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Length Monitor for 1 mm SLC Bunches*

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Abstract

A non-intercepting RF bunch length monitor for $\sigma_z = 0.5$ to 2.0 mm long electron and positron bunches in the Stanford Linear Collider (SLC) has been built with a design similar to a previous device for longer bunches[1]. For this device, fields from the beam pass through a ceramic gap, enter receiving cavities, are then measured with power detectors, and finally are recorded by the SLC control computer. The designs of the receiving cavities (25 and 36 GHz) are described as well as the choice of the RF power distribution and measuring systems. Beam measurements have been taken as a function of bunch compressor RF voltage, bunch intensity, and beam position. Long term bunch length measurements were recorded during SLC colliding beam operation indicating that the bunch length is constant to about 3%. Thus, 1 mm length monitors operating at 25 and 36 GHz have successfully monitored long term bunch length changes at the few percent level in the SLC.

Theory

We consider a highly relativistic electron (positron) bunch with a gaussian rms length nominally 1 mm traveling linearly along a vacuum chamber. The electric field lines of each charge in the bunch extend radially from the particle with a longitudinal angle of $1/\gamma$ where $\gamma = E / mc^2$. A integral over the longitudinal charge distribution gives the power spectrum of the bunch. For example, the power spectra for three representative bunch lengths and two shapes are shown in Fig 1. Using these plots frequencies of 20-40 GHz seem optimal.

Conversely, if the power spectrum is measured for a bunch then its length (distribution) can be deduced. In our system the bunch is made to pass by a ceramic gap in the vacuum chamber. The fields from the bunch radiate from the gap and enter a cavity through a small radial hole. The power in the cavity is then radiated out the entrance hole but also through a hole leading to a high frequency power meter after a length of rectangular waveguide. A schematic view of this arrangement is shown in Fig. 2. The frequencies of the cavity were chosen to optimally measure changes in the bunch length. For our case two cavities were made at frequencies of 25 and 36 GHz, allowing comparisons to be made.

In our situation the TM_{020} mode is used in the cavity and only one component is excited, namely H_ϕ. To obtain

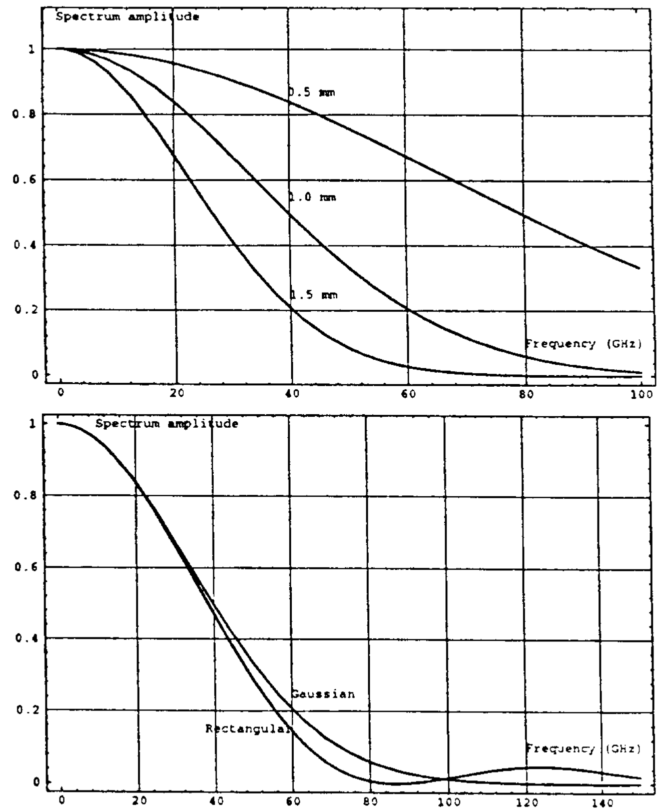

Figure 1 Theoretical beam power spectra for three different bunch lengths and two distributions.

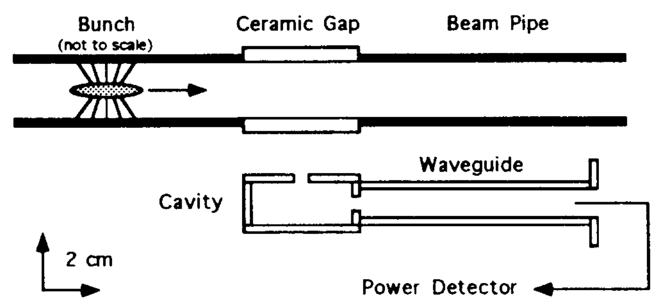

Figure 2 Layout of the bunch length monitor system.

the maximum power[2] one must consider the distance from the beam to cavity, the radius and depth of the coupling holes, the Q of the cavity, the ratio of the diameters of the input to output coupling holes (nearly equal is best), and the attenuation of the waveguide from the cavity to the power detector. The expected peak power P can be calculated[2]

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$$P_{peak} = d\, q^2 \exp(-\omega_0{}^2\sigma_t{}^2) \exp(-\alpha y) \qquad (1)$$

where ω_0 is the cavity frequency, σ_t is the bunch length in time, q is the bunch charge, α is the attenuation coefficient of the waveguide from the cavity to the detector at a distance y. The cavity design constants are included in d. The general parameters of the two cavities are listed in Table 1.

