A COMPACT BPM FOR THE FERMILAB MAIN INJECTOR

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Abstract

The Main Injector will use Beam Position Monitors (BPM) located inside the downstream end of every quadruple magnet. These magnets are reused (or derivatives of) Main Ring quads with existing beam tube still in place. The limited space available, and the desire to maintain the beam pipe aperture, required an unusual shaped BPM with innovative design and production techniques. Information on the various stages of the design, assembly, testing, calibration, and installation of the BPMs is presented.

1 INTRODUCTION

The design of the Fermilab* Main Injector (MI) reuses much of the Fermilab Main Ring (MR) equipment, including the quadrupole magnets (1). New quadrupole magnets were also fabricated baised on the original Main Ring design. These magnets have an beam pipe permanently fixed in place. The Main Injector elliptical shaped beam pipe telescopes inside the MR pipe, leaving a small space between them.

In order to conserve tunnel space and reduce beam impedance, the MI design uses these areas for the Beam Position Monitors (BPM). A total of 203 BPMs are required. The Main Injector tunnel cost approximately $2400 per foot. By conserving one foot per BPM, $487K is saved.

The MI beam pipe aperture must be maintained through the BPM. The available area consists of two small crescent shaped regions on the vertical axis. Elsewhere there is only space for the BPM housing. Fig.1 shows cross sections of the MI beam pipe, the BPM and the magnet beam pipe. Space limitations caused considerable restrictions on the BPM design, requiring compromises to be made.

1.1 Previous Work

The physical limitations on the BPM have driven the design, leaving few options in their configuration. Preliminary design work identified the basic layout available (2). The BPM would have four strip line electrodes, with the resulting signals combined externally to produce either vertical or horizontal positions. All connections must be made at the portion protruding from the magnet. To produce a non-directional BPM the electrodes were terminated with a ground connection at the opposite end. The MR BPM electronics will be reused. This electronics uses AM to PM conversion to obtain position information from signals between -38 dBm and +22 dBm.

Software from Artech House "Matrix Parameters for multiconductor Transmission Lines" was used to analyze the electrical characteristics of various combinations of the striplines electrodes (3). This program produces the 2D transmission line matrices and electrostatic charge distributions for user defined geometry's. It was determined that an electrode width of .5 inch by 20 cm would provide -24dBm at the beam intensity of 1E9 particles per bunch at the 53 Mhz RF frequency.

Two prototypes were designed and fabricated to test construction techniques and to verify the electrical characteristics. The first design attempted to "EDM" wire cut the electrodes directly into a section of MI beam pipe. The second design used separate electrodes weleded into a slot cut into the MI beam pipe (2). These designs proved to be impractical because the residual stresses in the formed elliptical shaped beam pipe are relaxed when it is cut or welded. In addition, the MI pipe did not have sufficiant strength to maintain an accurate geometry under vacuum

2 CONTINUING DESIGN

In an effort to overcome the problems, and reduce the amount of assembly work required, a new design was sought out. New mechanical problems also became apparent.

After available Quad magnets were measured, the aperture was found to have large variations in size from the design nominal. The standard deviation (σ) was over .060 mills. To insure that all the BPMs would fit, the outside dimension was choosen to be 3σ less than the mean reducing the already small vertical space available.

As the BPMs will be placed inside the magnet field, all components had to be non magnetic. Magnetic material would distort the field, causing undesirable higher order fields. The ramping magnet could exert force on components causing position measurement errors.

The limited space available required a thin housing, however it had to maintain shape under vacuum. A related issue of concern was differential thermal expansion between the housing and electrode.

2.1 Mechanical

In the final design, the BPM housing is formed by joining two identical stamped half shells. Finate elenent Analysis of the proposed shape indicated that 12 ga (.105) stainless steel would give adequate strength. Testing of completed housings under vacuum has shown -5 mills of vertical and + 5 mills of horizontal deflection. An electrode section, forming two striplines and a ground plane is stamped from 20 ga stainless steel. A channel shape is used to increase stiffness. The stampings

* Operated by Universities Research Association under contract with the U. S. Department of Energy.

incorporate intregal mounting provisions for the electrodes and alignment holes for assembly. The electrodes are grounded at one end, and attached directly to an SMA coaxial connector pin at the other end. Feedthrus with flexable pins are used to accomodate the differental thermal expansion expected. Including the ceramic feedthrus and an external protection and locating plate the assembly uses only four different parts. Shown below in Fig.1 are superimposed cross sections of the MR and MI beampipes. Fig. 2 a photo of the final BPM. Fig 3 is a photo of a BPM installation in the Mi beam line.

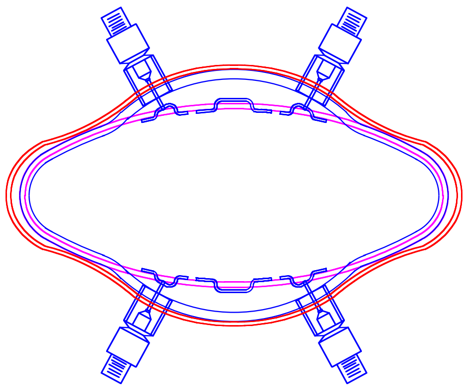

Fig 1: Sections of the BPM, MR, and MI beam pipe.

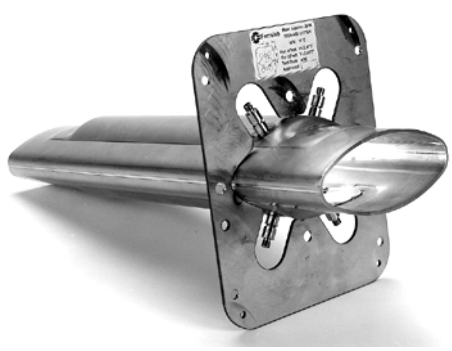

Fig 2: Photo of a complete MI BPM Assembly.

