.

2 Mechanical Design of XBPMS with Individual Actuators

2.1 Four-blade-drive Style

The profiles of photon beam from the IDs are changed in shapes and in intensities drastically when the ID gaps are changed. Additionally in the case of figure-8 undulators the profiles are asymmetric. A four-blade-drive style XBPM is adaptable for these beam profiles. The XBPM of this style is equipped with four individual actuators for driving detector heads in radial direction. As shown in Figure 5, each actuator of detector heads can be adjusted to the beam profile independently. Photograph of the four-blade-drive style XBPM installed at the front end is shown in Figure 6.

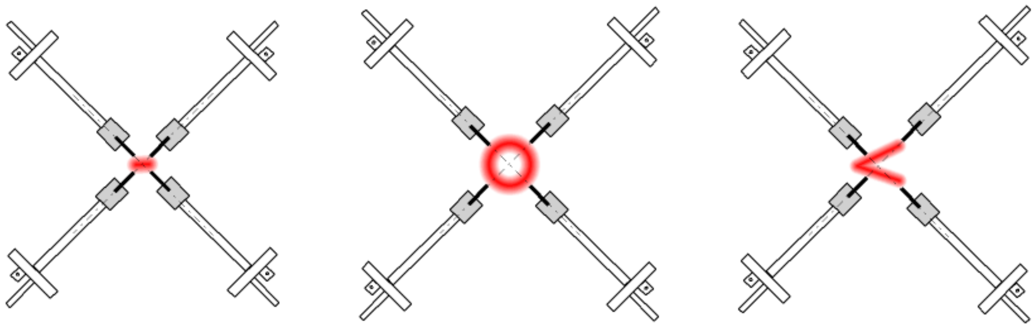


Figure 5. Schematic view of a fixed blade style XBPM. Four individual actuators are trimmed to match with the beam profiles of (a) a planer undulator, (b) a helical undulator and (c) a figure-8 undulator.

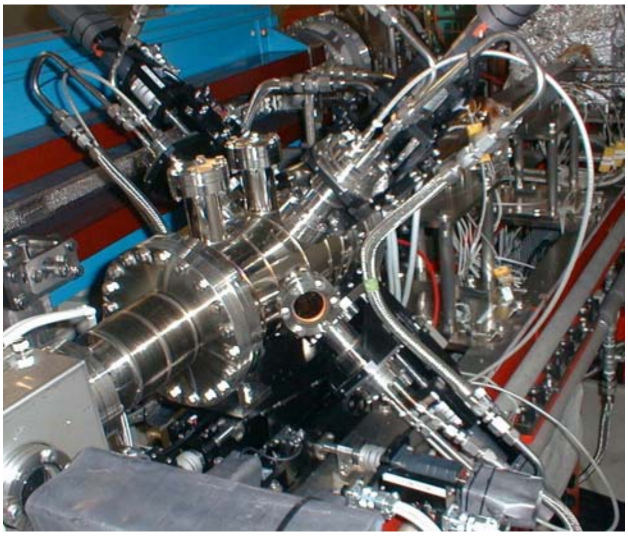


Figure 6. Photograph of a four-blade-drive style XBPM.

Using this mechanism, a perspective of the profile can be measured easily. Scanning measurements of the signal currents of the four-blade-drive style XBPM were carried out at the BL23SU front end [7]. This beamline has a helical undulator, which is utilized to switch polarization of light by driving the phase of its magnets arrays. Figure 7 shows that the signal currents decrease exponentially as the blades separate from the center of the beam. This behaviour is the results of the spectrum of the light and the detective efficiency of the detector head. The profiles of both circularly polarized lights are very similar, but linearly polarized light is different from those. The resolution of the XBPM becomes high as the detector heads are placed at the steepest slope in the line graph. In the case of the XBPM at this beamline, the positions of blades are set at 5.5 mm from the beam center.

