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MONITORING THE BEAM POSITION IN THE SLC INTERACTION REGION*

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Abstract

The Stanford Linear Collider requires special Beam Position Monitors near the Interaction Point (IP) to bring the two beams (e^+ and e^-) into collision. These beams pass through two monitors on each side of the IP with a short time separation (about 20 and 50ns). The mechanics of the monitors as well as the electronics will be described. In order to bring beams of several microns diameter into collision at the IP, these monitors measure beam deflection induced by the presence of the opposite beam.

Introduction

The e^+ and e^- beams of the Stanford Linear Collider (SLC) must have very small transverse dimensions, a few microns, at the Interaction Point (IP) in order to achieve high luminosity. Such a small size increases the difficulty of steering the beams into collision. A promising method[1] uses two Beam Position Monitors (BPM) on each side of the IP to measure the deflection of either beam induced by the opposing beam at the crossing point. First, the undeflected beam position is measured in a BPM, located after the IP, with the opposing beam turned off. Then the deflected position is measured relative to the previous one by turning on the opposing beam.

In this method, we do not need absolute measurements, accurate to a micron, but rather require a pulse to pulse resolution of the order of 20μm. Furthermore, to measure the actual deflection accurately, the cross talk from the incoming beam should not induce more than 10μm error on position measurements of the outgoing beam. Considering the short time intervals between beams (about 20 and 50ns respectively for each pair of BPMs) and the possible disparity between the two beam currents ($5\ 10^9$ to $5\ 10^{10}$ particles), this is a tight tolerance on the monitor directivity and the electronics performance. Our choice went to long and directive-coupler-type electrodes. Opposing beams are read out from opposite ends of the monitor[2,3]. Beam signals from the downstream end of the BPM measure the relative deflection of the outgoing beam. The beam signals from the upstream end have a different purpose: they must measure the centering of the incoming beam in the quadrupoles to 100μm.

All electrodes are connected to their processing electronics with identical cable lengths (about 60m of RG214 coaxial cable), matched within 100ps. The electronic racks are always accessible for ease of maintenance.

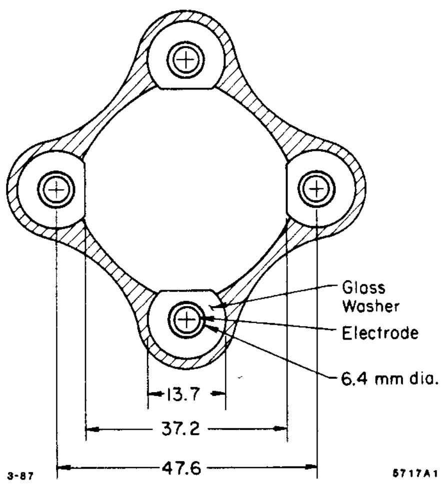

Figure 1 : Transverse cross section of the monitor. The electrode diameter is calculated for a 50Ω characteristic impedance[4]; each cable collects 2% of the beam charge; position sensitivity is 10 %/mm around the center.

Monitor Design

The Beam Position Monitors are designed[4] to mount in the bores of the final quadrupole triplets of the SLC on either side of the Interaction Point. Figure 1 shows the transverse cross section of the monitor. The external aluminum body extrusion has four hyperbolic surfaces which match the iron pole faces of the quadrupole magnet. In this way the monitor's straightness and alignment with the magnet are insured. Mounting monitors inside the magnets saves considerable space along the beam line and avoids separate support and alignment structures.

