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THE NEXT LINEAR COLLIDER TEST ACCELERATOR†

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ABSTRACT

During the past several years, there has been tremendous progress on the development of the RF system and accelerating structures for a Next Linear Collider (NLC). Developments include high-power klystrons, RF pulse compression systems and damped/detuned accelerator structures to reduce wakefields. In order to integrate these separate development efforts into an actual X-band accelerator capable of accelerating the electron beams necessary for an NLC, we are building an NLC Test Accelerator (NLCTA). The goal of the NLCTA is to bring together all elements of the entire accelerating system by constructing and reliably operating an engineered model of a high-gradient linac suitable for the NLC. The NLCTA will serve as a test-bed as the design of the NLC evolves. In addition to testing the RF acceleration system, the NLCTA is designed to address many questions related to the dynamics of the beam during acceleration. In this paper, we will report on the status of the design, component development, and construction of the NLC Test Accelerator.

INTRODUCTION

In order to control the linac length of the NLC, current designs at SLAC and KEK use acceleration gradients which begin at 50 MV/m for the 0.5-TeV linear collider (phase one) and finish with 100 MV/m in the upgraded 1-TeV collider (phase two)[1]. These gradients are provided by an 11.4-GHz RF system (X-band). Although there has been experience with short X-band accelerators in industrial and medical applications, there are presently no high-gradient X-band accelerators in operation.

During the past several years much experience has been gained with this RF frequency at SLAC and KEK. We have powered 11.4-GHz structures to reach peak surface fields in excess of 500 MV/m[2]. Short travelling wave accelerating structures have been powered to accelerating fields in excess of 100 MV/m[3,4]. High-power klystrons have been constructed which reach 50 MW in pulses one microsecond long and 85 MW in pulses 200 nsec long[5]. We have constructed high-power RF pulse-compression systems which achieve a factor of five in peak-power multiplication[6,7]. Designs for more efficient modulators have been completed[8]. Finally, we are developing low-loss components for manipulation of high-power pulses of 11.4-GHz RF[7].

The first goal of the NLC Test Accelerator, the subject of this paper, is to construct and reliably operate a high-gradient X-band linac in order to integrate the accelerator structures, RF sources, and RF systems being developed for the NLC.

The second goal of the NLCTA is to study the dynamics of the beam during the high-gradient acceleration of many bunches on each RF fill of the structure. The dynamics of transient beam loading is of particular interest in order to test strategies for multibunch energy compensation and higher-order mode suppression. It will also be possible to measure the residual transverse wakefield effects in the NLCTA.

The NLCTA is primarily a high-gradient X-band linac consisting of six 1.8-meter-long accelerator sections. These sections are fed by three 50-MW klystrons which make use of SLED-II pulse compression to increase the peak power by a factor of four. This yields an acceleration gradient of 50 MV/m so that the total unloaded energy gain of the beam in the X-band linac is 540 MeV.

The NLCTA parameters are listed in Table 1. The right-hand column of Table 1 lists the parameters for an upgrade of the X-band linac to 100 MV/m by the use of six 100-MW klystrons.

INJECTOR

The NLCTA injector will consist of a 150-kV gridded thermionic cathode gun, an X-band prebuncher, a capture section with solenoid focusing, and a rectangular chicane magnetic bunch compressor.

The prebuncher will be a velocity-modulating cavity. The capture section will be a standard linac section modified to comprise two half-sections, each with its own input and output couplers. The first half-section, with a minor modification of the first few cells, will capture the beam. The second half-section will provide additional acceleration, up to 90 MeV, to improve the spectrum and

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Table 1. NLCTA Parameters

Parameter	Design Value	Energy Upgrade
Energy	540 MeV	1280 MeV
Active linac length	10.8 m	
Accelerating gradient	50 MV/m	100 MV/m
Injection energy	90 MeV	
RF frequency	11424 MHz	
Number of klystrons	3	6
Klystron peak power	50 MW	100 MW
Klystron pulse length	1.0–1.5 μs	
Compression power gain	4.0	
Accelerating mode	$2\pi/3$	
HOM suppression	Detuning	

to reduce the transverse emittance at the entrance to the NLCTA linac.

The injector will produce trains of 1600 bunches with 0.09-nanosecond (11424 MHz) bunch spacing. The total charge in the bunch train will be 10^{12} e. The average current matches (or exceeds) that required for the NLC bunch train. This beam will be adequate for the energy gain measurements of the X-band accelerator. It will allow the study of multibunch loading and compensation techniques to achieve a small bunch-to-bunch energy spread, and will also allow studies of residual transverse beam breakup.

