SLAC-PUB-10726

A TEST OF NLC-TYPE BEAM LOADING IN THE SLAC LINAC*

F.-J. Decker, T.O. Raubenheimer, A. Seryi, J.L. Turner, M. Woods, J. Yocky,
SLAC, Stanford, CA 94309, USA

Abstract

The linac at the Stanford Linear Accelerator (SLAC) runs routinely with a beam loading of around 12% for the fixed target experiment E-158. Typical energy spread and energy jitter are 0.1% and 0.05%. To explore the conditions for the Next Linear Collider (NLC) the linac was operated with 20% beam loading. This was attained by increasing the beam charge from $5{\cdot}10^{11}$ to $9{\cdot}10^{11}$ particles and increasing the pulse length from 250 ns to 320ns. Although the beam loading compensation was more difficult to achieve, a reliable operating point was found with a similar energy spread and energy jitter as at the lower loading. Furthermore, using the sub-harmonic buncher (SHB), the beam was bunched at 178.5 MHz instead of the nominal 2.8 GHz so that the charge from 16 adjacent buckets was combined into one. Increased transverse instability and beam losses along the linac were observed indicating the possible onset of beam break-up.

1 INTRODUCTION

The fixed target experiment E-158 has similar parameters (not including the emittance) to the NLC (Tab.1). The main differences are total charge and the bunch spacing. Two different experiments were done at the end of E-158 Run II in the fall of 2002.

Parameter	E-158	NLC-500
Charge/Train	6 x 10^{11}	14.4 x 10^{11}
Repetition Rate	120 Hz	120 Hz
Energy	45 GeV	250 GeV
e^- Polarization	~80%	80%
Train Length	270ns	267ns
Microbunch spacing	0.3ns	1.4ns
Beam Loading	13%	22%
Energy Spread	0.15%	0.16%
Intensity Jitter	0.5% rms	0.5% rms
Energy Jitter	0.03% rms	0.3% rms
Transverse Jitter	5% of spotsize (x or y)	22% of x spotsize, 50% of y spotsize

Table 1: Comparison of E-158 and NLC parameter.

First the charge and pulse length was raised at a lower energy to accommodate the additional beam loading. Then the sub-harmonic buncher was switched on which puts the charge in every 16^{th} S-band bucket resulting in a bunch spacing of 5.6 ns. These two setups had quite some different difficulties, the first one getting the beam through the injector chicane (160 MeV point), the second one had signs of beam losses in the linac (beam break up).

2 INJECTOR

2.1 Phase Loading

The beam loading in the injector region is especially tricky, since the beam is not at the crest of the RF curve and therefore creates in general amplitude and phase variations along the beam. The phase loading is strongest in the capture region where the velocity is still far below the speed of light. A pulsed phase shifter, which quickly reverts the phase by 180° is installed at the klystron, which feeds the first acceleration section. A problem arises from the fact that it also feeds via a high power splitter a 4-cell S-band buncher just in front of this section. So any necessary adjustments cannot be optimized independently. Another problem is also the fixed 180° phase flip. Here a slower change of the order of the pulse length and with a variable amount in phase would help the high charge setup.

At the chicane a beam energy spread along the pulse would create different phases along the main linac. A 4° variation is normally already observed in E-158 with $6{\cdot}10^{11}$ particles. Higher currents make this more difficult to compensate. This compensation can have different setups, first with energy and phase all the same, or phase and energy in such a way that together with the following linac the end energy variation is compensated. A special scenario exists when a charge-induced phase offset can reduce the energy jitter at the end [1].

2.2 Diagnostics

Behind the capture section is a toroid and a gap monitor. Figure 2 shows the toroid signal with and without the sub-harmonic buncher (SHB). The sloped down distribution in necessary to achieve the best beam loading compensation and a small energy spread. The individual bunches which are 5.6 ns apart can be better resolved by a gap monitor, where the RF coming out of a ceramic gap is measured by a crystal detector. This devise is also sensitive to the bunch length (Fig. 3).

3 LINAC

3.1 Beam Break-Up

The long pulse current of about 450 mA ($9{\cdot}10^{11}$ particles or nearly 150 nC in 320 ns) is much higher than was achieved many decades ago in the SLAC linac.

