A METHOD TO CALIBRATE BEAM POSITION MONITOR AT HLS 200 MeV LINAC*

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Abstract

In order to improve injection efficiency of HLS 200Mev LINAC, we redesign a new strip line beam position monitor system, which is consisted of a strip line structure and a signal processing system. We decide on an online calibration method based on beam to find out the geometry centre displacement and relative gain offset. Before the BPM testing bench has been prepared, we make a simulation based on the model accounted for all factors influencing signal amplitudes and get the calibrating results. At last, we analyze the nonlinearity effect on the calibration results.

INTRODUCTION

In order to improve the injection efficiency and the performance of beam position measurement, we redesign a new beam position monitor system for HLS 200MeV Linac. The new system is consisted of a strip line structure and a signal processing system, which is non-interceptive, good in precision, and facilitates digitalizing the measurement results. The system needs calibrating because of pickup centre displacement and nonlinearity caused by machining, installment, cable matching, and signal processing circuits. We give out a calibration model accounting for the factors influencing signal amplitudes based on on-line calibration. Before the BPM testing bench has been prepared, we make a simulation based on the model and get the calibrating results. At last, we analyze the nonlinearity effect on the calibration results.

STRIPLINE BPM STRUCTURE

Beam position monitors at HLS Linac and transfer line will deliver the information about the transverse positions of the beam passing by. The original stripline BPM for HLS LINAC has an azimuthal angle of 20.8 degrees with a length of 300mm and an inner radius of 22mm. According to the simulation results of CST Microwave Studio, the character impedance of the original structure is 48.7 Ω in sum mode, 47.2 Ω in dipole mode, and 46.7 Ω in quadrupole mode. But the amplitude of pick up

signals is not large enough to deduce the beam positions.

We redesign a new strip line structure for HLS 200MeV Linac[1], which is 60 degrees in azimuthal angel with an inner radius of 19mm and an length of 183.8mm (7/4 wavelength according to HLS Linac RF frequency 2.856GHz). Figure1 shows the new designed electrode structure for HLS 200MeV Linac. The character impedance of the new structure is 59.7Ω in sum mode, 47.6Ω in dipole mode and 42.8Ω in qaudrupole mode. The discrepancy of characteristic impedance among different modes is larger because of the stronger coupling between the electrodes of the new BPM.
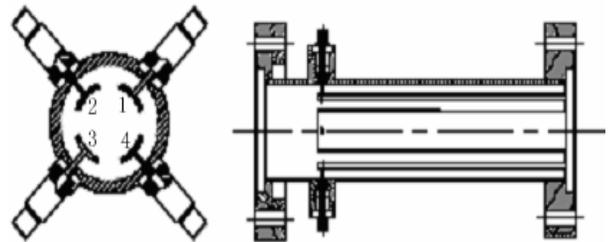
Figure1: Stripline BPM structure.

CALIBRATION METHOD

When it comes to the calibration scheme, we determine a beam based on-line calibration of the beam position monitor system for HLS 200MeV Linac. According to Kotaro Satoh and Masaki Tejima[4] , we get the calibration parameters based on a calibration model and a method of multi-measurement and function fitting, which can reduce the calibration errors than single measurement method. Additionally, the beam based calibration method has an advantage over the traditional antenna scanning and wire scanning methods [3], which use some simulation signals other than beam signals themselves and are prone to errors caused by electric centre displacement.

CALIBRATION MODEL

According to Kotaro Satoh and Masaki Tejima[4] , the 4 strip line pickup signals processed can be expressed as

$$V_i = g_i \cdot q \cdot F_i(x, y), \qquad i = 1,2,3,4 \qquad (1)$$

Where q is beam charge, x and y is horizontal and vertical beam positions respectively relative to geometrical monitor centre, $F_i(x, y)$ stand for pickup

response functions and are normalized as $F_i(0,0) = 1$, g_i stand for the relative overall gains of each electrode and $g_1 = 1$.

Firstly, we calculate the pickup response functions $F_i(x, y)$ by Mafia simulation and function fitting. The electrode signals induced by ultrarelativistic beam can be expressed as[5]

$$F_1(x,y) = 1 + \sum_{k=1}^{\infty} r^k (a_i(k)\cos k\theta + b_i(k)\sin k\theta) \quad (2)$$

Where θ stands for the azimuthal angle of each electrode. The pickup structure for HLS 200MeV Linac has a symmetry as $\theta = 45^0$ and $F_1(x,y) = F_1(y,x)$. So equation 2 can be expressed as

$$F_1(x,y) = 1 + a(x+y) + bxy \\ + c(x^3 + y^3) + d(x^2 y + xy^2) \quad (3)$$

Table 1 gives out the pickup response of electrode through Mafia[6] simulation about stripline pickup for HLS 200MeV Linac.

Table 1: Relations between beam potions and electrode responses.

