THE STUDY OF NEW SIGNAL PROCESSING TECHNIQUE IN PHOTON BEAM POSITION MONITORS*

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Abstract

A log-ratio signal processing technique in photon beam position monitors (PBPMs) was presented in this paper. The main performances (e.g. sensitivity, position offset and linearity range) of split PBPM and two-wire PBPM were analyzed. An inexpensive logarithmic and log-ratio amplifier chip (LOG112) that can measure currents from 0.1nA to 3.5mA was used in circuits.

INTRODUCTION

Beam stability of the synchrotron radiation source beamlines is very interested by the light source users. One of the most sensitive diagnostic tools for the observation of beam stability is the PBPM. The non-destructive PBPMs are widely used in many synchrotron light source facilities[1-3]. The commonly available method for deriving normalized PBMP signals is difference-over-sum (Δ/Σ). But log-ratio processing and amplitude-modulation-to-phase-modulation (AM/PM) are also available for deriving normalized the beam-position signals[4], and the log-ratio processing provides high bandwidth, the most linear response and wide dynamic range. It give us the idea that the log-ratio processing for deriving normalized the PBMP signals may give a better performance than Δ/Σ signal processing technique.

PRINCIPLE

Figure 1 shows the schematic of a split monitor. The two split triangular blades were irradiated by synchrotron radiation (SR) light, then photoelectrons occurred on the blades made of molybdenum. The photoelectrons were detected as currents. The photon beam position is commonly calculated with the Δ/Σ equation as follows

$$P_{\Delta/\Sigma} = (I_U - I_D)/(I_U + I_D) \quad (1)$$

Where $P_{\Delta/\Sigma}$ is the photon beam position, I_U and I_D are currents intensity from upper and down blades.

The photon beam position measured P_{Log} can also be calculated with the log-ratio processing as

$$P_{Log} = \log(I_U / I_D) \quad (2)$$

ANALYSIS OF PERFORMANCE

The main characters of a PBPM are sensitivity, linearity range and position offset. Sensitivity is defined by the equation as follows

$$S = \left(dP / d\delta\right)_{\delta=0} \quad (3)$$

Where P is the photon beam position, δ is the centre offset between SR light and the monitor.

The centre position of SR light measured y can be written as

$$y = P / S \quad (4)$$

Position offset is defined by the equation

$$\Delta = P / S - \delta \quad (5)$$

As followed we analyze the performance of the two signal processing methods to two-wire monitor and split monitor.

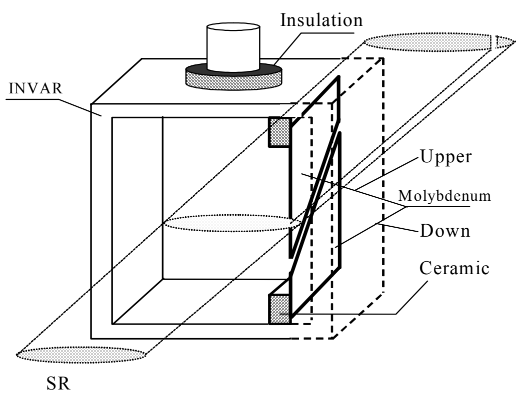

Figure 1: The schematic of a split monitor.

3.1 Two-wire monitor

Figure 2 shows the schematic side view of a two-wire monitor. G is the gap between the two wires, δ is the centre offset between SR light and the monitor. W is the diameter of the wire, and here W=0.1mm.

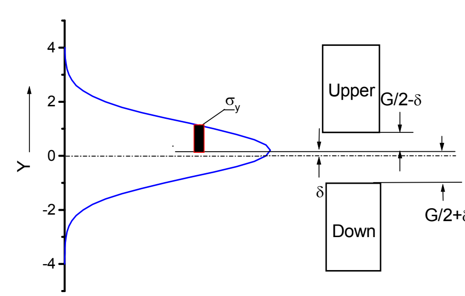

Figure 2: The schematic side view of a two-wire monitor.

