BPM Testing, Analysis, and Correction

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Abstract. A general purpose stretched-wire test station has been developed and used for mapping Beam Position Monitors (BPMs). A computer running LabVIEW software controlling a network analyzer and *x-y* positioning tables operates the station and generates data files. The data is analyzed in Excel and can be used to generate correction tables. Test results from a variety of BPMs used for the Fermilab Main Injector and elsewhere will be presented.

INTRODUCTION

The Main Injector (MI) Accelerator project at Fermilab required the design and construction of several new Beam Position Monitors (BPMs). Approximately 200 primary diagnostic MI BPMs were required. The MI design required these to be installed inside the quadrupole magnets, limiting design options. These BPMs use four striplines that are combined electronically to produce the horizontal and vertical positions. The Recycler Ring design uses BPMs of the split-plate design that are installed in the conventional manner. This BPM has two plates, and is used in either a horizontal or a vertical orientation. In addition, other varieties including *the 8 GeV line BPM*, a special *low-level rf BPM,* and a wide aperture BPM was also tested. The test stand is shown in Figure 1 and the BPMs are shown in Figure 2.

In order to test, characterize, align, and provide data for calibration, a general purpose test stand was designed and constructed. A similar stand was used for RHIC BPMs at Brookhaven (1). This stand was designed to accommodate a wide variety of devices, and is strong enough to support a small trim magnet. The LabVIEW (3) control system allows for easy development of custom routines for automatic testing.

[1] Operated by Universities Research Association under contract with the U. S. Department of Energy

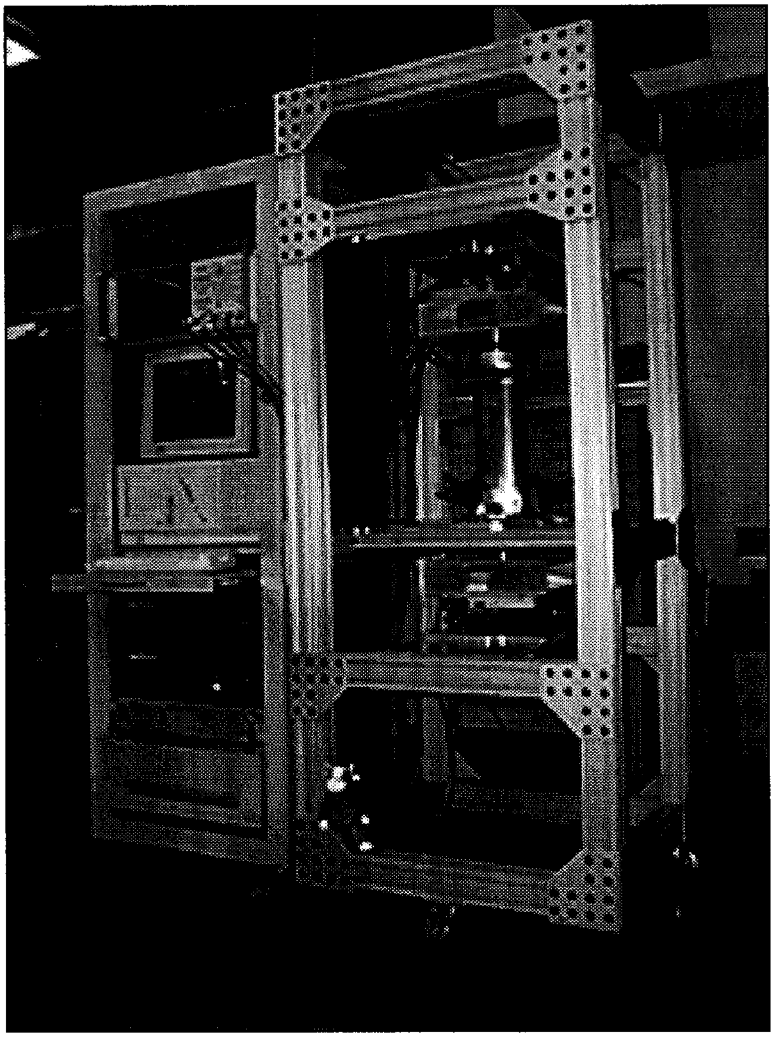

FIGURE 1. Photo of the test stand.