Table 1 Monitor Cavity Parameters for 3×10^{10} e^-.

Parameter	36 GHz	25 GHz
Cavity:		
Radius (cm)	0.73	1.05
Height (cm)	0.67	0.97
Distance to beam(cm)	3.8	5.0
Input hole diameter (cm)	0.3	0.45
Output hole diameter (cm)	0.35	0.4
Input Q Factor	490	750
Output Q Factor	700	1700
Pulse duration (ns)	1.2	3.2
Waveguide:		
Wide wall 'a' (cm)	0.71	1.07
Narrow wall 'b' (cm)	0.36	0.43
y length (m)	13.	13.
Attenuation constant	0.42	0.43
Detector peak power (mW)	12.7	3.3

SLC Hardware Configuration

Two cavities were built using the specifications in Table 1 and were brazed to short waveguide stubs. The finished units are shown in Fig. 3. Since the cavities are not used in vacuum the cover "side" plates are held in place by clamps. Both cavities were installed in the SLC in Sector 25 at the 2500 m location in the accelerator. At that location a ceramic gap had been installed with a 3 cm ID and 3.8 cm OD. The gap is about 1 cm long and is brazed to stainless steel tubes (2.5 cm diameter) on both ends. The cavities were installed one on each side of the gap. The distances from the beam to the cavities are listed Table 1. Here each bunch has an energy of about 42 GeV, has a transverse size of about 100 mm, and a repetition rate of 120 Hz.

The signals are transported out of the radiation enclosure through rectangular waveguides to respective Hewlett-Packard power detector diodes HP 8474E. A typical output signal is shown in Fig. 4. The signal levels are a few milli-watts, matching nicely the upper level capability of the detectors. The processed signals are then amplified, integrated by a gated ADC, and recorded in the SLC VAX control computer.

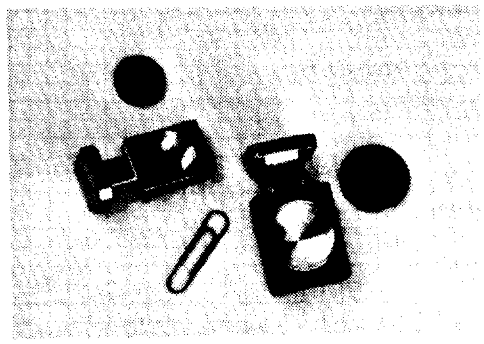

Figure 3 Photograph of the bunch length monitor cavities.

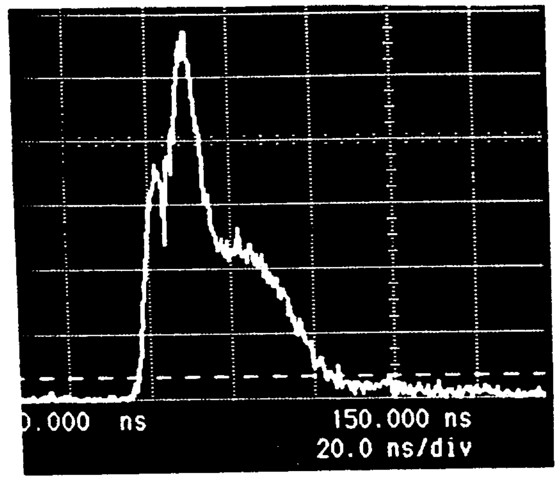

Figure 4 Measured signal from the 36 GHz monitor with $\sigma_z = 1.8$ mm and 3×10^{10} electrons. (Scale = 100 μW / div.)

Observations

The first test of the system was to measure signal sensitivities to transverse position changes of the beam as indicated by nearby position monitors. Only a very weak dependence was observed. The signals changed less than 2% when the beam moved by 1 mm. The beam positions are typically stable to 100 μm during long term operation.

The bunch length in the SLC is determined by the peak RF voltage of the compressor accelerator. The bunch length σ_z in the linac is given by[3]

$$\sigma_z{}^2 = \sigma_{dr}{}^2 [1 - 2\pi R_{56} f E_c / (E_{dr} \lambda)]^2 + R_{56}{}^2 (\sigma_E/E)^2 \qquad (2)$$

where $E_{dr} = 1.19$ GeV, $\sigma_{dr} = 6 - 10$ mm, $E_c = 0 - 40$ MV (typically 29 MV), $R_{56} = 603.$ mm, $\sigma_E/E = 1 \times 10^{-3}$, f is a calibration constant for the compressor RF voltage measurement, and $\lambda = 105$ mm. For the data below, f = 0.94. The minimum bunch length (about 0.5 mm) is obtained with $E_c = 36$ MV.

The length monitor signal was recorded as a function of compressor voltage (and bunch length). The resulting data are plotted in Fig. 5 for 3.3 x 10^{10} e^-. The solid line is the shape determined from Eqns. 1 and 2. The expectation matches the data. The nominal compressor voltage is 28.6 MV corresponding to a length of about 1.8 mm for 3 x 10^{10} e^-.

