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The Development of W-PBPM at Diagnostic Beamline

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The photon beam position monitor (PBPM) plays a critically important role in the accurate monitoring of the beam position. W (Wire)-PBPMs are installed at the front end and photon transfer line (PTL) of the diagnostic beamline and detect the change of position and angle of the beam orbit applied to the beamline. It provides beam stability and position data in real time, which can be used in feedback system with BPM in storage-ring. Also it provides beam profile, which makes it possible to figure out the specifications of beam. With two W-PBPMs, the angle information of beam could be acquired and the results coupled with beam profile are used with orbit correction. The W-PBPM has been designed and installed in the diagnostic beamline at Pohang Light Source. Herein the details of the design, analysis and performance for the W-PBPM will be reported.

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I. INTRODUCTION

The PBPM has been widely used for beam position monitoring in synchrotrons; it provides accuracy in radiation position measurement, which makes it a powerful tool for beam position measurement [1]. Figure 1 shows the layout of diagnostic beamline. The diagnostic beamline have two PBPMs to detect the orbit angle of photon beam. Usually the one is installed in front end and the other is installed in photon transfer line (PTL). Since the front end is a starting point of the beamline, the PBPM can provide information of the beam position stability from the viewpoint of the beamline user. In addition, we will use not only the BPM data but also the PBPM data for the global and closed orbit feedback. For this purpose, PBPM should meet following conditions:

(1) It causes little intensity perturbation downstream of its position

(2) It is non-destructive to the synchrotron radiation

(3) It is suitable for conditions use

(4) It must withstand high thermal loads and achieve submicron level spatial resolution while maintaining stability.

The function of front end is to confine the beam size and connect beamline to storage-ring with vacuum. Most optics, *i.e.* mirrors and double crystal monochromator (DCM), are installed in PTL and experimental equipment is located in end station. The PBPM can be divided into two types: blade and wire. Generally blade-type monitors consist of an electrode plate, cooling system and driving system. This system responds sensitively in a manner corresponding to change in the beam position. Due to this, the blade detector system is excellent for electrical signal extraction and connection with a storage-ring orbit, and it is widely used in third-generation synchrotrons. Most popular material on the detecting plate is AL6061 but it often produces gas when synchrotron radiation hits a detecting blade. Thus, it has recently been suggested that molybdenum should be used instead of Al6061 in blade-type PBMP [1]. Figure 2 shows the layout of detector system and assembly of blade PBPM, which have been widely used in several beamlines.

The W-PBPM scans the beam by means of a tungsten wire. Due to this, the overall configuration is simple and does not require a cooling system. The W-PBPM can be usefully applied in a small space. In particular, W-PBPM can be applied to an ID beamline. The reasons for this are as follows: 1) The ID beamline has a power density several hundred times higher than that of a typical synchrotron's radiation. It is not easy to design an adequately cooled electrode when the adjustment of the beam orbit is in trouble. 2) Radiation of an ID beamline will overlap with the normal bending magnet beamlines. In such a case, it is almost impossible to separate the two types of radiation technically with a blade detec-

