PHYSICS RESULTS OF THE NSLS-II LINAC FRONT END TEST STAND*

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Abstract

The Linac Front End Test Stand (LFETS) was installed at the Source Development Laboratory (SDL) in the fall of 2011 in order to test the Linac Front End. The goal of these tests was to test the electron source against the specifications of the linac. In this report, we discuss the results of these measurements and the effect on linac performance.

INTRODUCTION

The Linac Front End Test Stand (LFETS) was installed at the Source Development Laboratory (SDL) in the fall of 2011 in order to test the Linac Front End (LFE). The LFE is part of the linac produced by Research Instruments for the NSLS-II. It consists of the electron gun, 500 MHz subharmonic buncher, and a suite of diagnostics. As the diagnostics included on the LFE are meant for use in the linac, further diagnostics were needed to do the desired measurements. Radiabeam Technologies produced the components for the diagnostics. This report discusses the LFETS and the measurements that were made. These measurements are compared to simulations and linac specifications.

LAYOUT

The LFETS consists of the LFE and the test stand. Figure 1 is an illustration of the test stand layout. The LFE starts with the 90 keV DC triode electron gun which can be driven in two modes, single bunch mode and multibunch mode. Single bunch mode produces a single bunch with an adjustable charge. Multibunch mode produces a train of bunches separated by 2 ns.

Following the gun is a Faraday Cup and beam flag mounted on a common actuator. Wall Current Monitor 1 is located downstream of the Faraday Cup. The bandwidths of the faraday cup and wall current monitor are high enough to measure single bunches.

The 500 MHz subharmonic buncher (SHB) was used for some studies with the beam, focusing on bunch compression and stretching. RF studies are contained in Reference 1.

After the SHB is the second flag. The flag is identical to the first except that there is no attached faraday cup.

The second wall current monitor follows the second flag. It is based on a design that is used at NSLS. [2]

A pepperpot is used for the emittance measurements. It was produced by Radiabeam Technologies Inc.

After the pepperpot is a dipole that bends the electron beam 15 degrees. A 40 cm drift brings the beam to the final set of screens. These screens are phosphor screens. One is aligned to image the beam with the dipole off, and one with the dipole on. Viewports behind the screens are used to out couple the light to cameras behind the screens. As the screens are thick enough to stop the electron beam, they are also used as a faraday cup. No attempt was made to impedance match this cup so it is not possible to resolve the individual bunches in a train.

Seven solenoids and three dual plane correctors are available for beam focussing and steering. All solenoid magnets were measured at their respective vendors.

A full description of the components is given in the final design review for the linac and the LFETS.[3,4]

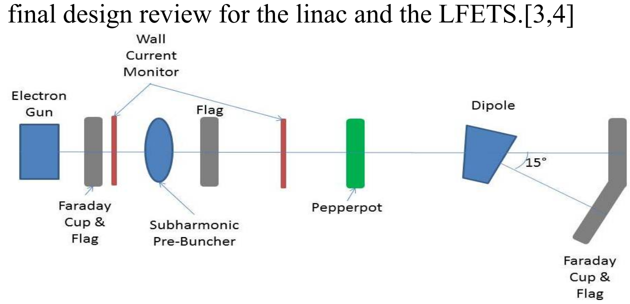

Figure 1: Layout of the Linac Front End Test Stand.

SIMULATIONS

Simulations of the LFETS were performed using PARMELA. The LFE part of the simulation comes from the vendor's simulation file of the linac.[3]

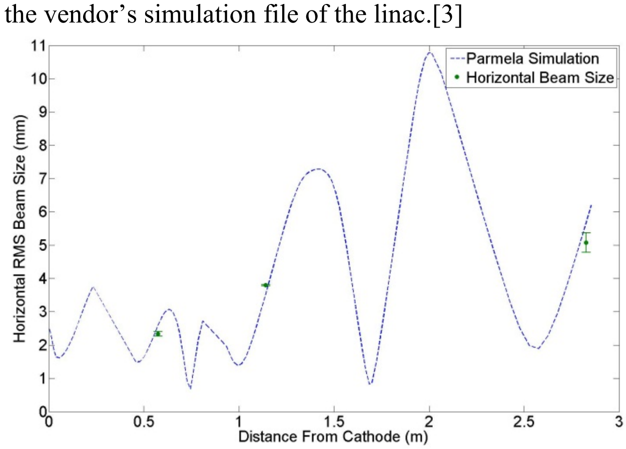

Figure 2: Comparison of the Horizontal Beam Size measurements and simulations with 100pC beam charge.

