CALIBRATION OF QUADRUPOLE COMPONENT OF BEAM POSITION MONITOR AT HLS LINAC*

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Abstract

The strip-line beam position monitor can be used as a non-intercepting emittance measurement monitor and it is independent of the beam distribution [1]. The most important part of emittance measurement is to pick up the quadrupole component. To improve the accuracy of measurement, the response of the strip-line BPM pickups will be mapped before it's installed in the HLS LINAC.

This paper introduces the calibration system of the BPM. The position calibration is done first because it's needed to get position information before pick up the quadrupole component. By analyzing the antenna's position and the data from electronics system, the offset between electronic center and mechanical one of the BPM and the position sensitivity can be gotten.

There are two methods for quadrupole component calibration: one is indirect evaluation method that estimates the sensitivity of quadrupole component by the factor of position second moment; the other is direct method by simulation of a Gaussian beam through together many Gaussian weighted grid points. The measurement results of two methods are given and compared. The effect of antenna's diameter upon the fitting size of simulate beam has also been analyzed.

INTRODUCTION

We have redesigned a non-interceptive precise strip-line beam position monitor (BPM) for HLS LINAC. To the BPM, its electrode opening angle is 45^0, and its inner radius is 19.8mm [2]. The strip-line position monitor can be used as a non-intercepting emittance measurement monitor and it is independent of the beam distribution. There exist errors in machining, cable matching and signal processing circuits, which results in not only producing difference between the actual value and the calculated value of the sensitivity of quadrupole component but also bringing in the influence of high-order moment. So before it's installed in the HLS LINAC, it's mapped in the laboratory by two methods with a drive-by-wire moving bench of which accuracy is less than 5μm.

CALIBRATION SYSTEM

The system is made up of a movable antenna with a RF signal source to simulate the beam, a BPM moving bench with its control system, electrode signal acquisition system and analysis software.

Calibration Bench

The calibration bench of the strip-line BPM is shown in Fig. 1.

We used an antenna of about 0.5mm diameter through BPM, and feed-in it with the high-frequency signal which has the same frequency with the real beam, to simulate the beam. In the HLS LINAC, the frequence of bunch micropulse is 2856 MHz, the width of mcrpulse is 1μs, and the frequence of mcrpulse is 1Hz. We set up the signal source according to these parameters.
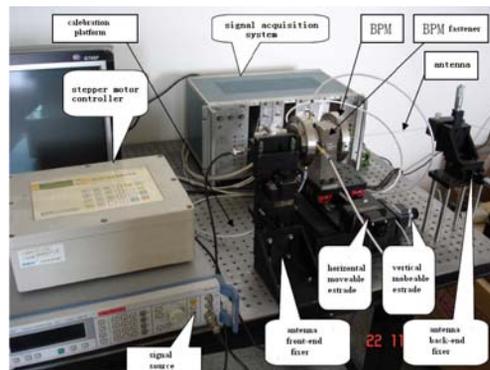
Figure 1: Calibration bench of HLS LINAC BPM.

To avoid the vibration of the antenna, we fixed up both ends of the antenna, putting the BPM on a drive-by-wire bench and moved the bench. We must make sure both the antenna and the BPM are in the same level.

Signal Processing System
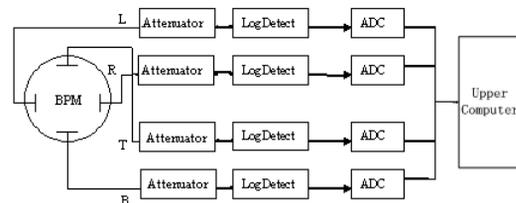
Figure 2: Signal processing system of BPM.

The signal processing system of HLS LINAC BPM in Fig. 2 consists of attenuator, logarithmic detector, signal acquisition module and the upper computer [3]. In order to process the signals in real-time, we use 4-way parallel processing approach. The RF signal inducts from the strip-line detector going through the coaxial attenuator and the logrithmic detector module. Then the amplitude information of the RF signal can be got. It's digitized by the analog-to-digital converter module and transferred to the computer to calculate the parameters of the beam.

An important parameter of this signal processing system is the dynamic range, which mainly depends on

the logarithmic detector module. The measurement results of 4-way logrithmic detector circuit are shown as Fig. 3, and the dynamic range is -45dBm to -5dBm. In this range, the output voltage of the logrithmic detector circuit has a linear relationship to the input signal power.
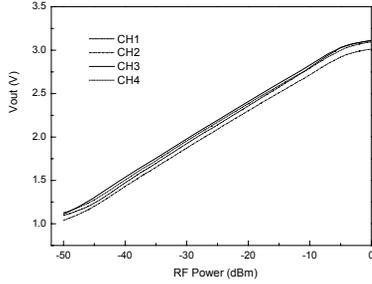
Figure 3: Dynamic range of BPM signal processing module.