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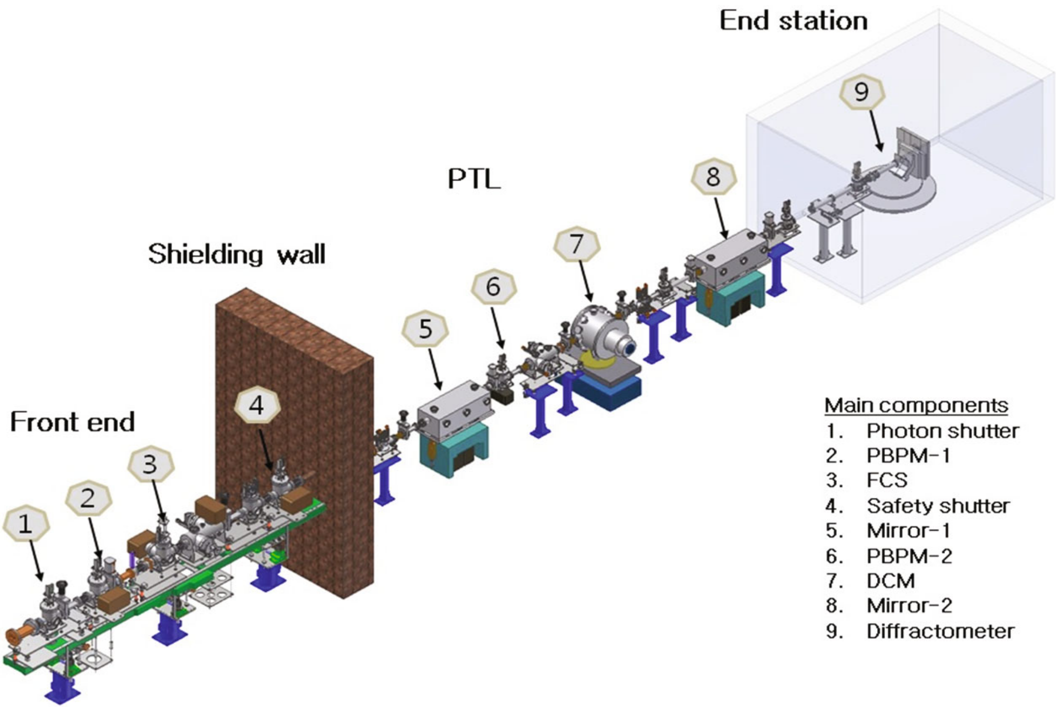

Fig. 1. (Color online) The layout of diagnostic beamline.

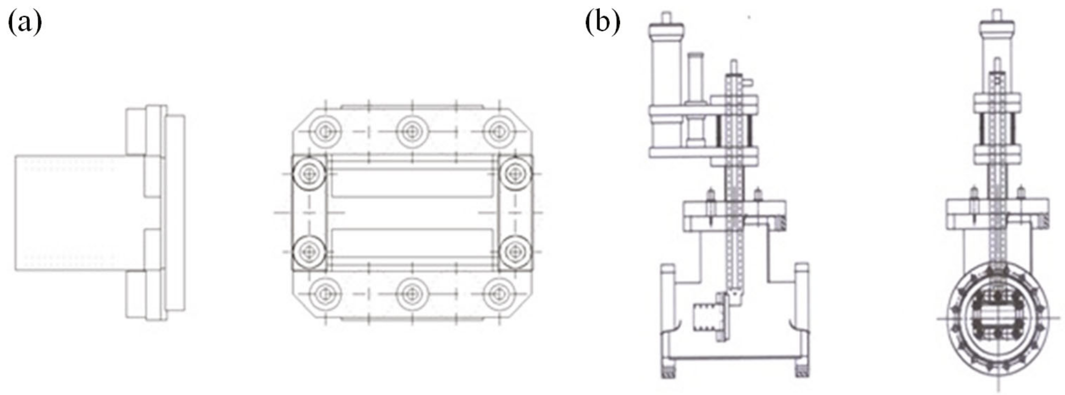

Fig. 2. Schematic drawings of (a) detector system and (b) assembly of blade PBPM.

tor. 3) The beamline user demands the ability to select an appropriate K value, because the spatial and spectrum placement of the undulator radiation, which can be changed according to changing of the K value, affecting the typical results of the PBPM [2]. The wire detector and assembly of W-PBPM are shown in Fig. 3. The diameter and length of detecting wire is 0.5 mm and 50 mm each. The W-PBPM have two manipulators in horizontal and vertical for easy control of the position of wire when orbit changes.

II. ANANLYSIS AND DATA ACQUISITION

The role of the W-PBPM is for early identification of the impact caused by several changes in the storage-ring and it enables to detect the changes of the height and position of a light source through the measuring of incident photons. In order to identify the W-PPM's characteristics, theoretical beam position and height can be calculated on the basis of the photon beam's vertical Gaussian distribution in the storage-ring.

