NSLS2 BEAM POSITION MONITOR CALIBRATION

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Abstract

To get accurate beam position measurements along the accelerator complex, beam position monitor (BPM) sensitivity and electric offset need to be calibrated. A good calibration is essential for day one commissioning and large beam offset measurements. For various types of BPMs used in NSLS2, the sensitivity curves were calculated and fitting by high order polynomial fit. Fitting errors are typically less than 50um. BPM electric offsets are measured using four port network analyzer. These offset values will supply a good reference for beam based alignment.

INTRODUCTION

NSLS2 is a third generation light source under construction at Brookhaven National Laboratory. With sub-nm horizontal emittance, the beam orbit needs to be measured and controlled with very high precision. To achieve that, BPM detectors need to be calibrated for their sensitivity and electrical offset.

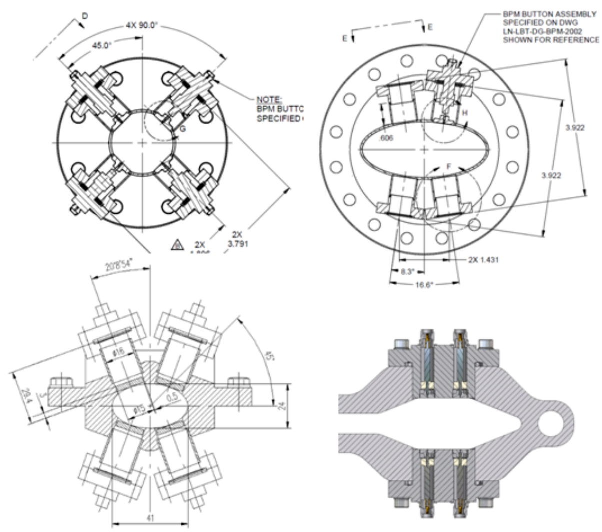

Figure 1: Types of the NSLS2 BPM. Top left: transfer line round type. Top right: transfer line elliptical type. Bottom left: booster elliptical type I. Bottom right: storage ring large aperture BPM.

There are various types of BPMs used in the NSLS2 complex. Table 1 lists the BPMs and their geometric sizes. The linear sensitivities of the BPMs are calculated and fitted with beam offset +/- 2.5mm. Storage ring BPMs may be rotated to have better vertical sensitivity. These rotated BPMs will be installed at the ends of insertion devices. Figure 1 shows some of the BPM assemblies.

With larger beam offset, nonlinearity of the BPM's response needs to be included. Figure 2 shows a storage ring large aperture BPM sensitivity curve, it's clear that nonlinear terms need to be included when beam deviations are large. With a 3rd or 5th 1-dimension polynomial fit, one can get good agreement of the raw value and fitted value. The maximum fitting error is ~100 μm with +/-10mm range. However, this 1-dimension fitting is good only for large beam offset in x plane with small y position offset (or y plane with small x position offset). Due to coupling, beam may have large x and y plane offsets. Huge systematic errors exist when only considering 1-dimensional fitting, as shown in Figure 3.

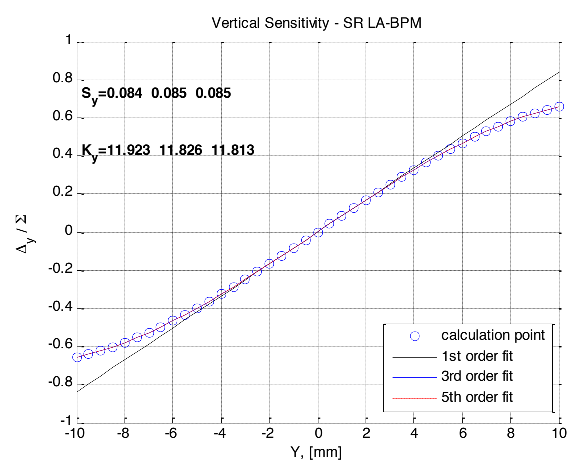

Figure 2: BPM sensitivity with 1-dimensional polynomial fit. Fitting errors are <100 μm with 3rd order fit and <50 μm with 5th order fit.

