THE NEXT LINEAR COLLIDER TEST ACCELERATOR: STATUS AND RESULTS

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Abstract

At SLAC, we are pursuing the design of a Next Linear Collider (NLC) which would begin with a center-of-mass energy of 0.5 TeV, and would be upgradable to 1.0 TeV and beyond [1]. To achieve this high energy, for the past several years we have been working on the development of a high-gradient 11.4-GHz (X-band) linear accelerator for the main linac of the collider. In this paper, we present the status and initial results from the "Next Linear Collider Test Accelerator" (NLCTA) [2]. The goal of the NLCTA is to model the high gradient linac of the NLC. It incorporates the new technologies of X-band accelerator structures, rf pulse compression systems and high-power klystrons into a 0.5 to 1.0 GeV linac which is a test bed for beam dynamics issues related to high-gradient acceleration.

1 INTRODUCTION

The Next Linear Collider Test Accelerator (NLCTA) is a 42-meter-long beam line consisting consecutively, of an injector, a chicane, a linac, and a spectrometer.

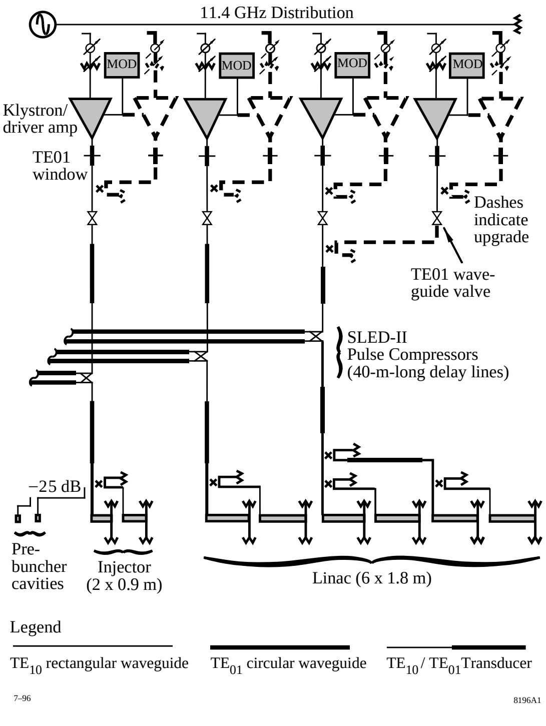

Figure 1. A schematic of the NLCTA rf system

The injector is a 150-KeV gridded thermionic-cathode gun, and X-band prebuncher, a capture section, and a preacceleration section. Downstream from the injector we have a magnetic chicane for longitudinal phase-space manipulation, energy measurement and collimation. After the collimation, the average current injected into the linac will be comparable to the NLC specification, 1.0 ncoul/1.4 ns.

The NLCTA linac when complete will consist of six 1.8-meter-long X-band accelerator sections which are designed to suppress the long-range transverse wakefield. These sections are powered by three 50-MW klystrons whose peak power is quadrupled by SLED-II rf pulse compressors. This will yield an unloaded acceleration gradient of 50 MV/m so that the maximum energy gain of the beam in the linac is 540 MeV. The NLCTA rf system parameters are listed in Table 1.

Downstream from the linac we have a magnetic spectrometer that can analyze the bunch train after acceleration. A vertical kicker magnet in the spectrometer will provide a method for separating the bunches vertically so that the energy and energy spread may be measured along the bunch train. We can also measure the emittance in the spectrometer and in the chicane.

In the future we plan to increase the linac gradient to 85 MV/m by installing six 75 MW klystrons as shown in Table 2. We also plan to upgrade the injector in order to increase the bunch spacing and intensity, each by a factor of 16. This will permit more detailed beam-dynamics studies on a train of bunches similar to that required for the NLC.

Table 1. NLCTA RF System Parameters

Parameter	**Design**	**Upgrade**
Linac Energy	540 MeV	920 MeV
Active Length	10.8 m	10.8m
Acc. Gradient	50 MeV	85 MeV
Inj. Energy	90 MeV	90 MeV
RF Freq.	11.4 GHz	11.4 GHz
No. of Klystrons	4	7
Klystron Power	50 MW	75 MW
Klystron Pulse	1.5 µsec	1.5 µsec
RF Compression	4.0	4.0
Structure Length	1.8 m	1.8 m

In the next few sections we discuss the status of the NLCTA, and we conclude the paper with a discussion of the initial results and plans for commissioning.