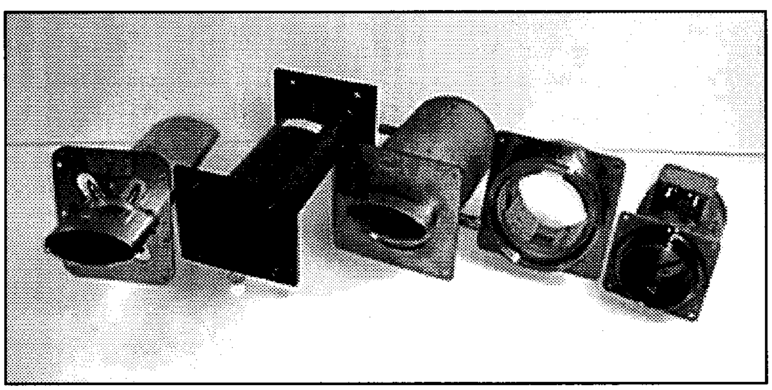

FIGURE 2. Recently tested BPMs, from left, Main Injector, Recycler Ring, Low Level rf, Wide Aperture, and 8 GeV line.

THE TEST STAND

The stand consists of two units, a rigid frame (3 ft × 3 ft × 6 ft) for the mechanical components and one standard six-foot relay rack. The rectangular frame contains the *x-y* positioning tables, a vertical stretched wire, and the BPM mounting fixtures. Both units are on wheels and can be easily relocated (Figure 1). A wire stretched through the BPM is driven at the appropriate rf frequency, to simulate beam, and produce output signals. A Macintosh Power PC, running LabVIEW virtual instrumentation software, controls *x-y* positioning tables, which moves the wire through a grid pattern. The number of points measured are approximately 50 to 160 producing reasonable file sizes. An HP network analyzer controlled through a GPIB bus collects the data.

The test stand was constructed from standardized aluminum "erector set" materials manufactured by 80/20 Inc. (5). The main frame rails are three inch square extrusions, with 1/2-in Al tooling plate for attaching components. The frame is aligned using gauge blocks and an optical survey. The BPM under test is located in a precision manner using hard drill bushings and matching alignment pins. The BPMs were constructed with precision-reamed alignment holes which mate with the test stand and are also used in the beam line for the alignment survey.

The stretched wire is driven from an HP network analyzer rf out port and is terminated to the R port. The wire has an impedance of approximately 200 ohms and required matching to the 50-ohm system. A small printed circuit board, with a 4:1 matching transformer, is used to couple to the wire at each end.

The Positioning tables used are "monolithic" *x-y* units (as opposed to single-axis units bolted together), which are more compact and have an orthogonality specification of 50 arc-sec (2). This eliminates construction and stand alignment steps. The tables have a three-axis position accuracy of .001 inch, and repeatability spec of .0005 inch (accuracy of the lead screws). The lead screws are metric to simplify calculations. The tables use stepping motors, controlled with nuLogic drivers and controllers. The motors can be used in full step, half step, or micro step modes, producing resolutions of 5 micron (.0002 in), 2.5 micron (.0001 in), and .5 micron (.00002 in) respectively (4). The tables also incorporate linear encoders that have a resolution of 2.0 microns (2). The Lab View measuring routine is set up with encoder feedback to position the tables to the desired coordinates. The ultimate limit on the accuracy is therefore set by the encoder resolution of 2.0 microns. Measurements have shown accuracy repeatable to within 20 microns (.0008 in). Shown in Figure 2 are some of the Fermilab BPMs recently tested.

Data Collection

The data is downloaded through a net connection for plotting and analyzing. An Excel spreadsheet is used to generate a set of plots, as desired, for each BPM. The files, charts, and serial numbers are recorded as permanent records for future reference. One sample BPM of each design is maintained as a reference. Plots generated include:

1. Electrically measured vs. mechanical position map.
2. Horizontal and/or vertical outputs represented as 20Log(A/B) vs. position.
3. Horizontal error from a least square fit vs. vertical position.
4. Horizontal error from a least square fit vs. horizontal position.

CORRECTION EFFORTS

We performed an initial off-line analysis on the BPM data for all detector types using Microsoft Excel. The data was imported into a spreadsheet, *A* and *B* values were calculated for each position, and a preliminary linear fit was performed using the built in LINEST function. The fit parameters were used with the *A/B* term to calculate a position that was compared to the measured position of the wire. A plot of the position error (calculated-measured) versus measured position became a primary tool in determining the validity of a measurement and the acceptability of the detector. Valid data sets are combined with BPM electronics data to generate the tables used by the control system database to display beam position. For the Fermilab Main Injector, a LabVIEW program is being used to calculate the coefficients of a fifth-order polynomial relating the output voltage for a given detector, combiner box, and rf module combination with the actual beam position.

