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Low Current, Long Beam Pulse with SLED [*]

F.-J. Decker, Z. D. Farkas, M.G. Minty

Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309, USA

Abstract

The 3 km long linac at the Stanford Linear Accelerator Center (SLAC) is used for fixed target experiments such as E-155, with energies up to 50 GeV. The SLAC Energy Development (SLED) system increase the maximum no-load energy by a factor of 1.6, but it also causes a varying beam energy curve. To provide a long pulse or bunch train for the experiment the energy profile has to be flat. Besides more sophisticated methods such as varying the phase of two klystrons feeding one structure section as proposed in the NLC design, we describe the method used for E-155 in spring of 1997. The desired low charged beam didn't have any significant beam loading, but by inserting a 180° phase notch during the SLED pulse, a beam pulse of up to 500 ns was achieved. The energy range without compensation would have been 15%, while with compensation the energy spread was reduced to about 0.15%. The phase notch was achieved by triggering a pair of two additional 180° phase switches about half a structure fill-time after the SLED pulse was triggered. Simulations are compared with the experimental result.

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The 3 km long linac at the Stanford Linear Accelerator Center (SLAC) is used for fixed target experiments such as E-155, with energies up to 50 GeV. The SLAC Energy Development (SLED) system increase the maximum no-load energy by a factor of 1.6, but it also causes a varying beam energy curve. To provide a long pulse or bunch train for the experiment the energy profile has to be flat. Besides more sophisticated methods such as varying the phase of two klystrons feeding one structure section as proposed in the NLC design, we describe the method used for E-155 in spring of 1997. The desired low charged beam didn't have any significant beam loading, but by inserting a 180° phase notch during the SLED pulse, a beam pulse of up to 500 ns was achieved. The energy range without compensation would have been 15%, while with compensation the energy spread was reduced to about 0.15%. The phase notch was achieved by triggering a pair of two additional 180° phase switches about half a structure fill-time after the SLED pulse was triggered. Simulations are compared with the experimental result.

1 INTRODUCTION

In a complementary paper [1] the current was varied to achieve a low energy spread. In this paper we treat currents that are so low that their self induced beam voltage is negligible, say, less than 0.1 % of the no-load voltage.

For a 460 ns pulse, the beam impedance of the SLAC linac is 30.5 GΩ hence a current of 1 mA, corresponding to a charge of $2.9 \cdot 10^9$ particles, has a self-induced voltage of only 0.1% of 32 GV, the operating voltage of E-155x experiment. The charge required by E-155x is somewhat less than $2.9 \cdot 10^9$. The SLAC linac has nearly the required energy without SLED, but with SLED the operating beam energy is attained with fewer klystrons.

Thus, we have to manipulate the SLED output (the rf input to the accelerator sections), to achieve a nearly constant no-load voltage for up to 500 ns. We can do this by varying the SLED output amplitude, but this is difficult. We achieve the same effect by inserting a 180° phase notch during the SLED pulse in a fraction of sectors. The number of sectors notched, n_{sn} out of the total number of sectors with rf, n_{st} determines the effective depth of the notch, hence the slope of the no-load beam voltage.

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Thus, at a given beam voltage and beam current pulse width, we can reduce the current amplitude from a maximum to zero.

2 SIMULATIONS

When after the normal SLED 180° phase switch, another pair of these switches is generated, a notch will appear in the SLED rf output. Figure 1 shows the relative SLED output with and without this notch. The notch begins 280 ns after the phase flip at the beginning of the SLED pulse and lasts for 400 ns. With this notch the energy is not wasted, but stored again in the SLED cavity, so the output is higher at the end.

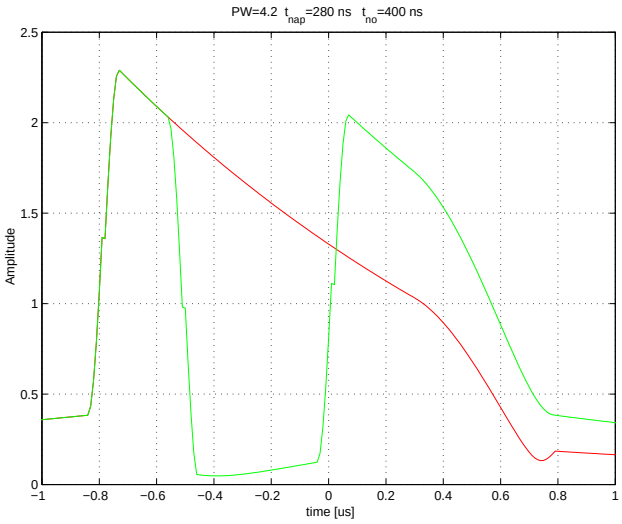

Fig. 1: Relative rf amplitude after the SLED cavity. The relative SLED output with and without a notch is shown as a function of time. With the notch the energy is not wasted but stored again in the SLED cavity, therefore the notched pulse is higher at the end.