2 CONVENTIONAL SYSTEMS

All the conventional systems for the NLCTA are essentially complete. All of the non-rf components in the beam line are installed; this includes magnets, beam position monitors, vacuum system and all shielding and cabling. All of the power supplies are installed and tested and are operated routinely with the NLCTA control system which is an extension of the SLC control system. The thermionic electron gun and all injector solenoids are installed and tested. Presently, the beam line is under vacuum with the linac accelerator structures replaced by vacuum spool pieces.

3 THE RF SYSTEM

A schematic layout of the NLCTA rf system is shown in Fig. 1. The beam is initially bunched with two prebuncher cavities at the fundamental frequency of 11.424 GHz. It is then accelerated in two 0.9 m-long rf structures with an unloaded energy gain of 90 MeV. The first of these two injector structures has several low-beta cells to capture the beam optimally. The injector accelerators and prebunchers are powered by a single 50 MW klystron compressed by a factor of 4 by a SLED-II pulse compression system. After the chicane, the linac consists of six 1.8 m-long structures. Each of the first two pairs is powered initially by a single 50 MW klystron. The final pair of structures and final klystron will be installed in 1997 and will use the SLED-II compression system in common with the middle pair of the linac as shown in Fig. 1.

Notice that an upgrade is shown to the rf system denoted by the dashed lines in Fig. 1. The parameters for this upgrade are given in Table 1. As klystrons become available, we plan to upgrade the energy of the NLCTA by adding an additional klystron to each modulator. Each of the four modulators are designed to accept and power two 75 MW klystrons. This will yield an unloaded accelerating gradient of 85 MV/m after the upgrade. The plan for the NLC includes a similar upgrade from 0.5 TeV to 1.0 TeV in which the accelerating gradient is increased by the same amount. We hope to test this upgrade path in the NLCTA. In the next several sections we show the status and results for the rf system to date in more detail.

4 KLYSTRON STATUS AND RESULTS

The NLCTA (and NLC) specifications call for a 50 MW Klystron operating with a 1.5 μsec pulse length (1.2 μsec for the NLC). Thus far the klystron development effort at SLAC has produced four klystrons that meet or exceed the NLCTA specification [3]. In Fig. 2 you see the output power of the fourth in the series, XL-4. It is a very robust klystron with a very stable output power. As you can see from Fig. 2, XL-4 can produce a 75 MW pulse 1.2 μsec long. Both XL-2 and XL-3 also produce more than the required 50 MW and all of the three klystrons have the required bandwidth to work with the SLED-II compression system. The XL-4 klystron has been installed on the NLCTA injector modulator and will be used to power the initial commissioning of the injector of the NLCTA.

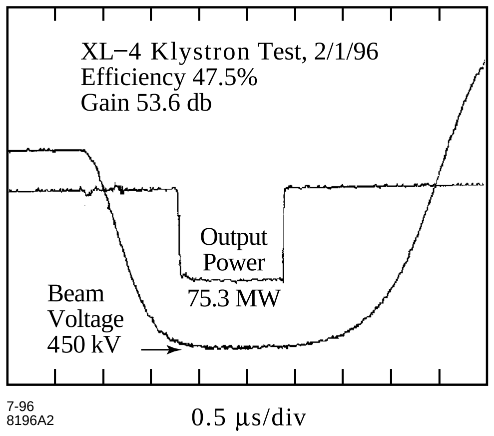

Figure 2. High-Power test of XL-4.

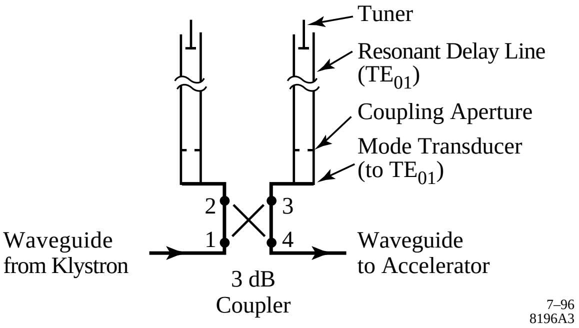

Figure 3. A schematic of the SLED-II rf compression.

Several more klystrons of the XL-4 type will be produced for the NLCTA. However, the development effort for NLC klystrons has been turned towards the development of a periodic permanent magnet (PPM) focused klystron[4]. This eliminates the focusing solenoid from the klystron which reduces both the capital and operating cost significantly. The initial tests of the first PPM klystron have just been completed yielding up to 60 MW with about 60% efficiency. This klystron power exceeds the 50 MW required for the 0.5 TeV NLC.