Figure 4 shows the beam direction and change ratio of height. Usually one beamline have two W-PBPMs. And the W-PBPM has four detectors, which are installed right and left in horizontal and up and down in vertical. The W-PBPM measures the changing of the beam direction and height by using the detected photoelectric effect with the leverage law. The direction and height of the light source can be identified by monitoring the center line passing point of the 1st and 2nd W-PBPM.

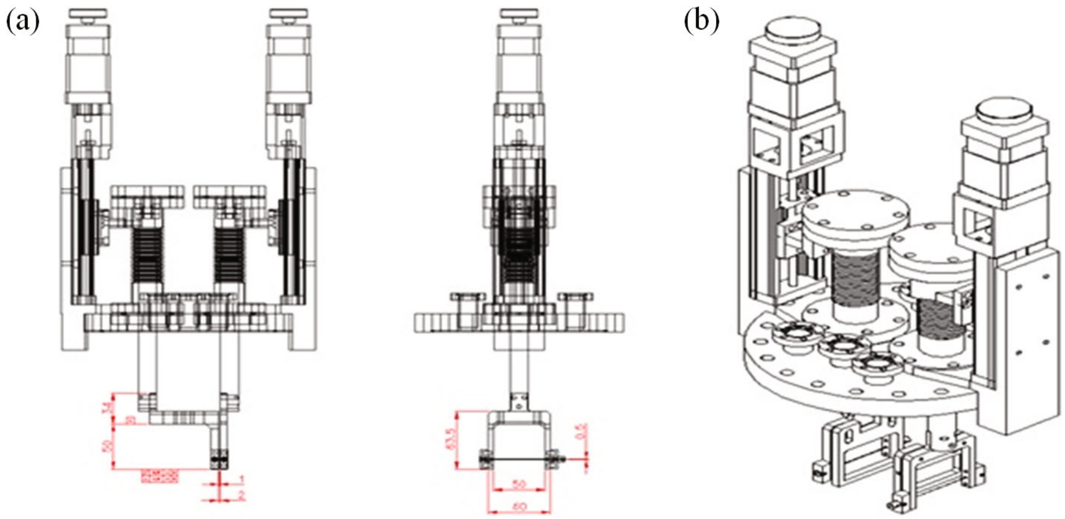

Fig. 3. (Color online) Schematic drawings of (a) detector system and (b) assembly of W-PBPM.

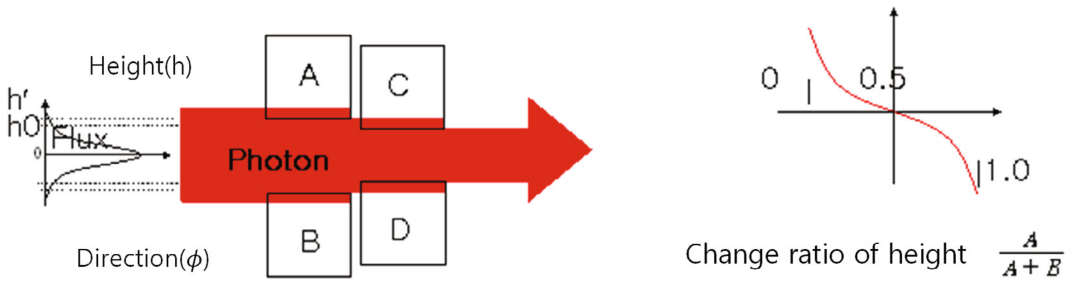

Fig. 4. (Color online) Beam direction and change ratio of height.

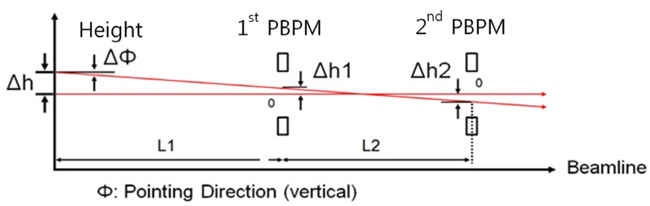

Fig. 5. (Color online) The variation of height in the beam direction.

