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INCLINED X-RAY BEAM POSITION MONITORS TO REDUCE INFLUENCE OF FILLING PATTERN FOR THE SPring-8 PHOTON BEAMLINES

H. Aoyagi†, Y. Furukawa, S. Takahashi
Japan Synchrotron Radiation Research Institute (JASRI), Hyogo, Japan

Abstract

Influence of bunch filling patterns on X-ray beam position monitors (XBPMs) increased year by year as the bunch current of the storage ring increased. We have performed a systematic evaluation of the influence of the filling patterns. As a result, the cause of the influence was to be found to be suppression of the XBPM current signal due to the space charge effect, and was able to be quantified by observing the behavior of the current signal while changing the applied voltage to a photoelectron collecting electrode. On the other hand, we have designed a new blade-shaped detection element having inclined configuration for the purpose of mitigating the space charge effect. It has been demonstrated that the influence of filling patterns is reduced to a few µm. We also report that, as a result of a series of efforts against the existing XBPMs for all insertion device beamlines, the influence has been reduced to approximately 5 µm RMS.

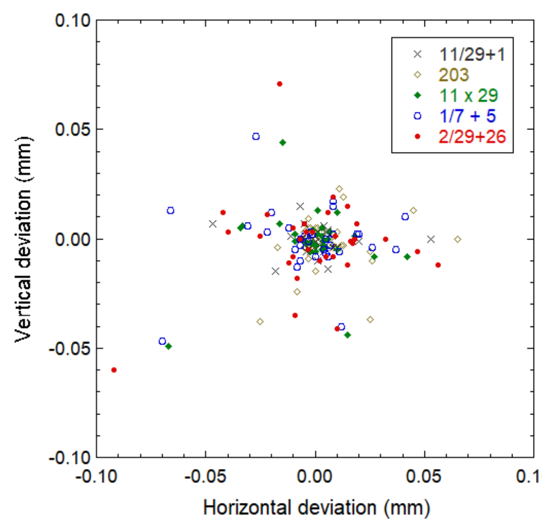
INTRODUCTION

The X-ray beam position monitors (XBPMs) at the SPring-8 storage ring works in a photoemission mode that is equipped with four blade-shaped detection elements made of tungsten as photocathodes [1]. The XBPMs are installed at insertion devise beamlines (ID-BLs) and bending magnet beamlines (BM-BLs), and have a stable operation record for over 20 years. Monitoring photon beam axes with the XBPMs, which have been fully evaluated for their performances, ensures the stable supply of the photon beam to beamline users. The rf-BPM of the storage ring excels in global diagnosis of closed orbit distortions, while the XBPM is suitable for accurate diagnosis of photon beams of individual beamlines.

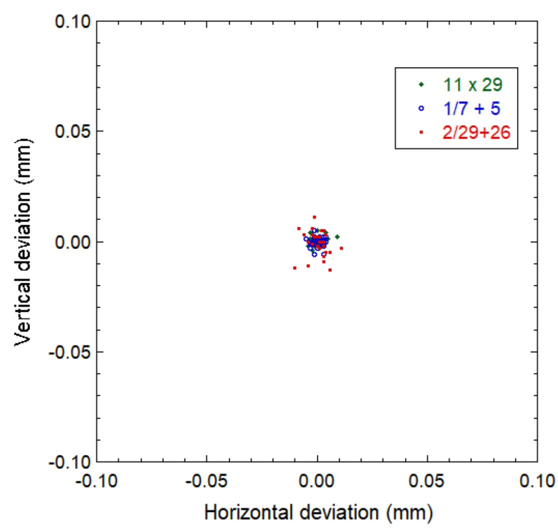
SPring-8 constantly provides various several-bunch mode operations, which combine single bunches (isolated bunces) and train bunches (partial full-filling) [2] to perform the time-division experiment. The bunch current has been gradually increasing, and reached up to 5 mA/bunch in a single bunch and 0.38 mA/bunch in partial full-filling. The bunch current of 1 mA/bunch corresponds to 4.8 nC in the storage ring. As the bunch current increased, the influence of bunch filling patterns on XBPM performance increased year by year.

