PICOSECOND BUNCH LENGTH AND ENERGY-Z CORRELATION MEASUREMENTS AT SLAC'S A-LINE AND END STATION A.*

S. Molloy†, P. Emma, J. Frisch, R. Iverson, M. Ross‡,
D. McCormick, M. Woods, SLAC, CA, USA
S. Walston, Lawrence Livermore National Laboratory, CA, USA.
V. Blackmore, Oxford University, Oxford, UK

Abstract

We report on measurements of picosecond bunch lengths and the energy-z correlation of the bunch with a high energy electron test beam to the A-line and End Station A (ESA) facilities at SLAC. The bunch length and the energy-z correlation of the bunch are measured at the end of the linac using a synchrotron light monitor diagnostic at a high dispersion point in the A-line and a transverse RF deflecting cavity at the end of the linac. Measurements of the bunch length in ESA were made using high frequency diodes (up to 100 GHz) and pyroelectric detectors at a ceramic gap in the beamline. Modelling of the beam's longitudinal phase space through the linac and A-line to ESA is done using the 2-dimensional tracking program LiTrack, and LiTrack simulation results are compared with data. High frequency diode and pyroelectric detectors are planned to be used as part of a bunch length feedback system for the LCLS FEL at SLAC. The LCLS also plans precise bunch length and energy-z correlation measurements using transverse RF deflecting cavities.

INTRODUCTION

Control of the bunch length is important for accelerator operation, especially in the case of modern free electron lasers (FELs) such as the Linac Coherent Light Source (LCLS) at SLAC. In some cases, such as initial beam tune-up, an absolute measurement of the length of the bunch is needed, while in other situations, for example in the case of a feedback system, a relative measurement is satisfactory.

This paper addresses two different techniques recently tested at SLAC's End Station A (ESA) [1] to quantify the length of the bunch in that region of the machine. One technique is based on various measurements of the intensity of the radiation in specific frequency bands emitted from ceramic gaps in the beam pipe. The second method is based on a measurement of the longitudinal phase space of the beam emerging from the linac, and using the R_{56} of the subsequent bend to determine the phase space distribution in ESA.

* Work supported by US Department of Energy Contract DE-AC02-76SF00515. This work was performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under contract W-7405-Eng-48.

† smolloy@slac.stanford.edu
‡ Permanent affiliation, Fermilab, Batavia, IL

BUNCH LENGTH IN ESA

As described in [1], bunches of $\sim 2 \times 10^{10}$ electrons are accelerated to 28.5 GeV by the SLAC linac, and directed around a 24.5° bend to bring the beam into ESA. Through control of the RF phase in the linac it is possible to tune the energy spread of the bunch, allowing for a range bunch lengths in ESA (~300 μm – 1 mm).

ABSOLUTE MEASUREMENT

The length of the bunch was measured by measuring the longitudinal phase-space at the end of the linac, and propagating this around the A-line bend using the known R_{56} value of 0.465 (see equation 1, where E is the design energy of the bunch, dE is the error in the energy of a particular particle, z_i is the longitidunal position of that particle, $i = 1$ indicates the bunch before the bend, and $i = 2$ indicates the bunch after the bend). Figure 1 shows the results from a LiTrack [2] simulation of the longitudinal profile at the end of the linac.

$$z_2 = z_1 + R_{56} \cdot \frac{dE}{E} \quad (1)$$

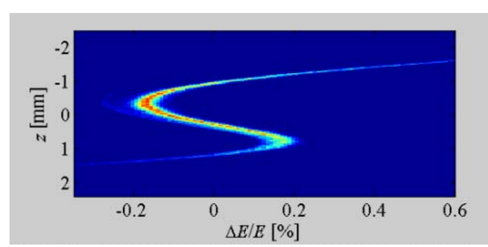

Figure 1: A simulation by LiTrack of the longitudinal phase space of the bunch at the end of the linac.

The synchrotron light generated by the passage of the bunch around the bend is captured with a CCD camera. Due to the non-zero dispersion of the bend, the width of the synchrotron stripe is proportional to the energy spread of the particles in the bunch. The synchrotron light monitor (SLM) is calibrated by varying the setpoint of the energy feedback and observing the horizontal position of the light spot.

The longitudinal profile was measured using a transverse deflecting cavity (LOLA) [3]. The transverse mode of a cavity is phased so that the centre of the bunch is at the zero crossing of the RF. This results in the particles within the bunch being given a transverse kick, whose amplitude is directly proportional (to first order) to the longitudinal position within the bunch. This is imaged on a screen in order to extract the bunch length.

For small changes of the LOLA phase, the vertical position of the image is directly proportional to the phase. As the frequency of the LOLA RF is known, a calibration of phase against vertical position on the screen gives a calibration of the position on the screen to the longitudinal position within the bunch.