5 RF PULSE COMPRESSION

A schematic diagram of the SLED-II compression system is shown in Fig. 3. The klystron power flows through a 3-dB hybrid where it is split to resonantly charge two delay lines. After several round trip times the klystron phase is flipped by 180 degrees, after which the power from the klystron adds to the power emitted from the delay lines to create a large compressed pulse of RF power. In Fig. 4 you see high-power tests of the SLED-II prototype for the NLCTA powered by the XL-2 klystron. The prototype exceeded the required output power of 200 MW but with a shorter pulse of 150 nsec [5].

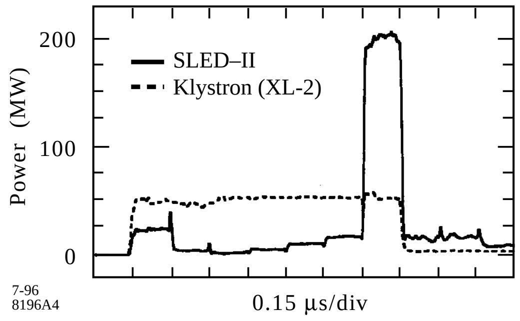

Figure 4. High-power test of the SLED-II prototype.

Three SLED-II systems have been completed for the NLCTA, and the injector compression system has been installed. Initial low-power tests of the injector SLED-II system have shown excellent performance with an overall efficiency that exceeded our expectations (see Fig. 5)[6]. High-power tests of the injector SLED-II system will take place in the summer of 1996 immediately prior to injector commissioning.

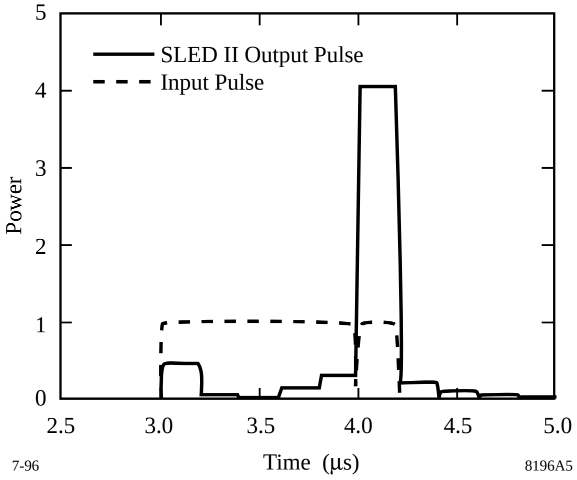

Figure 5. Low-power test of Injector SLED-II system.

6 RF STRUCTURE STATUS

The NLC requires accelerator structures that operate reliably with an unloaded gradient of 50 MV/m for the 0.5 TeV collider and 85 MV/m for the 1.0 TeV upgrade. The NLCTA will serve as a model of this upgrade path in that we will begin at the lower acceleration gradient and eventually increase the gradient to the required 85 MV/m (see Table 1).

In addition to the gradient requirement, the NLC structures must be designed to substantially reduce the long-range transverse wakefields that can cause beam breakup. To achieve this reduction we have pursued two basic types of accelerator structures, the detuned structure and the damped-detuned structure. As you can see in Fig. 1, there are a total of eight structures in the NLCTA. The first two are one-half-length detuned structures. The second pair are full-length detuned structures. The third pair are damped-detuned structures; and finally, the last pair will initially be KEK detuned structures and later will be damped-detuned structures.

6.1 Detuned Structures

In a constant gradient traveling wave structure the irises are tapered to vary the group velocity in order to keep the gradient constant in spite of the loses in the structure. This tapering produces a variation of the frequency of the first dipole mode along the structure length that can be as much as 10%. The detuned structure takes advantage of this by changing the profile of the iris taper in order to create a smooth Gaussian-like distribution of higher-order modes. This leads to a Gaussian like initial decay of the wake field behind the bunch[7]. We have tested this concept in the Accelerator Structure Test Set-up (ASSET) facility in the SLC. The results are shown in Fig. 6[8]. In the upper graph you see the measured data plotted with an idealized model. In the lower graph you see the data plotted with the same model but with frequency errors included. In general, there is excellent agreement with expectations although some of the detailed features of the wakefield differ from the model.

This technique has been used to manufacture four structures in the NLCTA. The first three are complete and the remaining structure will be brazed this summer.

