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 nano-
seconds. 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 detec-
tor 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 con-
necting 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 so that brings the moni-
tor 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 possi-
ble coupling to the accelerating fields. No significant
amount of power, however, was found with the present
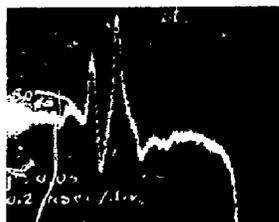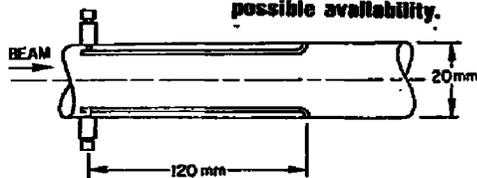electrode lengths of 12 cm, so the general rule has been

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

to make the strips as long as possible. Figure 1 indi-
cates 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) pro-
pagating 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 elec-
tronics of the actual beam signal.

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
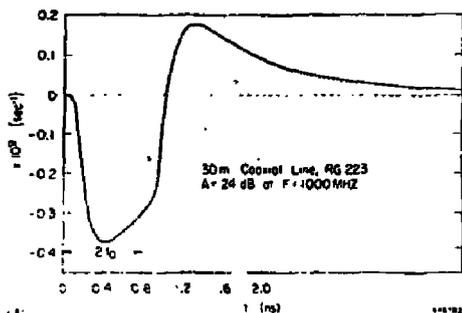impulse area of 10×10^{-9} Volt × sec. Multiplying the

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.
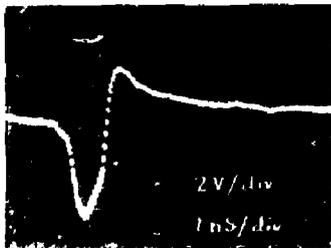

Fig. 3. Response of a monitor electrode and cable to a 2 mm bunch of 4 nanoCoulombs. Cable type: RG 223, length 30 m.

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. 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

$$\pm \frac{a}{\sqrt{2\pi e}} \frac{2t_0}{\tau^2}$$

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 $2t_0 = 0.8$ ns and $\tau = 7.5$ 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_0, 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 $\sin \omega t_0$ for the case of the strip lines; and $\omega \delta t$ 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 $t_0/\delta t$. 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.
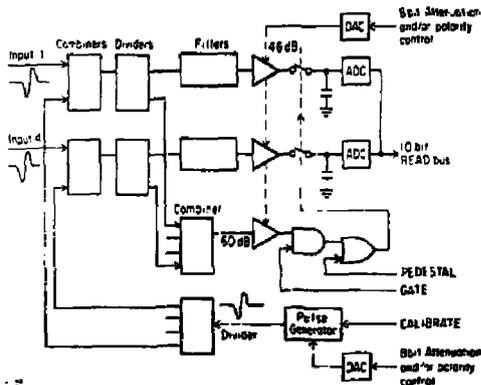

Fig. 4. Block diagram of the position monitor electronics.

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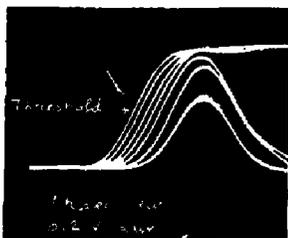
Fig. 5. Multiple exposure of the beam derived trigger with the input attenuated by 1.0, 0.5, 0.2, 0.1, 0.05, 0.02, 0.01.

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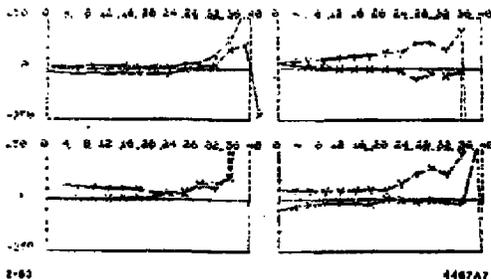

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Fig. 7. Laboratory test results of four pre-production modules. The horizontal scale is the beam intensity in dB below 10^{10} particles; the vertical scale is in microns.

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	I	NAME	X	Y	I
538	-0.3	4.3	1776	53H	-2.2	-2.3	1686
47	-5.3	0.2	1451	45	-1.3	2.6	1213
59	0.5	1.4	995	35	-1.5	-0.8	683
27	-5.2	-0.4	664	19	-4.4	1.5	516
178	-0.5	-0.4	536	15	5.0	-1.5	442
156	-1.6	-2.7	478	13F	-7.1	1.7	381
130	3.0	1.5	546	146	9.5	-4.0	225
149	2.0	-5.3	379	30	4.0	-6.2	153
36	6.6	6.0	0	34	0.0	0.0	9
1	0.0	0.0	0				

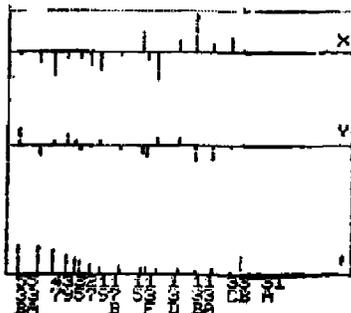2—83   4467A8

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:
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