Calibration of the Electrostatic Beam Position Monitors for VEPP-2000

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Abstract

The basic requirement for the VEPP-2000 Beam Position Monitor (BPM) is the measurement of the beam orbit with 0.1 mm precision. To improve the measurement accuracy, the response of the electrostatic BPMs (pickups) were mapped in the laboratory before they were installed in the VEPP-2000 ring. The wire method for the sensitivity calibration and position-to-signal mapping is used. The test stand consists of high frequency coaxial switches to select each pickup electrode, movable antenna to simulate the beam, signal source, spectrum analyzer to measure the pickup signals, and analysis software. This calibration showed possibility of required accuracy. During calibration the electrical center of the different BPMs was measured with respect to the mechanical center. Conversion between the BPM signal and the actual beam position is done by using polynomial expansions fit to the mapping data within ± 6 mm square. Results for these portions of the calibration are presented.

1. INTRODUCTION

A beam position monitor system is operated for two kinds of orbit measurements, a relative measurement and an absolute measurement. The former is to measure the orbit displacement from the initial or standard orbit when some optics perturbation is applied. The latter case is to measure orbit position relative to the geometrical monitor center. This function will be essential for maintaining stable operations in a ring where the optics depends strongly on the orbit, particularly at nonlinear optics elements.

Closed orbit stabilization and correction is routine operation for VEPP-2000 ring [1, 2]. To stabilize the beam orbit, the absolute beam position should be measured. The output data from a position monitor system usually shows the orbit position relative to the electric monitor center, not the geometrical center. So we should calibrate each beam position monitor to know the location of the electric center with respect to geometrical one i.e. relative to the reference frame of each BPM.

Moreover the system needs calibrating not only because of pickup characteristics (center displacement, sensitivity and nonlinearity) caused by machining, installment, cable matching, and signal processing circuits, but in order to meet the requirements on the accuracy of the measured beam position.

Basically there are 4 BPMs installed in VEPP-2000 ring, but there is reserve one. In order to test characterize, align, and provide data for calibration, a general purpose test stand was designed and constructed in 2006. All BPMs needed for operations was calibrated and data analyzed in the same year, and last one was processed in 2009 because of some replacement actions.

2. CALIBRATION TEST STAND

BPM Block

The electrostatic BPM for VEPP-2000 ring consist of four 15 mm diameter button style electrodes are mounted on the diagonals of its housing and are centered symmetrically. Buttons orientation is 45 degrees to avoid the fan of synchrotron radiation. All parts precisely machined from solid stainless steel blocks, isolated the electrodes and feedthroughs with ceramic material. The electrode surface is smoothed with that of the vacuum chamber, so the impedance induced by the electrode may be reduced greatly.