(x , y)	(3,0)	(3,3)	(0,3)
F_1	1.132	1.347	1.132
(x , y)	(-3,3)	(-3,0)	(-3,-3)
F_1	0.985	0.978	0.869
(x , y)	(0,-3)	(3,-3)	(0,0)
F_1	0.978	0.985	1

Making a least chi-square fitting at equation 3 based on table 1, we get

$$F_1(x,y) = 1 + 0.0746(x+y) + 0.0068xy \\ - 0.0048(x^3 + y^3) + 0.0016(x^2 y + xy^2) \quad (4)$$

Because of symmetry of the pickup structure, we can also get the other three response functions as

$$\begin{cases} F_2(x,y) = F_1(-x,y) \\ F_3(x,y) = F_1(-x,-y) \\ F_4(x,y) = F_1(x,-y) \end{cases}$$

We can get a set of electrode signals after measuring m times.

$$V_{ij} = g_i q_j F_j(x_j, y_j) = V(i,j;a) \quad (5)$$

Where $i=1,\ldots,4$, $j=1,\ldots, m$, $a=(g_2, g_3, g_4, q_1, x_1, y_1, \ldots, q_m, x_m, y_m)$,

Now there are 3m+3 parameters to determine and 4m equations. So we can calculate the parameters such as g_2, g_3, g_4, q_1, x_1, y_1, $\ldots$, q_m, x_m, y_m by least chi-square fitting when $m \geq 4$. That is, they make equation 6 minimized.

$$\chi^2(a) = \sum_{i=1}^{4} \sum_{j=1}^{m} [V_{ij} - V(i,j;a)]^2 \quad (6)$$

CALIBRATION RESULTS AND ANALYSIS

Since the testing bench of the beam position monitor for HLS 200MeV LINAC has not been prepared, we use the electrode signals simulated by Mafia instead at present for calibration. Table 2 gives out the relations between beam positions and electrode signals.

Making a least chi-square fitting at equation 5 based on table 2, we get all the parameters calibrated as table 3.

Table 2: Electrode responses simulated by Mafia.

(x_j,y_j)	(3,0)	(3,3)	(0,3)	(-3,3)
V_{ij}	1.132	1.347	1.132	0.985
	0.978	0.985	1.132	1.347
	0.978	0.869	0.978	0.985
	1.132	0.985	0.978	0.869
(x_j,y_j)	(-3,0)	(-3,-3)	(0,-3)	(3,-3)
V_{ij}	0.978	0.869	0.978	0.985
	1.132	0.985	0.978	0.869
	1.132	1.347	1.132	0.985
	0.978	0.985	1.132	1.347

($g_i=q_j=1$, i=2,3,4, j=1,2,…, 9)

Table 3: Fitting values and preset values.

Preset $X_j Y_j$	(3,0)	(3,3)	(0,3)
Fitting values	(3.294,0.012)	(3.359,3.359)	(0.012,3.294)
Preset $X_j Y_j$	(-3,3)	(-3,0)	(-3,-3)
Fitting values	(-3.415,3.392)	(-3.325,0.013)	(-3.418,-3.418)
Preset $X_j Y_j$	(0,-3)	(3,-3)	(0,0)
Fitting values	(0.013,-3.325)	(3.392,-3.415)	(0.017,0.017)
σ	0.311		
Preset q_j	1 1 1 1 1 1 1 1 1		
Fitting values	1.053 1.039 1.053 1.039 1.053 1.038 1.053 1.039 0.998		
σ	0.017		
Preset g_i	1	1	1
Fitting values	1.002	1.005	1.002

(i=2,3,4, j=1,2,…, 9)

During function fitting we set the resolution for V_{ij} as 10^{-3}, which agrees with the precision for signal processing circuits of HLS Linac beam position monitor system. Based on table 3, the resolution for beam position is 0.3mm and the electric centre of strip line structure is (0.017, 0.017) mm.

Now we study beam position offset caused by nonlinearity of strip line structure. We only take into account the linear components of equation 4 and get the electrode response function as equation 7.

$$F_1'(x,y) = 1 + 0.0746(x+y) \qquad (7)$$

We can also get

$$\begin{cases} F_2'(x,y) = F_1'(-x,y) \\ F_3'(x,y) = F_1'(-x,-y) \\ F_4'(x,y) = F_1'(x,-y) \end{cases}$$

$$V_{ij} = g_i q_j F'_j(x_j, y_j) = V(i,j;a) \qquad (8)$$

We make a least chi-square fitting at equation 8 based on equation 7. Table 4 gives out comparative figures which show the effect of nonlinearity.

Table 4: Nonlinearity effect on calibration values.

σ	$\sigma_{xj,yj}$	σ_{qj}
Equation 7	1.418	0.030
Equation 4	0.311	0.017

From table 4, we conclude that nonlinearity has an impact of about a magnitude degree on the beam position resolution. So equation 4 describes electrode response better than equation 7.

CONCLUSION

Before the BPM testing bench has been prepared, we make a simulated beam-based calibration of stripline beam position monitor for HLS 200MeV Linac through a model accounting for the factors influencing electrode signal amplitudes. Adopting the method of Mafia simulation and least chi-square fitting, we conclude the beam position resolution is 0.311mm and nonlinearity has an effect of about a magnitude degree on beam position resolution. The simulated results are good enough for HLS LINAC BPM. And we expect a calibration on testing bench and a calibration after installation in future.

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