Fig 3: Photo of BPM installed between magnets.

The magnetic material issue was solved by using 316L (low carbon) stainless steel. All major welding including the feedthrus was done with a CNC controlled laser welder, resulting in high quality with minimun weld beads. The magnetic permeability was checked with a commercial gauge, and is less than 1.05 along the weld, and equal or less than 1.01 elsewhere. The small weld beads produced with laser welding also reduced distortion. During final assembly only one of 250 housings and 10 of 1000 feedthru welds leaked.

Since the stripline electrodes are attached directly to the pin it was necessary for the pin itself to be somewhat flexible. Several coaxial Feedthrus were tested to determine their electrical characteristics, resistance to damage, and pin felxability. A semicustom feedthru from Ceramaseal Inc. proved to be rugged and inexpensive at $28 each. The Feedthru was manufactured with a longer housing, to allow for a longer and more flexable pin. A flat plate attached to the exterior of the BPM provides protection for the feedthrus, cable mounting and alignment holes.

2.2 Electrical

The "Artech House" software was used to select electrode spacing and shape to optimize response linearity. The channel shaped electrode has a more uniform electric charge distribution and is less sensitive to dimensional variations at edges near the ground plane. The electrodes are placed at the maximum horizontal spacing, while maintaining 50 ohm impedance. The electrode is .5 in wide by 11 in length. The length is aproximately 1.3 wavelengths at 2 Ghz., chosen to avoid resonance with the feedthru. Although the feedthru is not designed to be a 50 ohms connector, it is electrically idnetical to a 2.9 pf capacitor and is 1/4 wavelength long at 2 Ghz. The beam pipe cut off frequency is 1.5 Ghz.

2.3 Measurements

All BPMs were measured on a stretched wire xy positioning stand, controlled by Labview software. A HP 8753B network analyzer drives 30 mill wire at 53 Mhz. and measures the four output amplitudes. Forty Nine positions spaced on a 5mm qrid are measured for each BPM. This data along with beamline survey data will be used to make offset and linearity corrections. Shown below (Fig. 3) is a plot of measured wire positions.

The “pin cushion” shaped response is a result of the restricted electrode location. The accuracy can be improved by using curve fitting algorithms to partially linearize the output. Shown below (Fig. 3) is the error remaining after a correction doing a LSF on vertical 5 mm measurements. Shown below (Fig 4) is the error remaining after doing a LSF on average of the vertical positions of +5, 0, and, -5 mm.

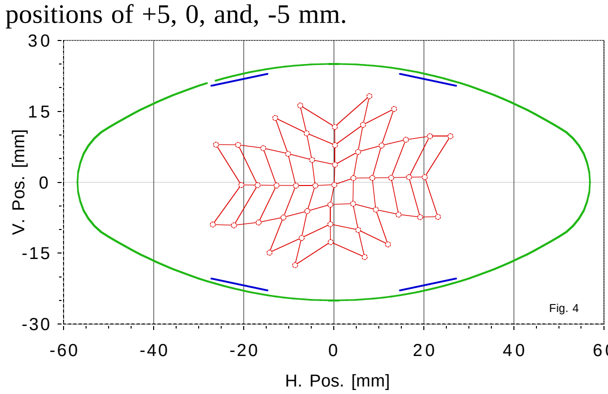

Fig 4: Typical plot of measured position vs wire position.

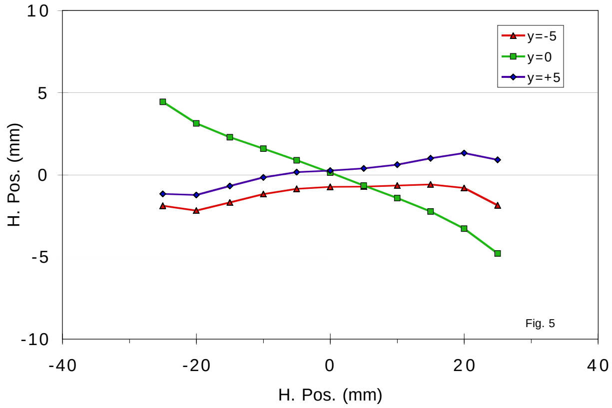

Fig 5: Horizontal fit (on y=5), error vs. xy position.

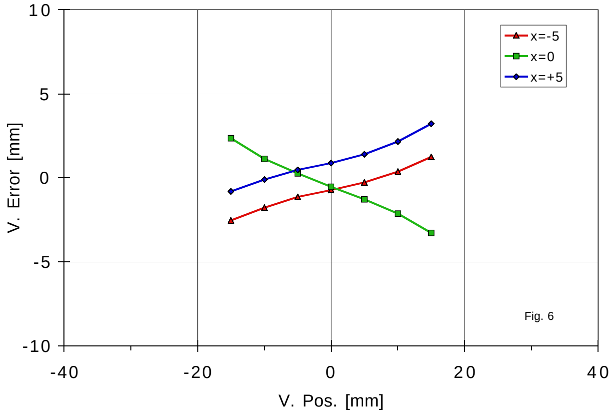

Fig 6: Horizontal fit (on ave.), error vs. xy position.

3 SUMMARY

The MI design saved some money by placing the BPMs inside the Quad Magnets, however, the linearity and the resolution of the BPMs is compromised. The limitation on the location of the electrodes forces the BPM output to have interdependent vertical and horizontal responses. The non linearity and variations between BPMs makes this difficult to correct.

This design demonstrated new fabrication and assembly techniques and has produced usable BPMs that fit into a very limited space.

4 REFERENCES

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