The bunch's length, height, and tilt, contribute to the height of the digitised image. The bunch length is extracted by fitting a parabola to a plot of the height of the SLM image versus LOLA amplitude, as in figure 2. The offset from zero of the parabola is due to the transverse bunch size, and the plot's horizontal asymmetry indicates the presence of bunch tilt.

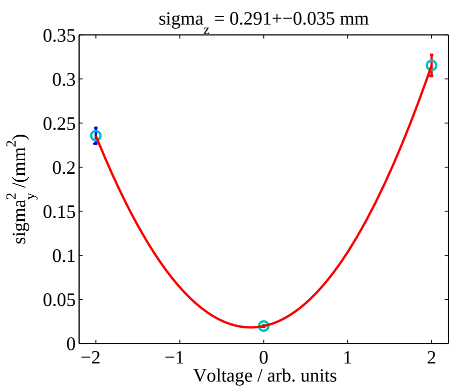

Figure 2: Parabolic fit of the standard deviation of the on-screen vertical projection to the LOLA amplitude (where negative amplitude implies a 180°change of phase).

By deflecting the bunch with LOLA at the end of the linac, the image formed on the SLM will be an expansion of the longitudinal phase space. Figure 3 shows the digitised image.

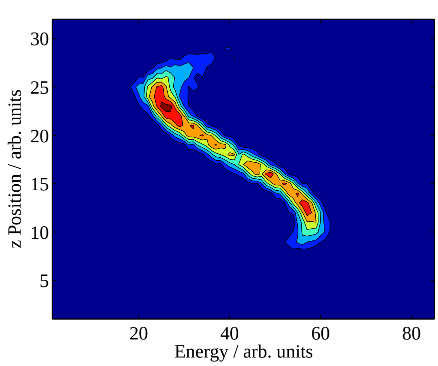

Figure 3: A digitisation of the SLM screen after being imported into Matlab.

The digitised image was converted into an array of several thousand points with the same distribution as in the image. The ESA distribution was predicted from this using equation 1. Measured bunch lengths at LOLA and ESA are shown in figure 4 for a range of linac phase settings, and a bunch charge of 1×10^{10} e$^-$/bunch. Figure 5 shows the longitudinal phase space before and after the A-line bend for a linac phase ramp of 26.5°.

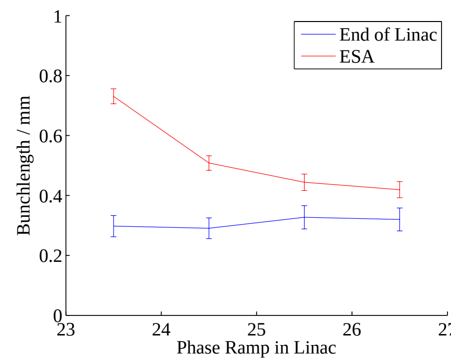

Figure 4: Bunch lengths measured at LOLA, and the predicted ESA bunch length for a range of linac phase settings.

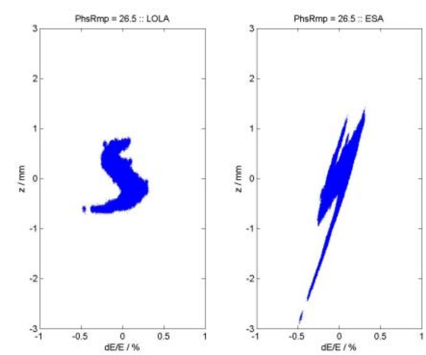

Figure 5: Longitudinal phase space of the bunch at LOLA and in ESA.

RELATIVE MEASUREMENTS

Direct bunch length measurements in ESA are made using the same principle as that employed in the SLC Final Focus [5]. The beam radiates energy as it passes the electrical discontinuity presented by a ceramic gap, and this is captured by a waveguide, and channelled to a diode for detection. Since the spectrum of the RF is dependent on the bunch length, the power in a frequency band is an indication of the bunch length. The frequency spectrum of a Gaussian charge distribution with rms length σ_z and total charge Q_b, moving at the speed of light, is,

$$I_b(\omega) = \frac{Q_b}{\sqrt{2\pi}} \cdot \exp\left(-\frac{\omega^2\sigma_z^2}{2c^2}\right) \tag{2}$$

For the ESA tests, the ceramic gap radiation was monitored at 16 GHz, 23 GHz, and 100 GHz using suitable filters and diodes (two 100 GHz diodes were used, therefore, four diodes were tested in total). The photograph in figure 6 shows two waveguides (WR90 and WR10) directed at a ceramic gap to couple the RF into the diodes. The ∼20 m long WR90 brought the signal to a lowpass filter (16 GHz for one channel, and 23 GHz for the other), and diode detectors (Agilent 8470B). The diode's output was amplified and measured by a charge sensitive diode. The signal path to the 100 GHz diodes (millitech DXP-10) used ∼1 m of WR10 waveguide instead of the WR90, and had no bandpass filter due to the strong high-pass nature of WR10 waveguide.

