# SIGNAL PROCESSING METHODS FOR THE STAGGERED PAIR PHOTON BEAM POSITION MONITOR *

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*Abstract*

A new photon beam position monitor (PBPM) called staggered pair PBPM for photon beam position measurement in Hefei Light Source (HLS) is presented in this paper. For photon beam with Gaussian distribution, signal processing methods, include difference-over-sum ($\Delta/\Sigma$) method, ratio method and log-ratio method, were introduced, and based on these methods, as well the main performances (e.g. sensitivity, position offset and linearity) of staggered pair PBPM were analyzed. Comparing those three methods, log-ratio method is found to have the widest range of linearity, and can obtain identical beam position with different bunch size. Also we compare staggered pair monitor with double-blade monitor. The staggered pair monitor is found to have a higher sensitivity; and it can ignore the influence of bunch size.

## INTRODUCTION

The stability of electron beam orbit in electron storage ring is of great significance for synchrotron radiation users. If we want to measure the beam orbit accurately to stabilize it, position monitors must be produced, which have the required resolution and sensitivity. In general, we use beam position monitor (BPM) to measure the beam position. There are two types, which are button, and stripline. But these BPMs are often used near the quadrupole, and can not measure the change of source beam position and phase angle directly. Also for high stability high precision users, the stability of synchrotron radiation source is more important, and an accurate and reliable PBPM is essential for success of synchrotron radiation experiments. With the development of PBPM and position measurements, a more stable source can be achieved by building a local closed orbit feedback system. For these reasons, many labs from countries put much emphasis on developing different types of PBPM.

After developing two-wire PBPM [1] and four-quadrant PBPM [2] in HLS, a new PBPM called staggered pair PBPM [3-6] is now developed. Its main advantage is to reduce the influence of bunch size.

To develop the staggered pair PBPM, we analyse its performance.

## MONITOR DESIGN

Fig. 1 shows the blades positioning scheme and the main parameters of the staggered pair PBPM geometry. The blades are named as: Top outside (1), Top inside (2), Bottom inside (3) and Bottom outside (4). Here, G is the separation between the two pairs, H is the central height of the blade, L is the length and D is the thickness of each blade. In HLS, we use molybdenum for blades for its photoelectric efficiency.

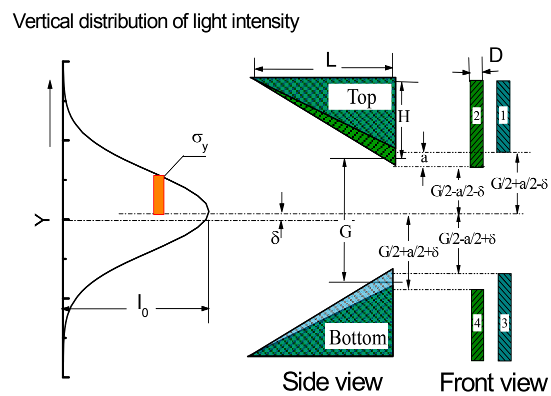


Figure 1: Layout of the staggered pair monitor.

## ANALYSIS OF PERFORMANCE

For a PBPM, linearity range and sensitivity are the main targets to evaluate its performance.

The linearity range defines the range of position change in allowable linearity position offset. It is also defined by the equation:

$$\Delta = P / S - \delta \tag{1}$$

and sensitivity is defined as:

$$S = (dP / d\delta)_{\delta=0} \tag{2}$$

where $P$ is the position signal, and $\delta$ is the offset between the central of photon beam and monitor.

We calculate the central of beam in linearity range by using position signal $P$ and sensitivity $S$ as following:

$$y = P / S \tag{3}$$

For photon beam with Gaussian distribution, the vertical luminous density is

$$\Phi(y) = \Phi_0(t)\frac{1}{\sqrt{2\pi}\sigma_y}\exp(-\frac{y^2}{2\sigma_y^2}) \tag{4}$$

where $\sigma_y$ is the vertical size of photon beam in PBPM.

Therefore current signal from each blade is calculate as:

* Supported by the National Science Foundation of China (10675118, 10875117)
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$$\begin{cases} I_1 = I_0 \displaystyle\int_{G/2+a/2}^{G/2+H} \exp[-\frac{(y-\delta)^2}{2\sigma_y^2}]dy \\ I_2 = I_0 \displaystyle\int_{G/2-a/2}^{G/2+H} \exp[-\frac{(y-\delta)^2}{2\sigma_y^2}]dy \\ I_3 = I_0 \displaystyle\int_{-G/2-H}^{-G/2+a/2} \exp[-\frac{(y-\delta)^2}{2\sigma_y^2}]dy \\ I_4 = I_0 \displaystyle\int_{-G/2-H}^{-G/2-a/2} \exp[-\frac{(y-\delta)^2}{2\sigma_y^2}]dy \end{cases} \quad (5)$$

The current signals from the staggered pair monitor must be processed with appropriate algorithm to give the positions. Next, we compare three methods of Δ/Σ, ratio and log-ratio in linearity range and sensitivity.