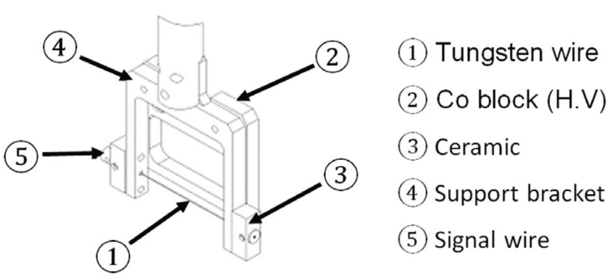

Fig. 6. The schematic drawing of W-PBPM detector.

Figure 5 shows the changes of height in the beam direction, and can be calculated with the four equations below,

$$\Delta h1 - \Delta h2 = L2 \tan\theta \Delta\phi \rightarrow \tan^{-1}\left(\frac{\Delta h1 - \Delta h2}{L2}\right), \quad (1)$$

$$\Delta h = \Delta h1 + L1 \tan\Delta\theta, \quad (2)$$

$$\text{First } W - \text{PBPM}(\Delta h1) = \alpha 1 \frac{A - B}{A + B}, \quad (3)$$

$$\text{Second } W - \text{PBPM}(\Delta h2) = \alpha 2 \frac{C - D}{C + D}, \quad (4)$$

where $\Delta h1$: height variation in front end, $\Delta h2$: height variation in PTL, θ: incident angle, L1: distance between beam source and first W-PBPM, and $L2$: distance between first and second W-PBPM. Figure 6 shows the configuration of the wire detector system. A tungsten wire is fixed with ceramic insulators and connected to the signal wire to get the current value. A harmonic motor with a 100:1 reduction gear ratio was fitted to increase the accuracy of the driving system, and as a result, the accuracy of 1 μm could be ensured.

To identify the horizontal and vertical beam accurately, the dual system in each direction has been adopted. This system was configured to adjust its interval by appropriately adjusting the stroke when the beam size was changed. The performance of the thermal analysis of the heat power was calculated using the

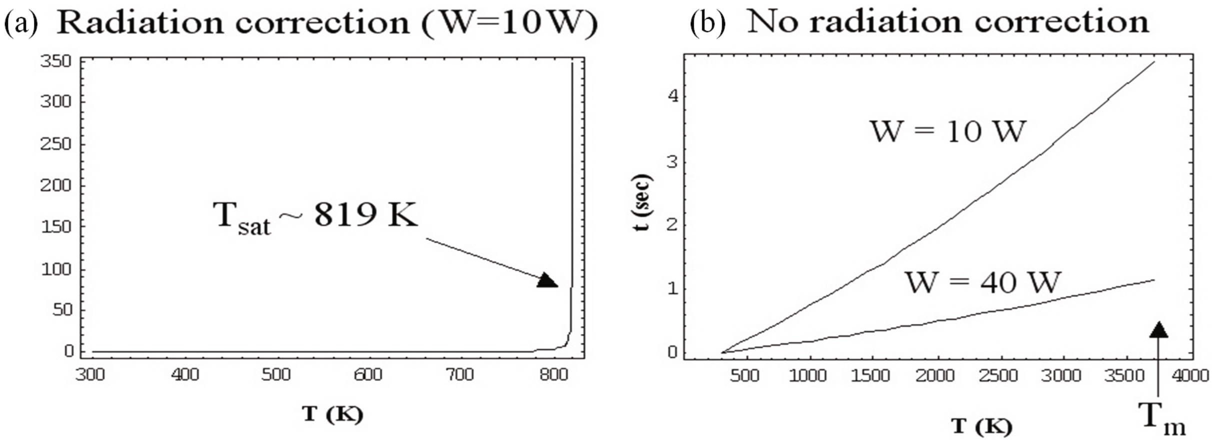

Fig. 7. The theoretical calculation of temperature distribution. (a) Radiation correction (W = 10 W). (b) No radiation correction (W = 10 and 40 W)