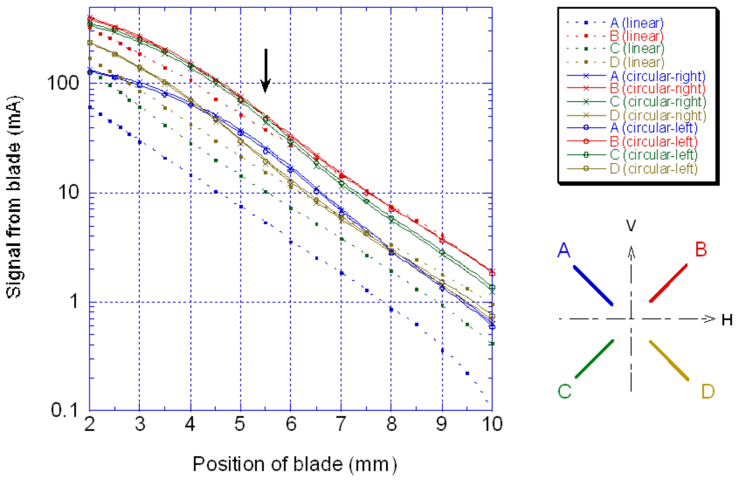
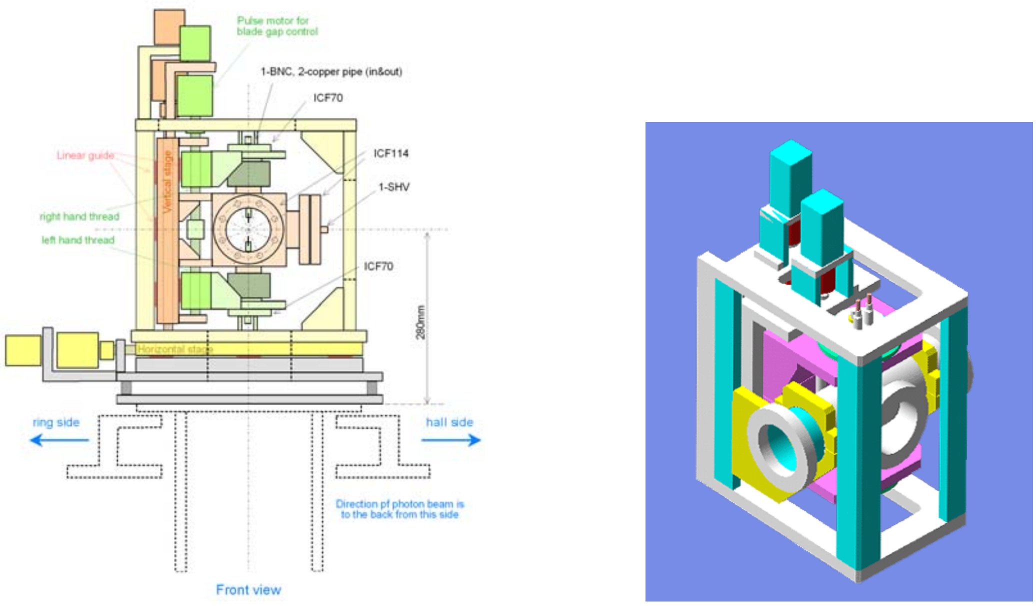


Figure 7. Scanning measurements of the signal currents of the four-blade-drive style XBPM. ID gap was 36 mm during this measurement.

2.2 Vertical-blade-drive Style

In the SPring-8 front end, the sites of the second XBPMs are already prepared. The second ones are necessary to define both the displacement and the angle of the beam axis. But most of front ends have no second XBPMs because of difficulties in design. The design conditions that are taken in consideration are shadowing effect caused by upstream XBPMs, small apertures of masks which are placed in the upstream of second XBPMs, and so on. In many cases, the vertical beam position is essential rather than the horizontal position. If monitoring is limited to the vertical direction, these problems are conquerable. So we have developed a vertical-blade-drive style XBPM, which is equipped with two detector heads in vertical direction. Unique feature of this type is mechanical structure of changing distance between detector heads by a single stepping motor, as shown in Figure 8.



(a) *(b*

Figure 8. (a) Schematic view (front view) of a vertical-blade-drive style XBPM, and (b) the 3D picture.

The vertical-blade-drive style XBPM has been installed in the BL17SU front end. ID17 is a multi-polarization-mode undulator [8]. There are two XBPMs, which are the four-blade-drive style (XBPM_1) and the vertical-blade-drive style (XBPM_2). XBPM_1 and XBPM_2 are operated in photoemission mode and in photoconduction mode, respectively. Figure 9 shows and the vertical beam positions that were observed by XBPM_1 and XBPM_2, as well as the horizontal by XBPM_1. The feasibility of the vertical-blade-drive style XBPM has been demonstrated.