In the future, we plan to upgrade the injector to produce a train of bunches identical to that required for the NLC, in order to carry out additional beam dynamics studies. The present specification for the NLC bunch structure calls for total charge of $6 \times 10^{11} e$ in trains of 90 bunches with 1.4-nanosecond (714 MHz) bunch spacing. Injecting the proper NLC multi-bunch structure in the NLCTA will allow us to measure true single-bunch beam loading, and to further verify the beam-loading compensation techniques necessary for maintaining small bunch-to-bunch energy spread. Proper suppression of the higher-order modes in the accelerating structure can be verified by measuring the bunch-to-bunch energy offsets and bunch-to-bunch position offsets. We are presently investigating alternatives for this gun upgrade.

RF SYSTEM

The high-gradient accelerator will be fed with RF power through overmoded circular waveguides which penetrate the shielding blocks above the accelerator. Three 50-MW klystrons will be positioned along the accelerator, outside the shielded enclosure[5]. Each klystron is powered by an independent modulator, allowing the flexibility needed for multibunch energy control and adequate power for an upgrade to a 100-MV/m accelerating gradient with six 100-MW klystrons, as indicated in Table 1. Each klystron feeds a SLED-II pulse compressor[6,7]. The pairs of delay lines of the SLED-II pulse compressors are overlapped, parallel to the accelerator, outside the shielding. The output of each SLED-II is split to feed two accelerator sections. In the case of the injector, the SLED-II output is split to feed the two short injector sections to provide overhead for beam loading.

ACCELERATOR STRUCTURE[9]

In order to increase the luminosity of an NLC well beyond the minimum levels necessary for high-energy physics experiments, a train of bunches must be accelerated on each RF pulse. The primary impact of this choice is in the design of the RF structure. As each bunch traverses the structure, it excites wakefields which can remain until the next bunch passes. If this happens, each bunch resonantly drives all the bunches behind it. This leads to transverse multibunch beam-breakup. However, beam-breakup can be eliminated by choosing an RF structure in which the wakefields damp significantly between bunches.

There are two methods which can be used to achieve this damping. In the first, the higher-order modes in the structure can be damped by coupling them to radial waveguides which are terminated with matched loads. This causes the energy to radiate out of the structure between bunches. The second technique involves changing the frequency of the higher-order modes (HOMs) of each cell. Qualitatively, the total wakefield is then composed of a sum of wakefields, one from each cell. Behind the driving bunch, the wakefield decoheres because of the differing frequencies, and the net effect is a reduction of the wakefield. With this technique, the frequency distribution is important in determining the subsequent decay of the wakefield behind the driving bunch. Both of these techniques have been tested experimentally[10,11].

For the NLCTA, we plan to use a detuned structure. It is a $2\pi/3$ "constant-gradient-like" structure which is modified every half meter to include four symmetric pumping holes. These holes lead to parallel vacuum manifolds which provide sufficient pumping speed despite the small beam aperture. The cavities are machined to provide a precise mechanical reference from the inside dimensions to the exterior of the structure[12].

In order to achieve the reduced wakefield, the structure is configured to be very nearly constant gradient. The decoherence of the wakefield between bunches will be achieved by a Gaussian distribution of HOM frequencies with a standard deviation of 2.5%, which results in a Gaussian decay in time for the initial wakefield. This distribution can be obtained by tailoring a constant-gradient section so that more cells are near the central frequency while fewer are near the ends of the frequency band. This choice results in a structure in which the iris size along the structure first decreases rather quickly, then decreases slowly in the middle, and finally decreases quickly along the structure towards the output end[13].

With this distribution of HOMs, the wakefield decoheres to less than 1% of its peak value[14]. This decoherence is sufficient to eliminate beam breakup in the NLC or NLCTA[15]. Because of the low injection energy, the NLCTA has a sensitivity to transverse wakefields comparable to the much-longer NLC linac. The NLCTA will permit the verification that detuned structures can indeed supress wakefields to the levels necessary for stable acceleration.

BEAM ANALYSIS

A magnetic spectrometer has been designed which will analyze the bunch train after acceleration in the linac in order to determine beam energy and energy spread, and bunch-to-bunch offsets. The optics in the beam analysis region allow for the measurement of emittance in both transverse planes. A vertical kicker magnet upstream of the spectrometer provides a method for separating the bunches vertically so that the energy, energy-spread and horizontal offsets can be independently measured along the bunch train. After initial commissioning, an extensive set of experiments is planned to verify that the NLCTA can indeed stably accelerate trains of low-emittance bunches suitable for a full-scale NLC.

SUMMARY AND PLANS

The conceptual design for the NLCTA is complete and detailed engineering is presently underway. The facility to house the NLCTA is under construction in End Station B at SLAC. Prototypes of the klystron, pulse compression system and the accelerating structure are under construction and will be complete in 1993. These prototypes will be tested in the Accelerator Structure Test Area at SLAC[16]. The wakefield of the detuned structure will be measured in the Accelerator Structure Setup in the SLC[17]. We plan to complete the NLCTA and begin beam dynamics experiments in 1996.

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