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# On the Concept of an Emittance-Dynamics Test Area for NLC Studies based at the SLC*

John T. Seeman
Stanford Linear Accelerator Center
Stanford, California 94309

Contents:



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# 1 Introduction

The lion's share of the increase in luminosity of the Next Linear Collider (NLC) [1] comes from very substantial reductions in the beam emittances. Experimental verification of the new concepts used to produce and control these reduced emittances must be obtained so that a realistic and practical design can be proposed. Several experiments are presently underway at several laboratories concerning other aspects of the NLC [2]. For example, at SLAC the Final Focus Test Beam (FFTB) [3] will investigate techniques to produce a 60 nm vertical beam size in an NLC type final focus given small input emittances. An NLCTA test accelerator [4] at SLAC and a similar test at KEK will check key features of the generation and use of high power, short pulse x-band RF with multiple bunches. Also at KEK, a low emittance, high repetition rate damping ring and single bunch length compressor are being built [5]. However, no comprehensive tests of the acceleration and second length compression of beams with very low emittances are now planned.

In this note an accelerator test area is described to investigate the complete front end of the electron arm of an NLC collider to address many of the appropriate accelerator physics and instrumentation issues needed for a more comprehensive low emittance test.

*Overall goal statement of the experiment:*
*"The accelerator physics issues of the production and acceleration of low emittance beams through a complete NLC injector and into the main linac have been shown to be complete and controllable."*

In the test, the electron damping ring produces a train of flat, low emittance bunches which are then transported through a bunch length compression section, the preaccelerator, a second compressor, and an RF / wakefield test area. The bunches are then shown to have the proper bunch length, energy spectrum, horizontal to vertical size ratio, and low emittances as needed for the NLC.

These experiments are to be performed after modest hardware improvements are made to the SLC. The hardware improvements are only those related directly to the development of the NLC and do not duplicate any existing hardware. Therefore, all development work would be at the frontier of linear collider technology.

The SLC is uniquely suited for these tests since the basic infrastructure exists and works. This experimental area could be called the "Emittance and Dynamics Test Area" or EDTA.

## 2 General Overview of the EDTA

The section of the SLC of interest for the EDTA is CID through Sector 10 including the tunnel spur to the north. A schematic layout of the test area is shown in Figure 1. In general terms the beams in the experiment travel from CID through the north damping ring, are accelerated to Sector 10 (900m), and, then, are extracted into a transport line in the north tunnel spur.

CID is made to operate with multiple bunches but with the sum of the charges up to a few X $10^{11}$. The damping ring is operated at low energy and uncoupled so that flat and very low emittance beams can be produced. The multiple bunches can have variable spacings but may be as close as one damping ring RF bucket (0.42 m or 1.4 ns) apart with about one half the ring filled. Up to 40 bunches can be damped and accelerated. The injection and extraction kickers need not be changed. The post kickers in the RTL and linac can reduce any small trajectory differences between the bunches. The NRTL compresses the bunch length from 5 mm to 0.5 mm.

All the bunches are then accelerated in the SLC in the first 8 Sectors in what will be called the NLC style "preaccelerator" using the best possible BNS damping configuration. The preaccelerator klystrons will have phases so that a specific head-tail energy spread in each bunch is obtained at the beginning of Sector 10. In Sector 10 the electron bunches are extracted and passed through a complete NLC second compression section (to be built) where the bunch length is shortened to 0.05 mm.

Following the second bunch compression, the bunches pass through a transport line (to be built) containing an instrumentation section, a potential x-band RF accelerator section, a strong wakefield and structure alignment section, and a spectrometer with a beam dump. All regions are instrumented to verify the appropriate NLC beam conditions. The Sector 10 tunnel spur is shielded from linac radiation (concrete blocks) to allow access during normal straight ahead beam running. (A possible low energy gun and injector into the RF test area can be accommodated if desired.)

## 3 Project Goals

As stated above, a modified SLC front end coupled to a second bunch length compressor constitutes a complete NLC injector. The underlying methodology here is to reuse as much of the SLC as possible, which is experimentally understood, well instrumented, and working. All upgrades deal directly with NLC studies.