In general, Δ/Σ method is used in domestic and foreign labs for its easy implement and simple design. But with the development of electronics technology in recent years, high-precision processing can be easily achieved using computers, so log-ratio method are also chances of position signal processing[7], and this method is used more and more widely. Also we think ratio method is a good way to process signals for its small computational complexity and fast speed. Below is the instruction of these methods.

In the Δ/Σ method, the equation used to describe displacement of the beam is as:

$$P_{\Delta/\Sigma}(\delta) = \frac{P_{1/3} + P_{2/4}}{P_{2/4} - P_{1/3}} \quad (6)$$

where $P_{1/3}(\delta) = \frac{I_1 - I_3}{I_1 + I_3}$, $P_{2/4}(\delta) = \frac{I_2 - I_4}{I_2 + I_4}$.

In the ratio method, the equation used to describe displacement of the beam is as following:

$$P_{\text{ratio}}(\delta) = \frac{I_1 + I_2 - I_3 - I_4}{I_2 + I_3 - I_1 - I_4} \quad (7)$$

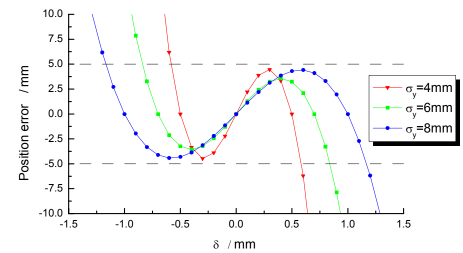
In the log-ratio method, the equation used to describe displacement of the beam is as following:

$$P_{\log}(\delta) = \frac{\log(I_1) + \log(I_2) - \log(I_3) - \log(I_4)}{\log(I_2) + \log(I_3) - \log(I_1) - \log(I_4)} \quad (8)$$

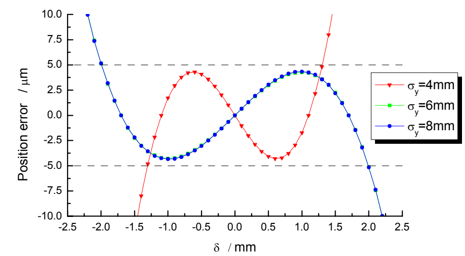
Based on the analysis above about staggered pair monitor, synchrotron photon beam position can be measured with this detector. Table 1 gives the linearity range using Δ/Σ method, ratio method, and log-ratio method for different bunch sizes; here the position offset is ±5μm.

Table 1: Linearity range for different bunch sizes.

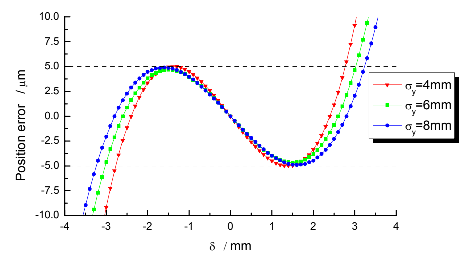
| Method / Bunch size | Δ/Σ (mm) | Ratio (mm) | Log-ratio (mm) |
|---|---|---|---|
| $\sigma_y$ =4mm | 1.0 | 2.6 | 5.4 |
| $\sigma_y$ =6mm | 1.6 | 3.8 | 6.0 |
| $\sigma_y$ =8mm | 2.2 | 3.8 | 6.4 |




(a) Δ/Σ method




(b) Ratio method




(c) Log-ratio method

Figure 2: Comparison of the linearity ranges of using different methods.

Fig. 2 show the linearity range of using Δ/Σ method for different bunch size, the linearity range of using ratio method, and the linearity range of using log-ratio method respectively.

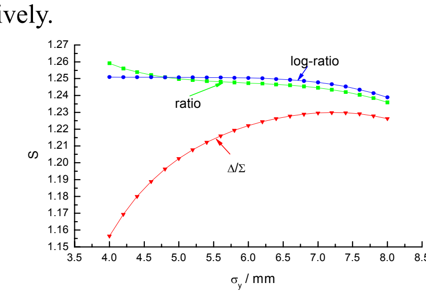
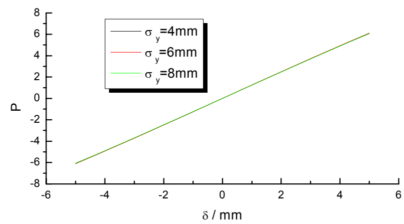



Figure 3: Sensitivity of using different methods.

