Progress on the Development of APS Beam Position Monitoring System*

Glenn Decker and Youngjoo Chung

Advanced Photon Source
Argonne National Laboratory
Argonne, IL, 60439

Abstract- This paper describes the development status of the beam position monitoring system for the Advanced Photon Source (APS), a third-generation light source now under construction at Argonne National Laboratory. The accelerator complex will consist of an electron linac, a positron linac, a positron accumulator ring (PAR) , an injector synchrotron and a storage ring. For beam position measurement, striplines will be used on the linacs, while button-type pickups will be used on the injector synchrotron and the storage ring. A test stand with a prototype injector synchrotron beam position monitor (BPM) unit has been built, and we present the results of position calibration measurements using a wire. Comparison of the results with theoretical calculations will be presented. The current effort on similar storage ring BPM system measurements will also be discussed.

1. Introduction

The Advanced Photon Source storage ring at Argonne is designed to operate at 7 GeV with an operating current of 100 mA, and has a circumference of 1104 meters. Along this circumference will be placed 360 beam position monitoring stations, each composed of four button-type capacitive pickup electrodes. The injector synchrotron, which is exactly one third the circumference of the storage ring, has BPMs that are also of the button-type, and a total of 80 stations are planned.

Ultimately, a measurement accuracy of $\pm$ 200 μm for the storage ring is required relative to the magnetic centerline of adjacent sextupole magnets, with a required resolution of better than 25 μm. The reason for the tight accuracy specification is that, at commissioning, the dynamic aperture of the machine approaches the physical aperture when the rms placement error of the sextupole magnets is equal to 200 μm. After commissioning, the insertion device vacuum chambers (1.2 cm vertical full aperture) will be installed and become the limiting aperture.

In addition to measuring the beam position of stored positron beams, the BPM system must have a first turn capability for commissioning. The accuracy specification for the storage ring BPM measurement in first turn mode is $\pm$500 μm with a resolution better than $\pm$200 μm. At this time, it is planned to also incorporate turn by turn capability in both the storage ring and injector synchrotron designs. Accuracy and resolution specifications for the injector synchrotron are $\pm$500 μm and $\pm$100 μm, respectively.

2. Beam Position Monitor Mechanical Design

The pickup electrode design is similar to that developed at ESRF in Grenoble, France, and being used in the Elettra machine in Trieste, Italy. A high vacuum feedthrough with a small (.425" dia.) button attached on the vacuum side is welded into a 1.33" diameter flange. Alumina (Al_2O_3) is used to insulate the center pin of the feedthrough and provide a good RF match. The flange is machined to accept a Helicoflex vacuum seal. Mounting the feedthroughs on individual flanges allows convenient replacement of defective units. Specifications for the pickup electrodes to be used in both the storage ring and injector synchrotron are shown in Table 1.

Table 1   BPM Feedthrough Specifications

He. Leak Rate	$< 10^{-10}$ atm-cc/sec.
Bakeable to	400 °C
VSWR @ 6 GHz (12 GHz)	$\leq$ 1.04 (1.08)
Dielectric Strength @ 60 Hz	$\geq$ 1500 Volts

Two complete injector synchrotron BPM prototypes, each having four button-type pickup electrodes, were fabricated for electrical testing. One such device is shown in Figure 1. The BPM was machined from a solid block of AISI 316L stainless steel using a wire EDM technique in combination with NC machining. The inner bore is elliptical with major axis 3 cm and minor axis 1.85 cm. The overall length of each prototype is 10.2 cm.

The storage ring vacuum chamber is an aluminum extrusion with a roughly elliptical inner bore near the positron beam, a photon exit slot, and an antechamber containing NEG pumping strips [1]. The pickup electrodes will be mounted on machined flats surrounding the positron side of the chamber. They will be located with a tolerance of $\pm$.004"($\pm$100 μm) relative to the positron chamber center.
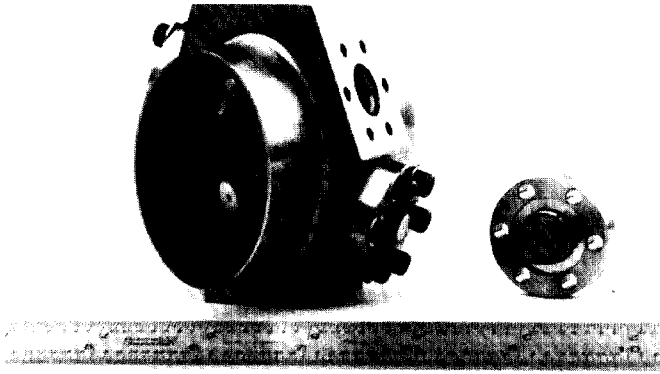
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Figure 1. Injector Synchrotron BPM

3. BPM Electrical Characterization

The electrical characterization of BPM assemblies consists of measuring button capacitance, calibrating the assembly using a coaxial wire technique, and finally extracting electrical offsets from button to button transfer function measurements for comparison with those determined using the wire calibration. The final step provides the possibility of determining offsets under vacuum in the final configuration using only the buttons themselves and their associated cabling.

