HLS NEW BPM CALIBRATING AND ERROR ANALYSIS*

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Abstract

A precise calibrating system for newly adopted beam position monitors (BPM) of upgraded injection system in NSRL phase II project is described. The fitting error of the electric field is presented. Using the calibrating system and the method which has a system error about $\pm15\mu m$ and the precision of $1\mu m$, we have completed the calibration and checking of the quality to the developed equipment. Due to the beam pipe is fixed vertically and move the antenna to simulate beam orbit deviation, as well as we adopt the RF CW simulating the beam and not the previously 5MHz CW, and the results show fine precision and better reliability.

1 INTRODUCTION

BPM is a detector mounted for monitoring the transverse beam orbit in the vacuum chamber in operation. It is an indispensable diagnostics instrument while machine physics studying and insertion device commissioning. In 1995, we rebuild the key parts of the BPM system and achieved operating which total 27 BPMs around the ring[1]. For the sake of NSRL injection system upgrade, 8 BPMs for two ends of 4 groups modified vacuum pipe are newly manufactured, see next section in detail. The BPMs have the same structure as that of the previous. In general, BPM should be scaled and calibrated before application. The involved method is antenna simulating beam and fitting position-electrode voltage function.

2 CALIBRATING SYSTEM

The system is made up of a mechanical device which positions antenna in the beampipe, pickup electrodes & signal detection modules, computer control and signal processing module.

2.1 Constitution of Calibrating System

The improved injection system consists of two 1.21m and two 1.84m line sections, each with 2 BPMs on either end. The BPM button electrodes are all at skew directions. In our calibrating system, the beam pipe is fixed vertically which avoid that the antenna prolapses in the long pipe if layed horizontally. The repositioning of antenna is performed by a machine tool with a precision of 10μm. The machine tool could be controlled by computer or manually. Antenna induced eight signals which are from two BPMs on up and down end of beam pipe are respectively fed into two Bergoz BPM modules[1]. The modules work on heterodyne receiving with up to 75dB dynamic range and 1μm resolution. The BPM modules are adjusted to 204MHz center frequency which is RF of HLS and ±200kHz BP filtering. Button electrodes Δ/Σ operation is done internally and output V_x, V_y are proportional to x and y position, respectively. Here we use RF CW simulating the beam and not the previously 5MHz CW, and the results show fine precision and better reliability. The schematic diagram of the system is shown in Fig.1.
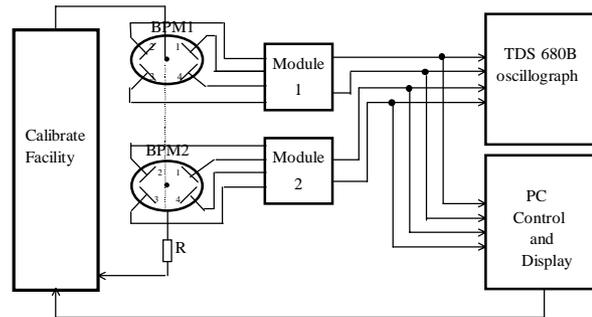

Fig.1 Schematic diagram of HLS calibrating system

2.2 Antenna Simulating Facility

To better the repositioning precision, we fix the beam pipe and move the antenna to simulate beam orbit deviation[2]. The antenna clamper has a high precision guiding bracket and before measurement, the clamping and slacking should be repeated for a number of times and the average position deviation should be recorded. This ensures that antenna well parallel to the axis of beam pipe and the BPM measurement precision and repeatability. The antenna is fixed parallel to pipe mounting reference with a nominal precision of 0.01mm. The running step resolusion of antenna driving on the X-Y plane is 0.001mm. The driving bench position is read out with two grating rules. To ensure the measurement coincidence of up and down BPMs, all read-outs are relative to the zero-point of the grating rule. The mechanical error of measurement could be limited below 10μm.

3 DATA PROCESSING AND ESTIMATE OF THE SYSTEM PRECISION

The electronic signal detection we using are a commercial available module from Bergoz Company. The output Vx, Vy is functions of beam X and Y position.

$$X\,(mm) = \frac{V_x}{G_x} = K_x * U = \frac{U}{S_x} = \frac{V_x}{S_x * G_{ex}}$$

$$Y\,(mm) = \frac{V_y}{G_y} = K_y * V = \frac{Y}{S_y} = \frac{V_y}{S_y * G_{ey}} \qquad (1)$$

where :

$$U = \frac{(V_1 + V_4) - (V_2 + V_3)}{\sum_{k=1}^{4} V_k}, \qquad V = \frac{(V_1 + V_2) - (V_3 + V_4)}{\sum_{k=1}^{4} V_k}$$

V_k is button electrode induced voltage (k=1,…,4), S_x, S_y [%/mm] is the mechanical sensitivity, Gex, Gey is the electronics gain and Gx, Gy is the total gain: $Gx\,[V/mm]= Gy\,[V/mm]= S\,[\%/mm] \times Module\,Ge(V/\%)$.

$$V_X(V) = U(\%) * G_{ex}(V/\%)$$
$$V_y(V) = V(\%) * G_{ey}(V/\%) \qquad (2)$$

In the bench test we found the Gex,Gey have departure rating slightly for each modules and even the x and y channel in one module. To assure the accuracy, we measured and corrected each module.