Work supported by the Department of Energy contract DE-AC02-76SF00515.
Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309
To appear in the Proceedings of Particle Accelerator Conference (PAC 03), Portland, OR, 12-16 May 2003.

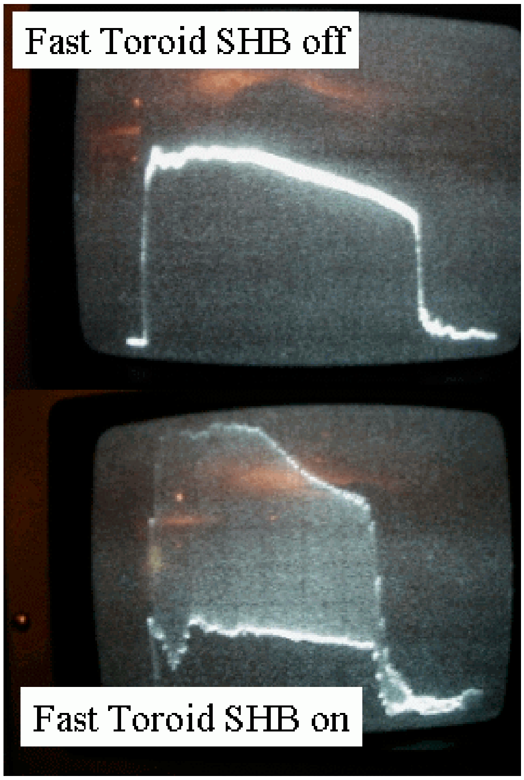

Figure 1: The current signal of a fast toroid shows the sloped distribution (50 ns/div). Individual bunches have more charge and can nearly be resolved with the SHB on.

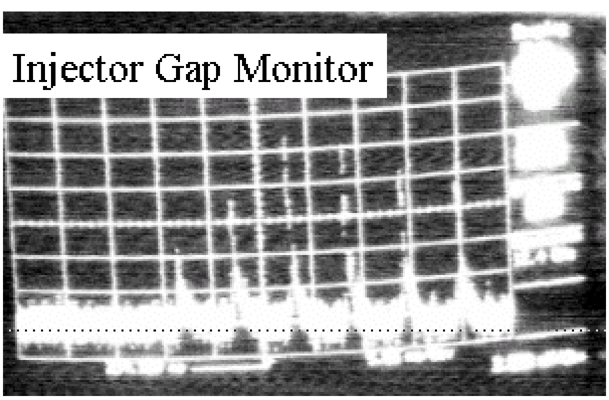

Figure 2: Gap monitor showing the beginning of the bunch train (5 ns/div).

$$I_{breakup}(mA) \propto \frac{\varphi \varepsilon}{z \tau}$$

- φ focusing strength of quad lattice
- ε energy gradient
- z length of Linac
- τ pulse length

The reasons are the higher RF gradient due to SLED, a stronger quadrupole focusing introduced for the SLC, the shorter beam pulse (<500 ns instead of 1.5 μs), and the early dimpling of cell 3, 4, and 5 in some accelerator sections, which changed the 4140 MHz transverse deflecting mode.

No beam break-up [2,3,4] was observed when the sub-harmonic buncher was turned off and each consecutive bucket was filled. As soon as the SHB was turned on the injector had actually less problems, but there was beam loss observed in the linac when the pulse was lengthened above 90 ns. Figure 3 shows the beam spot of a synchrotron light monitor (SLM) in the following A-Line at a high dispersion in *x*. The top shows a long pulse (320 ns) were the energy spread is not totally compensated, while the bottom shows a shorter pulse (and therefore less energy variation) with a blow-up in *y*. This is an indication of beam break-up, which should be first visible in *y*, since the RF couplers are in *x* and therefore the *x* transverse mode can better decay.

