The APS Linac Beam Position Monitors and Electronics*

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Abstract

Beam position monitors using stripline pickups for 30 ns long electron and positron beam bunches have been built and responses were measured in the vertical and horizontal directions. Log amplifiers used for signal processing have a dynamic range of 40 dB and are scaled for 50 mV/dB sensitivity. In this paper we describe the design of the detectors, the signal processing electronics, and the results of the position-to-signal mapping using a wire. Beam position measurements using a prototype detector and electronics on the APS linac test stand are discussed.

Beam Characteristics

The beam parameters used to design the striplines are:

	Electron	Positron
Average current	1.7 Amps	8 mA.
Charge	50 nC	240 pC
Macro pulse		30 ns
Micro pulse (FWHM)		14.6 ps
Frequency		2856 MHz

Received by OSTI

DEC 09 1992

Detectors

The linac design requires 4 beam position monitors (BPMs) in the electron linac and 7 BPMs in the positron linac, generally after each accelerating section. To obtain maximum signal from the positron beam, striplines were chosen for the pickup medium. The 50 ohm striplines are one inch long, subtend a 1 radian arch, and are shorted at the downstream end. The detector's linear region of sensitivity is approximately ± 1 cm.

The Wheeler and Schneider formulas¹, were used to design the striplines because they provide accuracy better than 2 percent. The detector and beam pipe have the same inside diameter, 3.48 cm, making it difficult for beams with large spot size to strike the electrodes. For our design the electrode thickness is 1.524 mm and the gap is 3.81 mm.

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The equations given by R. Shafer² were used to calculate the rms voltages at the detector outputs and the sensitivity of the cylindrical geometry pickups. For a centered gaussian beam with a FWHM micropulse duration of 14.7 ps, the rms voltages at the fundamental frequency is 18.4 volts and .089 volts for electron and positron beam-generated signals, respectively. These voltages correspond to power levels of 38.3 dBm and -8.2 dBm. For our detectors, which have an average electrode and beam pipe radius of 18.16 mm, the calculated sensitivity is 1.83 dB/mm.

The detectors are machined in two pieces from stainless steel tube. One piece is the outer body assembly and the other is the stripline assembly. The stripline assembly is pressed into the outer body assembly and brazed at the joint. Kyocera sma electrodes and Conflat vacuum flanges are welded on. A cross section of the detector is shown in Fig. 1. The assembled detectors are vacuum checked then field mapped.

Fig. 1 Cross section of Beam Position Monitor

Detector Mapping

Calibration of the offset and the sensitivity of the BPM was performed using the wire method. A rf source of 2.856 GHz was applied to a thin wire of 12 mils diameter suspended in the detector and signal was measured at the four striplines. The position of the wire relative to the detector center was adjusted by moving the detector using two stepper motors.

Fig. 2(a) shows the results of 2-dimensional contour plotting of the BPM response mapped over a region of ± 8 mm on both axes. The horizontal direction is the x-axis. The BPM response exhibits very uniformly linear response over the region due to the relatively large 1 radian transverse size of the stripline. The BPM response in the x and y directions at the midplanes as functions of the distance from the center is shown in Fig. 2(b) and 2(c). From curve fitting of this data, we find the sensitivities are 1.817 dB/mm for x and 1.793 dB/mm for y, and the offset of the electrical center relative to the mechanical center is $-65 \mu\text{m}$ for x and $364 \mu\text{m}$ for y.

Fig.2. (a) Contour mapping of the BPM response in x and y directions. The grid spacing is 2 dB. (b) and (c) Plotting of the BPM response in x and y directions. The sensitivities are 1.817 dB/mm for x and 1.793 dB/mm for y, and the offset of the electrical center to the mechanical center is $-65 \mu\text{m}$ for x and $364 \mu\text{m}$ for y.

Signal Processing Electronics.

Inspired by a paper out of Los Alamos by F.D.Wells et.al³, a logarithmic amplifier signal processing scheme was chosen for measuring the beam positions. Fig. 3 is a diagram of one channel of the electronics package.