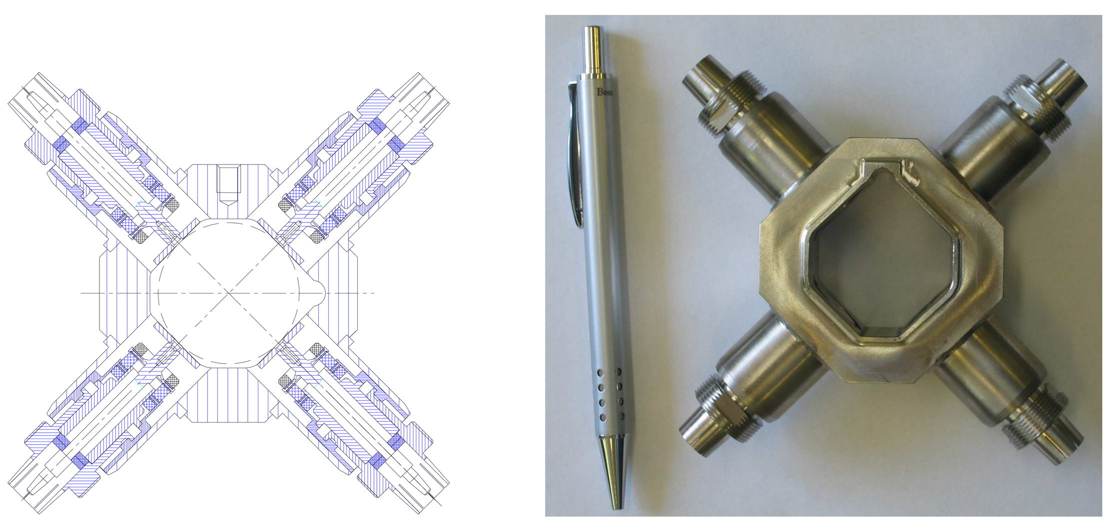

Figure 1: *The electrostatic BPM for VEPP-2000 ring.*

The vacuum chamber of VEPP-2000 is not the same along the ring. With exception of the bending magnets, it has approximately square form (35 mm inscribed circle diameter). The BPM is integral part of the quadrupole vacuum chamber of the technical strait section, which in turn is referenced to the magnet axis by means of supporting arms, and assembled on the vacuum chamber by welding, assuring no gas leak. To reduce the mechanical surveyment for the BPM with the same vacuum chamber dimensions, BPM housing has the same cross section form and dimensions, and coincides with the vacuum chamber within ± 0.2 mm. Figure 1 shows a transverse section and common view of the pickup before assembling.

Test Stand and Data Collection

The approach used to determine the position of the electron beam is to treat the effect of the beam as a two dimensional electrostatic problem. An electron beam passing through a BPM induces a charge on the buttons, which uniquely depends on the position of the beam. Due to the lack of longitudinal variation, the electron beam appears to be essentially a line charge. Using the voltage on the buttons, one can solve for the position of the electron beam.

In order to calibrate different BPMs, a general purpose test stand was designed and constructed. The picture of the test stand is shown in Fig. 2. To simulate the real beam traveling through the BPM more accurately, we send a continuous signal down a movable antenna with stretched wire through the BPM. In this case, we believe that the low-frequency measurement yields the same information as the real beam using the usual subtrac/sum algorithm. The wire, which diameter is 100 μm, is made of tungsten material is driven from an Agilent 4402B Network Analyzer RF out port. The $1 \div 200$ MHz RF signal (sweep time 100 ms) is amplified to about 3dB and delivered to the stretched wire through the coaxial cable. The RF signal on the wire induces signal on the four buttons of the pickup at the test. Each button is connected sequentially to the analyzers RF in through the same coaxial cable.