INFLUENCE OF FILLING PATTERN

The XBPM readouts in five types of several-bunch modes systematically were evaluated using the readouts in multi-bunch mode as the reference data to quantitatively understand the phenomenon that affects the XBPMs by changing the filling pattern. The multi-bunch mode, a type of a filling pattern, has the least impact on the accelerator beam operation. This measurement is performed in the same procedure as for the fixed point observation that is regularly conducted before the beginning of each user operation cycles with setting the ID gap of each ID-BL to a certain fixed value. As shown in Fig. 1 (a), it was found that different filling patterns have different effects on XBPMs.



(a) Before the series of measures



(b) After the series of measures

Figure 1: Deviations of XBPM readouts from the reference positions (multi-bunch) due to variations of five different filling patterns of the storage ring.

† aoyagi@spring8.or.jp

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Table 1: Bunch Current and the Deviation of the Readouts of Existing XBPMs

Filling pattern	Bunch current (mA/bunch)		Deviation of XBPM readouts (µm RMS)	
	Train	**Isolated**	**Horizontal**	**Vertical**
Multi	0.05	—	3.6	2.0
11/29 + 1	0.10	5.0	13.9	5.8
203	—	0.5	17.6	12.6
11 x 29	0.31	—	27.7 → **2.7** *	14.6 → **2.0** *
1/7 + 5	0.24	3.0	33.5 → **2.4** *	15.2 → **2.1** *
2/29 + 26	0.38	1.4	40.3 → **4.3** *	20.5 → **5.6** *

* after taking a series of measures

Table 1 shows the bunch current value in each filling pattern and the deviation of XBPM readouts in root mean square (RMS). The most significant effect was seen in 2/29 filling + 26 bunches mode, where the maximum horizontal and vertical displacements are approximately 40 µm RMS and approximately 20 µm RMS, respectively [3]. We verified the cause of the influence by changing the applied voltage to photoelectron collecting electrodes (normal applied voltage HV = +100 V). In the significantly affected XBPMs, current signals of the blade-shaped detection elements were greatly attenuated in the several-bunch modes, and were sensitive to the change in the applied voltage. We presumed that the cause should be space charge effect of photoelectrons near the surface of the detection elements. Therefore, we changed the operating conditions of the fixed point observation to confirm whether the influence of the filling pattern could be reduced. The major changes were 1) increasing the applied voltage to the collecting electrodes, 2) widening the ID gaps for the fixed point observations. As a result, as shown in Fig. 1(b), we succeeded in suppressing the influences of changing the filling pattern to less than several µm in RMS [4, 5]. Table 1 shows the deviation of XBPM readouts in RMS after taking a series of measures.

However, as long as the XBPMs having the existing detection elements are used, the ID gaps for fixed point observation must be widened. Therefore, we attempted to solve the problem of the space charge effect of the detection elements by newly designing and manufacturing.

STRUCTURE OF INCLINED-XBPM

We designed a new XBPN aiming at generating a high electric field between the detection elements and the collecting electrodes to mitigate the space charge effect. Since the existing detection elements are placed parallel to the beam axis, actual irradiated spots were concentrated on the edge of the blade tip (t = 0.2 mm). Therefore, the effective electric field was not efficiently applied to the detection elements. In the new design, we have devised a way for the broad side area of the blades to be the irradiated spots by adopting an inclined configuration arranged at an inclination of 1/60 to the beam axis [5]. Accordingly, it is expected that the effect of extracting photoelectrons by the electric field applied between the blades and the collecting electrode will be improved, resulting in mitigation of the space charge effect. In addition, as an additional function, concentration of heat load on the tips of the blades can be reduced by introduction of a curved forming of the blades. Furthermore, the location of the maximum heat load moves to the central of the blades, so that the cooling effect could be improved. Figure 2 shows the difference in shape and configuration between the existing and newly designed detection elements.

