SSRL Beam Position Monitors*

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Abstract

As part of its project to improve the stability of photon beams, SSRL has designed and is installing new electron beam position monitors (BPMs) in the SPEAR storage ring that will allow determination of the electron orbit to better than 10μm [1] [2]. The monitor was designed to add minimal impedance to the ring, so its geometry and that of its connecting transition pieces were largely determined by the adjoining vacuum chamber dimensions. Given this geometry, analytical calculations and numerical techniques were used to optimize the size and location of the button electrodes. Further analyses were performed to design the shape of the electrode and its feedthrough for optimal performance at a processing frequency of 717.08 MHz, the second harmonic of the ring RF. Special attention was given to the monitor support to limit transverse motion while permitting longitudinal motion during thermal cycling. Details of the design procedure are presented.

1 INTRODUCTION

SPEAR, a 3 GeV electron storage ring used for synchrotron radiation, has twenty six button style BPMs located around the ring. Sixteen are from the original complement, having 25mm diameter buttons mounted inside a circular pipe on ion pump style feedthroughs. Two, on the RF cavities are of smaller diameter. Four others have the buttons mounted flush to the wall and the remaining four are rectangular in cross-section. Since not all of its 26 BPMs produce signals of the quality necessary to accurately measure and control an orbit with betatron tunes ~7, we plan to increase the total number of BPMs.

The existing BPM and bellows modules in the arcs (292mm long) are located at the upstream ends of straight sections except at two of the insertion devices which have BPMs at both ends. A pump port and bellows module of the same length occupies the downstream end. Since SPEAR was designed and commissioned in the early 70's it is somewhat challenging to install new BPMs without extensive changes to existing components. For this reason, and from operational requirements we installed our prototype BPM at the downstream end of an undulator straight section in place of a pump module. Since the undulator chamber shields the BPM from synchrotron radiation it was only necessary to replace the single module. In this paper we report on the design of the prototype and subsequent BPMs.

2 PROTOTYPE

The BPMs must be designed to produce electrical signals of sufficient strength and sensitivity so that the beam position can be measured to resolution of better than 10μm. The BPMs should also be as transparent as possible to the beam, having minimal broad-band impedance and introducing no higher order modes (HOMs) to the ring.

Table 1: SPEAR BPM Parameters

Energy	3	GeV
Nominal Beam Current	20–100	mA
Resolution	10	μm
BPM Width	155	mm
BPM Height	44	mm
Button Diameter	20	mm
Button Gap	1.5	mm
Button Offset	16.5	mm

The BPM is rigidly mounted on, and supports, the end of the dipole bend chamber supports. A pumping port and expansion bellows are an integral part of the module since there is not room for an additional flange pair to put them on a separate module (Figure 1).

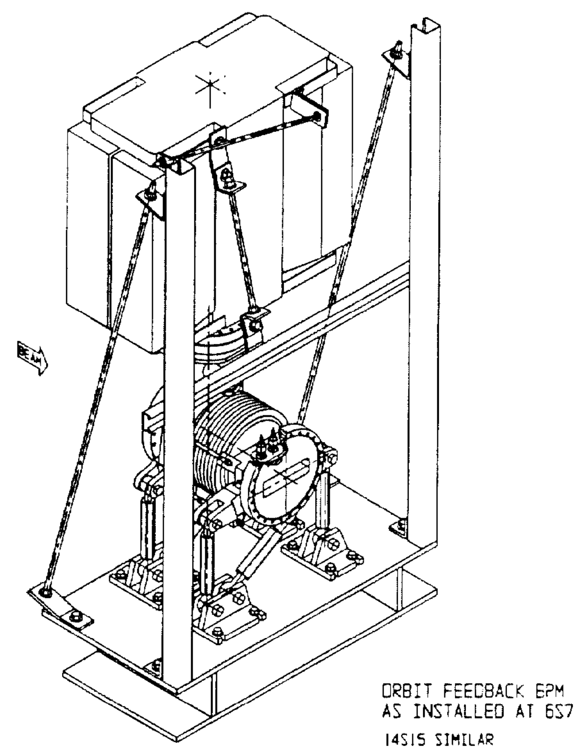

Figure 1: SSRL Prototype BPM Assembly

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2.1 Button Size and Placement

The section of the BPM containing the sensor buttons is 100mm long and of uniform cross-section identical to that of the dipole bend chamber, to which it is rigidly attached. The horizontal aperture is 155mm and the vertical is 44mm. It is extremely rigid having been machined with 16mm thick walls out of solid SST plate.