METHOD TO PICK UP THE QUADRUPOLE COMPONENT

Usually, two methods are used to pick up the second moment $\sigma_x^2 - \sigma_y^2$ (quadrupole component) from BPMs' signals, which are the difference/sum ratio (Δ/Σ) method and the log-ratio method [2].

Difference/Sum Ratio Method

We use R, L, T and B to express the four voltage signals from four electrodes (right, left, top and bottom). After some analysis and calculations we can get:

$$Q_{\Delta/\Sigma} = \frac{R+L-T-B}{R+L+T+B}$$
$$= 2\frac{\sin\beta}{\beta}(\frac{\sigma_x^2 - \sigma_y^2}{b^2} + \frac{x_0^2 - y_0^2}{b^2}) + O\left(\frac{1}{b^6}\right) \quad (1)$$

Here the O is the infinitesimal. In the equation (1), there are the item $\sigma_x^2 - \sigma_y^2$ and the item $x_0^2 - y_0^2$. To get the second moment $\sigma_x^2 - \sigma_y^2$, the item $x_0^2 - y_0^2$ must be known.

While omitting 3rd order, we approximately get:

$$\begin{cases} \dfrac{R-L}{R+L} = 4\dfrac{\sin(\beta/2)}{\beta}\dfrac{x_0}{b} \\ \dfrac{T-B}{T+B} = 4\dfrac{\sin(\beta/2)}{\beta}\dfrac{y_0}{b} \end{cases} \quad (2)$$

Here β and b mean the electrode opening angle and inner radius of BPM.

We can solve x_0 and y_0 from the equation (2), and then take the results into the equation (1), to get the second moment.

For the second moment, the sensitivity of Δ/Σ is:

$$S_{\Delta/\Sigma} = 2\frac{\sin\beta}{\beta}\frac{1}{b^2} \quad (3)$$

Log-ratio Method

When we use logarithmic detector after BPM, the signal we got is $20\lg R$, $20\lg L$, $20\lg T$ and $20\lg B$ at the

output of data acquisition system. So, the log-ratio method can be put forward.

$$Q_{log-ratio} = 20\lg\frac{RL}{TB} = \frac{160}{\ln 10}\frac{\sin\beta}{\beta}\times$$
$$\left[\frac{\sigma_x^2 - \sigma_y^2}{b^2} + \left(1 - \frac{\tan(\beta/2)}{\beta}\right)\frac{x_0^2 - y_0^2}{b^2}\right] + O\left(\frac{1}{b^4}\right) \quad (4)$$

While omitting 3rd order, we approximately get:

$$\begin{cases} 20\lg\dfrac{R}{L} \approx \dfrac{160}{\ln 10}\dfrac{\sin(\beta/2)}{\beta}\dfrac{x_0}{b} \\ 20\lg\dfrac{T}{B} \approx \dfrac{160}{\ln 10}\dfrac{\sin(\beta/2)}{\beta}\dfrac{y_0}{b} \end{cases} \quad (5)$$

The sensitivity of log-ratio is:

$$S_{log-ratio} = \frac{160}{\ln 10}\frac{\sin\beta}{\beta}\frac{1}{b^2} \quad (6)$$

POSITION CALIBRATION

Because it's needed to get position information before pick up the quadrupole component. So we do the position calibration first.

During the experiment, the antenna is remained unchanged on the horizontal direction, and moved on the vertical direction. We make the horizontal direction x_0 equal to 0, and get the data per 0.1mm on the y direction. The vertical direction information by the difference/sum ratio (Δ/Σ) method and the log-ratio method are shown in Fig. 4. We can find that the linearity of the log-ratio method is better than the Δ/Σ method. Through the Fig. 4 the actual vertical position sensitivities of two methods are 0.0929 mm^{-1} and 1.652 mm^{-1}.
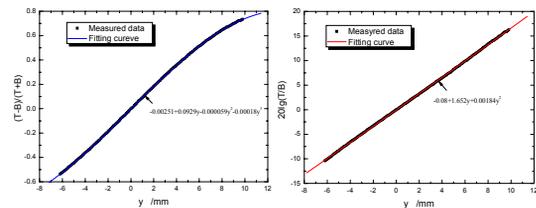
Figure 4: The setting value and measured value on y direction.

QUADRUPOLE COMPONENT CALIBRATION

We combine equation (1) and (4):

$$Q_b = K_{b0} + K_{b1}(\sigma_x^2 - \sigma_y^2) + K_{b2}(x_0^2 - y_0^2)$$
$$+ K_{b3}x_0 + K_{b4}y_0 + \cdots \quad (7)$$

The aim of quadrupole component calibration is to calculate the actual calibration coefficient through the calibration data. The most important is to get the quadrupole component coefficient K_{b1}, that is, the sensitivity S_b. According to the principle of getting the calibration coefficient, it can be divided into indirect method and direct method.