Table 1: NSLS-II BPM geometry and 1st Order Sensitivity

Machine		LINAC	LtB/BtS		Booster		SR Large Aperture BPM			SR Small Aperture BPM			
BPM Type		LINAC BPM	TL Round	TL Elliptic	BO type-I	BO type-II	SR LA-BPM	LA-45deg	LA-90deg	SR DW-BPM	DW-60deg	SR EPU-BPM	EPU-60deg
Geometry	Chamber type	Round	Round	Elliptic	Elliptic	Elliptic	Octagon	Octagon	Octagon	Octagon	Octagon	Octagon	Octagon
	Chamber size [mm]	40 dia.	40 dia	90*40 (w*h)	41*24 (w*h)	62*22 (w*h)	76*25 (w*h)	76*25 (w*h)	76*25 (w*h)	60*11.5 (w*h)	60*11.5 (w*h)	60*8 (w*h)	60*8 (w*h)
	Button size [mm]	10.8	15	15	15	15	7	7	7	4.7	4.7	4.7	4.7
	Button gap [mm]	0.25	1	1	0.5	0.5	0.25	0.25	0.25	0.25	0.25	0.25	0.25
	Button thickness [mm]	2	3	3	3	3	2	2	2	2	2	2	2
	Button location	45-deg	45-deg	27.8 H sep	20.7 H sep	25.2 H sep	16	16*cos(45)	16*cos(90)	10	10*cos(60)	10	10*cos(60)
1st order sensitivity	ky [mm]	14.37	14.55	18.37	11.51	14.52	11.92	9.78	8.21	6.95	4.43	7.34	3.40
	kx [mm]	14.37	14.55	17.19	9.93	8.24	11.08	14.30	NA	4.44	7.63	2.85	4.60

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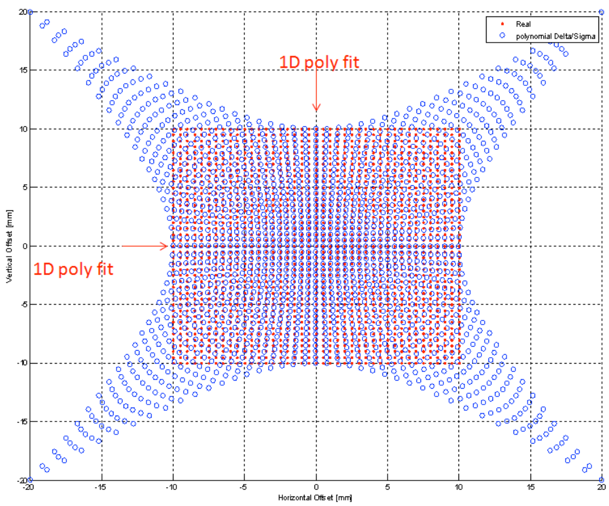

Figure 3: Huge errors at large x and y offsets. Red dots show the 2D beam offsets; blue dots, the fitted value using the coefficient from 5th order 1-D polynomial fitting. The 1-D fit is good for the x=0 or y=0 line.

BPM NONLINEARITY

2D nonlinearity fitting of BPM sensitivity is required to get rid of large systematic fitting error. Due to symmetry of the BPM geometry, six coefficients are needed, as shown in the following equations.

$$x_{mea} = p_{10}\left(\frac{\Delta}{\Sigma}\right)_x + \tag{1}$$
$$p_{30}\left(\frac{\Delta}{\Sigma}\right)_x^3 + p_{12}\left(\frac{\Delta}{\Sigma}\right)_x\left(\frac{\Delta}{\Sigma}\right)_y^2 +$$
$$p_{50}\left(\frac{\Delta}{\Sigma}\right)_x^5 + p_{32}\left(\frac{\Delta}{\Sigma}\right)_x^3\left(\frac{\Delta}{\Sigma}\right)_y^2 + p_{14}\left(\frac{\Delta}{\Sigma}\right)_x\left(\frac{\Delta}{\Sigma}\right)_y^4$$

$$y_{mea} = p_{01}\left(\frac{\Delta}{\Sigma}\right)_y +$$
$$p_{03}\left(\frac{\Delta}{\Sigma}\right)_y^3 + p_{21}\left(\frac{\Delta}{\Sigma}\right)_x^2\left(\frac{\Delta}{\Sigma}\right)_y^1 +$$
$$p_{05}\left(\frac{\Delta}{\Sigma}\right)_y^5 + p_{23}\left(\frac{\Delta}{\Sigma}\right)_x^2\left(\frac{\Delta}{\Sigma}\right)_y^3 + p_{41}\left(\frac{\Delta}{\Sigma}\right)_x^4\left(\frac{\Delta}{\Sigma}\right)_y^1$$

Figure 4 shows the 2D nonlinearity fitting of the linac BPM. The fitting error is less than 50µm in most area of +/-10mm square. At the corner, the error is ~100µm. Other types of BPMs have the similar fitting results. These nonlinearity coefficients can be used offline for large beam position calculation. It's possible to integrate the calculation inside the BPM electronics FPGA firmware as necessary.