Because of the ultrarelativistic nature of the beam, the transverse fields can be considered as the solutions of a 2-D Laplace's equation. This problem is then solved with conformal mapping techniques [3][4]. The coupling of these fields to the electrode can then be solved by microwave techniques [5].

To minimize impedance and ease manufacturing, we chose buttons over striplines for BPMs. Since the buttons increment the ring impedance by a negligible amount, our variables in the BPM design were the button size and placement. The rectangular shape of the BPM shapes the field lines, and hence the image currents, so that they are concentrated above and below the beam on the top and bottom walls of the BPM. To maximize signal, we chose a large button size, 20mm, so that 13% of the image charge sweeps over each button. A larger button also increases the induced voltage measured at our processing frequency.

Our system must be capable of accurate measurements whenever the beam is within ±10mm of the BPM center horizontally and ±7mm vertically. We do not require linearity over that range; non-linear effects will be compensated by the control system. There is no clear optimal position at which to place the buttons. One trades off absolute sensitivities for relative sensitivities. Fortunately all of these variations are rather broad, so we could select a BPM geometry that satisfied both electrical and mechanical considerations (Figure 2).

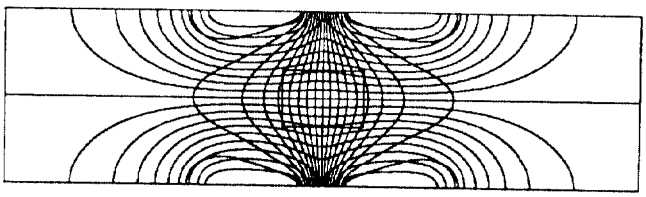

Figure 2: BPM Equi-signal Contours (Pincushion)

Button feedthroughs are welded in pairs to intermediate plates which are in turn welded to the top and bottom of the body. This method of construction was employed for two reasons. If a failure of the feedthrough occurs it facilitates removal and replacement. Procurement of the feedthroughs is often a critical path item and this permits assembly and leak check of the body of the BPM in advance of welding the feedthroughs.

2.2 Feedthrough Design

The feedthrough [6] (Figure 3) has a 20mm diameter button surrounded by a grounded shell. The nominal impedance is 50Ω and button capacitance 1pF. A type N connector was chosen as being less prone to damage than an SMA type. The button is recessed 0.25mm from the face of the shell to help shield it from scattered photons. Before designing the feedthrough we surveyed existing designs. Since few were found to have a button diameter close to 20mm we developed our own. Design considerations included the electrical properties, mechanical properties as regards uniformity and vacuum integrity and past experience with manufacturers of ceramic insulators.

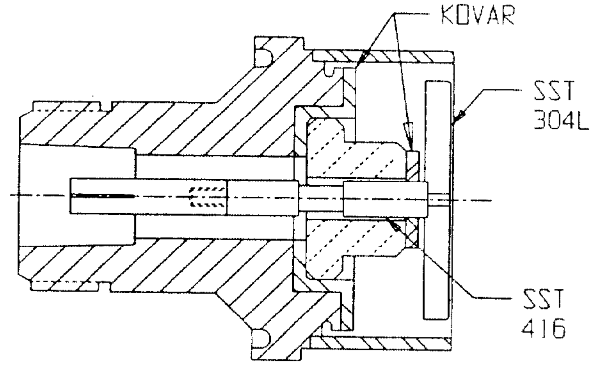

Figure 3: BPM Feedthrough

The button must provide adequate coupling to the beam, without generating any resonances that can couple back onto the beam. To satisfy the electrical requirements, the feedthrough should have a minimal number of different cross-sectional geometries, and those that it has should be confined over a short distance with smooth connecting transitions [5]. Since the coupling impedance of a 'coaxial' structure with outer radius, r_o, inner radius, r_i, varies with distance between centers, d, as $2\cosh^{-1}[(r_o^2 + r_i^2 - d^2)/2r_or_i]$ [7], standard tolerances for concentricity were adequate.

