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Calibration of the Beam-Position Monitor System for the SLAC PEP-II B Factory*

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CALIBRATION OF THE BEAM-POSITION MONITOR SYSTEM FOR THE SLAC PEP-II B FACTORY

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The Beam-Position Monitors (BPM) for the PEP-II B Factory consist of four 1.5-cm diameter button style pickups mounted on the diagonals of the quadrupole vacuum chambers. Before installation of the vacuum chambers in the quadrupole assemblies, the electrical center of the BPMs is measured with respect to the mechanical center in a calibration test stand. In this paper the calibrations test stand is described and the precision and accuracy of the calibrations are presented. After installation of the quadrupole assemblies in the PEP-II tunnel, the passive attenuation for each channel of the system is measured to preserve the accuracy of the calibration. Finally, the active electronics includes an on-board calibrator. Results for these portions of the calibration are presented.

1 INTRODUCTION

The Beam-Position Monitors (BPM) for the PEP-II storage rings are monunted in vacuum chambers which are part of the quadrupole assemblies. The BPMs consist of four 1.5-cm diameter button style pickups mounted on the diagonals of the vacuum chambers. In general there are three types of chambers, *i.e.*, for the high-energy ring (HER) arcs, the low-energy ring (LER) arcs, and the HER and LER straights. Each of the three systems is the responsibility of a collaborator in the PEP-II project, SLAC for the HER arcs, LBNL for the LER arcs, and LLNL for the HER and LER straights.

An absolute calibration of the BPM system requires several steps. This calibration is defined relative to an ideal orbit, which is determined by a global survey. The steps required to relate the measured positions with respect to this ideal orbit are:

- Establish the electrical center of the BPMs with respect to defined mechanical center of the vacuum chambers. (Section 2)
- Measure and correct for the attenuation of the signals through cables and the passive electronics. (Section 3)
- Measure and correct for the offset of the active electronics. (Section 4)
- Establish the offset from the mechanical center of the chambers to the ideal orbit. (Section 5)

In this paper calibration for the HER BPMs will be discussed. This system is complete and installed. Calibration for the LER BPMs is underway; but, will not be described.

2 CALIBRATION TEST STAND

The BPMs and vacuum chambers require calibration to determine the electrical and mechanical centers before they are installed in a quadrupole assembly.

Various methods have been used for electrical calibration of BPMs. These include sending a short pulse or a continuous rf signal down a stretched wire or rod which is terminated in the characteristic impedance. The method selected here is to launch a travelling wave using a short antenna centered in the vacuum chamber. Signals induced on the BPM buttons are measured with a power meter. To reduce systematic errors, measurement channels are swapped and averaged.

The mechanical design of the calibration test stand used at SLAC is shown in Figure 1.

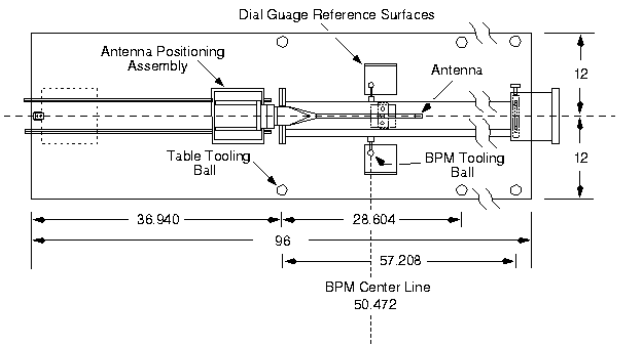

Figure 1. BPM Calibration Test Stand (SLAC). Dimensions in inches.

The quadrupole chambers are located by a pin and reference plate located at the BPM position. At the other end of the chamber a mounting surface positions the chamber in the test stand. Tooling balls (fiducials) mounted at the sides of the chamber (at the BPM position) are measured with respect to reference surfaces using precision dial guages.