The calibration data for the Fermilab Main Injector (FMI) Beam Position Monitors have been used in at least two ways. (1) It provides database tables of the mapping from raw (ix, iy) values to real (x, y) values. (2) It provides accurate raw readings from the beam physics model of the FMI to the controls system, when the control system is redirected to get device readings from this model. A pair of database tables have been created from the BPM calibration data so that one may obtain reasonable real (x, y) values, given the raw digitizations received from the electronics. This has been accomplished in the following manner. For each calibrated BPM, the mechanical and electrical offset is determined from the calibration data. Then, this offset is subtracted from the entire calibration data set for this BPM. Third, the calibration grid points are averaged for all BPMs at each point. Finally, these averaged gridpoint values are stored as a pair of database tables that, on average, represents the calibration of all the BPMs. The axes of the tables are raw (digital) x and y readings (0–255); one table produces the real x value (in mm) and the other produces the real y value.

A user can get an accurate reading of the actual (x, y) position of the beam within the BPM. He would use the raw readings obtained from the BPMs through the control system as keys to these two database tables. This gives the real x and the real y position. The offset of that BPM, determined from a separate control database, is then added. The second use of the FMI BPM calibration data is for producing reasonable raw BPM reading from a simulated FMI. Simulated positions are generated from a beam-physics model of the FMI at each BPM. Attached to each BPM object in the software is the calibration information for that BPM. Using a four-point interpolation, raw digitized values are reported back to the control system application that is running with its connection to the real world redirected to this model. Thus, a programmer, physicist, or engineer can test algorithms for removing the nonlinearities in the FMI BPMs long before the FMI is actually available.

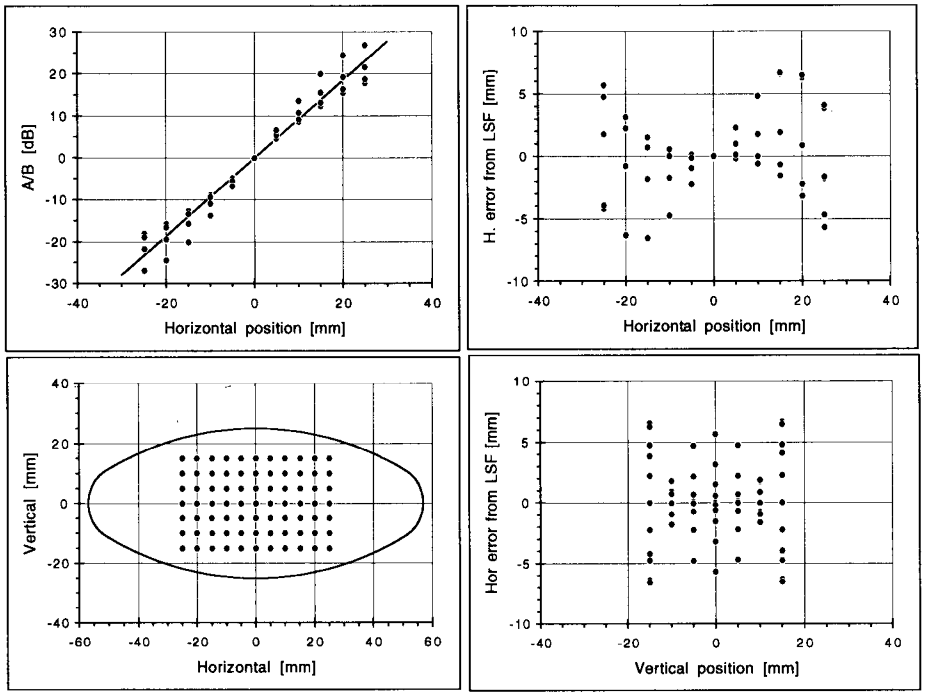

FIGURE 3. Main Injector BPM data.