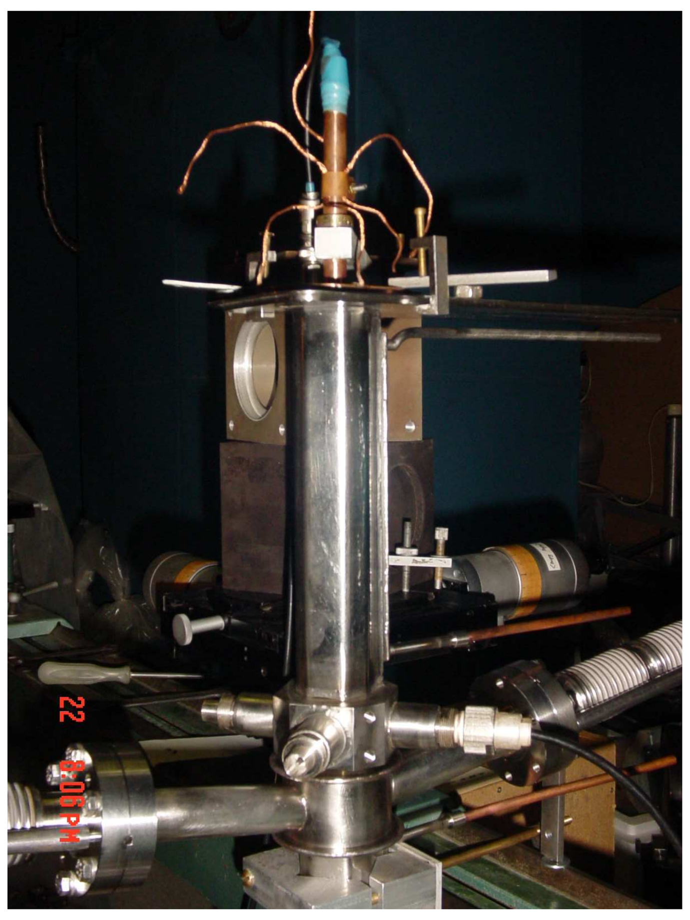

Figure 2: *Test stand view.*

The antenna is placed inside the BPM and is straightened along the vacuum chamber, and can be manually moved by the $x - y$ positioning tables in a grid patten, while the BPM block is fixed by the BPM mounting fixtures. The $x - y$ positioning tables have a position resolution of 0.01 mm (half step mode) and 0.001 mm repeatability.

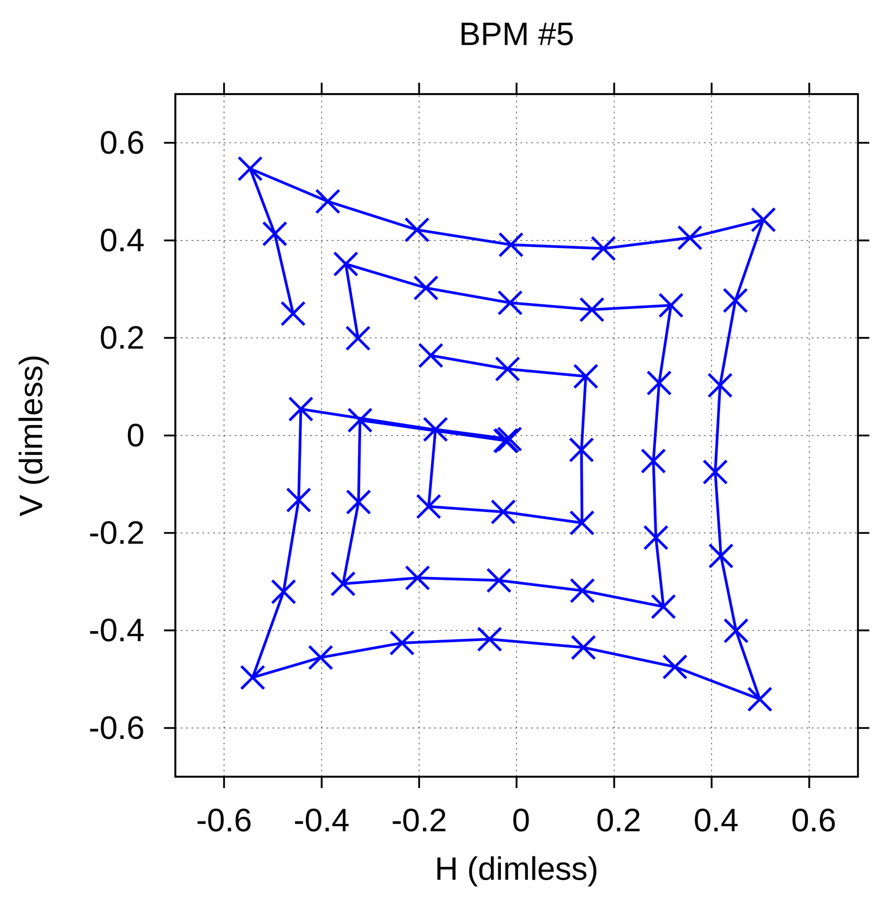

Figure 3: *The H and V distribution from four buttons.*

The vacuum chamber was scanned along constant lines and measurements were made with the antenna positioned at $x = 0, \pm 2, \pm 4, \pm 6$ mm and $y = 0, \pm 2, \pm 4, \pm 6$ mm grid-points, where $x = y = 0$ corresponds to the geometrical center. Figure 3 shows a nomograph of measured h and v, as defined in (3). The horizontal lines drawn at constant Y position, while the vertical lines corresponds to X constant. The distance between lines is 2 mm. It shows that there is a good linearity in the central area of BPM, while pin cushion distortion appears clearly far from the central.