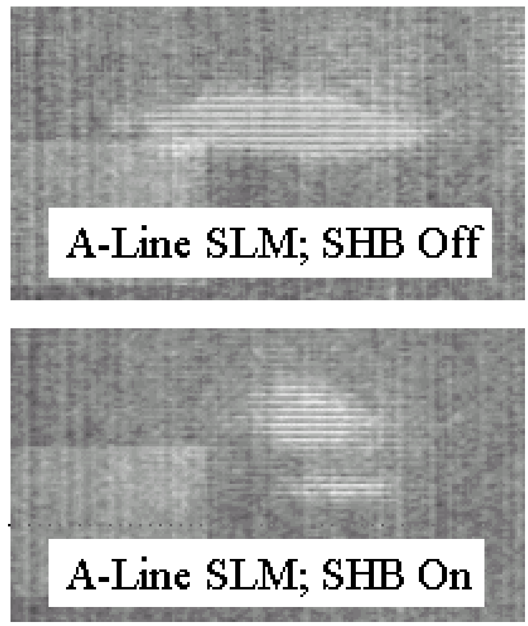

Figure 3: Beam spot on Synchrotron Light Monitor.

3.2 BPM at End of Linac

A quick check to look at the raw BPM signal is shown in Fig. 4. The signal didn't show any instability, but it was in *x* and the pulse was reduced just to 80 ns to minimize losses in the linac.

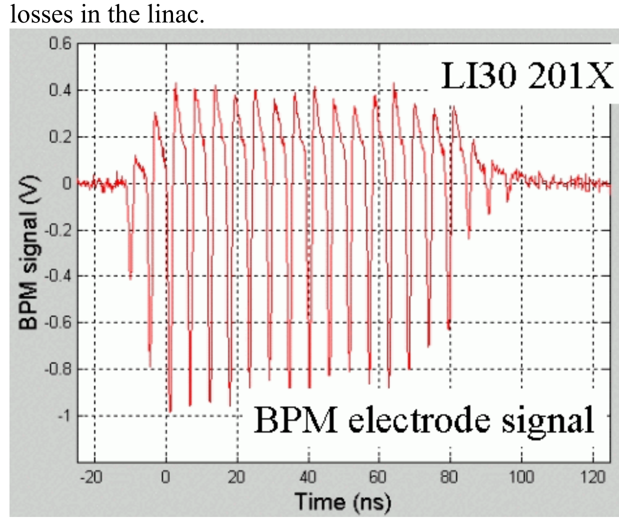

Figure 4: BPM raw signal at the end of linac.

4 A-LINE

4.1 Gated Camera

The A-Line bents the beam to the fixed target experiment E-158 in Endstation A. The bending creates synchrotron radiation, which is monitored by a gated camera. The gate was fully open for Fig. 3, but can be reduced down to 60 ns, so the energy and energy spread along the pulse can be measured (Fig. 5). This measurement is normally used to fine-tune the charge distribution so that there is no energy variation along the pulse. This was not done in this case leaving about a 100 MeV slope. The energy spread also shows some increased values near the tail end of the pulse. This can be the case if the tail shifts in phase and therefore is further off the crest of the RF.

