THE ONLINE CHARACTERIZATION OF THE MAIN INJECTOR BPM

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Abstract

The design of the Main Injector beam position monitor (BPM) was driven by the desire to minimize its beam impedance and longitudinal space requirements. The resulting BPM consists of four striplines inset into a section of Main Injector Beam pipe. The striplines are combined in pairs to form either a horizontal or a vertical BPM by switches located nearby in the tunnel. The BPM response is decidedly non-linear and furthermore shows sensitivity to the beam position on the orthogonal axis. This paper presents the method in which consecutive measurements in both planes are used to derive the actual (x, y) position in an online environment.

1 INTRODUCTION

The Fermilab Main Injector (FMI) was designed as a high intensity medium energy (150 GeV) injector into the Tevatron to replace the original Main Ring Accelerator. In addition the FMI can operate as a 120 GeV Fixed Target Accelerator and antiproton production facility. In either modes the anticipated particle intensities are expected to be high (>3 10^{13}). In order to avoid beam instabilities it was desired to reduce any sources of beam impedance. The resulting BPM [1, 2, 3] consists of four striplines inset into a section of Main Injector Beam pipe, which to the beam appears as nearly as possible as just another section of beampipe. The striplines are grounded at one end and a sheet metal vacuum enclosure is welded over the inserts.

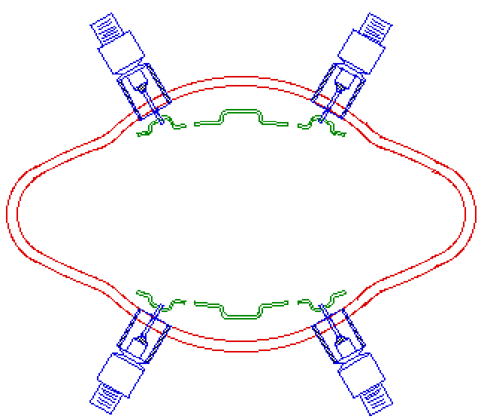

Figure 1. Schematic drawing of MI BPM.

A front–view diagram is depicted in figure 1. The design was also guided by the desire to minimize non-magnetic space, so the entire BPM can be inserted into one end of a quadrupole magnet.

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The four striplines are combined in pairs to provide either horizontal or vertical BPM's. This summing of the individual plates is accomplished by an external switching box located in the tunnel next to the BPM. Whether a BPM operates as a horizontal or a vertical pickup can be changed from the control room. However the slow nature of the switches (relays) prevents the simultaneous measurement of both planes. The two summed signals are cabled to the Service Building. This scheme was implemented as a cost saving method, as two cabling runs per BPM were eliminated and the old Main Ring processing electronics could be reused. The disadvantage of this scheme is due to the particular characteristics of these BPM's. Not only do the BPM's exhibit a non-linear response, but they are also relatively sensitive to the beam position in the orthogonal plane. Since we can read only a single plane at a time during the acceleration cycle, two acceleration cycles are needed to capture both horizontal and vertical measurements. The assumption is that the two cycles are (nearly) identical. The default configuration of the BPM system is such that horizontally focusing quads have horizontal BPM configurations, and horizontally defocusing quads have vertical BPM configurations. This is called the (normally) "ON" configuration. The switched configuration is referred to as the (normally) "OFF" configuration (vertical BPM in horizontally focusing quad and horizontal BPM in horizontally defocusing quad).

2 CHARACTERIZATION OF THE BPM RESPONSE

Figure 2 shows the response of a particular BPM that was measured by the stretched wire method [4]. The wire was moved on an x-y grid with 5 mm gridlines between $|x| \leq$ 25mm, and $|y| \leq$ 15mm. The horizontal (and vertical) positions are plotted as a function of the voltage output (V_{rf}) by the processing electronics RF module [5]. The family of curves is the result for the wire at different vertical (horizontal) positions. The dots are the actual data points, while the curves are the result of fitting the data with the function, Position(V_{rf}) = $a_0+a_1*V_{rf}+a_2*V_{rf}^3$. As one can see the fit is reasonably accurate over the range of the data. However it can be noticed that a_0, a_1, and a_2, are themselves functions of the orthogonal coordinate of the wire.

