MONITORING OF THE STANFORD LINAC MICROBUNCHES' POSITION*

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Abstract

A new hardware has been developed to measure the trajectory of microbunches along the Stanford Linac. To be suitable for the operation of the SLAC Single Pass Collider, the bunches absolute position must be kept within ±100 microns of the accelerator center, and the acquisition of this measurement must be made along the machine in a snapshot fashion. Typically, the position of three bunches will be monitored during subsequent shots; we expect a minimum charge of 10^9 particles per bunch and a time spacing between bunches of 50 nanoseconds. The mechanics of the position detectors is described as well as the general system organization and the calibration of various components.

1. Summary

One of the most exacting requirements of the Linear Collider project[1] is that the beams trajectories be rigorously centered along the linear accelerator as well as along the two collider arcs. A beam position detector system has been developed and is in the process of installation along the first third of the accelerator. The pick-up stations are situated approximately every 10 meters, and are an integral part of the focusing system. The beam pulse processing is done in the gallery above the accelerator, three monitors being "read" simultaneously. To this effect the cables connecting the pick-up electrodes to the electronics have been arranged in groups of three lengths such that the beam signals of three consecutive stations be enabled by the same selection gate.

The goal of this measurement is to be able to track the beams along the whole machine within ±100 μm or better. Since the vacuum chamber radius is 10 mm one can expect a requirement for measuring with a precision of the order of 1 percent. Further, to relieve the tight tolerances on the fabrication of the monitors, these are evaluated in the laboratory and an adjustment of the electrodes position is made that brings the monitor electrical center within the desired specifications. Also, for the purpose of eliminating various effects that would lead to errors comparable or larger than our absolute position error, the connecting cables to the electronics have been matched for identical impulse response and the processing electronics includes a calibration mode of operation.

2. Monitor Construction and Geometry

A sketch of the monitor geometry is shown at the top of Fig. 1. The monitor tube is machined to precise dimensions so as to fit snugly into the quadrupoles' bore. The four electrodes are 50 Ω, stainless steel strips with a width of 4 mm, and a wall separation of 1 mm; they are short-circuited at the downstream end since this is mechanically convenient and has no direct effect on the upstream signal. It has been considered at one time to build the monitors with strip lengths of 10.7 cm (the RF wavelength at S-band) to eliminate possible coupling to the accelerating fields. No significant amount of power, however, was found with the present electrode lengths of 12 cm, so the general rule has been to make the strips as long as possible. Figure 1 indicates a reflectometer waveform such as the ones we have used for matching the four strip impedances. Once the impedances are matched within 1 or 2%, a second test is carried out which involves a measurement of the strip responses to a narrow pulse (typically 300-800 ps) propagating along a rod threading the monitors. The effect of the rod not being perfectly centered or showing a slight bow was removed by repeating the measurement, rotating the monitor in steps of 90° and averaging the results. The detection circuit for this measurement includes the same input filter as the processing electronics of the actual beam signal.

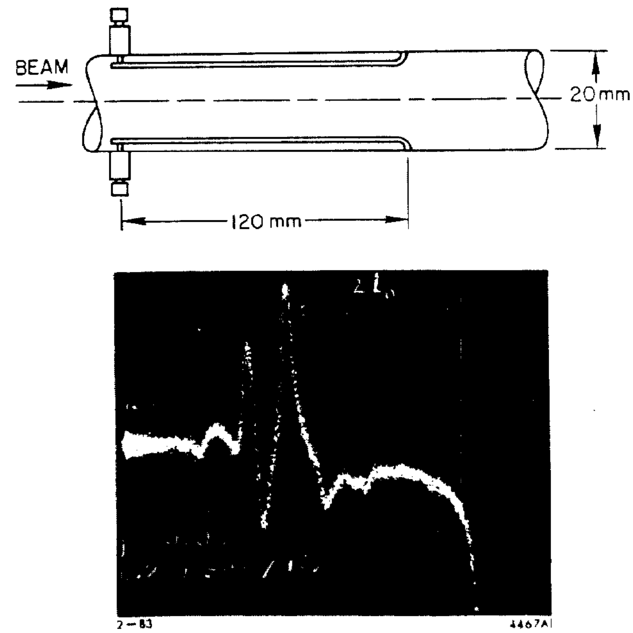

Fig. 1. Strip line position monitor and reflectometer output of one electrode.