2.1 Electrical Calibration

The antenna is designed to launch a TEM wave (at 952 Mhz) from a point beyond the buttons to the near end of the quadrupole chamber where it is absorbed in an electrical lossy material (ECHOSORB). The length of the antenna is specified by balancing the requirements of mehanical stability and starting the traveling wave at a point sufficiently beyond the buttons so that higher order modes damp out. A distance of 25 cm is sufficient for 40 dB of damping for the next higher mode. The diameter of the rod, 1.59 cm, is selected for mechanical stability. The antenna can be moved in the xy plane by the precision

stage and the assembly is mounted on rails to facilitate installation and removal of quadrupole chambers.

Power at 952 Mhz is delivered to the antenna from a supply that consists of a phase-locked oscillator, an amplifier, and a narrow band filter. The rf signal is delivered to an open stub at the end of the antenna through semi-ridged coaxial cable. The coupling stub is simply 2.86 cm of the center conductor of the coax. A 1.59-cm diameter cylinder of nylon both protects the stub and increases the efficiency of the antenna through dielectric loading.

The travelling wave created by the antenna induces signals on the four buttons of the BPM. Each button is connected to a 4P1T rf switch and the common terminal of the switch is connected to a power meter. The rf switch and power meter are controlled by a MacIntosh IIci running LabView.

A position measurement is made by measuring the power on each button sequentially. Then the cables at the buttons are diagonally swapped and the measurement is repeated. Calculation of the position can then be made [1]. An average of the measurements helps to eliminate systematic errors while the difference in the measurements represents the systematic error.

2.2 Mechanical Calibration

The calibration test stand was measured and aligned by a survey. In particular the primary requirements are the accurate centering of the antenna in the quadrupole chamber and accurate knowledge of the reference surfaces with respect to the locating pin and surface. The surveys were repeated several times over the period in which the quadrupole chambers were calibrated.

Measurement of the position of the tooling balls are made at each calibration. The x and y positions of the tooling balls are entered into the LabView program and become part of the calibration database.

The description on the calibration test stand as described applies to the setup at SLAC. At LLNL the mechanical system was somewhat different. There the system was based on a CCMM.

2.3 Calibration Test Stand Results

In commissioning the calibration test stand extensive test were performed. These include tests for electrical reproducibility, mechanical reproducibility, response mapping, and survey errors. Also a standard chamber was checked periodically during calibrations. The standard errors for electrical and mechanical reproducibility totaled about 15 μm while the survey errors were about 25 μm.

The mapping of the chamber out to a radius of 8.13 mm from the center was done to estimate the accuracy of the calculated calibration factors. The precision of these factors was determined to be 0.5% and 1.3% in the x and y directions, respectively.

3 ATTENUATION OF PASSIVE ELECTRONICS

A block diagram of the electronics for the BPM system [2] is shown in Figure 2.