The coefficients, a_0, a_1, and a_2, for a particular BPM are plotted as a function of the orthogonal coordinate in figure 3. The shape of the curves for a_1 and a_2 vs. the orthogonal coordinate is similar to a gaussian and in actual fact, we have fit this data to a gaussian function with a pedestal as a way to characterize the functional dependence of the

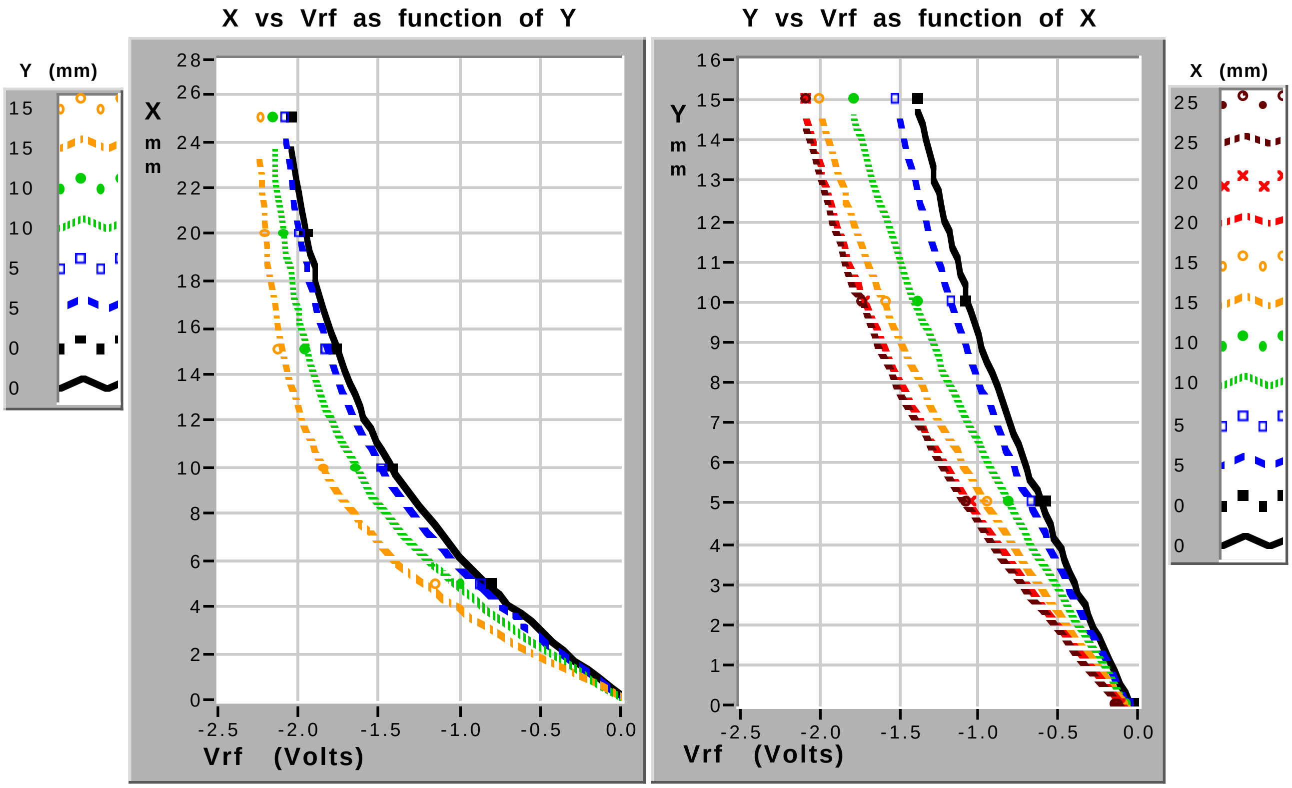

Figure 2. The Position vs. V_{rf} for a particular MIBPM as a stretched wire is moved on a x-y grid (5mm spacing). The left (right) plot is that BPM configured as a horizontal (vertical) BPM. Only the positive positions are shown for reasons of plot legibility.

coefficients on the orthogonal coordinate. When all BPM's are put through this analysis, the average parameterizations for a_1 and a_2 represent the BPM's adequately.

Only a_0 tends to defy parameterization. One reason is that this coefficient is very sensitive to actual electrical and mechanical aspects of the BPM construction, whereas the linear and cubic terms are more representative of the electric field map (which in any case would contain only odd powers of V_{rf}). The actual a_1 and a_2 were taken from the entire BPM ensemble average. The choice for a_0 was the value found by averaging a_0 over the orthogonal coordinate for each individual BPM. The final result is that each BPM has a unique a_0, but all BPM's share a common a_1 and a_2, or

$$x(V_{rf}, y) = a_0^x + a_1^x(y)V_{rf} + a_2^x(y)V_{rf}^{\,3}$$

$$y(V_{rf}, x) = a_0^y + a_1^y(x)V_{rf} + a_2^y(x)V_{rf}^{\,3}$$

where, (1)

$$a^x_{(1,2)}(y) = A^x_{(1,2)} e^{-\frac{1}{2}\left(y/\sigma^x_{(1,2)}\right)^2} + B^x_{(1,2)},$$

and similarly for $a^y_{(1,2)}(x)$.

The values for A, σ, B are given in table 1 for a_1 and a_2.

The algorithm for calculating the actual beam positions, x and y, is as follows (for a particular BPM).