3. Coaxial Cable Response to SLC Bunches; Filtering

Long, dispersive coaxial lines have very predictable impulse responses. In Ref. 2 it is shown that a very good approximation for the impulse response of a line, taking into account skin effect but neglecting dielectric losses, is given by:

$$h(t) = \sqrt{\beta/\pi}\; t^{-3/2}\; e^{-\beta/t} \qquad t \geq 0$$

β is determined from the total cable attenuation A (dB) and the frequency (Hz) at which A is quoted, through the relation:

$$\beta = \frac{1}{\pi F}\left[\frac{A}{2 \times 8.6}\right]^2$$

In Fig. 2, we plot $h(t) - h(t-2t_0)$ for a 30 meter line, the longest run we have used, where t_0 is the electrical length of the strips. In Fig. 3, we show the response of the same electrode and coaxial line to an SLC bunch of 4 nanoCoulombs and a σ of approximately 1 mm. If one assumes that one-tenth of the beam charge flows into the electrode circuit (25 Ω) one obtains an impulse area of 10×10^{-9} Volt × sec. Multiplying the

* Work supported by the Department of Energy, contract DE-AC03-76SF00515.
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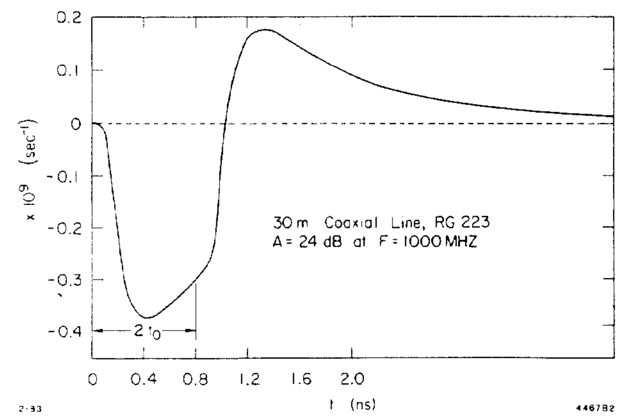

Fig. 2. Calculated response of a lossy cable to the output of a strip line, for very short bunches. The vertical scale yields "Volts" when multiplied by the proper impulse area.

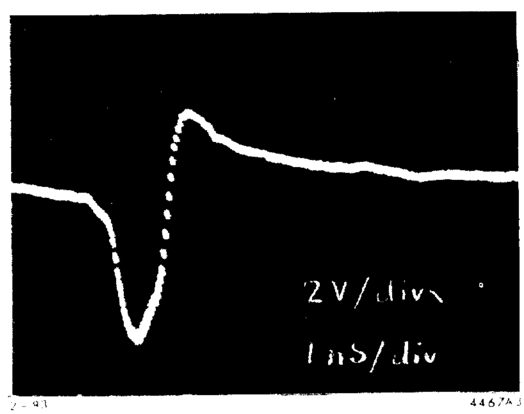

Fig. 3. Response of a monitor electrode and cable to a 2 mm bunch of 4 nanoCoulombs. Cable type: RG 223, length 30 m.

peak of the curve of Fig. 2 by this impulse one gets a peak output voltage of 3.7 V; we measured a little over 4 Volts, and we conclude that agreement is reasonably good. To insure that the response to one bunch will be sufficiently damped at the time of arrival of the second bunch, the filter selected is designed to have a Gaussian impulse response.[3] Other types of networks would achieve this function, particularly filters with maximally-flat delay. Approximating the filter response as $(a/\tau\sqrt{2\pi})\exp(-t^2/2\tau^2)$ with "a" the impulse area, the extrema of the filter response to the strip line output are found to be

$$\pm \frac{a}{\sqrt{2\pi e}} \frac{2t_o}{\tau^2}$$

a variation inversely proportional to the square of the stretching. Our design should allow reasonable measurements with beams of at least 10^9 particles or 0.16 nano-Coulomb. This yields pairs of impulses with an area of 0.4×10^{-9} Volt × sec at each electrode, and with $2t_o$ = 0.8 ns and τ = 7.5 ns we get for the minimum peak signal to be processed 1.4 mV.