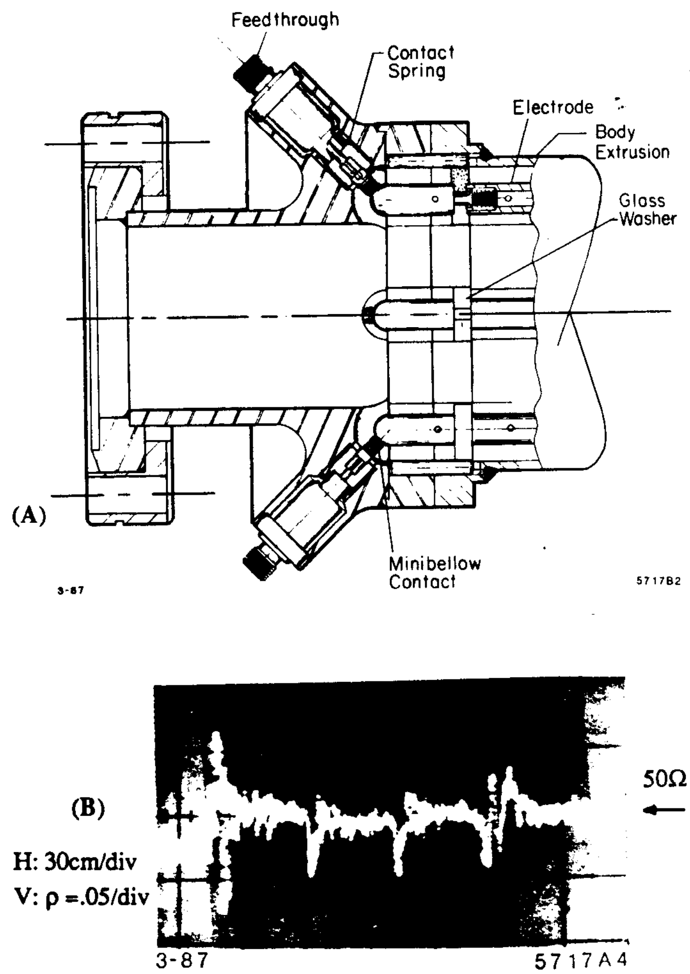

Figure 2 : (A) Cross Section of the monitor end: To keep a 50Ω impedance, the electrodes have a smaller diameter inside the support washers as a compensation for the dielectric constant of glass. The coaxial feedthroughs carefully match the electrode impedance.
(B) Reflectometer measurement of an electrode connected to a 50Ω reference load.

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The four pickup electrodes are round tubes rather than the usual flat plates. Each is supported in a semi circular corner cavity by four glass insulating washers and form a coaxial line slotted toward the center of the monitor. The high directivity necessary to eliminate the downstream signals call for a steady 50Ω characteristic impedance everywhere along the electrode. The mechanical design shown in figure 2 is an attempt to satisfy this requirement.

To correct for unequal electrode sensitivities, we measured the resulting offsets in a clean room. Because of their length and of the way their signals are processed, each monitor has two different offsets, one for each beam direction. The results are all within ±400μm with an accuracy of 25μm rms.

We believe that, overall, the monitors have less than 100μm of accumulated errors. This includes the precision of positionning of the body in the pole tips of the magnets, the possible electrode movements inside the monitor, and the offset calibration accuracy.

Electronics

The signal processing is derived from the Linac[5] and Arc[6] electronics, with two Track and Hold circuits (T&H), used as detection devices. There are two main concerns for the electronics; one is the noise which limits the resolution and the other is the low pass filter which should stretch the signal but not the crosstalk. The cross talk rejection should be better than 60dB (1/1000). The electronics can reduce the error due to an imperfect directivity of the monitor by using an integrator. Figure 3 illustrates the way this is done with a perfect integrator. Figure 4 shows a directivity test of a BPM with an integrator.

Figure 5 is a block diagram of the circuits.The signals from two opposite electrodes are processed together. A coupler picks up a small part of each input signal for producing a trigger which synchronizes the T&H detectors. A hybrid junction provides a sum and a difference signal which are fed to two channels.