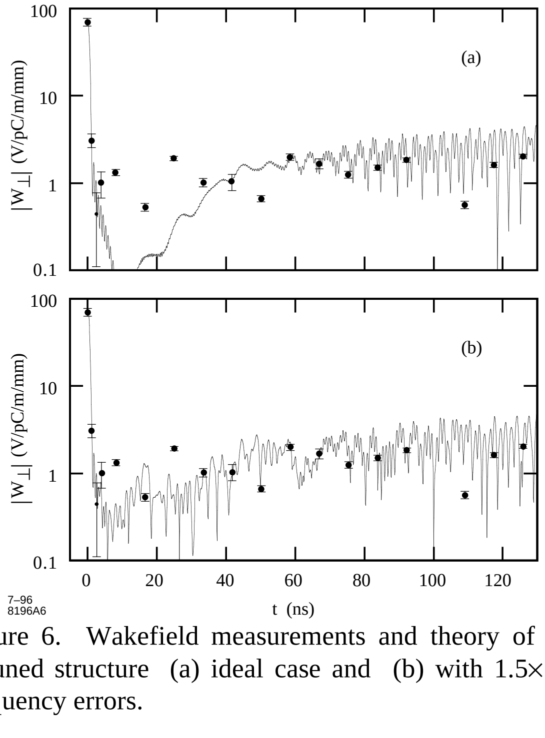

Figure 6. Wakefield measurements and theory of the detuned structure (a) ideal case and (b) with 1.5×10^{-4} frequency errors.

6.2 *High-Power Tests of Structures*

During the past several years we have performed many high-power tests of different types of structures[9]. These tests indicate that surface fields up to 500 MV/m can be obtained in copper structures at 11.4 GHz. In power-limited tests, average acceleration gradients in short structures have reached 120 MV/m[10].

In Fig. 7 we plot the dark current observed versus accelerating field in the first 1.8 m damped structure. The highest field reached was 67 MV/m which was limited by available power at that time. Although the dark current grows rapidly, at 50 MV/m it is well within acceptable levels, and there is evidence that the level can be reduced by more than an order of magnitude when care is taken to keep the structure surfaces clean during manufacture[11]. Accelerating gradients of up to 85 MV/m in full-length structures should be straightforward to obtain with proper conditioning.

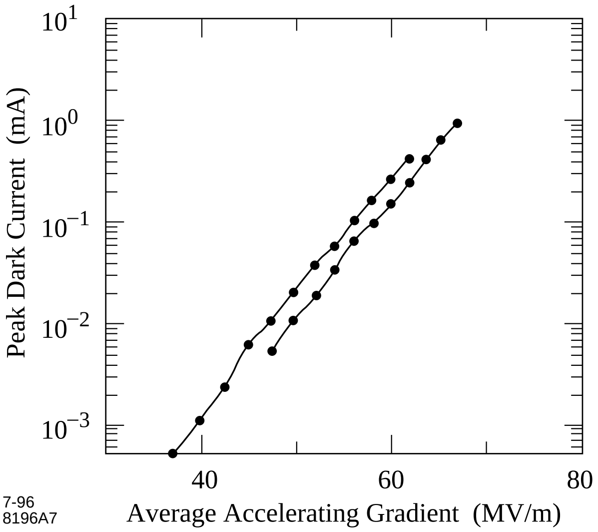

Figure 7. High-power tests of the 1.8 m detuned structure.

6.2 *Damped-Detuned Structures*

In order to further reduce the wakefield and the tolerances, it is necessary to provide some moderate damping for the higher-order dipole modes. To accomplish this we have developed a damped-detuned structure that uses four symmetrically placed manifolds to provide the damping [12]. A schematic of the cell for the structure is shown in Fig. 8. The structure cells are coupled to four waveguides that are formed when the cells are diffusion bonded together. The dipole mode is coupled out to the waveguide where is propagates to the end of the structure to a load. This techniques should damp the first dipole modes with Qs of about 1000. The signals from the manifold can be used as a beam position to align the structure to the beam.

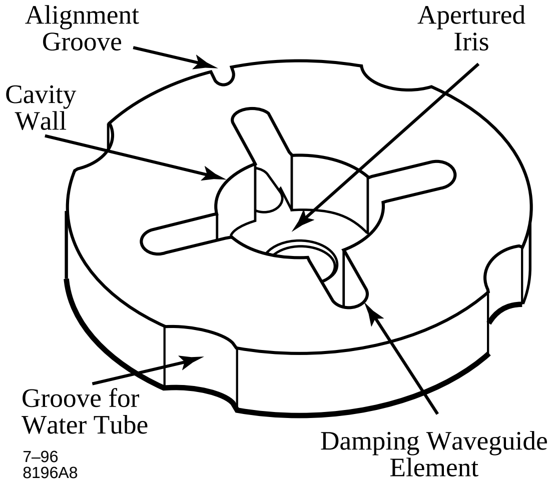

Figure 8. A cell of the Damped-Detuned structure.