Assuming that synchrotron radiation light is a Gaussian distribution, we can write the distribution of the vertical light intensity as

$$\Phi(y) = \Phi_0(t)\frac{1}{\sqrt{2\pi}\sigma_y}\exp\left(-\frac{y^2}{2\sigma_y^2}\right) \quad (6)$$

Where σ_y is the vertical dimension of SR light. Since σ_y is much lager than the diameter of the wire, σ_y<<W, the currents density from the two wires have the positive

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correlation with the light density, and the currents density can be expressed as

$$\begin{cases} I_U = I_0(t)\dfrac{1}{\sqrt{2\pi}\sigma_y}\exp[-\dfrac{(G/2-\delta)^2}{2\sigma_y^2}] \\ I_D = I_0(t)\dfrac{1}{\sqrt{2\pi}\sigma_y}\exp[-\dfrac{(G/2+\delta)^2}{2\sigma_y^2}] \end{cases} \quad (7)$$

Inserting (7) into (1) gives

$$P_{\Delta/\Sigma}(\delta)=\frac{I_U-I_D}{I_U+I_D}=\frac{\exp(\frac{G\delta}{2\sigma_y^2})-\exp(-\frac{G\delta}{2\sigma_y^2})}{\exp(\frac{G\delta}{2\sigma_y^2})+\exp(-\frac{G\delta}{2\sigma_y^2})} \quad (8)$$

The sensitivity and zero offset is

$$S_{\Delta/\Sigma}=\left.\frac{dP_{\Delta/\Sigma}}{d\delta}\right|_{\delta=0}=\frac{G}{2\sigma_y^2} \quad (9)$$

Inserting (7) into (2) gives

$$P_{Log}(\delta)=\log\frac{I_U}{I_D}=\frac{G}{\sigma_y^2\ln 10}\delta \quad (10)$$

The sensitivity calculated with Eq.(3) and Eq.(9) is

$$S_{Log}=\frac{dP_{Log}}{d\delta}=\frac{G}{\sigma_y^2\ln 10} \quad (11)$$

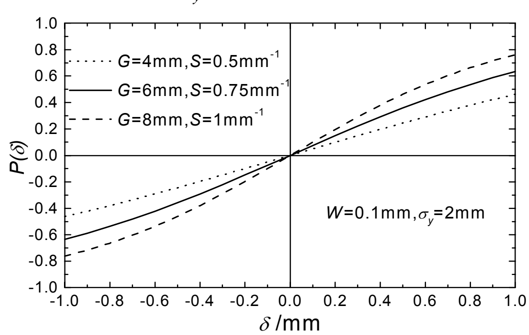

Figure 3: The position signal curves of a two-wire monitor at different gap.

Figure 3 shows the position signal curves of a two-wire monitor at different gap calculated with Eq. (8). We can find that sensitivity increases with increasing gap.

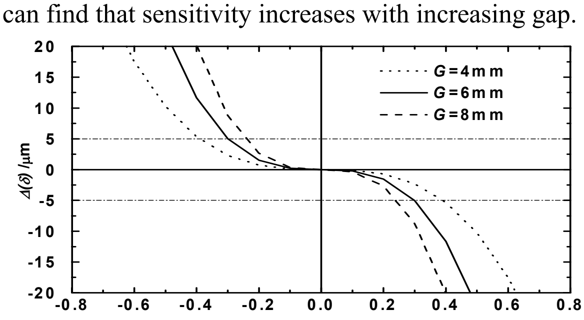

Figure 4: The position offset curves of a two-wire monitor at different gap.

Figure 4 shows position-offset curves of a two-wire monitor at different gap calculated with Eq. (5). We notice that linearity range decreases with increasing gap, so it is a trade-off between sensitivity and linearity range if we process the signals of a two-wire PBPM with the Δ/Σ method. We commonly choose G=(2~4)σ_y with giving attention to sensitivity and linearity range. If σ_y=2mm, G=3σ_y=6mm, the sensitivity is about 0.75mm^{-1}, the linearity range equals about ±0.3mm when the acceptance position offset is less than 5μm.

With Eq. (10) and (11), one finds that the position signal curve is a beeline obviously, and the idea position offset equals 0 exactly, so the idea linearity range can be very wide if we process the signals of a two-wire monitor with log-ratio processing method, and we can obtain a larger S_{log} than $S_{\Delta/\Sigma}$ with choosing a wider gap.