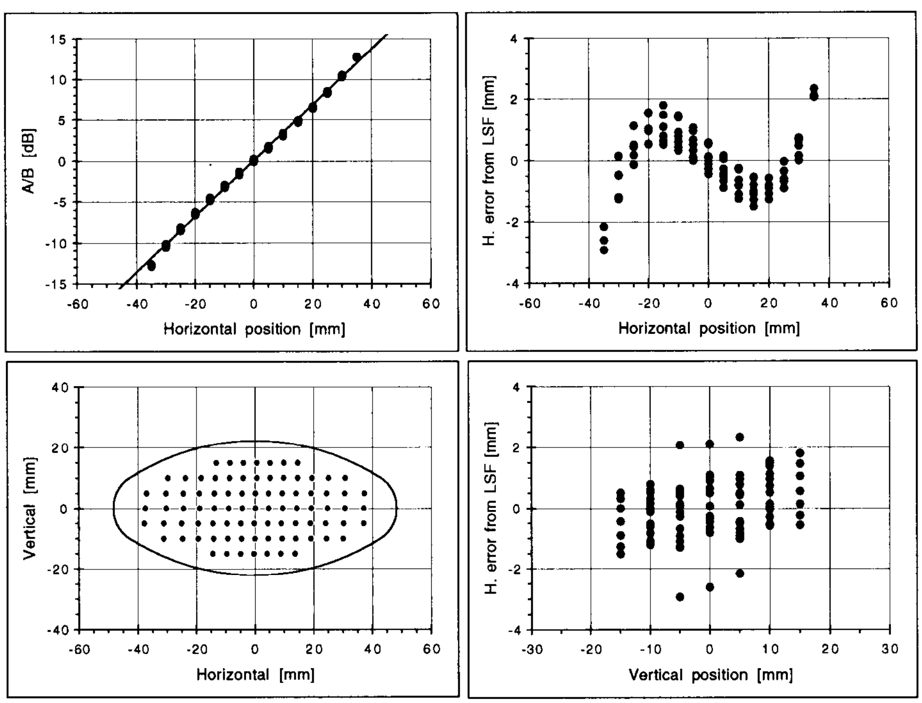

FIGURE 4. Recycler Ring BPM data.

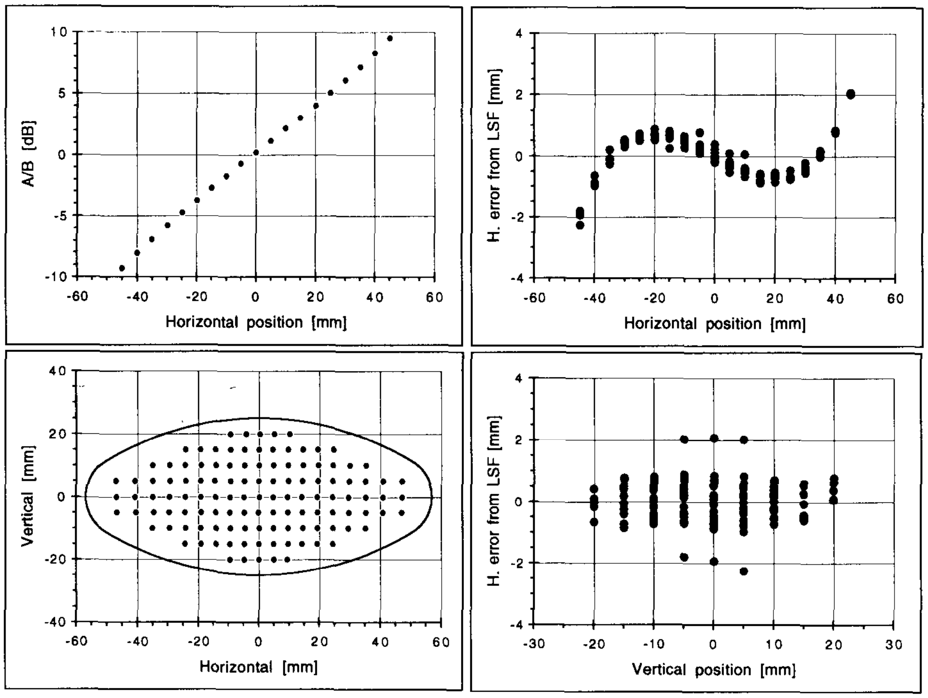

FIGURE 5. Low Level rf BPM data.