1) Using the measured V_{rf} from the "On" and "Off" BPM configurations, the zeroth order positions are calculated assuming the orthogonal measurement is zero, i.e.

$$x(V_{rf}, 0) = a_0 + a_1^x(0)V_{rf} + a_2^x(0)^3$$

$$y(V_{rf}, 0) = a_0 + a_1^y(0)V_{rf} + a_2^y(0)^3.$$

2) Using these values for x and y, the equation is iterated.

3) When the change of x and y is below some threshold (e.g. 0.1 mm) or after a maximum number of iterations, the iteration stops. Typically this is less than 7 iterations for positions <$\pm$ 10mm.

Table 1. Parameterization of coefficients $a_{1,2}$ on the orthogonal plane position. The function is a gaussian of amplitude A, rms width σ, and pedestal B. See equation 1.

Horizontal Coefficients			
	A	σ	B
$a_1(y)$	6.07e-1	10.5	0.459
$a_2(y)$	1.16e-3	12.0	-2.81e-4
Vertical Coefficients			
	A	σ	B
$a_1(x)$	7.19e-1	8.18	0.915
$a_2(x)$	2.27e-3	3.79	-4.31e-4

Using this prescription, the data from the wire measurements of all the BPM's were fed back into the analysis. For positions within $\pm$10mm of the BPM center, the rms error over the BPM ensemble is less than 0.33 mm. The residual difference between the actual position and the parameterized curve is less than 1.0 mm

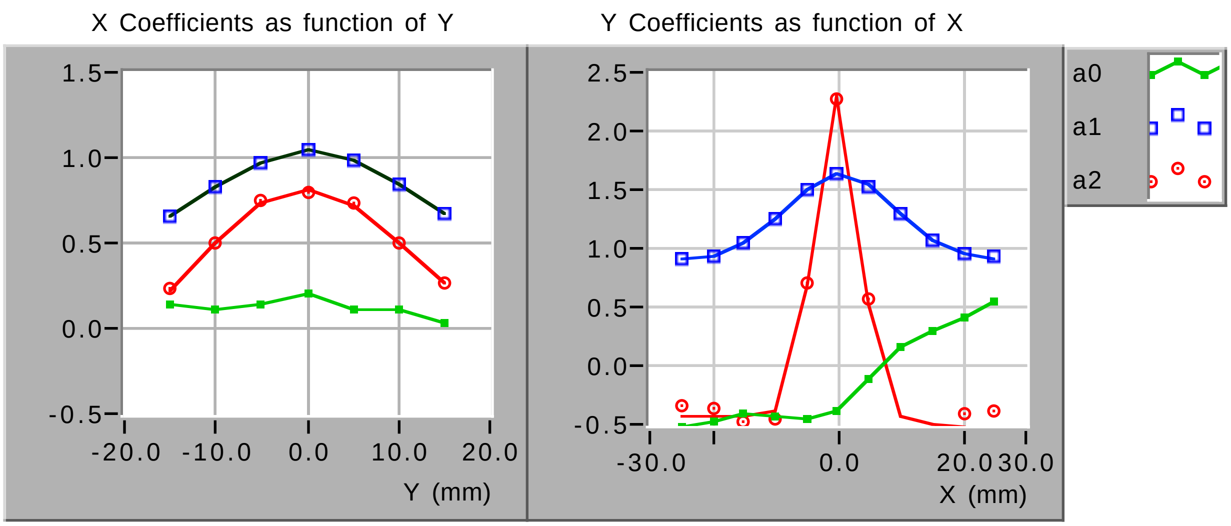

Figure 3. The variation of the coefficients a_l as a function of the orthogonal plane position. The points were derived from the fitted curves of figure 2, while the lines (for a_1 and a_2) are derived from fitting the points to a gaussian function (see text). In the case of $a0$, the line simply connects the points. It should be noted that a_2 has been multiplied by 1000 for display purposes on this plot.

rms. This level of absolute accuracy is adequate as the smallest beam rms size will typically be ~1.0 mm at extraction). Precision use of the bpm system is usually confined to lattice studies. Since under these circumstances, only orbit differences matter, the precision will be much better.

3 CONCLUSION

It is possible to parameterize the response of the MI BPM system, even though the behavior of the pickups is non-linear and exhibits a significant cross plane coupling. During Main Injector Commissioning, it has been possible to ignore the cross plane effect and use the system as a "normal" BPM system (as of this writing, the implementation of remote switching of the tunnel switch boxes has been delayed due to other considerations). Once we begin to systematically study the MI, the higher precision needed will require the use of the cross plane knowledge to correct the BPM response.
Currently the algorithm (iteration scheme) has been written and installed in the Console Application written for the MI BPM system. Since the BPM digitizer is only an 8-bit system, it is possible to implement the algorithm as a 65k element x-y lookup array. As future hardware would most likely use a higher bit ADC, it has not seemed worthwhile to make this change (in addition modern processors make the iterative method very fast).

4 ACKNOWLEDGEMENTS

It must be noted that all actual measurements of the MIBPM's were made by members of Beams Division RFI department and not this author.

5 REFERENCES

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