Figure 2 shows the relative SLED gain, which is the rf output integrated over the accelerator structure. When the output has a notch, the relative SLED gain (which is also the relative beam voltage) falls sharply and can be used to compensate the rising slope of the SLED gain curve without notch. With 6 out of 16 sectors notched the gain is nearly flat. Fig. 3 shows the beam voltage and energy spread for the mixed sectors. The maximum beam voltage with n_{st} = 16 is 38.5 GV. The charge is $1.6 \cdot 10^9$ and the current is only 0.56 mA.

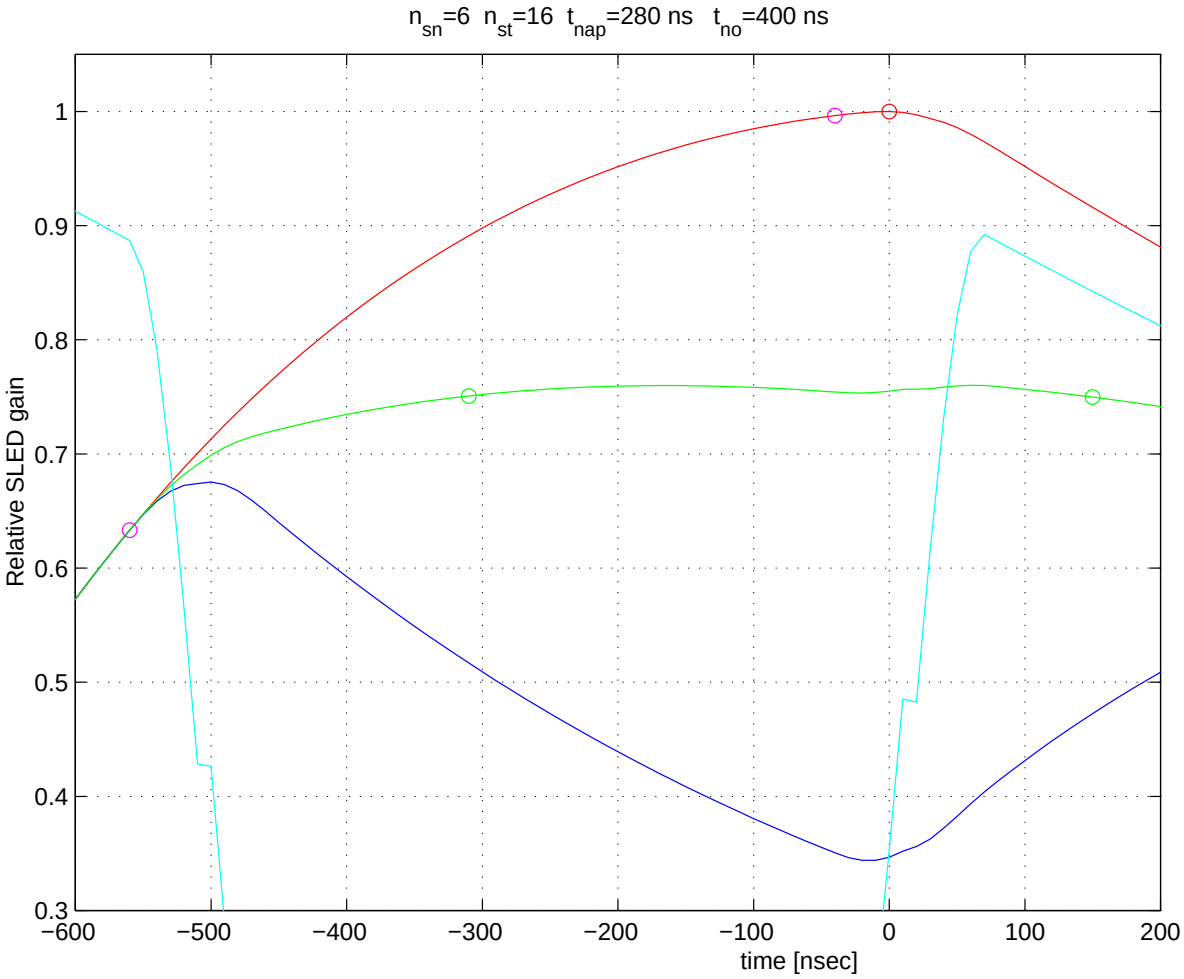

Fig. 2: SLED energy curve.
The relative SLED output (top) and with a 450 ns long notch (bottom) changes by about 30% over 500 ns, but with 6 out of 16 sectors notched (middle) the average variation is reduced.

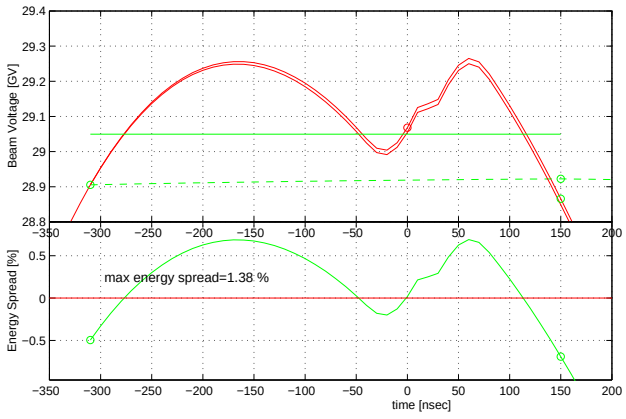

Fig. 3: No-load, loaded voltage and energy spread.
In simulations with 6 out of 16 sectors notched the energy variation along the pulse can be reduced to ±0.5%.