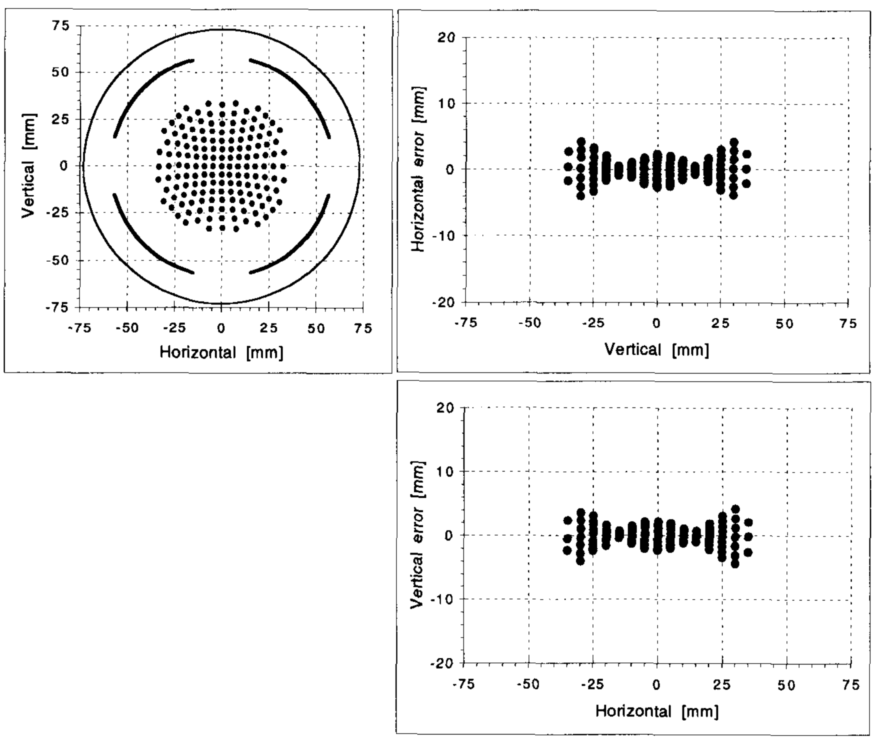

FIGURE 6. Wide Aperture BPM data.

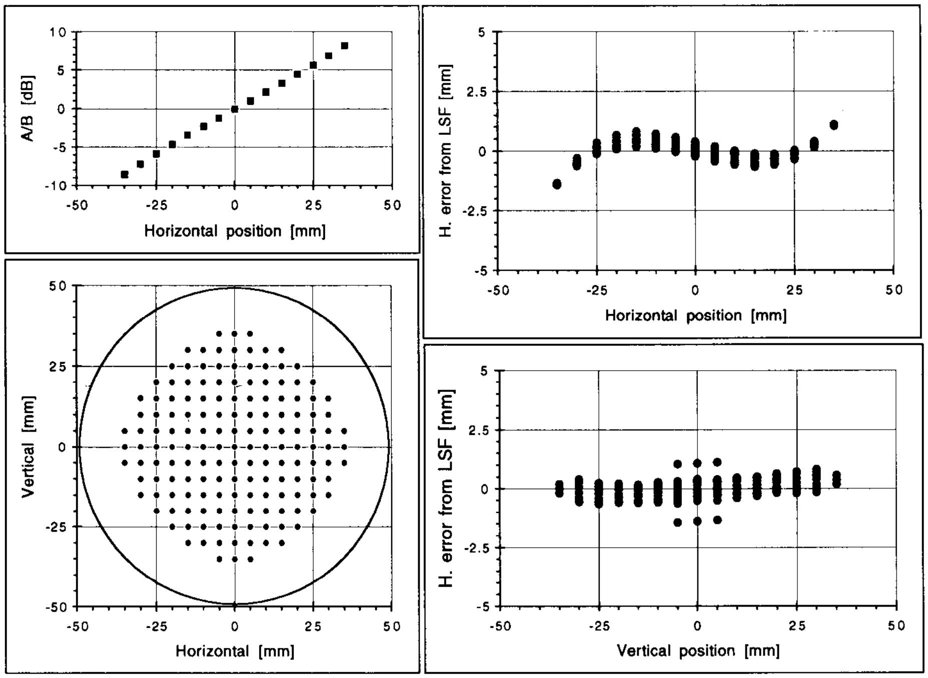

FIGURE 7. 8 GeV Line BPM data.

SUMMARY

The test stand has a theoretical resolution capability of 2 microns, as limited by the encoder. Although we have not verified to this accuracy, we have demonstrated its repeatability to at least 20-micron level with actual BPM measurements. We have shown that most BPMs are accurate near the center axis, but have increasing nonlinearities in the off-axis locations. Work is in progress to implement correction algorithms to compensate for these nonlinearities.

It was found that better results are obtained if the BPM ends have a 360-degree ground connection to the frame enclosing the wire. The proximity of a plate to an open end results in distorted position measurements in some cases. Sliding plates and bellows were used to make a ground connection to the tables. The split-plate BPMs are sensitive to standing waves on the stretched wire as each plate is effectively at a different location. The linearity mapping for some of the split plate BPMs was therefore done at a reduced frequency.

ACKNOWLEDGMENTS

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