Fig. 3. BPM signal processing electronics

Detector signals are carried an average distance of 85 feet, over 1/4-inch heliax cable, to the signal conditioning electronics. The 2856-MHz signal is filtered, amplified, and down converted to 70-MHz, then filtered again to remove unwanted mixer products. The 70-MHz signal is amplified and excites a ringing filter with a bandwidth of 5 MHz. The ringing filter stretches the 30 ns pulse to about 200 ns and reduces its amplitude by 12 dB. The signal conditioning electronics has an overall gain of 6.2 dB and a noise figure of 7.2 dB. The stretched signal is fed to a single section logarithmic amplifier with a dynamic range of about 40 dB. The current output of the logarithmic amplifier is converted to a voltage then amplified, making the overall video sensitivity 50 mV/dB. The output pulses of the logarithmic amplifiers are captured in track and hold circuits, then digitized by 12-bit analog-to-digital converters.

A VXI card containing 8 log circuits, 8 track and hold circuits, and 8 12-bit analog-to-digital converters handles the signals from 2 detectors. A computer subtracts the appropriate video signals, divides the difference by 0.09 volt/mm, and obtains the displacement information in mm. The position of each 30 nsec, macro beam pulse is displayed on a computer screen. Any averaging required is performed by the computer.

Signals picked up on detectors located in the electron beamline must be attenuated approximately 40 to 45 dB before they can be fed to the signal conditioning electronics. Signals generated by positron beams need no further conditioning.

The thermal noise power, in a 5 MHz bandwidth, at the input to the logarithmic amplifier is about -93.5 dBm. The noise power of the logarithmic amplifier, in 10 MHz bandwidth, referred to its input, is -91 dBm. The total noise power at the input to the logarithmic amplifier is -89 dBm.

Signal levels at the logarithmic amplifier inputs are -12.8 dBm from electron linac detectors and -14 dBm from the positron linac detectors. These signal levels give signal-to-noise ratio levels of 76.2 dB and 75 dB respectively. A 75-dB signal-to-noise ratio predicts ± 1 micron resolution.

Log-Amplifier Section

The log-amplifier circuit built is shown in Fig. 4 and the calibration results of two such circuits are shown in Fig. 5.

Fig. 4 Logarithmic amplifier circuit.

Fig. 5. Transfer curve, straight line fit and error curve for logarithmic amplifiers #1 and #2.

The calibration results show the transfer curves, a straight line fit to the data, and the percentage error of the residuals. The data shows an error of about $\pm 3\%$ between the transfer curves and the straight line fit curves over a range from 0 dBm to -40 dBm. It also shows an error of less than 1% between the two calculated curves.

Fig. 6. Beam position measurements on the APS linac test stand.

Test Results With Beam

A prototype detector with associated electronics was installed in the APS linac test stand. The operation of the linac test stand is described in a paper by A.Nassiri⁴. The test injector was operated at a 3 Hz rate and electrons were accelerated to 56 MeV. Beam currents of 1.1 amperes were measured by a fast current transformer, Faraday cup, and the ancillary measurement of a BPM.

Absolute beam position measurements were not obtained due to a lack of diagnostics. The pulse outputs of the logarithmic amplifiers were peak-detected then read by a multiplexed 12-bit analog-to-digital converter located on a VME card. A computer subtracted the appropriate signals, multiplied the difference by a constant and displays the results. Fig. 6 shows the results of the data taken for 900 pulses. Each point represents the position of one 30-ns macro pulse. The grid scale is 1 mm square and the blob in the center represents a ± 0.25 mm vertical and a ± 0.25 mm horizontal variation in beam position. The line to the left represents samples when the modulator did not fire. It is unlikely the parameters of the accelerator were varying sufficiently to cause such beam variations. EMI/RFI radiation emanating from our unshielded modulator and playing havoc with our computer-controlled systems contributed to some of the beam position variations observed. For the data presented, no averaging was performed, and taking 8 averages before plotting a data point would reduce the jitter by half.

Conclusions

The results of the detector mapping agree closely with the calculation, and the detector performed satisfactorily in the beamline. Calibration of the electronics, especially the logarithmic amplifiers, suggests better beam position resolution than obtained. Time constraints prohibited confirming the detector and electronics calibration, using another position measuring device, and the cause of the observed beam position jitter. The pulse forming network (PFN) is now being shielded and that will reduce the amount of radiated energy. The linac is being assembled and further diagnostic testing will be continued.

Acknowledgements

Many thanks to Charles Gold and David Jefferson for assembling and installing the electronics and to Lester Erwin for assisting in the BPM field mapping. Our thanks to Eric Ko and Ned Arnold for writing the programs that displayed the beam positions.

* This work is 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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