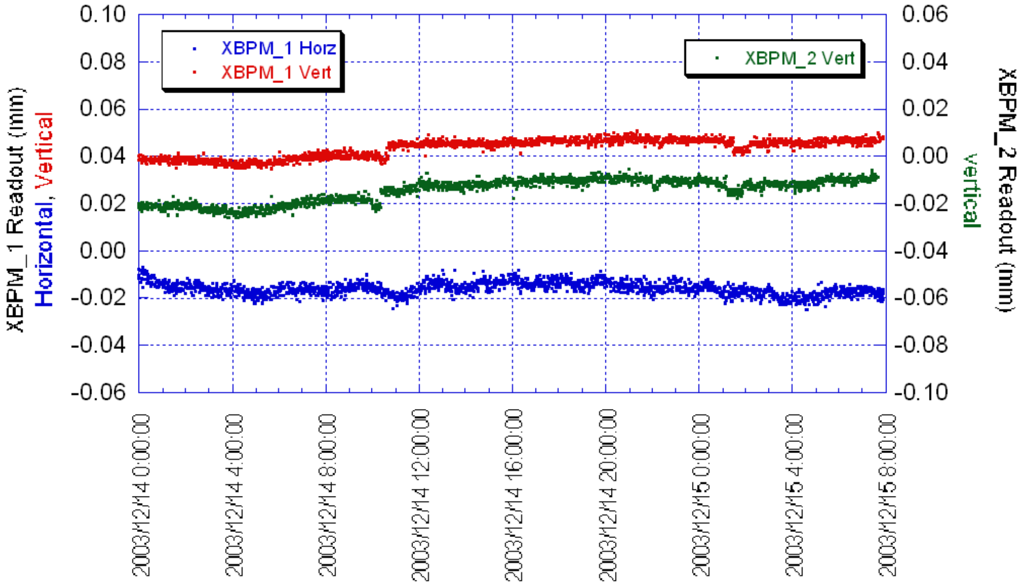


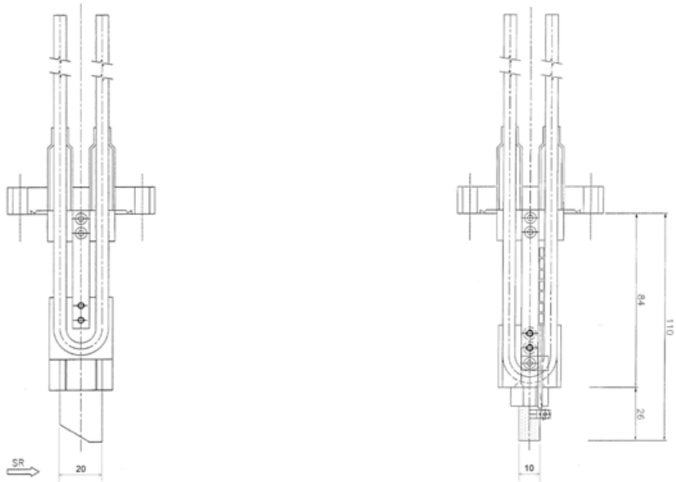
Figure 9. Measurement of the vertical-blade-drive style XBPM. XBPM_1 and XBPM_2 indicate the four-blade-drive at upstream and the vertical-blade-drive style XBPM at the downstream, respectively. Both are installed at the BL17SU front end. ID-phase was 140.5 mm during this measurement.

3 Common Structure of Blade Cramps

There are two kinds of detector heads, which are photoemission type and photoconduction type, as shown in Figure 10. Since the sizes of detector heads and the wiring for signals are different, a different clamps must be prepared. The mechanism of the blade actuators themselves can be used for both types of detector heads, so the clamps are designed to be exchange without difficulty. The blade cramp having a cooling pipe on a copper holder is fitted on a flange (ICF70). A coaxial feed-through (BNC) is also on the flange. It is very important to always standardize parts, when developing many mechanisms of blade actuators and their accessory, such as blades clamps.

4 Summary

X-ray beam position monitors (XBPMs) with individual actuators for driving detector heads have been developed for the SPring-8 front ends of insertion device beamlines in order to match with the beam profile, which is varying drastically when gaps of insertion devices are changed, and which is asymmetric occasionally. The four-blade-drive style XBPM is equipped with four individual actuators for driving detector heads in radial direction, and a vertical-blade-drive style XBPM is equipped with two detector heads in vertical direction. These XBPMS have been routinely utilized for daily beam diagnostics.



(a) *(b)*

Figure 10. Drawings of blade clamps. (a) Photoemission type. The size of blade is 20×40×0.3 mm. (b) Photoconduction type. The size of blades is 10×26×0.3 mm. Both clamps can be used for both the four-blade-drive style and the vertical-blade-drive style.

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References

[1] H. Kitamura, J. Synchrotron Rad. (1998). 5, 184-188.
[2] Y. Sakurai, M. Oura, S. Takahashi, Y. Hayashi, H. Aoyagi, H. Shiwaku, T. Kudo, T. Mochizuki, Y. Oikawa, M. Takahashi, K. Yoshii and H. Kitamura, J. Synchrotron Rad. (1998). 5, 1195-1198.
[3] H. Aoyagi, T. Kudo and H. Kitamura, Nucl. Instr. And Meth. A 467-468 (2001) 252-255.
[4] H. Sakae, H. Aoyagi, M. Oura, H. Kimura, T. Ohata, H. Shiwaku, S. Yamamoto, H. Sugiyama, K. Tanabe, K. Kobashi, H. Kitamura, J. Synchrotron Rad. (1997). 4, 204-209.
[5] H. Aoyagi, T. Kudo, H. Tanida and H. Kitamura, AIP conf. Proc. (2003) 705, 933-936.
[6] T. Tanaka, T. Hara, M. Oura, H. Ohashi, H. Kimura, S. Goto, Y. Suzuki and H. Kitamura, Rev. Sci. Instrum., 70 (1999) 4153-4160.
[7] A. Agui, H. Aoyagi, A. Yoshigoe and T. Nakatani, JAERI-Tech 2003-089
[8] K. Shirasawa, T. Tanaka, T. Seike, A. Hiraya and H. Kitamura, AIP conf. Proc. (2003) 705, 203-206.