3. CALIBRATION AND ERROR ANALYSIS

Calibration of all monitors was made in the laboratory at a test bench. Now the voltages (A, B, C, D) on the BPM buttons as a function of wire position are known and position is the desired variable. The challenge is to invert the function and solve for the position of the wire as a function of the voltage on the electrodes.

$$V(A, B, C, D) \to P(x, y) \tag{1}$$

A simplistic approximation, involves linearization of summing over the differences

$$x = K_x * h, y = K_y * v \tag{2}$$

where K_x and Ky are calibration factors set by the geometry of the BPM, and signals (A, B, C, D) normalized as defined in (3).

$$h = \frac{A - B - C + D}{A + B + C + D}, \quad v = \frac{A + B - C - D}{A + B + C + D} \tag{3}$$

Though accurate when the wire beam is close to the center of the BPM, these equations are not accurate at large deviations from the center. The lack of accuracy is unfortunate because the need for the BPMs is the most acute when the wire is not near the center. So one have to use nonlinear least-square fitting method.

After calibration data are obtained, the mapping data are fitted by least-square method to fourth polynomials of (4), where $0 \leqslant i, j \leqslant 4$, $0 \leqslant i + j \leqslant 4$.

$$x = \sum a_{ij} * h^i * v^j, \quad y = \sum b_{ij} * h^i * v^j \tag{4}$$

In these expression, $a_{0,0}$ and $b_{0,0}$ gives the deviation of the electrical center from the geometrical one, and $a_{1,0}$ and $b_{0,1}$ one can interpreter as the sensitivity of BPM in the x and y direction, respectively. Special code in C language using GNU Scientific Library (GSL) was written to do fit and calculate all coefficients. We obtain the offset (x_0, y_0) between the geometrical center and the electrical center $(h = 0, v = 0)$, and the coefficients (K_x, K_y) for position from the full mapping data. Figure 4 shows mapping plot of one of the BPMs.

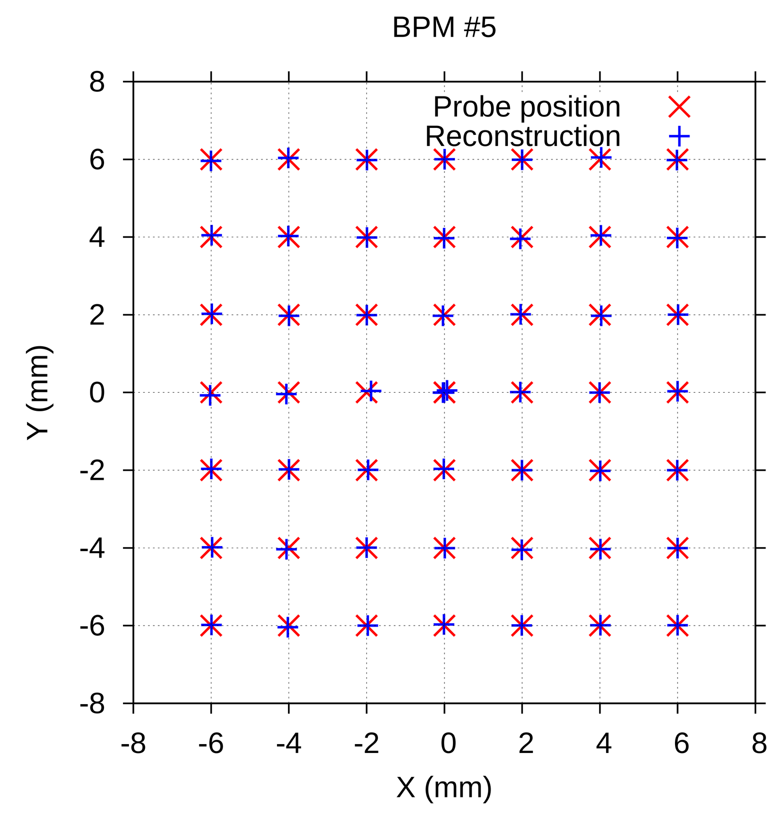

Figure 4: *Reconstructed probe position with respect to real one.*

The maximum fitting rms error is found as follows:

$$\sigma_k = \sqrt{\frac{\sum_{i=0}^{n-1} (k_{fi} - k_{mi})^2}{n}}, \tag{5}$$

where k stands for x or y respectively, and x_{mi} and y_{mi} are the values from the probe position i-th measure point, while x_{fi} and y_{fi} are the values calculated by the least-square method.

