Conf- 9210246--5

ANL/ASD/CP--77465

DE93 004180

Test Results of a Monopulse Beam Position Monitor
for the Advanced Photon Source*

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Received by PSTI

DEC 09 1992

*Work supported by the U.S. Department of Energy, Office of Basic Energy Sciences,
under Contract No. W-31-109-ENG-38.

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TEST RESULTS OF A MONOPULSE BEAM POSITION MONITOR FOR THE ADVANCED PHOTON SOURCE*

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Abstract

A prototype of the Monopulse Beam Position Monitor (BPM) was tested to determine the resolution capability for various signal levels and beam configurations. The BPM was tested in two environments: using a wire simulation of the beam in the laboratory and using real beam at various positions and levels at Stanford Synchrotron Radiation Laboratory. Both tests showed a resolution capability of better than 25 microns. This paper presents the procedures and measurements' results.

General

A new design for a BPM, using the monopulse receiver based upon the AM/PM technique, was presented in references 1 and 2. Furthermore, we built a laboratory prototype in order to test the feasibility of the method and verify the performance. The prototype was tested in two environments:

- a. In the laboratory, using an actual beam pipe section, real "buttons," and a wire connected to an RF source to simulate the beam.
- b. At SSRL, measuring actual beam position for various bunch configurations, currents, and pick-ups.

Prototype Description

The prototype that was built is a simplified version of the final unit. The simplification consists of looser component specifications, measurement capability on one axis only, no automatic offset cancellation, and simulated signal processing. Still, we expected to prove the resolution capability of less than 25 microns, although within a smaller dynamic range than the final unit. Figure 1 shows a block diagram of the BPM prototype.

* Work supported by the U.S. Department of Energy, Office of Basic Sciences, under contract no. W-31-109-ENG-38.

Figure 1: Block Diagram of Prototype.

The prototype used circuits built in-house with off-the-shelf components. In order to provide the necessary matching between the channels, we included amplitude and phase trimmers. As a signal processor we used a digital oscilloscope HP 54503A. The data was gated by a 50 nsec gate at the signal location and was integrated up to 256 times. The output was recorded on a PC.

Wire Tests

The BPM was tested using buttons installed on a test section of the APS Storage Ring vacuum chamber. The beam was simulated by a wire through the center of the pipe, connected to a signal generator. The wire in the pipe could be very accurately positioned by stepping motors controlled by a PC. Due to instrumentation limitations, we could not generate enough power with pulse waveform; therefore, the test was done at 352 MHz CW. Due to power limitations, the test was conducted close to the low end of the dynamic range of the prototype, about -40 dBm. To improve the signal-to-noise ratio, 256 measurements were averaged. We moved the wire on the Y axis in steps of 10 mils (254 microns), from -15 mm to +15 mm, and in steps of 1 mil (25.4 microns), from -1 mm to 1 mm. Figures 2 and 3 show the phase detector output voltage, as a function of the wire position.

Figure 2: Output voltage vs. wire position - coarse

Figure 3: Output voltage vs. wire position - fine

In Figure 2 we can see the familiar curve of the AM/PM conversion receiver. In Figure 3 we took fine readings every 1 mil and drew a linear regression through the points. We can see the very good fit, with a slope of 18 mV/mm. In order to comply with the specified signal processor range of ± 1 V for the final system, the detector output will have to be amplified with a gain of 6, giving 108 mV/mm. Since the amplitude resolution of the final system is 1 mV in the worst case, we predict a position resolution of $1/108$ mm, or less than 10 microns.

SSRL Tests

The purpose of the tests at SSRL was to test the BPM electronics in a real environment with various bunch patterns and currents. The test was possible because the ring frequency at SSRL is 358 MHz, close to the APS frequency of 352 MHz. In order to do measurements on the Y axis, we combined the two upper and the two lower pick-ups. Although the diameter of the beam pipe at SSRL is about four times that at APS, we could scale and still obtain useful results. One basic problem was to define a beam location reference. We had to rely on the SSRL BPMs, which are of an old design. Also, the nominal beam position at SSRL is about 2.5 mm off-center, therefore we had to remove the offset by subtracting the middle voltage value and shift the data around zero.

The BPM electronics were installed in the control room at the end of about 100 feet of cable. We tested the BPM with the following beam configurations:

(a) A cluster of 20 bunches with 3-4 buckets separation between bunches, at total currents of 70 mA, 15 mA, and 3.6 mA, using striplines.

(b) A single bunch, at 9.6 mA and 1.3 mA, using striplines.

(c) A single bunch, at 5 mA and 10 mA, using buttons.

We moved the beam by a local bump in several steps on the Y axis and measured the output of the BPM. As the position reference, we used the SSRL BPMs. The analysis was made by a linear regression through the measured points, after removing the offset.

Figure 4 shows the output voltage as a function of position deviation on the Y axis, for configuration (a).

Fig. 4: Output voltage vs. position for a 20 bunch cluster, using striplines.

We can see from Figure 4 that the measurement points fit a straight line very well. The slope changes very little with current and the errors are mostly due to SSRL reference errors. The slope is about 11 mV/mm. Fig. 5 shows the output voltage curve for a single bunch.

Figure 5: Output voltage vs. position for single bunch, using striplines.

For the single bunch case, another source of errors is introduced, which is the accuracy of the gate that determines the bunch location. Since the pulse width of the BPM filter output and the integrator gate are both about 50 nsec, the measurement is very sensitive to the gate location relative to the pulse. We can see that the slope using striplines is about 1/2 that measured in the wire test (see Figure 3), due to the different geometric sensitivities. The APS storage ring geometric sensitivity was calculated to be 0.53/cm and that of the SSRL ring 0.264/cm (Reference 3); therefore, the ratio is 2:1, in compliance with the measurements.

We repeated the measurements with a single bunch, using button-type pickups. Figure 6 shows the output voltage curve for a single bunch, using buttons.

Figure 6: Output voltage vs. position for single bunch, using buttons.

We see that the in this case the slope is much smaller. This is probably due to the low signal picked up by the buttons, which may be below the prototype's dynamic range. We can evaluate the drop in signal level by calculating the coupling impedance of the SSRL stripline relative to the button. The ratio of the coupling impedance is given by:

$$\frac{Z_s}{Z_b} = \frac{A_s}{A_b} * \frac{R_b}{R_s} * k$$

where A_S , A_b , R_S and R_b are the stripline and button areas and radius, respectively, and k is a correction factor given by:

$$k = \frac{\sin\left(\frac{\pi}{2} \frac{l}{\lambda/4}\right)}{\frac{\pi}{2} \frac{l}{\lambda/4}}$$

where l is the stripline length and λ is the wavelength. For SSRL:

- $A_S = 130.66 \text{ cm}^2$
- $A_b = 3.14 \text{ cm}^2$
- $l = 27.8 \text{ cm}$
- $R_S = 7.45 \text{ cm}$
- $R_b = 7.82 \text{ cm}$
- $\lambda = 83.8 \text{ cm}$

We obtain $Z_S/Z_b = 18.25$ or 25.2 dB. Therefore, the signal from the buttons is 25.2 dB lower than that from the striplines. In order to confirm that this level is below the dynamic range of the BPM, we looked at the BPM limiter output. We saw that for 5 mA of beam current the limiter just started to compress and at 10 mA it was not yet in saturation.

Conclusion

Both the wire test and the tests at SSRL gave us confidence in our design and in the ability to obtain the BPM specifications. In the next step we will build the final unit and repeat those tests.

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Acknowledgment

We would like to thank Bob Hettel, Jim Sebek, and Jeff Corbett from SSRL for their support during the tests.

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