Indirect Method

To the indirect method, we get the calibration coefficient K_{b2} first, and then figure out the sensitivity S_b by use K_{b2}.

The antenna of calibration is basically circular, that is $\sigma_x^2 - \sigma_y^2 = 0$. So the data information get from the antenna at ever position do not include the $\sigma_x^2 - \sigma_y^2$ term in equation (7). But they include the information of the $x_0^2 - y_0^2$ term. So we can figure out K_{b2} by fitting these data. According to some theoretic analysis, the theoretical value of K_{b1} is same with K_{b2} to the Δ/Σ method, and K_{b1} of the log-ratio method is $K_{b2}/\{1 - [\tan(\beta/2)]/\beta\}$.

Since $\sigma_x^2 - \sigma_y^2 = 0$ and x_0 has been set as 0, the equation (7) can be simplified as:

$$Q_b = K_{b0} + K_{b3}y_0 - K_{b2}y_0^2 + \cdots \qquad (8)$$

Fig. 5 shows the relationship between Q_b and y_0 of two methods. After the quadratic term fitting with these data, the fitting result shows as follows:

$$\begin{cases} Q_{\Delta/\Sigma} \approx 0.021 + 0.00713y_0 - 0.004y_0^2 \\ Q_{\log-ratio} \approx 0.711 + 0.241y_0 - 0.06y_0^2 \end{cases} \qquad (9)$$
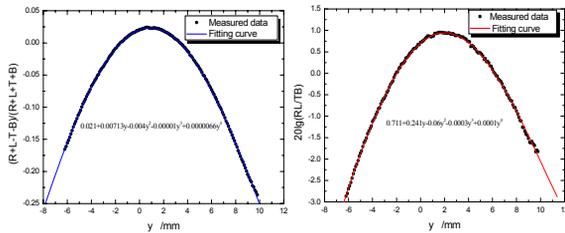
Figure 5: Relationship of Q and y .

According to equation (9), the actual quadrupole component sensitivities of two methods are 0.004 mm^{-1} and 0.127 mm^{-1}.

Direct Method

Since it is impossible to directly feed-in a Gaussian distribution current to the antenna to simulate the beam, we use some grid points with Gaussian weighting to simulate the Gaussian distribution beam [4].

To this method, the quality of the results has a significant relationship with the diameter of the antenna and the step length of the grid. After some calculation, analysis and contrast, we choose diameter 0.5mm and step length 0.1mm, and the error is about 1%, which is acceptable.

The measure is done on vertical direction, set $\sigma_x = 0$, change σ_y to simulate different beam with different diameter. Affected by the stepper motor, the range of the relative movement on vertical direction is (-6mm, 10mm). So the RMS (Root Mean Square) of the Gaussian beam which we want to simulate should not be too big, and we choose less than $3\sigma_y$. Considering the symmetry, we just choose the data on the range of (-6mm, 6mm) on the y direction. The results are shown in Fig. 6.

We can find that the results of two methods are almost the same.
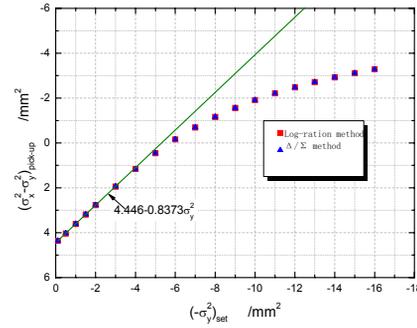
Figure 6: Quadrupole component pick-up results after Gaussian weighted.

We can find that the actual results have a linear relationship just when $\sigma_y \leq 2$mm. Because just when $\sigma_y \leq 2$mm, 3σ is with the range of (-6mm, 6mm).

Do the linear fitting with these data, we can get:

$$\left(\sigma_x^2 - \sigma_y^2\right)_{pick-up} = 4.446 - 0.8373\sigma_y^2 \qquad (10)$$

The normalized value of sensitivity is 0.8373 which is not the same as the theoretical value of 1, affected by the error of electrode opening angle and its radius. There's a constant term at equation (10), which is the effect of asymmetry of four electrodes. Besides, the size of the antenna do not equal 0 has also impact on that.

CONCLUSION

Before the BPM is installed in the HLS LINAC, it's mapped in the laboratory by the difference/sum ratio (Δ/Σ) method and the log-ratio method. To improve the accuracy of quadrupole component calibration, the two-dimension gridding calibration is going to be done.

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