4. Strip Lines or Small Capacitive Electrodes

We have wondered whether small electrodes could not accomplish the same function as strip lines and produce a signal of equivalent strength, in the pass-band of the filter. We compared the signal obtained from a strip line of electrical length t_o, with the output of a small electrode of identical cross section, and terminated with the same coaxial line such as to suffer a differentiation with time constant Δt.

We found that the low frequency spectra are described by $\sin n\omega t_o$ for the case of the strip lines, and $n\omega\Delta t$ for the small capacitive electrode. This simple result indicates that if the capacitive electrode has a dimension comparable to the bunch length, and if the strip line extends over many bunch lengths, the gain of one system compared to the other will be $t_o/\Delta t$. For millimeter bunches there appears to be an advantage in using strip lines instead of small electrodes.

5. Processing Electronics

The scheme elected for the measurement of the beam position (Fig. 4) consists in digitizing the peak of the filter output for each electrode, and to form the proper differences and normalization with the computer. The four amplifier chains must therefore be matched to 1%; they include a PIN diode, transformer-coupled attenuator which allows covering the dynamic range of 10^9 to 5×10^{10} particles per bunch and is also used to reverse the signal polarity when measuring the position of the e^+ bunch. A calibration pulse generator produces a 2 ns bipolar waveform which is injected in each channel for measuring its gain at various attenuation settings, and both polarities.

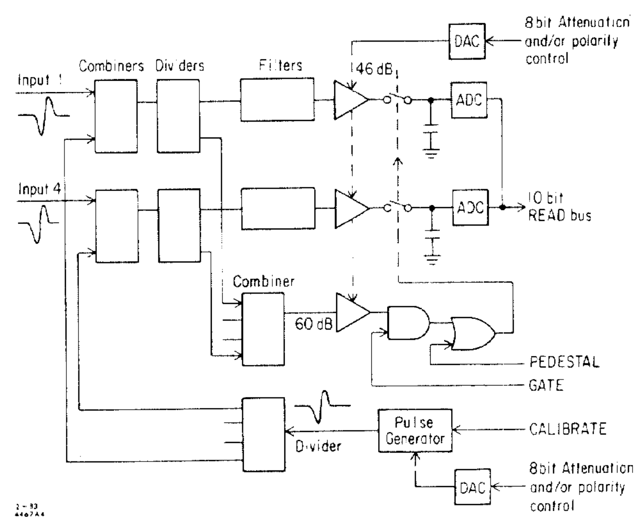

Fig. 4. Block diagram of the position monitor electronics.

The acquisition of the analog signal is done with a track-and-hold circuit (hot-carrier diode bridge) triggered with the fast sum signal. A typical slewing characteristic for this circuit is shown on Fig. 5. The track-and-hold waveform is shown on Fig. 6. The four channel digital conversions are completed in 25 µsec upon receiving the first beam gate following a CAMAC CLEAR or after READING of the fourth channel. In addition to the READ ADCs' or DACs' and WRITE function codes, other functions include the control of the trigger for a pedestal measurement, and the trigger of the calibration pulse generator.

6. Some Results

The processing electronics has been tested in the laboratory by applying four equal bi-polar pulses at the inputs and varying their amplitude to simulate beam intensities of 10^9 to 10^{10} particles. Each channel output was corrected by the subtraction of its pedestal offset and the calibration of its gain. The plots of Fig. 7

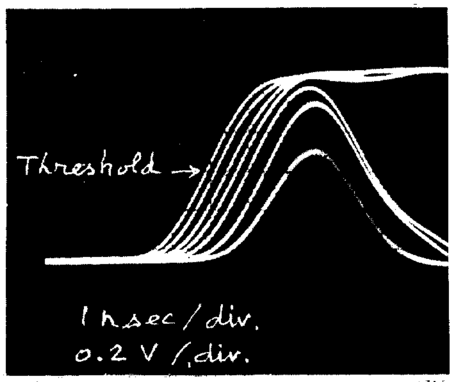

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Fig. 5. Multiple exposure of the beam derived trigger with the input attenuated by 1.0, 0.5, 0.2, 0.1, 0.05, 0.02, 0.01.