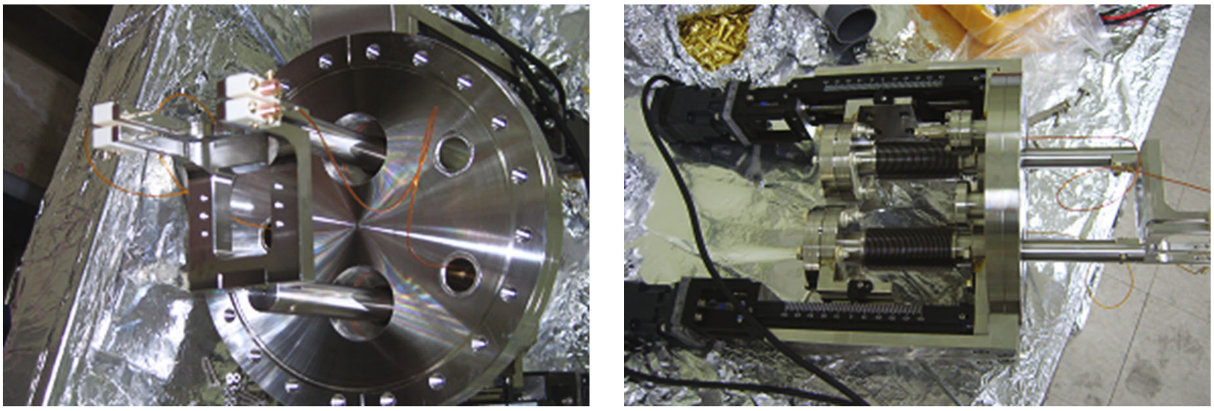

Fig. 8. (Color online) The assembly of W-PBPM.

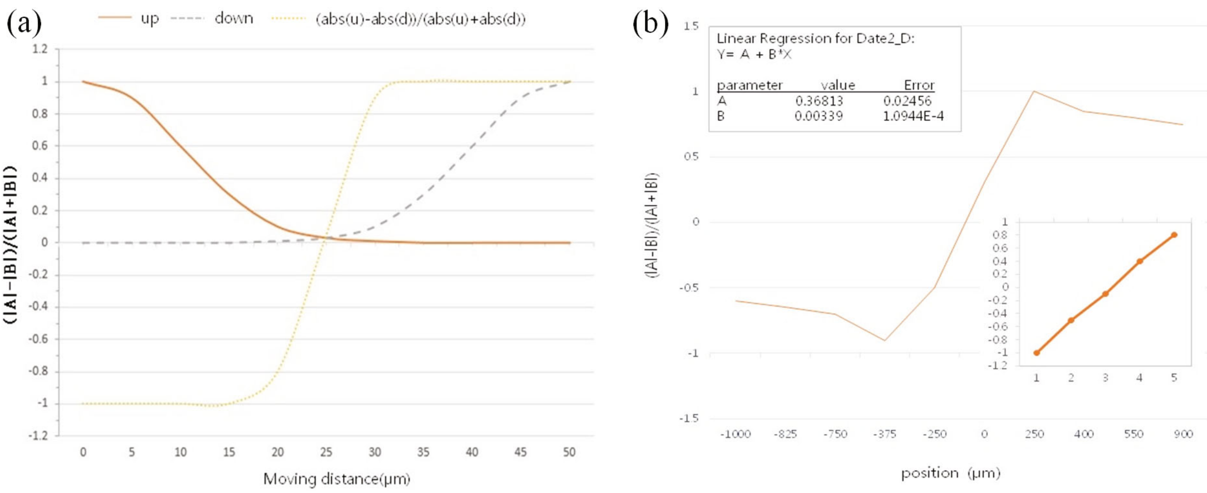

Fig. 9. (Color online) (a) The process of data acquisition and (b) data graph of the first W-PBPM.

theoretical calculation.