3.1 Data Processing

In the beam pipe, electro-field is complex and the relation between beam position and electrode voltage is expressed as

$$X = \sum_{i=0}^{N} \sum_{j=0}^{i} a_{i-j,j}(U-U_0)^{i-j}(V-V_0)^j$$
$$Y = \sum_{i=0}^{N} \sum_{j=0}^{i} b_{i-j,j}(U-U_0)^{i-j}(V-V_0)^j \qquad (3)$$

where U_o, V_o are U, V when antenna set at pipe axis(x,y=0) and N is the fitting polynomial order.

In order to calibrate the BPM measurement, we measured electrode voltages and antenna positions at 19x19 points in the beam pipe, the mapping reference [2]. By applying least square fitting, a number of coefficients $a_{i-j,j}$, $b_{i-j,j}$ can be calculated with matrix operation. In our case, N=3 can limit the fitting error below 10μm, and we got 20 coefficients.

3.2 Estimate of the System Precision

Since the mechanical sensitivity is linear around the center of beam vacuum chamber, so we can calculate it with analytic method[4]. We measured module outputs at different moment and using Equation(1) we got the system measurement error is about ±15μm. The results are shown in Tab.1.

Tab.1 Vacuum Pipe 001

V_{X0} (V)	ΔV_{X0} (V)	Gex [V/mm]	ΔX (μm)
-.6743			
-.6669	0.0099	0.7155	12.6
-.6664			
-.6763			

The result consists of the following factors: about 10μm machine tool repositioning error; 10μm module output jitter; the manufacturing error etc. They corresponds to a 15-20mV module output.

4 SYSTEM MEASUREMENT ERROR

4.1 Fitting Error

RMS fitting error of measurement points for the X direction is[3]:

$$\sigma_{XN} = \left[\frac{1}{P} \sum_{p=1}^{P} \left(X_{N,P} - X_{m,P} \right)^2 \right]^{1/2} \qquad (4)$$

where Xm,p the measured antenna transverse position, Xn,p the N-order fitting value.

4.2 Effect Of Measurement Error

We can rewrite the fitting polynomial (3) as:

$$X = \sum_{i=0}^{N} \sum_{j=0}^{i} a_{i-j,j}(U-U_0)^{i-j}(V-V_0)^j \qquad (5)$$

For the Bergoz modules we are using, $U = V_X/G_{ex}$, $V = V_Y/G_{ey}$. Then the measurement error introduced fitting error at the pth point is[4]:

$$\delta X_p = \left[\left(\frac{\partial X(U,V)}{\partial U} \delta U \right)^2 + \left(\frac{\partial X(U,V)}{\partial V} \delta V \right)^2 \right]^{1/2}$$

$$= \left[\left(\sum_{i=0}^{3} \sum_{j=0}^{i} a_{i-j,j}(i-j)(U-U_0)^{i-j-1}(V-V_0)^j \right)^2 \left(\frac{\delta V_X}{G_{ex}} \right)^2 \right.$$
$$\left. + \left(\sum_{i=0}^{3} \sum_{j=0}^{i} a_{i-j,j} j(U-U_0)^{i-j}(V-V_0)^{j-1} \right)^2 \left(\frac{\delta V_Y}{G_{ey}} \right)^2 \right]^{1/2}$$

$$(6)$$

To be simple, we suppose that Vx and Vy with the same drift: $\frac{\delta V_X}{V_X} = \frac{\delta V_Y}{V_Y} = \frac{\delta V}{V}$, In our case, N is 3 and total 19x19 measured points, the RMS fitting error as:

$$\sigma_X = \left[\frac{1}{361}\sum_{P=1}^{361}\delta X_P^2\right]^{1/2}$$

$$= \left[\frac{1}{361}\left(\frac{\delta V}{V}\right)^2\left\{\sum_{p=1}^{361}\left[\left(\sum_{i=0}^{3}\sum_{j=0}^{i}a_{i-j,j}(i-j)(U-U_0)^{i-j-1}(V-V_0)^j\right)^2 U^2\right.\right.\right.$$

$$\left.\left.\left.+\left(\sum_{i=0}^{3}\sum_{j=0}^{i}a_{i-j,j}j(U-U_0)^{i-j}(V-V_0)^{j-1}\right)^2 V^2\right]\right\}\right]^{1/2} \qquad (7)$$

From the above results we can see, given a 15-20mV deviation, the measurement decination induced error is limited below 25μm.

5 CONCLUSION

From the various processing methods mentioned above, we could see that they are in agreement with each other. The fact that the fitting error is small than that of the measured. It proved that our calibrating and data processing is appropriate for this application, the results are reliable and they can reflect the manufacturing quality of the newly delivered BPMs and beam pipes. Using this calibrating system, we established the device checking and BPMs calibrates during injection upgrade project.

6 REFERENCES

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