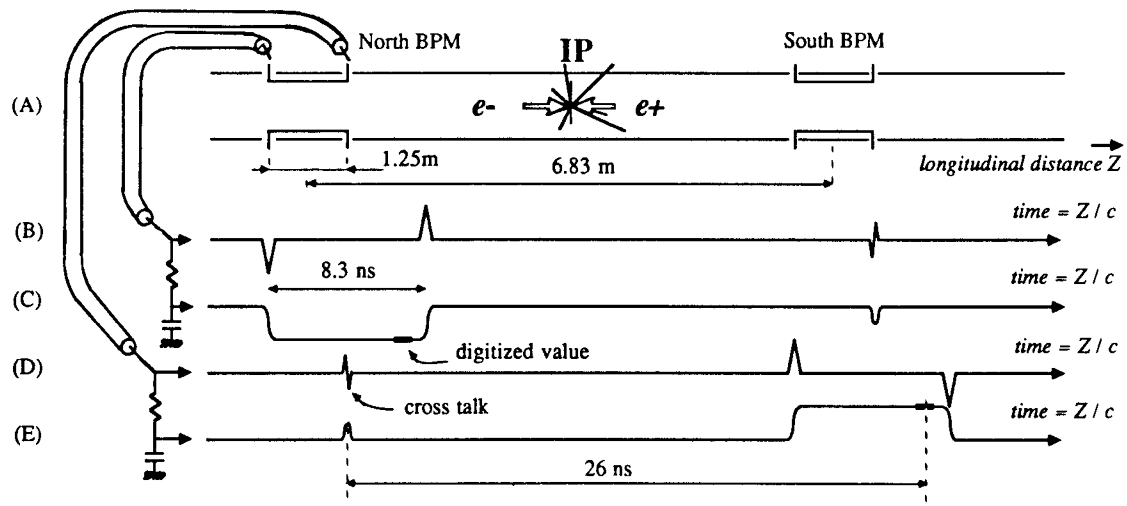
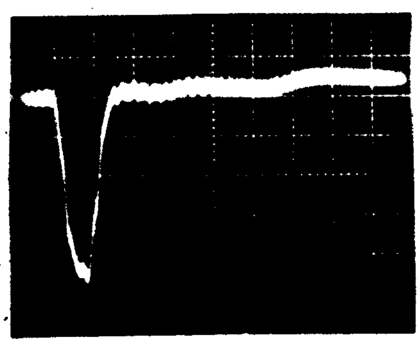


Figure 3: Signals on both ends of a monitor, before and after integration, assuming that the electrodes are perfectly matched to 50Ω along their entire length.
(A) Location of two monitors, one on each side of the IP.
(B) Signal on the upstream end for incoming electron beam.
(C) The same signal after integration; note the sampling time taking place slightly before the amplitude returns to zero.
(D) Cross talk and signal available at the downstream end of the same monitor. Assuming that the electrode is perfectly adapted, we still have a cross talk; it is due to the electrode supports which slow down the wave travelling along the electrode.
(E) The same signal after an ideal integration.

(A)

Hor.: 10ns/div.
Vert.: 0.1V/div.



(B)

Hor.: 10ns/div
Vert.: 0.1V/div.

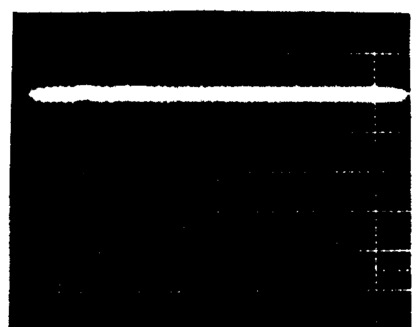


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Figure 4: Directivity of an electrode after integration. A short impulse (400ps), injected in a coaxial rod inside the monitor, simulates the beam. The rod and the monitor form a 50Ω transmission line matched at the end.
(A) Signal from the upstream end after integration and amplification.
(B) Signal from the downstream end processed the same way. Although the cross talk is not visible on the picture, it can be measured with a sampling detector. The ratio between the peak values is about 100, but improves over 1000 when the sampling time occurs more than 20ns later.