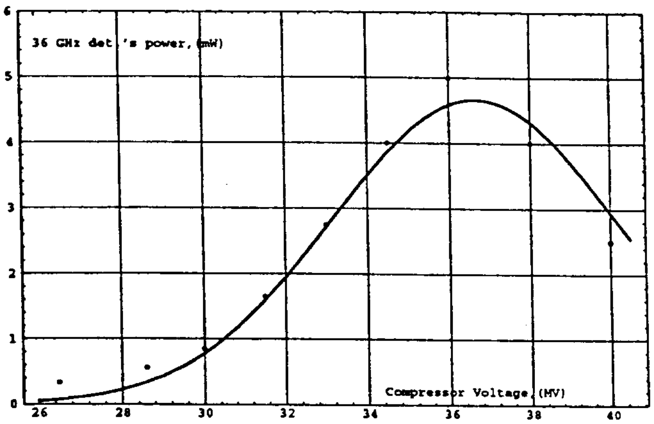

Figure 5 Signal (36 GHz) versus damping ring compressor voltage. The bunch length changes from 1.2 mm at 28.6 MV to 0.5 mm at 36 MV at low beam charge.

The length signal was measured as a function of bunch intensity as is shown in Fig. 6. From Eqn. 1 we expect a quadratic increase in signal with intensity, which is seen at low intensities. However, at high intensities the damping ring exhibits bunch lengthening[4] which reduces the signal rise. Thus, the solid line in Fig. 6 is a calculation of the expected signal versus intensity including the lengthening effects in the damping ring. The data and the calculation are in good agreement.

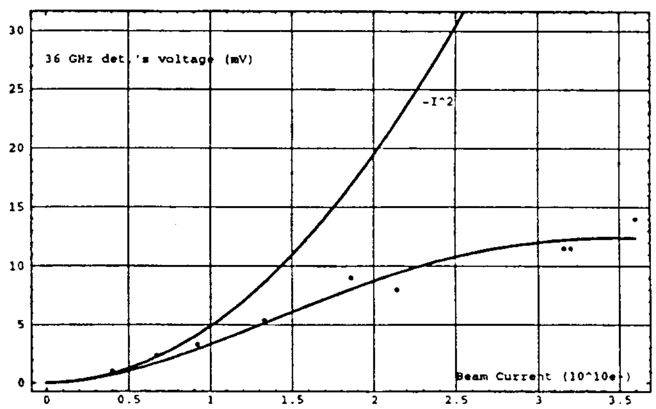

Figure 6 Signal (36 GHz) versus bunch charge. The solid line represents the power expected including bunch lengthening in the damping ring with current.

During colliding beam conditions the bunch length must be held constant. Any change in this length will affect the energy gain in the accelerator from beam loading changes and, thus, change the emittance growth along the accelerator. The VAX control computer has been setup to record the bunch length signals as a function of time. One eight day history plot is shown in Fig. 7. Here we see that the bunch length is quite stable in time showing only small changes of order 3%, mostly diurnal. Some of the diurnal changes are due to temperature effects in the amplifiers (under investigation) and some of the step changes may be due to compressor voltage changes.

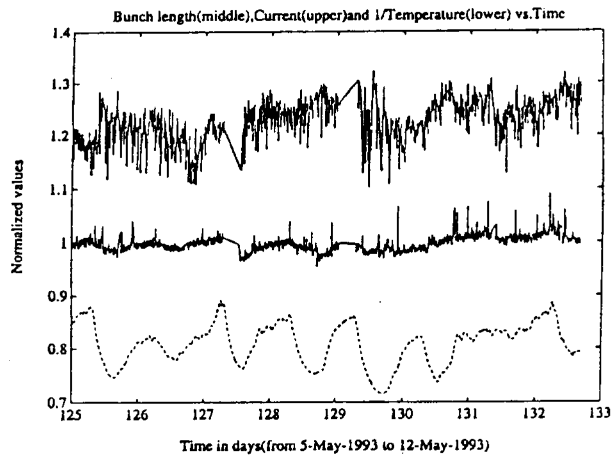

Figure 7 Long term signals for an SLC electron beam with 3 x 10^{10} particles and compressor amplitude of 28.5 MV. The center data are the fractional bunch length changes with time. Note only a few percent change over days. The lower plot shows the changes of temperature (1/T) with time on an arbitrary scale. Some temperature effects are seen in the length signal. The upper plot is the fractional change in the beam charge (x1.2 for clarity) versus time. The changes of bunch charge with time have been removed from the length data.

Acknowledgments

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References

1 A. Kulikov, *et al.*., "A Monitor of Single Bunch Lengths," SLAC internal note, April 1986 (unpublished).

2 E. Babenko, "Length Monitors for Single Bunches", SLAC internal note, March 1993 (unpublished).

3 L. Merminga, et al, "Bunch Length Measurement in the Linac," SLC Experimental Report 116, January 1990, (unpublished).

4 K. L. F. Bane, "Bunch Lengthening in the SLC Damping Rings," Stanford, SLAC-PUB-5177 (1990).