The typical values of the offset, position coefficients, fitting rms error of data collection are summarized in Table 1 and Fig. 5. Mean rms error values all over BPMs:

$$\sigma_x = 4.5 * 10^{-2} mm, \sigma_y = 3.8 * 10^{-2} mm \tag{6}$$

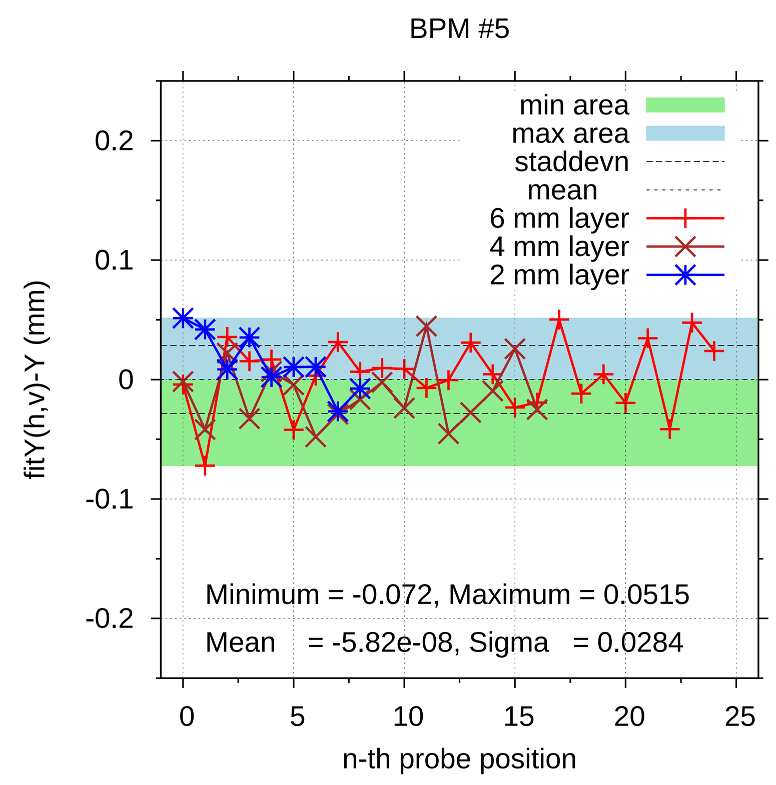

Figure 5: *Difference between reconstructed and real probe position.*

Table 1: *Individual BPM parameters.*

	Offset		Coeficient		Error	
♯	$a_{0,0}$	$b_{0,0}$	$a_{1,0}$	$b_{0,1}$	σ_x	σ_x
1	0.037	-0.011	12.732	12.874	0.071	0.055
2	-0.258	0.081	12.331	13.203	0.058	0.046
3	1.088	-0.302	12.467	12.942	0.031	0.029
4	0.482	0.306	12.443	13.056	0.041	0.035
5	0.245	0.176	12.556	13.204	0.029	0.028

The repeatable accuracy of the scheme has been measured. Wire was placed in the same position after every 10 wire movements, and differences of the buttons voltages was compared. The iterances of these results were no more than $(3 - 5)$ μV. These results show the accuracy of electronics system is about 3 μm.

4. SUMMARY AND CONCLUSION

The BPM calibration system has been established and tested. It has a theoretical resolution capability of 0.01 mm, as limited by the movable stage system. We designed a new calibration scheme, measuring the power on each pickup electrode sequentially by the spectrum analyzer. Although we have not verified to this accuracy, we have obtained the clear BPM mapping using 2 mm step of wire movement. The calibration of the BPM system has been shown to be better than the requirements which VEPP-2000 BPM system wants. All calibration results saved as a tables of polynomial coefficients appropriate for using in software or other calculations.

References

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