We have performed tests of the vacuum integrity on various feedthroughs. Whilst the conventional kovar to ceramic braze washer pin seal does not give the most uniform impedance we decided to use this technology as being the most reliable in our experience. We are studying alternate assembly techniques that we feel will result in feedthroughs with improved electrical performance.

2.3 HOM Considerations

The BPM module can introduce HOMs through cavities it adds to the vacuum chamber either because of differences between its cross-section and that of the chamber, or because of openings in its walls. Even within the module there are discontinuities – an expansion bellows (82mm long) and then a tube with an oval shaped pump port to which is attached, in the ring, a 400 l/s ion pump. We tapered all of our transitions to minimize any standing waves that could be established in the BPMs. For the bellows and pumping section, sliding contact is accomplished by means of closely spaced beryllium copper fingers sliding against a polished SST transition which tapers down to the cross-section of the undulator chamber. The transition and fingers are easily removable to allow for variations at other sites. Also, there is an uniform aperture of 1.5 times the vertical height on either side of the buttons to reduce the effect at the buttons of these discontinuities.

As stated above, we minimize the HOMs created by the wall openings required for the BPMs, the gaps surrounding the buttons, by requiring the transitions in feedthrough geometry to be short and smooth, wherever possible. Our initial set of feedthroughs adequately meets these criteria, but we feel that with some minor modifications, their performance can be noticeably improved.

We satisfy the ion pump flow requirements by using a series of long, thin slots machined into the transition. Slots that are parallel to the beam provide the lowest impedance [8]. The slots are narrow (4mm) near the center and wider at the sides, so that most of the openings are located where the density of field lines is lowest.

2.4 *Mechanical Support*

The BPM is supported at the plane of the feedthroughs by two struts, one on each side, for vertical adjustment and a third diagonal strut for horizontal adjustment. These are mounted on a bracket at the end of the concrete raft supporting the magnets. They are simply turn buckles with ball joints at each end. The ball joints were pre-stressed and the ball tightly clamped in a clevis at each end to eliminate play. The BPM is allowed to float in $\hat{z}$, the axis of the beam, since the center of the dipole chamber is rigidly constrained. The ion pump is separated by a bellows from the BPM, and is thus independently supported.

3 CALIBRATION

Although our calibration method has not been finalized, we present our current thinking on the subject. We divide calibration into two problems – finding the correct 'pincushion' our BPM detects, and finding the relationship between the mechanical and electrical centers of the modules. To find the latter, we will use either the button-to-button transfer technique [9], or build a fixture with very limited travel about the BPM axis. For mapping out the pincushion, however, we need a device that allows centimeters of motion.

A calibration fixture always has the problem that the environment of antenna and fixture is different from the real environment of beam and chamber. While passing the module, the beam acts as a TEM wave. It is the response to this TEM wave that we want to measure. After the beam has passed, the remaining fields in the BPM are only cavity modes. But the test fixture always has a center conductor in it, so can always support TEM modes the BPM will never see in the ring. Therefore, we need to insure that our antenna is properly terminated at its TEM impedance to minimize reflections. Also, higher order spatial modes will be created at the discontinuity between the antenna input connector and the fixture. At high enough frequencies, these modes propagate down the fixture, corrupting the measurement of the TEM wave. Even at lower frequencies, when evanescent, they still extend a finite distance into the fixture.

Our fixture, then, will consist of a movable, terminated antenna inside of a long rectangular chamber, at the center of which is the BPM. We will calibrate at a frequency lower than our designed processing frequency to insure that the evanescent fields originating at the fixture ends are negligible at the buttons. As long as the excitation signal is a TEM wave, different signal frequencies will just produce different strength responses on the buttons, but since all buttons are the same size, the relative strengths between buttons will just be a function of position. We will use one type of antenna arrangement for the pincushion calibration that will be performed only on a representative sample of BPMs, and a less versatile, but easier to use version for the offset calibrations of each BPM.

4 PHASE II

After installation of the prototype it was necessary to design BPMs for installation at either end of the beam line 9 wiggler magnet, currently under construction. Several changes to the original design were implemented. The module was shortened to 184mm long since the pump port is not required, whilst retaining the expansion bellows. The horizontal aperture was widened and tapered to allow passage of synchrotron radiation without the necessity for a water cooled mask.

5 ACKNOWLEDGMENTS

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