3.2 Split monitor

Figure 5 shows the schematic of a split monitor, where *H* is the height of the triangle blade; *L* is the length of the triangle blade. The horizontal distribution of SR light from the bend magnet beam is a uniform distribution in the acceptance angle, and the horizontal distribution of SR light is a Gaussian distribution approximately.

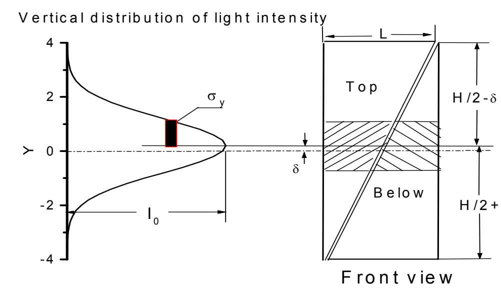

Figure 5: The schematic of a split monitor.

Thus the vertical distribution of light intensity can be expressed as Eq. (6), where σ_y is the vertical dimension of the SR light, which about equals 3.5mm for HLS. So the currents intensity from the upper and lower electrode can be written as

$$\begin{cases} I_U = k\dfrac{\Phi_0(t)}{\sqrt{2\pi}\sigma_y}\displaystyle\int_{-H/2}^{H/2}\left(\frac{L}{2}+\frac{L}{H}y\right)\exp[-\frac{(y-\delta)^2}{2\sigma_y^2}]dy \\ I_D = k\dfrac{\Phi_0(t)}{\sqrt{2\pi}\sigma_y}\displaystyle\int_{-H/2}^{H/2}\left(\frac{L}{2}-\frac{L}{H}y\right)\exp[-\frac{(y-\delta)^2}{2\sigma_y^2}]dy \end{cases} \quad (12)$$

Where k is conversional coefficient.

With Eq. (11) substituted into Eq. (1) the photon beam position measured $P_{\Delta/\Sigma}(\delta)$ can be deduced as

$$P_{\Delta/\Sigma}(\delta)=\frac{2}{H}\frac{\int_{-H/2}^{H/2}y\exp[-(y-\delta)^2/2\sigma_y^2]dy}{\int_{-H/2}^{H/2}\exp[-(y-\delta)^2/2\sigma_y^2]dy} \quad (13)$$

If $H \gg \sigma_y$ ($H=6\sigma_y$), the sensitivity of a split PBPM approximately is

$$S_{\Delta/\Sigma}=\left(dP_{\Delta/\Sigma}(\delta)/d\delta\right)_{\delta=0}\approx 1.95/H \quad (14)$$

With Eq. (11) substituted into Eq. (2) one can obtain $P_{\log}(\delta)$ as

$$P_{\log}(\delta)=\frac{\int_{-H/2}^{H/2}(\frac{1}{2}+\frac{1}{H}y)\exp[-(y-\delta)^2/2\sigma_y^2]dy}{\int_{-H/2}^{H/2}(\frac{1}{2}-\frac{1}{H}y)\exp[-(y-\delta)^2/2\sigma_y^2]dy} \quad (15)$$

And the sensitivity measured $S_{\log}$ at H=6σ_y approximately is

$$S_{\log}=\left(dP_{\log}(\delta)/d\delta\right)_{\delta=0}\approx 1.69/H \quad (16)$$

Comparing Eq. (14) and (16), one can find that the sensitivity is irrelative with σ_y approximately, and $S_{\Delta/\Sigma}$ is 11.5% lager than S_{log}. With Eq. (13) and (15) we obtain the position signal curves of a split monitor at H=20mm and σ_y=3.5mm (Figure 6).

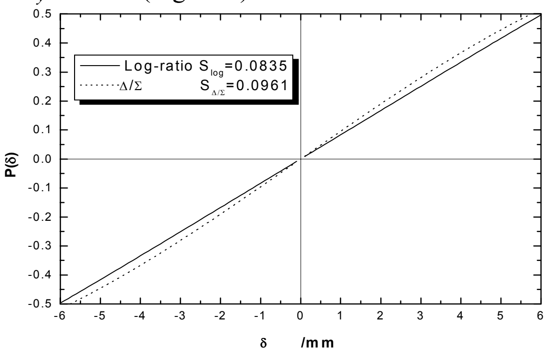

Figure 6: The position signal curves of a split monitor at H=20mm and σ_y=3.5mm.