A. Button Capacitance Measurement

A time domain reflectometer technique was used to measure button capacitance. The time constant of the exponential reflected waveform resulting from a step function input yields the capacitance according to $\tau = RC$, where R is the characteristic impedance of the coaxial line, 50 Ω. A linear least squares fit to the logarithm of the data accurately determines τ.
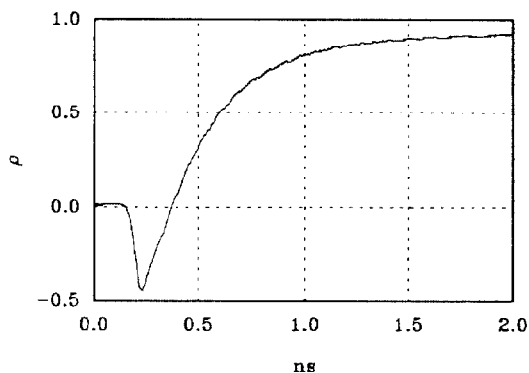

ns

Figure 2. Button Pickup TDR Measurement

Shown in Figure 2 are data obtained in this way. Notice the absence of any parasitic resonances, indicating that the button is a pure capacitor up to very high frequencies. The TDR rise time was less than 20 ps for this measurement.

Typical results of the technique showed that a button capacitance of approximately 5 pf could be measured with a

standard deviation for random errors of ±.05%, or ±2.5 femtofarads. Disconnecting and reconnecting the button from the cable would typically shift the measured capacitance by about 10 femtofarads. Using a different SMA F-F adaptor moved the measured value by 4%, presumably because of the change in characteristic impedance of the line, which was assumed to be exactly 50 Ω.

B. Coaxial Wire Calibration

Shown in Figure 3 is the test stand used for calibration of the injector synchrotron BPM's. The BPM block was mounted on an x-y translation stage, with a .012" dia. steel music wire strung coaxially. Both ends of the wire were attached to SMA bulkhead connectors. A 4:1 ferrite impedance transformer and 133Ω parallel trimming resistor were used on the input to approximately match the 50Ω input line to the 320Ω wire/chamber impedance. On the output, a 270Ω carbon resistor was placed in series to match into the 50Ω output line. This matching scheme proved adequate over the range DC - 400 MHz.
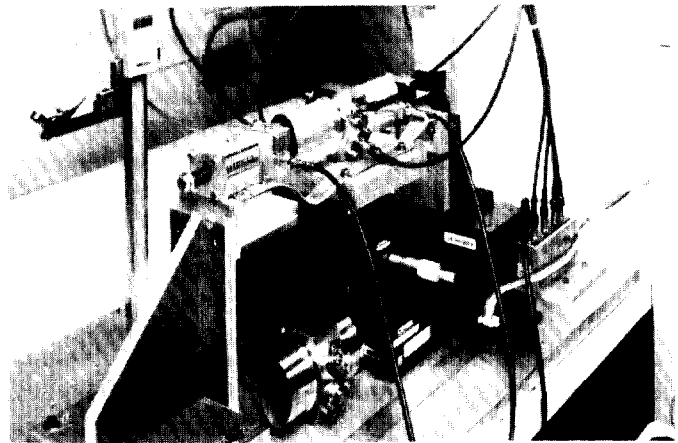

Figure 3. Injector Synchrotron BPM Test Stand

A spring tensioning device was located on the left hand side, and on the right was a manual x-y stage for precise wire alignment. During data collection, aluminum foil RF shields were wrapped around the elliptical ends of the BPM block, to within about 0.5" of the ends of the wire, extending the elliptical transverse profile.

The buttons were multiplexed in a mechanical SP4T switch shown at lower right. Calibration was performed at the APS RF frequency, 351.92 MHz, using a network analyzer. Button voltages ("A") were normalized using the transmitted RF waveform ("R") coming out the right hand side of the test stand (producing "A/R"). Because the 270Ω series resistor provides a reasonable RF match, the current flowing into the network analyzer "R" input is essentially the same as that flowing on the wire. Therefore the coupling impedance, defined as the button output voltage into 50 Ω divided by the beam current (or wire current), is simply the fraction "A/R" multiplied by 50 Ω.
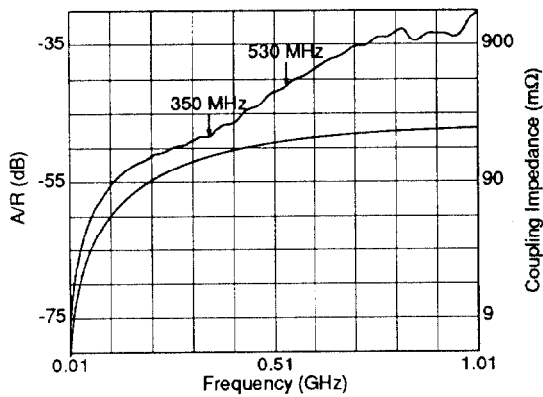
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Figure 4. Injector Synchrotron BPM Coupling Impedance