We are presently constructing two damped-detuned structures in collaboration with KEK. The cells have been diamond-point machined at KEK and are diffusion bonded to create the full structure at SLAC. We have just completed the first damped-detuned structure, and we plan to test it in the ASSET facility in August 1996.

One critical aspect of the construction process is the internal alignment of the structure. For the damped-detuned structure this is accomplished by bonding short stacks of cells together that have been aligned in a precise V-block. In Fig. 9 you see a plot of the alignment of a short stack of 38 cells. The tolerance for this scale of alignment is also shown. It is evident that for this short section we have achieved an rms. alignment of a few microns, far better than required. In some cases the short sections develop a bend after bonding, but we have found that it is quite straightforward to straighten after bonding. We will be testing the alignment of the full structure just prior to testing in ASSET in August 1996.

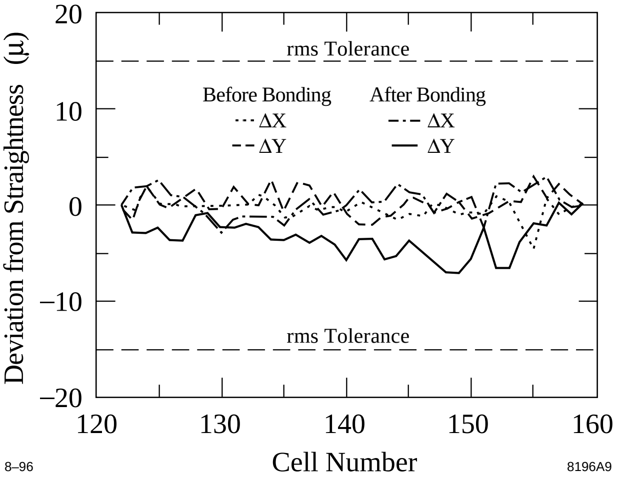

Figure 9. Alignment after diffusion bonding of a short stack of cells in the Damped-Detuned structure.

7 INJECTOR STATUS AND TESTS

The NLCTA injector as shown in Fig. 1 consists of a 150-KV gridded thermionic gun, two prebuncher cavities and two 0.9 m detuned accelerator structures. This section is surrounded by solenoids to provide the necessary focusing. The beam is bunched at the fundamental RF frequency and is the same average current as required in the NLC. A later gun upgrade will provide the bunch structure of the NLC. As of this writing all of the components in the injector are installed.

We have performed our first tests of the NLCTA injector. The gun was conditioned up to 150 KV and we produced a stable 2.5 A beam with 170 nsec pulse width. The beam profile was measured one meter downstream from the gun and was the size and shape expected.

The injector klystron, SLED-II system and structures are now all installed. We plan to condition the injector rf system in August 96 and accelerate beam in the injector around the same time.

8 FUTURE PLANS

The NLCTA injector commissioning began in May 1996. We plan to continue the injector commissioning in the summer to obtain accelerated beam in August 1996. The remainder of the rf system will be installed in the fall of 1996, and we plan to accelerate beam in the linac by the end of 1996.

In 1997 we will begin beam dynamics tests in the NLCTA. After initial commissioning we plan an extensive study of multibunch beam loading compensation. The beam loading in the NLCTA is about 25%, and we hope to achieve 0.1% energy spread along the bunch train by shaping the RF pulse.

We will also investigate beam break up in the NLCTA. In spite of the short length, the NLCTA is quite sensitive to beam break up due to its low injection energy. If our structure development program is successful, we expect to see only a few percent beam break up.

Transverse accelerating fields due to misalignments or structure fabrication errors can cause an effective emittance dilution by tilting the bunch from head to tail. This effect will be measured in the NLCTA with a sensitivity necessary for NLC tolerances.

In addition to the running planed for 1997, we will complete the full linac with the final rf station and the installation of the KEK prototype accelerator structures. In the future, as klystrons become available, we plan to complete the energy upgrade of the NLCTA as shown in Fig. 1 and Table 1.

9 ACKNOWLEDGMENTS

The NLCTA progress has been and continues to be the result of the hard work of many people. I would like to thank the NLCTA group for the ongoing success in the construction and commissioning of the NLCTA.

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