3 EXPERIMENTAL RESULTS

The E-155 experiment and now in spring of 1999 its extension E-155x can use beam pulses up to 500 ns length. Creating this pulse had some longitudinal and transverse challenges.

3.1 Energy Spread

The full energy spread due to the rising part before the peak of the SLED output energy curve is about 30% (Fig. 2). The compensation with a one-size notch gives about 1.2% (full width, Fig. 3). To get this further down, especially the two high energy peaks, we had to use different size notches with different timing and/or a double-notch consisting of two additional 130 ns long phase flips (see Fig.4).

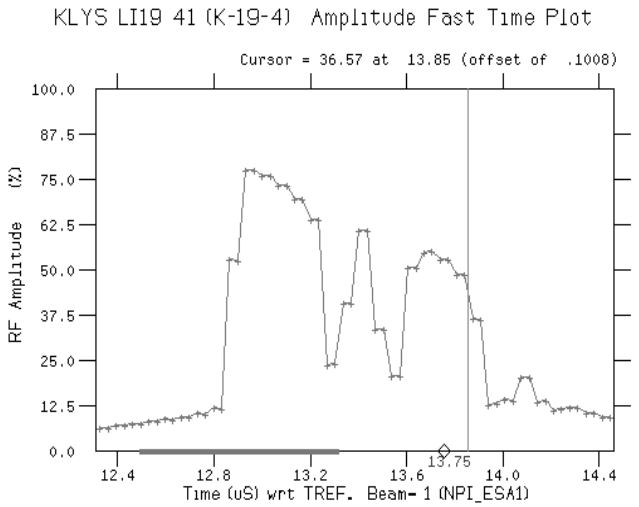

Fig. 4: Measured RF amplitude with a double notch.

By having some sectors with a double notch or a shorter pulse length, the energy spread can be minimized further.

This reduced the energy spread over the 450 ns long pulse to about ±0.1% which is better than the single bunch energy spread of 0.15% rms. The measurement of Fig. 5 was obtained using the synchrotron light at a dispersive location, which was digitized by a gated camera with a 70 ns gate width. The overall energy spread of the pulse is about 0.15% with some small lower energy tails in the front and the back. Shorting the pulse could eliminate these, but since the experiment accepts a whole energy range of ±0.4% the whole pulse was used.

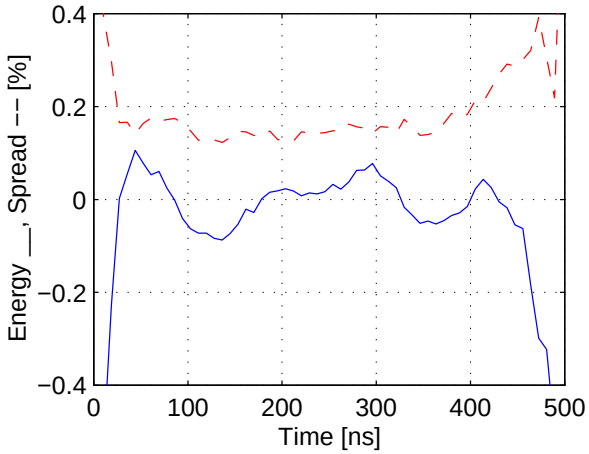

Fig. 5: Energy and energy spread along pulse.

3.2 Transverse Dynamic

Since the compensation of the energy spread is global over 30 different sectors and not a local cancellation, the beam would have a huge energy spread mainly in the early part of the accelerator. This was initially observed when increasing the pulse length from 300 to 500 ns, that part of the beam got lost near the first 100 to 200 m. An explanation is that in the first two sectors (= 200 m) there is no notch and therefore a 30% energy spread, which could not pass through the betatron focussing lattice. This was improved to 10% by putting the beam centered over the peak. A fine-adjustment was the use of a short notch in Sector 1, creating a local M-shaped energy distribution. All these have helped to get the full transmission of the whole pulse, but some parts of the beam have still a different betatron match. This is visible on a screen, where the different parts of the pulse have up to a factor of two different spot sizes.

4 SUMMARY

Notching the SLED output or, in other words, using SLEDF (for a Flat SLED energy "curve") has made it possible to increase the pulse length from about 100 ns to 500 ns with an energy spread of 0.15%.

5 ACKNOWLEGDEMENT

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5 REFERENCES

[1] F.-J. Decker, Z.D. Farkas, J.Turner, *High Current, Long Beam Pulse with SLED,* PAC99, New York, March 1999.