The power balance was calculated with the equations below,

$$t = \frac{M \int_{T_{RT}}^{T(t)} C_p(T)dT}{W - \int_{T_{RT}}^{T(t)} \varepsilon(T) S w_B(T) dT} \tag{5}$$

where t: irradiation time, M: mass of tungsten wire ($\pi D^2 L/4$), C_p: heat capacity, W: Bending magnet photon power on S, ε: emittance, S: surface area (πDL), w_B: Black body radiation power density, and σ: Stefan-Boltzman constant.

The temperature is in equilibrium at any moment due to the heat power applied to the wire and the cooling action of the thermal radiation. The safety of the wire can be determined by measuring the time and temperature at which equilibrium is reached. The total power of the bending magnet beamline was 10 W. The first W-PBPM was installed at 14 m away from the beam source. The length and width of the wire were 50 mm and 0.5 mm, respectively. The temperature saturation occurred at 819 K under the radiation correction, whereas the temperature of the wire rose up to 3,700 K without radiation correction, which caused the plastic deformation of the wire. To get comparison values, a case in which the total power of 40 W was also considered [3]. Figure 7 shows the temperature distribution by theoretical calculation.

Therefore, even if the temperature of the tungsten wire in contact with the beam rises, there is no problem in safety and functionality when the radiation correction is applied. Figure 8 shows the assembly process of the W-PBPM; it was installed at the diagnostic beamline of PLS-II. The purpose of W-PBPM installation is the optimization of the beamline, so that the status of photon beam can be identified quickly. This instrument is significantly important for monitoring the accuracy of the data. In general, the position and size of the synchrotron are more important for microscopic structure sample than the homogenous sample.

The test of W-PBPM was performed after installation in the diagnostic beamline of PLS-II. Electrons were produced when the X-ray beam contacted with the tungsten wire by the photoelectric effect. The amount of electrons was measured by each wire and picoammeter. Figure 9(a) is an ideal current graph obtained when using the upper and lower detector of PBPM. At this time, the upper and lower detectors move only in a certain region within the vertical Gaussian distribution of the incident current. Figure 9(b) shows the measurement of electrons from each wire in the W-PBPM installed on the front end. Firstly, the current values of A and B were obtained by using vertical detectors, and the linear region was secured although some errors were included in a certain section. The slope of the graph can be calculated from the measured current values A and B assuming that the photon beam travels only within the linear region. First, set any two positions in the linear region, and then if we check the current values and moving distance at two positions, we can obtain the slope using the above-mentioned Eqs. (2) and (3). The detectors travel in a certain area of the linear region and do not deviate 0.5 mm up and down with respect to the origin. Although the linear region is small, the detector system can be worked because the variation of beam orbit is smaller than the range of linearity. So if the X-ray beam moves in the linear region, the amount of current measured by each wire tells us the position of the beam. These results will be immediately reflected in the beamline operation.

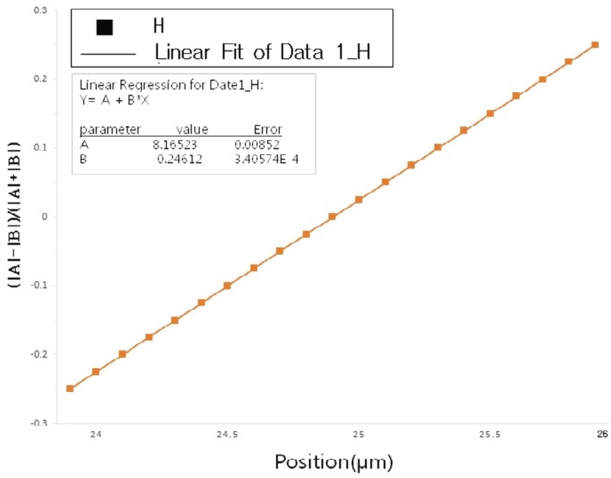

Fig. 10. (Color online) Data graph of the second W-PBPM.