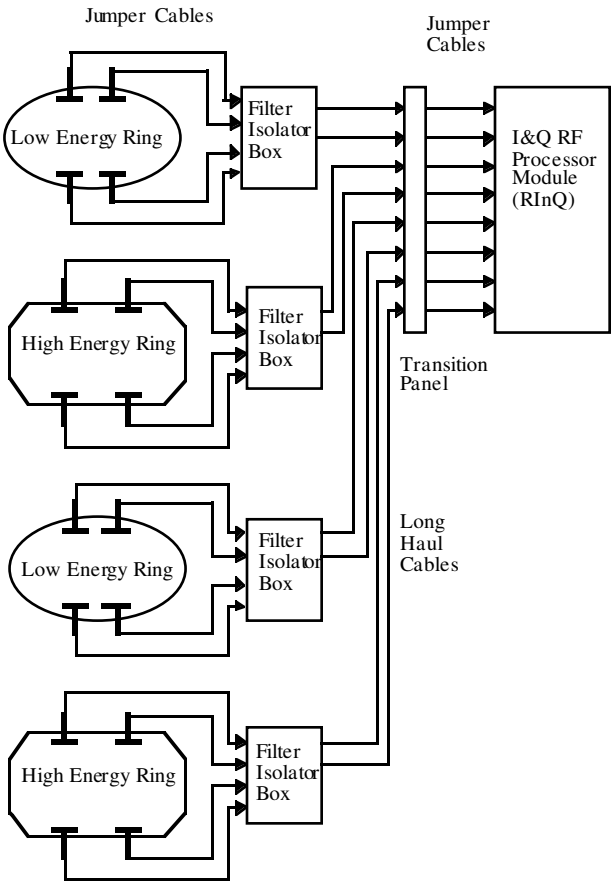

Figure 2. BPM System Block Diagram

The components that contribute to the passive attenuation are the button to Filter Isolator Box (FIB) jumper cables, the FIB, the long haul cables from the FIB to the transition panel, and the transition panel to processor module (RInQ) jumper cables.

Attenuation of the button to FIB jumper cables were measured before being installed. The attenuation of the long haul cables and the transition panel to RInQ module jumper cables were measured together following installation. The system was designed to have an attenuation of at least 8 dB in order to reduce the effect of reflections. Here the concern is in the difference in attenuation from channel to channel. The average difference in attenuation leads to an offset of about 130 μm. The measurement error is approximately 15 μm.

4 CALIBRATION OF ACTIVE ELECTRONICS

The active electronics [I&Q RF Processor (RInQ) Module] processes signals using baseband conversion by in-phase and quadrature demodulators. The signals are then digitized and the position calculated. The RInQ module also contains an on board calibrator. The calibrator injects

rf signals (near 952 Mhz) through a 10-dB coupler at the input of each channel. Using this calibrator several sources of error can be reduced. These errors include channel gain mismatch, channel offset, and amplitude and phase unbalance. The total offset due to these sources was specified to be less than 0.12 dB. Production modules have measured offsets of less than 0.04 dB or 30 μm with an error of approximately 10 μm.

A part of the channel offset is not measured through these calibration procedures. An offset can be present from the input circuit through the coupler. This offset is measured during the acceptance testing of the modules. A single source is used to drive a splitter and the split signal is sent to the module and the position offset measured. To help eliminate systematic errors the cables to the input channels are swapped and the offset measured again. The average of these measurements is then used.

The average offset measured through this procedure is about 30 μm with an error of approximately 10 μm.

5 GLOBAL ALIGNMENT

For the puposes of this paper the global alignment is a process in which the idealized beam transport and the placement of the beam line structures as determined by their fiducials results in a set of ideal coordinates [3]. Even more specific to the BPM system the required information is the offsets between the ideal beam position and the BPM mechanical center (defined as the position of the antenna at calibration).

The errors involved in this process are primarily the survey errors, *i.e.*, determination of the position of the fiducials on the magnet to the fiducials on the vacuum chamber and determination of the position of the fiducials on the magnet with respect to the magnetic center. These errors have not been fully analyzed at this time; however, they do not exceed the requirements, 60 μm and 45 μm, respectively .

6 SUMMARY AND CONCLUSIONS

As part of the planning for the PEP-II BPM system the precision or accuracy requirements were specified. In the following table the actual results are compared to the requirements. The errors listed in the table represent one standard deviation.

Table 1. BPM System Requirements and Performance

Calibration Element	Required (μm)	Actual (μm)
Calibration of electrical center to fiducials on chamber	90	
Electrical center to antenna		15
Antenna to fiducials		25
Fiducials on chamber to fiducials on magnet	60	60
Fiducials on magnet to magnetic center	45	45
Electronics and cables	175	
Passive attenuation		15
External calibration of RInQ		10
Internal calibration of RInQ		10
Mechanical stability of electrical with respect to magnetic centers	60	40
Total (quadrature)	220	90

The calibration of the BPM system has been shown to be better than the requirements. Offsets for each of the effects discussed in this paper will be entered in the on-line data base and will help in the tuning of the PEP-II beams.

7 ACKNOWLEDGEMENTS

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