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For the simulations discussed in this paper, the bunch length is chosen to match the measured data. The initial transverse conditions at the cathode were chosen to be consistent with the cathode size and produce a 20 mm-mrad emittance, consistent with the data. Solenoids, dipole, buncher cavity and gun are all simulated "as run", that is, with parameters matching the beamline conditions.

We performed simulations using a variety of bunch charges to simulate the effects of space charge in the beam. All other parameters were kept constant.

Figure 2 shows a comparison of the simulated and measured horizontal beam size through the test stand 100 pC/bunch.

SINGLE BUNCH CHARGE AND LENGTH

In single bunch mode, we were able to measure 292±40 pC per bunch on the wall current monitor after the gun. Figure 3 shows a typical trace. The bunch length was 492 ± 85ps Full Width at Half Maximum (FWHM) which is within specifications. The small post pulse is due to a faulty transistor on the pulser board. This post pulse limited the charge we could produce while maintaining a good bunch structure and only affect single bunch mode.

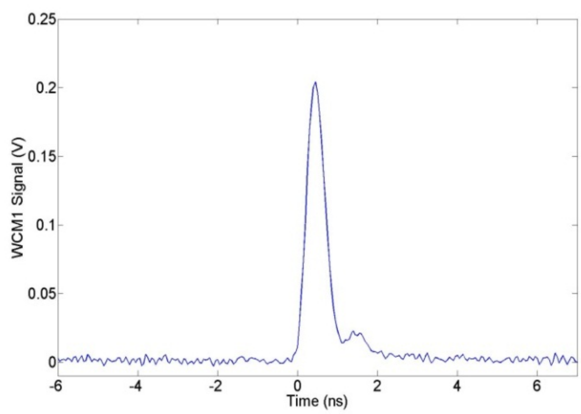

Figure 3: Typical WCM1 trace. The charge is 350 pC with 471 ps full width half maximum. The small post pulse is due to the pulser.

EMITTANCE

The transverse emittance was measured using the pepperpot. It consists of an aluminium screen with a square grid of holes. The holes are 250 µm diameter and are 2 mm apart. A 100 µm thick Ce:YAG screen is 2 cm behind the pepperpot to image the holes. The transverse normalized rms emittances for a 100 pC beam is 16±2 ×18±2 mm-mrad. The transverse emittance for a 300 pC beam is 25±5 × 29±8 mm-mrad. These numbers are averaged over all of the single bunch mode data. The linac specification corresponds to a normalized rms emittance of 15 mm-mrad.

BUNCHER OPERATION

The subharmonic buncher will be used in the linac to compress the nominally 1 ns long bunches into the 3 GHz RF buckets for acceleration. The buncher induces a velocity chirp on the bunch, slowing the head and accelerating the tail so that the bunch is fully compressed when it reaches the 3 GHz prebuncher cavity. The cavity provides a voltage of 49 kV for a gradient of 390 kV/m [1].

One of the goals of the LFETS was to measure the bunching of the beam. This was not possible because of the ringing in wall current monitor 2, located at the position of maximum compression. Measurements of stretching on the bunch were still possible.

The RF phase was scanned over 125 degrees around the phase where the bunch was the longest. The limits on the scan were due to the loss of charge. Figure 4 shows the full width half maximum of the bunch vs. the buncher phase with the simulation results. The simulations are routinely 300 ps longer than the measurements through most of the scan, but otherwise reproduce the shape of data very well.

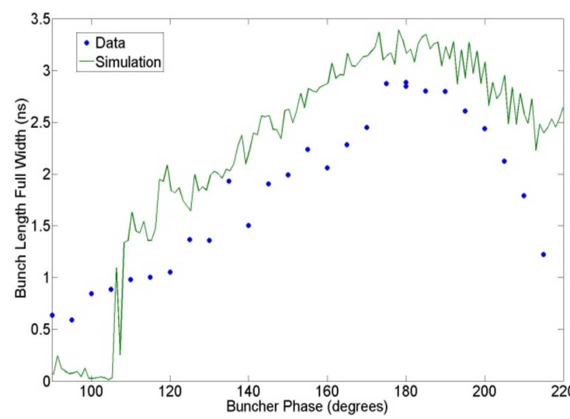

Figure 4: Bunch length full width vs. Buncher Phase.

The normalized horizontal emittance changed from 22 mm-mrad to 24 mm-mrad when the buncher was turned on. The vertical emittance increased from 24 mm-mrad to 36 mm-mrad when the buncher was on. The simulations predict the horizontal emittance increasing to 51mm-mrad and the vertical emittance increasing to 28 mm-mrad when the bunch is fully stretched. The reason for this discrepancy between the data and the simulation is not understood, especially since the system is symmetric around the beam axis. Nevertheless, it is clear that we can expect the buncher to increase the beam emittance due to the induced energy spread needed for compression.