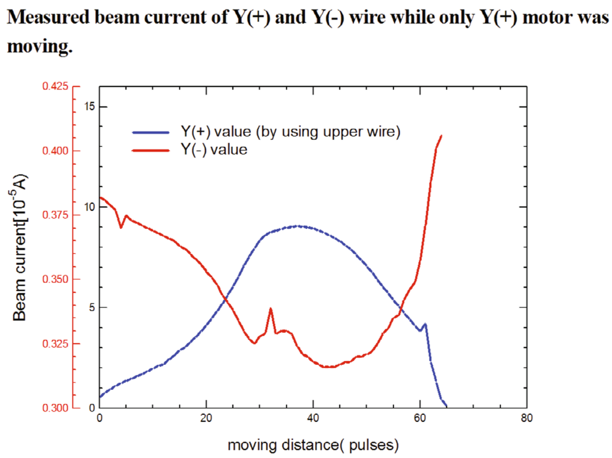

Fig. 11. (Color online) The profile measured by W-PBPM.

Figure 10 shows the current values measured by W-PBPM installed in the PTL. The linear region is subdivided for more detailed inspection. As shown in the figure, a very good linear region was obtained, and although the driving distance of W-PBPM is not long, it is not difficult to determine the status of the beam, considering that the actual beam size is only a few μm [4]. The space of the horizontal and vertical of wire are adjusted properly according to the beam size of each beamline. Because each wire is moving independently, it can be driven corresponding to the variation of the beam size.

The installed W-PBPM has a high voltage system equipped for an anti-scattering system, so a high voltage system can be used to solve the scattering problem. Figure 11 shows the current value of the y (+) and y (−)-wires when only the y (+)-wire is driving. We can find the results when y (+) is moving, as the current value of y (−) will be affected by the scattering effect. To solve

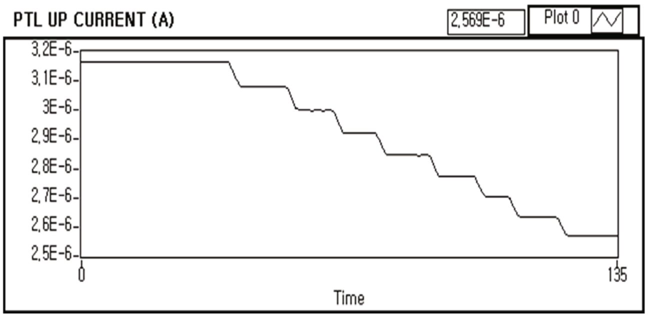

Fig. 12. The beam current of y (+) wire.

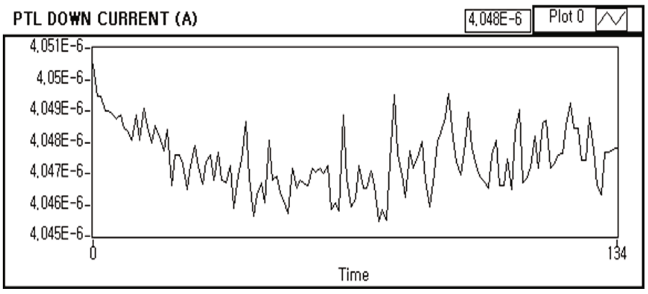

Fig. 13. The beam current of y (−) wire.

this problem, we modified the wire distance (lengths) from 50 mm to 80 mm, and the scattering effect was greatly reduced.

Figure 12 shows the current value of W-PBPM for the movement of the y (+)-wire. It is the current value for a given distance, and it shows the whole beam profile.

Figure 13 shows the measurement of the current value of the y (−)-wire while the y (+)-wire is moving. The result shows that the current values are almost consistent, and this result indicates that the scattering effects for the y (+)-wire almost disappeared.

III. CONCLUSION

We designed detector system with wire to control orbit change. The W-PBPM was developed and installed successfully in diagnostic beamline of PLS-II and its feasibility and operation stability were also verified well. Now it provides the beam position to BPM in storage-ring in real time as a feedback system. In the future, W-PBPM is planned to be installed in all beamlines at PLS-II to check the position and profile of beam and it will be helpful for checking the status of the storage-ring beam.

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