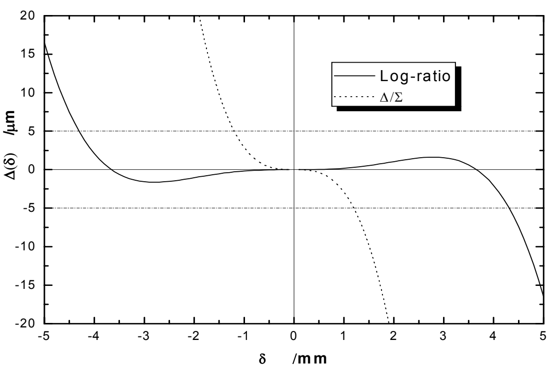

Figure 7: The position-offset curves of a split monitor at H=20mm and σ_y=3.5mm.

Figure 7 shows the position-offset curves of a split monitor at H=20mm and σ_y=3.5mm. Notice that the linearity range equals about ±1.3mm (Δ/Σ) and ±4.3mm (Log-ratio) when the acceptance position offset is less than 5μm. The log-ratio processing method provides a wider linearity range than Δ/Σ method.

SIGNAL PROCESSING BOARD

As up following analysis the log-ratio processing can provide a much wider linearity range and a less sensitivity than the conversional Δ/Σ signal processing technique, but until recently, the log-ratio processing has not been commonly available in PBMP signals processing because of high precise log-ratio amplifier cost and accuracy constraints. In 2002, Texas Instruments Cop. announced the LOG112 high precision logarithmic and log-ratio amplifier that provides a high accuracy up to 0.2% FSO over 5 decades and a wide input dynamic range up to 7.5 decades from 100pA to 3.5mA [5]. The idea transfer function of the log-ratio amplifier (LOG112) is

$$V_{OUT} = 0.5\log(I_1 / I_2) \tag{17}$$

Where V_{OUT} is output voltage; I_1 and I_2 are input currents.

Figure 8 shows the function block diagram of log-ratio processing board. LOG112 converts the input currents from the PBPM to analog voltage according to Eq. (17). Then the single-ended voltage is converted to differential voltage by amplifier AD8138. The differential voltage is converted to digital signal by 16bit analog digital converter AD9675. The digital signal is processed in a ARM7 (LPC2292, PHILIPS Cop.) chip. The embedded μC/OS II system with networking capabilities simplifies integration into a processing board that has a good performance price ratio.

SUMMARY

As the theory analysis, the log-ratio processing method for deriving PBPM signals can provide a wider linearity range than Δ/Σ method, a large sensitivity characteristics than Δ/Σ method for a two-wire monitor, and a less sensitivity characteristics than Δ/Σ method for a split monitor. An inexpensive LOG112 log-ratio amplifier chip was used in the signal processing board, but the electric board has not been finished, so the test results of the electric board have not been given out yet.

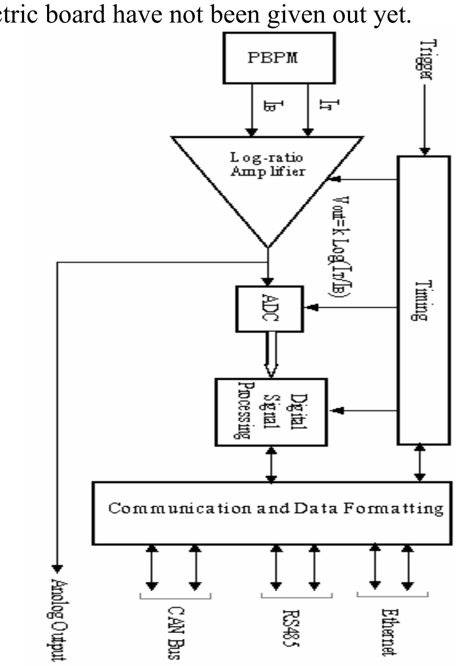

Figure 8: The function block diagram of log-ratio processing board.

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