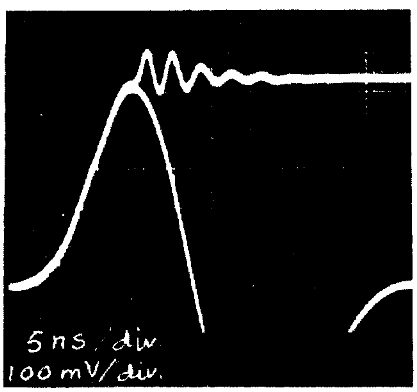

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Fig. 6. Track-and-hold output in the two modes, "Track" or "Hold".

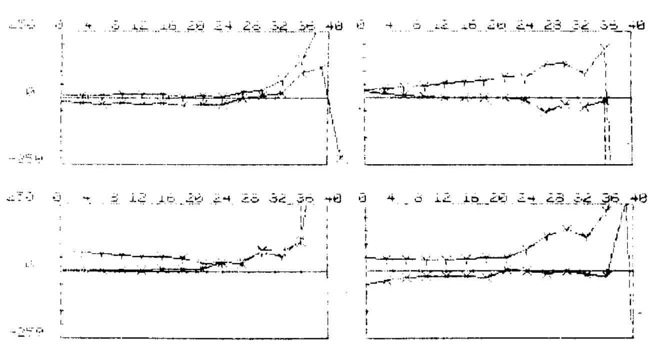

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Fig. 7. Laboratory test results of four pre-production modules. The horizontal scale is the beam intensity in dB below 10^{10} particles, the vertical scale is in microns.

show the equivalent electrical center variation for four such circuits; each point is the average of 100 test pulses, and the coordinates are referred to a monitor of 10 mm radius. The equivalent noise was measured to be 7 μm for bunches of 10^{10} particles; it increases in inverse proportion with the beam intensity because of the normalization process.

To date this electronics is operated temporarily with a minicomputer to track the SLC beam in the LINAC to Damping Ring transfer line. Figure 8 shows one of the initial snap shots of the beam position as well as the transmission loss along the transfer line.

NAME	X	Y	T	NAME	X	Y	T
53B	-0.3	4.3	1770	53A	-2.2	-2.3	1665
47	-5.3	0.8	1451	45	-1.3	2.6	1213
39	0.5	1.4	993	35	-1.5	-0.8	803
27	-3.2	-0.4	664	19	-4.4	1.5	516
17B	-0.5	-0.4	536	15	5.0	-1.8	442
13G	-1.8	-2.7	470	13F	-7.1	1.7	301
13D	3.0	1.5	346	13B	9.5	-4.0	225
13A	2.8	-3.3	379	3C	4.0	-0.2	193
3B	0.0	0.0	0	3A	0.0	0.0	0
1	0.0	0.0	0				

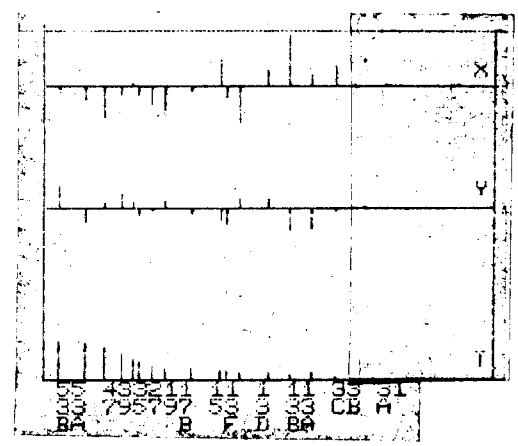

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Fig. 8. Beam position (mm) and transmission (arbitrary units) along the Linac to Damping Ring transfer line at turn on.

7. Conclusion

We would like to make several improvements on this circuit so as to be able to fabricate a large number of them and spend a minimum of time testing them. It appears that we could obtain a good electrical center zero with less difficulty if we used hybrid junctions; the advantage would be that the circuit nonlinearities would influence the measurement of the off-axis beams only. We plan also to improve the calibration procedure by using the beam pulse itself as a calibration pulse. The input filters, also, are difficult to match in pairs and costly to fabricate; a printed circuit version is being developed.

Among the many contributors to this project we would like to name a few, some for their constructive criticism, others for their stimulation and suggestions, and all of them for their dedicated effort: M. Breidenbach, J. Fox, R. Melen, R. Noriega, A. Nuttall, V. R. Smith, W. B. Smith, R. Stiening, the CID group. Thanks to all.

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