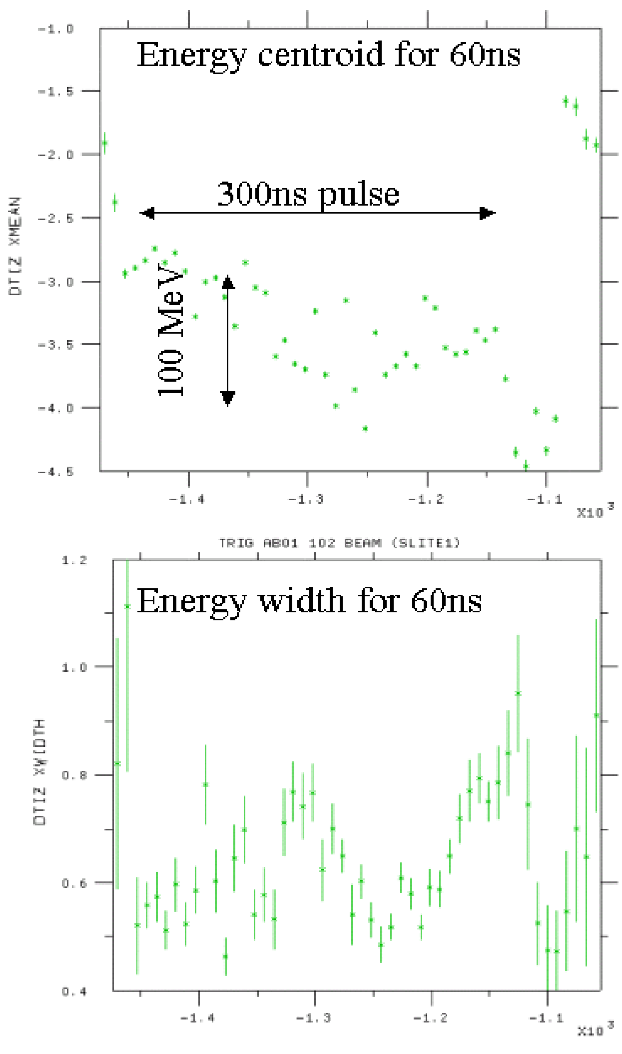

Figure 5: Energy and energy spread along the beam pulse.

4.2 Toroids

The toroids in the injector and linac were all saturating and only A-Line toroids were measuring the transported charge up to $9 \cdot 10^{11}$ particles per pulse. So it was difficult to check or quantify any possible beam loss. On the other hand any substantial loss in the main linac would have triggered the Machine Protection System, which would have caused the beam to rate limit or trip off.

4.3 Beam Loading and Jitter

The beam energy of the A-line was lower to 40 GeV to accommodate a beam loading up to 25% or $1.4 \cdot 10^{12}$ particles in a 450 ns pulse [5]. About 20% loading with $9 \cdot 10^{11}$ particles in 320 ns was achieved. With the bigger loading the energy jitter of the tail of the pulse also increase since the intensity jitter was about constant. Figure 6 shows the beam tail moving up to ±10 mm at the highest dispersion point of η_x = 5 m for charge variation between 7.6 and $7.7 \cdot 10^{11}$ particles per pulse.

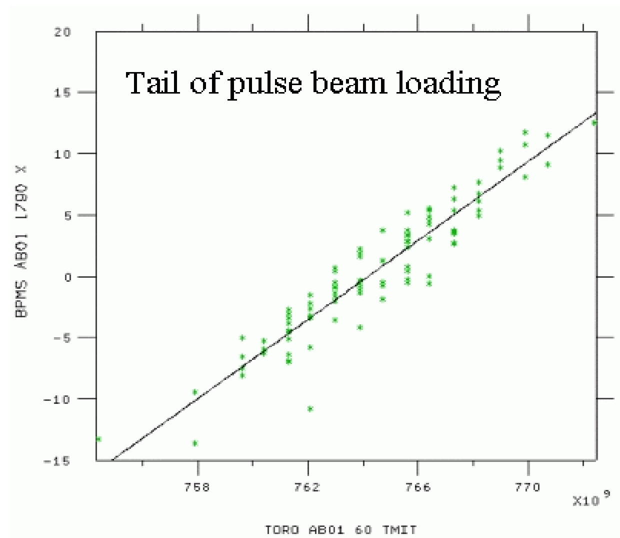

Figure 6: Beam loading measured for the tail of the pulse.

5 SUMMARY

Although this test was done with not much time in the last shift of the E-158 experiment before Thanksgiving of 2002, it accomplished quite some results. A peak charge of $9 \cdot 10^{11}$ particles in 320 ns at 40 GeV in a stable condition, with problems near the 160 MeV chicane. And beam break-up effects in the linac for pulse length over 90 ns. Analytical and simulation efforts were not done yet to check whether these results are within the expectations.

6 REFERENCES

[1] F.-J. Decker et al., “High Power Beams at SLAC”, PAC01, Chicago, June 2001.
[2] R. Neal et al, “The Stanford Two-Mile Accelerator,” W.A. Benjamin, Inc., NewYork, 1968, p. 203-237.
[3] G. Loew et al., SLAC-PUB-0659.
[4] R. Helm, G. Loew, SLAC-PUB-083.4
[5] F.-J. Decker, Z.D. Farkas, J. Turner, “High Current, Long Beam Pulse with SLED, SLAC-PUB-8113, Apr 1999, or PAC 99, New York, Mar 1999, p 774-776.