An additional bunch length measurement was made using a pyroelectric detector (Infratec LME-301) at an alternative ceramic gap. Due to its wideband response, the pyro is sensitive to higher frequencies than the diodes, and so will be capable of measuring shorter bunches.

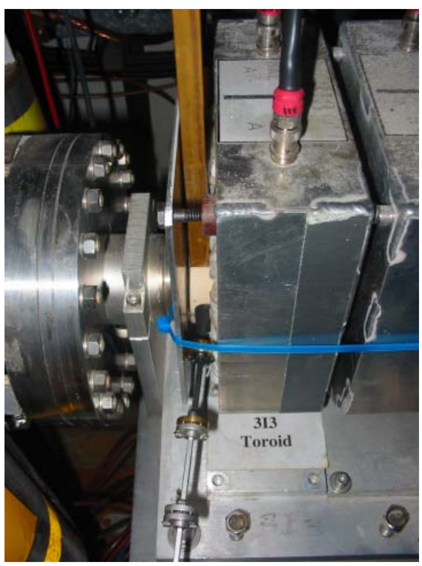

Figure 6: Photograph of the ceramic gap in ESA.

The bunch length monitor (BLM) signals were recorded for various linac phases. The response curves of the 16 GHz and 23 GHz diodes were flat, implying no dependence on the bunch lengths measured. The 100 GHz and pyro-detector signals have been plotted in figure 7 after normalisation by the square of the bunch charge, and it can be seen that they have a very clear response. The pyro-detector peaks at a higher linac phase due to its increased sensitivity range.

Figure 8 shows the 100 GHz diode's response during a phase ramp scan, alongside the bunch length data from figure 4. The sensitive range of the diode extends from a phase ramp of $\leq 23°$ to $\sim 26°$, which equates to a range of ≥ 800 μm to ~ 400 μm. This fits well with expectations based on the theory presented in [5].

CONCLUSIONS

The longitudinal phase space distribution of the beam was measured using LOLA and a SLM in a dispersive region of the beamline, and the optical model of the machine was used to predict the phase space distribution downstream of this point.

High frequency diodes and a pyro-detector were used in ESA to monitor the bunch length. The range of sensitivity of the diodes was calculated using the LOLA measurements, and matches well with theory.

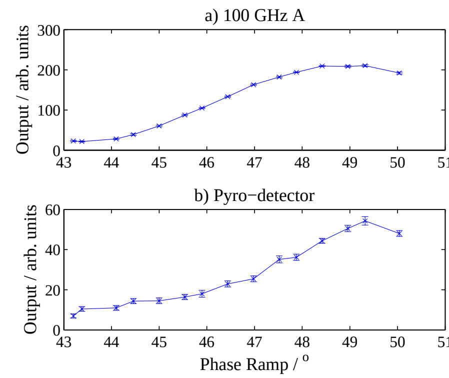

Figure 7: Normalised output of the 100 GHz diode and pyroelectric detectors at a range of phase ramp settings.

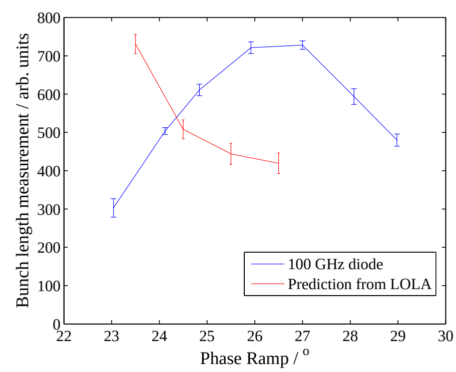

Figure 8: Normalised output of the 100 GHz diode during a phase ramp scan.

REFERENCES

[1] M. Woods, et al, "A Test Facility for the International Linear Collider at SLAC End Station A for Prototypes of Beam Delivery and IR Components", SLAC-PUB-11180

[2] P. Emma and K. Bane, "LiTrack: A Fast Longitudinal Phase Space Tracking Code with Graphical User Interface", SLACPUB-11035 (2005), contributed to PAC-05.

[3] O. H. Altenmueller, R. Larsen, and G. Loew, "Investigations of Traveling-Wave Seperators for the Stanford Two-Mile Linear Accelerator." The review of scientific instruments, Vol. 35(4), April 1964.

[4] The Mathworks Inc., MATLAB R2007a, 2007.

[5] M. Seidel et al, "Bunch-Length and Beam-Timing Monitors in the SLC Final Focus", 8th Workshop on Advanced Accelerator Concepts, Baltimore, MD, 1998