Figure 3 shows a photograph of the blade-shaped detection elements mounted with the inclined configuration [6]. Collecting electrodes are provided on both sides of the detection elemenct. Since the actual irradiated spots are the outer surface of the curved forming tip, the emitted photoelectrons are efficiently extracted to the collecting electrode (positive potential). In the existing design, the distances between the tips of the four detection elements were 6 mm in horizontal and 4 mm in vertical, but the new design adopted 7 mm in horizontal and 6 mm in vertical from the viewpoint of heat resistance. As a result, the output current signal of each detection elements decreases, and it can be also expected that the space charge effect will be mitigated. Figure 4 shows schematics of newly designed detection elements, a water-cooled blade holder and a monitor vacuum chamber that conforms to the design of th existing XBPM.

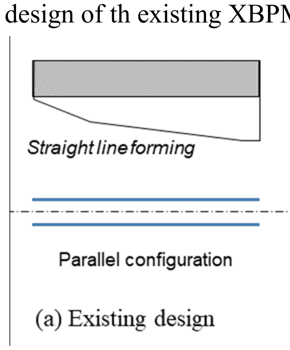

Figure 2: Schematics of blade-shaped detection elements. The difference in shape (top) and the difference in configuration (bottom) between (a) existing design and (b) new design are shown. The size of the tungsten plates are 60x20x0.2t. The shaded parts are sprayed by ceramic (60x10x0.1t).

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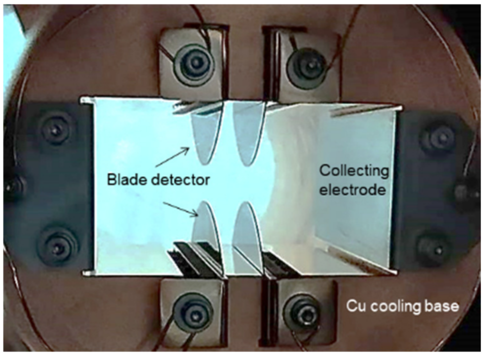

Figure 3: Photograph of detector heads.

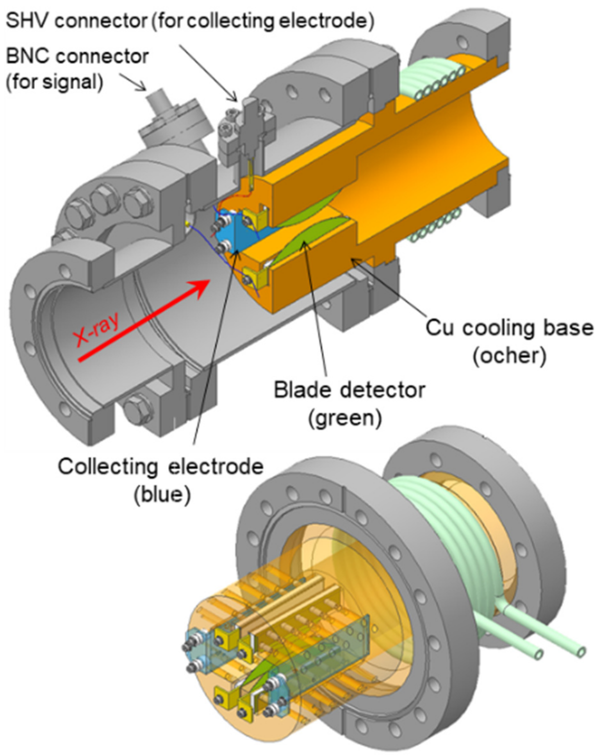

Figure 4: Schematics of an inclined-XBPM, a view of the internal configuration along a vertical cross-section (top) and a perspective view (bottom).