Shown in Figure 4 is the measured coupling impedance of the injector synchrotron BPM over the frequency range 10 MHz to 1.01 GHz for a typical button with the wire centered. The smooth curve in Figure 4 is the theoretical coupling impedance [2]. The expected 3 dB point, $1/2\pi RC$, is at about 530 MHz in this case. The high frequency data is an overestimate, simply because the 270Ω resistor provides a poorer match at high frequency, making "R" smaller, and "A/R" larger.

Sensitivities

Measurement
$S_x = 0.697$ cm^{-1}
$S_y = 0.568$ cm^{-1}

Theory
$S_x = 0.695$ cm^{-1}
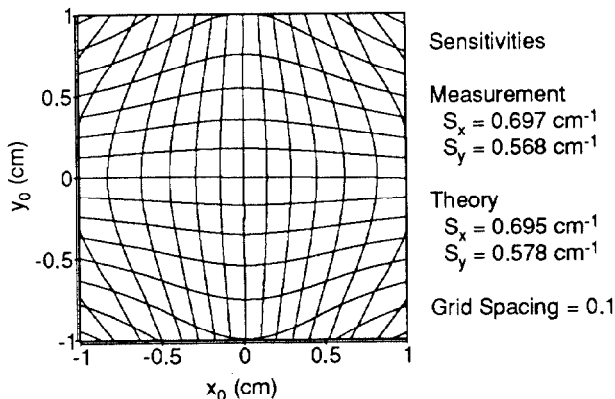$S_y = 0.578$ cm^{-1}

Grid Spacing = 0.1

Figure 5. Injector Synchrotron BPM Calibration Measurement

In Figure 5 is shown a contour plot of measured data from the test stand. Plotted as a function of transverse wire position x_0 and y_0 are the quantities Δ_y/Σ and Δ_x/Σ, where Σ is the sum of the four button voltages, Δ_y is the difference between the top and bottom pairs of button voltages, and Δ_x is the difference between left and right hand pairs. Here x and y take on the usual accelerator conventions (note that Figures 1 and 3 show the monitor rotated by 90 degrees relative to its final installed orientation). The data are in agreement with theoretical calculations to ± .0043 Δ_y/Σ units and ± .0033 Δ_x/Σ units rms [2].

C. Button-Button Transfer Function

The beam position monitor test stand described in the previous section for APS injector synchrotron BPM calibration was also used as a test bed to determine the accuracy and reliability of a technique pioneered at Berkeley by Lambertson [3] and Hinkson [4] for the determination of electrical offsets by non-invasive means. By measuring the twelve button to button transfer functions between the four button pickups, ratios of relative gains can be extracted, equivalent to electrical offset determination. Using this technique, Hinkson has shown offset determination with an accuracy of better than ±100 µm [4].

Shown in Table 2 are comparisons between offsets determined using the wire and using the Lambertson button-button transfer function method with the APS injector synchrotron BPM shown in Figure 1. Three button configurations were characterized; starting from configuration 1, the pickups were transposed across the x plane (config. 2), and then the y plane (config. 3).

Table 2 Comparison of Offset Data (µm)

Config.	x_w	y_w	x_L^*	y_L
1	-150±6	103±13	-159	100
2	-167 ±4	185 ±4	-152	194
3	81 ±4	189±6	73	189

* Typ. Meas. errors were ≤ 3 µm.

The relative button voltages caused by a current flowing on a mechanically centered wire determines the "true" electrical offsets. The ordered pair (x_w, y_w) is, by definition, the displacement of the mechanical center relative to the electrical center, measured using the wire technique. The values x_L and y_L are similarly defined for the button-button transfer function technique. For both measurements the SP4T RF switch was used. Its insertion loss was measured and corrections were made to the data.

4. Conclusion

Calibration of the APS injector synchrotron BPM pickups are complete, and results agree well with theory. The technique developed by Lambertson and Hinkson for non-intrusive electrical offset determination shows promise of working down to the 25 µm level or better. This has been tested using the slotted Berkeley ALS chamber by Hinkson and will be investigated further with the APS storage ring BPM test stand which is under construction.

5. Acknowledgements

6. References

[1] R.C. Niemann et. al.,"APS Storage Ring Vacuum System Development", these proceedings

[2] Y. Chung, "Theoretical Studies on the Beam Position Measurement with Button-type Pickups in APS", these proceedings.

[3] G.R. Lambertson, "Calibration of Position Electrodes using External Measurements", Lawrence Berkeley Laboratory, LSAP Note-5, 1987.

[4] J. Hinkson, Lawrence Berkeley Laboratory, private communication.

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