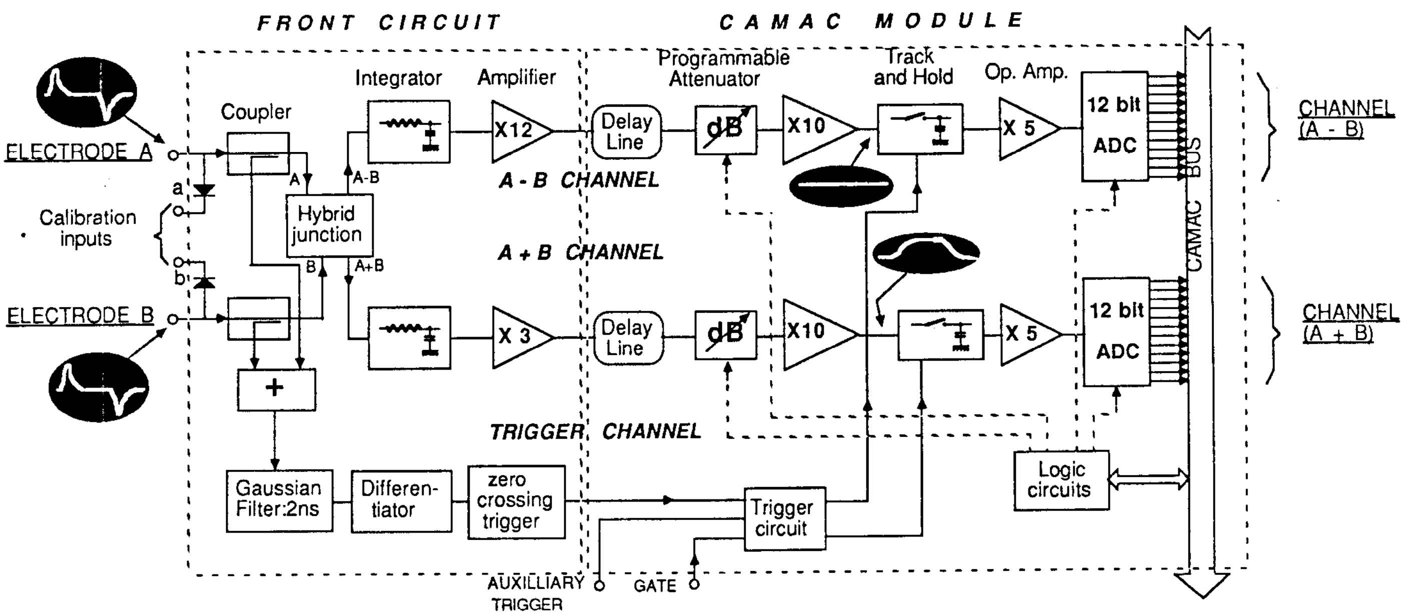

Figure 5: Block diagram of the processing electronics.

Forming Sum and Difference signals before filtering and amplification relaxes the tolerances on linearity and similarity of the two channels. These channels are identical except for their gains which are in a ratio (diff./sum) of 4/1.

The front end of each channel is comprised of a wide bandwidth integrator (from .8 to 300MHz) for stretching the signal. A couple of amplifiers and an 18dB attenuator, programmable in 6dB steps, adjust the signal amplitude to the T&H over the beam dynamic range. The circuits, from inputs to T&Hs, have a wide bandwidth (~ 0.5 to 250MHz). A delay line, inserted in each analog channel, compensates for a longer propagation time on the trigger circuits. To prevent the trigger from firing on the crosstalk, two inputs are added: a gate and an auxilliary trigger.

Like in the other BPM detectors of SLC, there are some on-line calibrations. Two inputs can accept calibration pulses over a range of amplitudes similar to actual beam signals. By injecting two equal pulses, we can compensate for the hybrid imperfections. A small part of the sum signal going to the difference channel appears as an offset. If we inject only one of the two previous pulses, we measure the gain ratio of the two channels. Furthermore, a CAMAC function allows us to read the combined offset of the T&H and of the ADC.

Conclusion

The monitors are installed and the electronics is being built. From the tests done with the prototype electronics modules, we hope for a resolution better than 10μm and a directivity which does not affect the measurements by more than 10μm when the two beams have the same intensity.

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