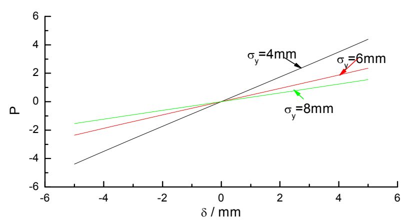
From Table 1 and Fig. 2 and Fig. 3, we can conclude that log-ratio method has the widest linearity at same beam size. In the same processing algorithm, we also find the linearity of the position signal curve gets worse with the beam size decrease. For the same bunch size, the log-ratio method has largest sensitivity of the three methods, as well it can ignore the influence of bunch size.

## COMPARING STAGGERED PAIR MONITOR WITH DOUBLE-BLADE MONITOR

Double-blade monitor [8] is already used in synchrotron radiation source world-widely for its high sensitivity and none zero-bias, but it is impacted by bunch size greatly, for which it can not do high precision measurements in a large range, and not be used in position feedback system. Next we will compare the staggered pair monitor with double-blade monitor.




(a) Staggered pair monitor




(b) Double-blade monitor

Figure 4: Position signal with respect to offset for different bunch size of using log-ratio method.

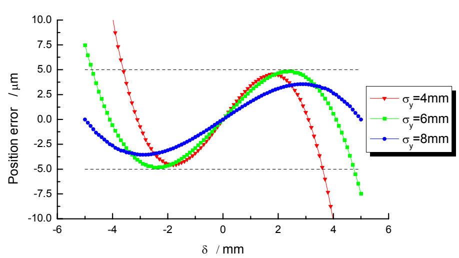



Figure 5: The linearity range for double-blade monitor of using log-ratio method.

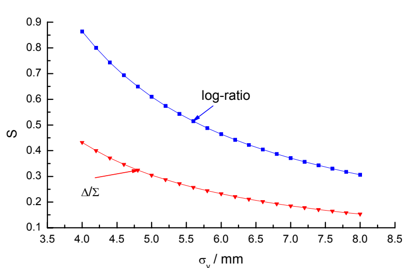



Figure 6: Sensitivity of using different methods for double-blade monitor

Using log-ratio method, Fig. 4 shows the result of staggered pair monitor, and the double-blade monitor. From Fig. 4 and Fig. 5, we can see that the double-blade monitor has a wider linearity range than staggered pair monitor of using log-ratio method. However it is impacted by bunch size greatly, while the staggered pair monitor obtains identical beam position with different bunch size. Using $\Delta/\Sigma$ method, we can receive the same conclusion.

Comparing Fig. 6 with Fig. 3, it is shown that the staggered pair monitor has the higher sensitivity and the sensitivity is smoother than the double-blade monitor.

## SUMMARY

Based on the theory analysis above, we can come to the conclusion that, log-ratio method has the best linearity range and the most excellent sensitivity of the three methods. Though the linearity range of the double-blade monitor is a little larger than the staggered pair monitor, the sensitivity is more susceptible to bunch size.

In the future, we will implement this new type of PBPM in undulator beam lines, which is newly built by HLS to examine its functionality. And then, we will design a PBPM system with staggered pair PBPM and log-ratio method for its high dynamic range, wide linearity and good sensitivity.

## REFERENCES


[1] S. F. Lin, B. G. Sun, et al, "Photon beam position monitor with spring system in HLS", High Power Laser and Particle Beams, Vol. 19, No. 8(2007), p. 1369.

[2] C. B. Shen, B. G. Sun, et al, "Research of Signal-processing Methods in Four-quadrant Photodetector", Proceedings of ICEMS'2008, Oct. 2008, p.917.

[3] S. Marques, P. F. Tavares, "Commissioning of the LNLS X-ray BPMs", Proceedings of EPAC 2006, Edinburgh, Scotland, p.998.

[4] K. Holldack, D. Ponwitz, et al, "Beam stability of undulator and dipole radiation on BESSY II obtained by synchrotron radiation monitors", Nuclear Instruments and Methods in Physics Research A 467–468(2001), p.213.

[5] W. B. Peatman, K. Holldack, "Diagnostic front end for BESSY II", J. Synchrotron Rad. 5 (1998), p.639.

[6] K. Holldack, W.B. Peatman, "Synchrotron Radiation Diagnostics on BESSY II", AIP Conf. Proc. 521(1999), p.354.

[7] S. F. Lin, B. G. Sun, et al, "Photon beam position monitor signal processing system with logarithmic ratio method", High Power Laser and Particle Beams, Vol. 18, No. 11(2006), p.1903.

[8] G.Mrotzek, R.Cernik, "Photon Beam Position Monitors on the SRS at Daresbury", Proceedings of EPAC1994, London, England, p. 1563.