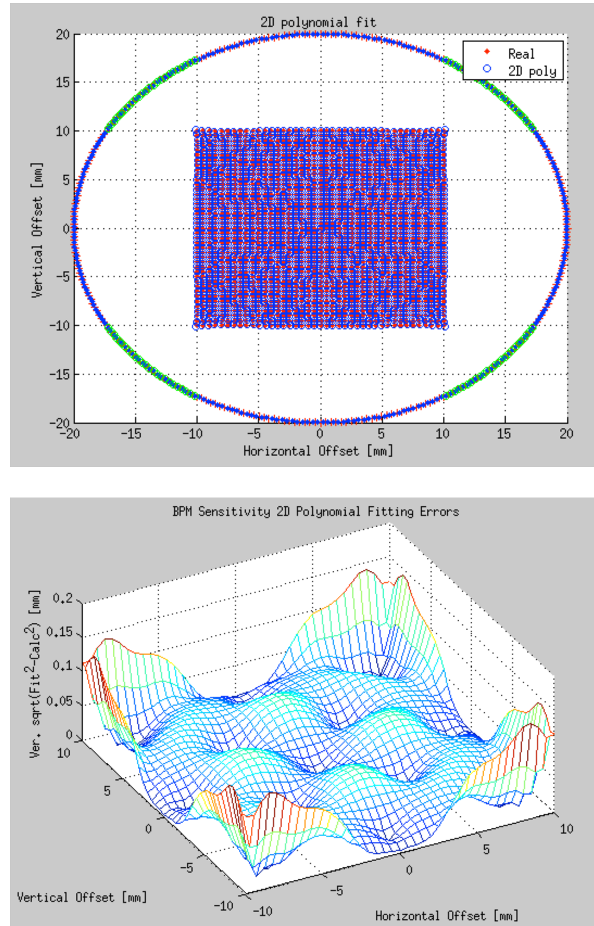

Figure 4: 2D BPM nonlinearity fit. Upper one shows the raw data (red) and fitting data (blue) as well as the chamber geometry. Lower picture shows the fitting errors.

ELECTRICAL OFFSET MEASUREMENT

BPM sensor will have electrical offset relative to the mechanical center of the housing chamber. The offset may come from mechanical tolerance, button capacitance variation, feedthrough gain variation, etc. With beam based alignment, one can get BPM offset relative to the nearby magnet's center. However, it's not practically easy to have beam based alignment for the linac and transfer line BPMs. Besides, an electrical offset of the BPM sensor itself, together with the mechanical alignment dat,a will give a rough estimate of BPM offset to the nearby magnets, which could be helpful for the beam alignment. These offsets will be useful in early stages of machine commissioning to improve the absolution beam position readings as well.

A 4-port S-parameter method has been used to measure NSLS2 BPMs [1]. The method assumes mirror symmetry of the BPM geometry. Hence the geometry coupling factor between buttons is symmetric ($G_{12}=G_{34}$, $G_{14}=G_{23}$, $G_{13}=G_{24}$). That is to say, by measuring the S-parameters between buttons, gain variation of the four buttons can be obtained.

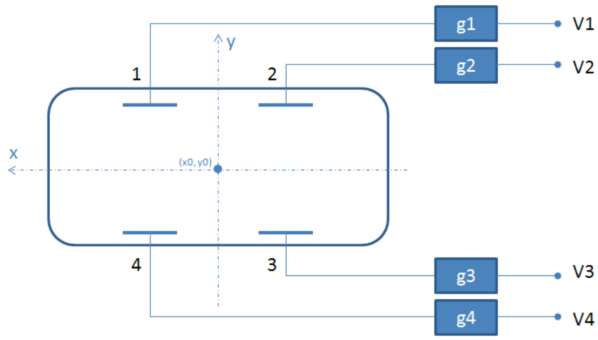

Figure 5: Typical 4-button BPM schematic layout. Four buttons are symmetric to x and y plane.