APPLIED VOLTAGE TO COLLECTING ELECTRODES

The dependences of the each blade current signal on the applied voltage to the collecting electrodes was measured to evaluate the influence of the space charge effect on the inclined-XBPM. The operation mode consists of the multi-bunch mode ("160 bunch train x 12") as the reference and two several-bunch modes ("11/29-filling + 1 bunch" and "2/29-filling + 26 bunches"). ID gap is set to 8.1 mm (minimum gap) and 13.0 mm (fixed point observation gap). The average values of four blade current signals were plotted in Fig. 5. In the multi-bunch mode, a lower limit voltage of the plateau region appears below the applied voltage of +100 V even under the condition of Gap = 8.1 mm. On the other hands, in the several-bunch mode ("2/29-filling + 26 bunches"), the lower limit voltage of the plateau region appears at +100 V under the condition of Gap = 13.0 mm, while the plateau region appeared at approximately +200 V under the condition of Gap = 8.1 mm. In other words, the lower limit voltage of the plateau region increases as the impact of the operation mode on the beam operation is greater (several-bunch mode) and as the ID gap becomes narrower, resulting in the increase in the blade current signal.

For comparison, the data of the existing XBPM ("parallel" configuration) in the several-bunch mode ("2/29-filling + 26 bunches") are also plotted. In the existing XBPM, the plateau region is clearly above +200 V or higher, even though the ID gap is set wider. This suggests that the inclined-XBPM in more effective than the existing XBPM in terms of reducing the influence of the filling pattern.

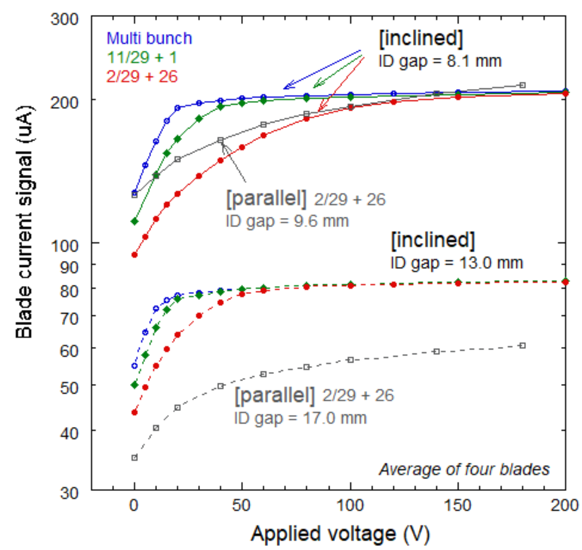

Figure 5: Applied voltage curves of blade current signal (average of four detection elements).

DEMONSTRATION BY FIXED POINT OBSERVATION

Beam position measurements in the operation mode of "2/29-filling + 26 bunches", having the most significant impact on the beam operation, were performed with the inclined-XBPM to directly evaluate the influence of the filling patterns using the same procedure as the fixed point observation. The differences in XBPM readouts from those in the multi-bunch mode were evaluated under four condition consisting of two different applied voltage to the collecting electrode (+100 V and +500 V) and ID Gaps (13.0 mm and 8.1 mm) combination. As shown in Table 2, the differences in horizontal of approximately 5 µm were observed, when the applied voltage to the collecting electrodes was +100 V. It can be seen that the influence of changing the filling pattern is small enough when the applied voltage is +500 V.

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Table 2: Fixed Point Observation Results for the Inclined-XBPM

Condition		Difference in Readouts	
ID Gap (mm)	XBPM HV (V)	Δx (µm)	Δy (µm)
13.0	100 V	4.5	1.0
	500 V	-1.5	1.0
8.1	100 V	-5.0	-1.5
	500 V	0.0	1.0

CONCLUSION

We succeeded in suppressing the filling pattern dependency of the existing XBPM to less than several µm in RMS by taking a series of measures, such as, 1) increasing the applied voltage to the collecting electrodes, 2) widening the ID gaps for the fixed point observations.

To essentially solve the filling pattern dependency problem, a newly designed inclined-XBPM, whose detection elements were arranged with inclined configuration to mitigate the space charge effect, was manufactured. The dependence of each blade current signal on the applied voltage to the collecting electrodes was measured, and it was shown that the lower limit voltage of the plateau region decreases. In addition, we performed evaluation tests using the same procedure as for the fixed point observation, and demonstrated that the influence of filling pattern can be reduced.

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