MULTIBUNCH MODE

The linac specification calls for bunch trains of 80-150 bunches with 15 nC of charge. This corresponds to a bunch train length of 160-300 ns. We measured a 150 ns train with 17.5 nC. The average bunch length in this mode is 531±2 ps. FWHM. We measured a 300ns train with 19.0 nC. The average bunch length is 429±2 ps FWHM. The train uniformity is 25% peak to peak for both bunch trains. Figure 5 shows a typical 300 ns bunch train. This is sufficient for linac operation. Typical rise times for the pulses were 10 ns, or 5 bunches. If the pulse voltage is used to turn off the train, then turn off times are 10 ns. However, it is possible to turn off the RF pulse before the pulse voltage and achieve a very fast turn off of less than 4 ns but this is at the expense of the last or second to last bunch being of very high charge. This can be seen in Figure 5.

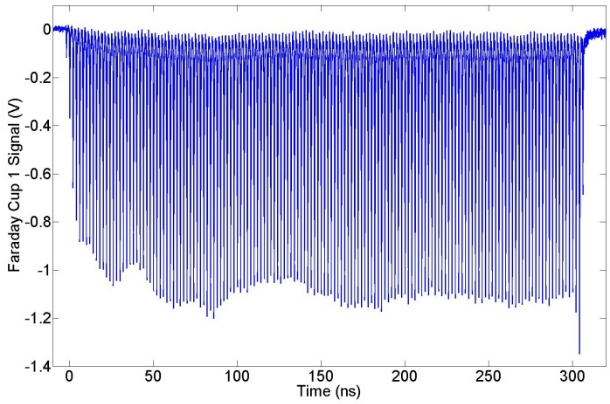

Figure 5: Faraday Cup 1 signal for a 300ns bunch train. Train charge is 19nC.

We measured the transverse emittance as a function of bunch train length for 100 pC/bunch and 200 pC/bunch trains. The measurments are shown in Figure 6. There is a clear trend of increasing emittance vs. bunch train length which is unexplained.

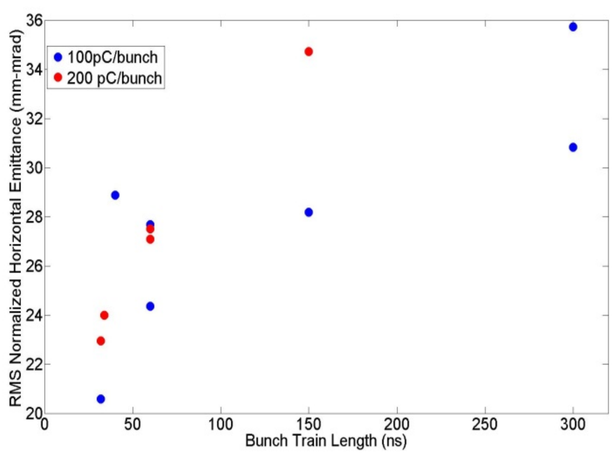

Figure 6: The horizontal emittance vs. bunch train length for two different bunch charges.

RESULTS SUMMARY

The results of the test stand can be summarized as follows:

- The charge was low compared to the specification in single bunch mode. This was traced to a bad part on the pulser board. There is no physics reason that a replacement board should not produce the necessary charge.
- The gun is capable of producing the appropriate bunch trains in multiple bunch mode. Though the bunch to bunch variation is larger than specification, it is on par with similar linacs.[5]
- The single bunch emittance at high charge is larger than specification or as expected from simulation. The measured multibunch emittance increases with train length. This is not understood.
- The bunch length from the gun is within specification in all bunch modes.
- It was not possible to measure the compressed bunch length because of a 2.4 GHz mode in the ceramic of Wall Current Monitor 2.
- It was possible to stretch the bunch. The stretched bunch length agreed well with simulations.

A full report of the results of the test stand are available in Reference 6.

CONCLUSION

The Linac Front End was tested in the fall of 2011 at the Source Development Laboratory.

In single bunch mode the bunch charge was low due to a bad component in the pulser board. The emittance was slightly high as compared to the linac specification. The bunch length was sufficient for bunching in the linac. Problems with a wall current monitor prevented measurements compression, however, measurements of bunch stretching showed reasonable agreement between simulations and data except for the predicted change in emittance. Multibunch mode was tested with the pulser board from PPT. The peak to peak variation is 25% in the flat part of the pulse. The emittance was measured for a variety of bunch train lengths and two different charges per bunch. It was found that the emittance increases with train length.

In December of 2011, the LFE was installed in the NSLS-II linac. The NSLS-II project would greatly benefit from continued use and development of the test stand. Further testing can answer some of the remaining open questions and provide a means to develop future generation of guns for the NSLS-II linac.

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