BPM electric offset can be calculated as:

$$R_x = K_x \frac{g_1 + g_4 - g_2 - g_3}{g_1 + g_2 + g_3 + g_4} \qquad (2)$$

$$R_y = K_y \frac{g_1 + g_2 - g_3 - g_4}{g_1 + g_2 + g_3 + g_4}$$

Taking into account the symmetric geometric coupling factor, the gain variation of four buttons can be written as Equation (3). In which V_{ij} is measured S-parameter between button i and j (i, j = 1,2,3,4). To get the electric offset, the absolute value of gain is not important. Once the *Kx*, *Ky* are known, the BPM offset can be calculated from Equation (2).

$$\frac{g_2}{g_1} = \sqrt{\frac{V_{32}V_{42}}{V_{31}V_{14}}} = \sqrt{\frac{V_{21}V_{42}V_{32}}{V_{14}V_{12}V_{31}}} = \sqrt{\frac{V_{32}V_{42}}{V_{41}V_{31}}}$$

$$\frac{g_3}{g_1} = \sqrt{\frac{V_{32}V_{43}}{V_{21}V_{14}}} = \sqrt{\frac{V_{43}V_{32}}{V_{14}V_{12}}} = \sqrt{\frac{V_{32}V_{43}}{V_{21}V_{41}}} \qquad (3)$$

$$\frac{g_4}{g_1} = \sqrt{\frac{V_{43}V_{42}}{V_{31}V_{21}}} = \sqrt{\frac{V_{43}V_{42}}{V_{12}V_{31}}} = \sqrt{\frac{V_{14}V_{42}V_{43}}{V_{21}V_{41}V_{31}}}$$

Using an Agilent E5071C network analyzer, four port S-parameters of 4-button BPM have been measured for NSLS2 BPMs. One example of a measured curve is shown in Figure 6. This particular measurement was for storage ring BPM C25S4-BPM1; due to antechamber structure, one can see trapped TE modes appear around 900 MHz.

Deformation of the storage ring vacuum chamber is expected due to the antechamber slot with and w/o vacuum. This deformation may introduce button BPM offset change. Measurements will be carried out with and without vacuum on the storage ring BPMs to investigate the effects.

Capacitance of BPM button is measured using TDR and VNA, both methods give consistent value. At NSLS2, we concluded the S-parameter method is a better representation to measure the BPM electric offset. Feedthrough gain variation and jump cables are included in the measurement.

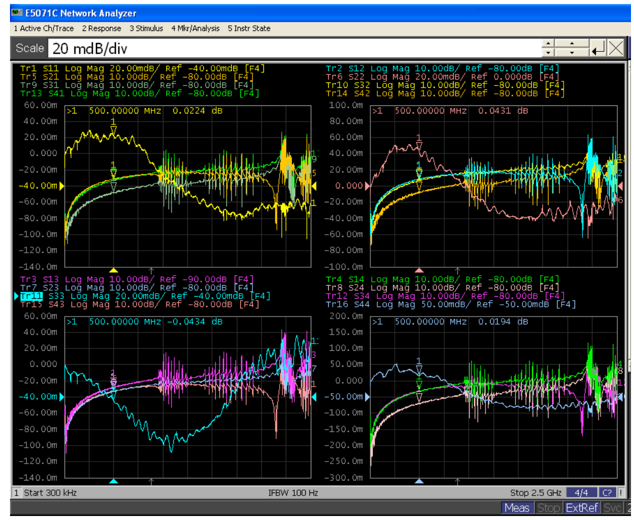

Figure 6: Four port S-parameter of NSLS2 BPM

Table 2 summarizes the LINAC and LtB BPM offsets measured using the network analyzer. These value are used for the machine commissioning which is going on now.

BPM electronics offset is measured as well, together with the BPM sensor offset. The beam position reading accuracy is expected to be greatly improved.

Table 2: NSLS2 LINAC LtB Phase I BPM Offsets

Machine	BPM #	Offset from S-para [um]		1st order linearity	
		Offset_X	Offset_Y	Kx [mm]	Ky [mm]
LINAC	P1	28.78	372.79	14.37	14.37
LINAC	P2	-97.37	-267.44	14.37	14.37
LINAC	P3	426.85	399.94	14.37	14.37
LINAC	P4	71.37	-218.20	14.37	14.37
LINAC	P5	498.36	-437.13	14.37	14.37
LtB	P1	0.47	7.98	14.55	14.55
LtB	P2	-111.40	1255.31	18.37	17.19

SUMMARY

NSLS2 BPM nonlinear sensitivities are calibrated using 2-dimensional nonlinearity fit. BPM offset measurement using 4-port network analyzer is applied. With 0.1 dB resolution on the S-parameter values, the calculated BPM offset will have a precision of 11 µm.

The author wants to thank Igor Pinayev on various help of the BPM sensitivity fitting.

REFERENCES

[1] Y. Chung, G. Decker, “Offset Calibration of the Beam Position Monitor Using External Means,” AIP Conference Proceedings, Volume 252, pp. 217-224 (1992).

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