Milestones: To demonstrate that the source, damping ring, bunch compressors, pre-accelerator (5-10 GeV), and new instrumentation for an NLC injector can be operated as predicted. There are many possible sub-goals to be demonstrated.

a) Very low beam emittances (both horizontal and vertical) can be produced.

b) Flat beams can be manipulated.

c) Multiple bunches can be handled given long range transverse and longitudinal wakefields.

d) Vibration isolation concepts and hardware for the low energy portion of the NLC ( $< 20$ GeV) are appropriate and functional.

e) The tolerances for the first and second bunch length compressors are fully within expectations.

f) Accelerator alignment and stability can be achieved.

g) The beam dynamics in the presence of strong wakefields have been verified.

h) The effects of coulomb scattering and coherent phenomena on the equilibrium emittance in low emittance storage rings are understood.

## 4 CID - Sector 1

The generation of 1 to 40 bunches with variable spacing (in units of the NDR RF wavelength 42 cm) is the required task of the CID-Sector 1 region. Gun pulsers must be developed for this task. The requirements on the control of the energy, spectrum, and trajectory of the average of the many bunches must be accomplished so that good charge equality can be obtained in the damping ring. (Two easy alternate goals are (1) two bunches with variable spacing and (2) every bucket filled.)

Knowledge obtained:

a) Production and bunching of multiple bunches.

b) Control of the energy spread and energy of multiple bunches.

c) Control of the bunch populations in the damping ring.

# 5 Damping Ring

The energy of the damping ring is to be lowered until the emittance is at a minimum. Somewhere in the energy range of 400 to 700 MeV, the invariant emittances produced by radiation and intrabunch coulomb scattering are about equal near $5 \times 10^{-6}$ r-m, or so, in the horizontal plane. (An SLC damping ring has already run successfully at 950 MeV.) The ring is to be operated uncoupled so that the vertical emittance is more than one order of magnitude smaller than the horizontal. The storage time of the bunches in the ring will be made as long as is needed to reach the equilibrium emittance values. A pulse rate of 1 to 10 Hz is satisfactory. Of course, gas scattering and coherent effects must be investigated. Thus, the intention is for the beams to emerge from the ring with emittances not unlike that needed for the NLC. The bunches are then compressed with the NRTL where coupling and emittance control are paramount.

Knowledge obtained:

a) Verification of small emittance predictions given damping times and intra-bunch scattering.

b) Demonstration of very decoupled beams.

c) Verify predictions of the thresholds for bunch lengthening with energy.

d) Verify predictions of the thresholds of longitudinal and transverse single and multiple bunch instabilities.

e) Determine the required trajectory stability for injection into the linac.

f) Verify the required tolerances on the RTL bunch compression with flat beams.

g) Demonstrate the injection and extraction of multiple bunches.

## 6 Linac

The NLC style "preaccelerator" (Sectors 2 through 9) accelerates the bunch train up to 5 to 10 GeV and provides the proper energy spread needed for injection into the second bunch length compression section located in the Sector 10 tunnel spur. Throughout the acceleration cycle, the very low emittance and the uncoupled beam profiles must be maintained. Several changes to the quadrupole magnets, power supplies, corrector dipoles, and alignment fixturing may be needed.

Knowledge obtained:

a) RF tolerances determined for the 5-10 GeV preaccelerator.
b) Alignment techniques proven for the 5-10 GeV preaccelerator.
c) Verification of the predicted BNS damping effects.
d) Demonstration of acceleration of multiple bunches.
e) Demonstration of the proper induced energy spread in each of the bunches in the train.
f) Demonstration of skew control at low emittances during acceleration.
g) Demonstration of trajectory and dispersion control.

## 7 Sector 10 Bunch Compressor

The second bunch length compressor is located just downstream of the extraction point in Sector 10 at Girder 10-1. An NLC compressor, complete in every detail, is to be installed in this location with a design called for by present studies [6] but suited to this geometry. After passing through the compressor, the beam is launched into a straight section leading into the Sector 10 tunnel spur which simulates the geometry of the NLC main linac. The beam conditions exiting the compressor are to be measured precisely. The desire is to make them sufficient for launching into an actual NLC.

Knowledge obtained:

a) Experimental verification of calculated compressor tolerances.
b) Verification that flat beams can be maintained during compression including x-y coupling tolerances.

c) Demonstration that radiation excitation does not enlarge the emittance.

d) Check of the full multi-order transport calculations.

e) Stability measurements of energy and energy spread.

f) Determination of coupled tolerances of the entire system: the damping ring, first compressor, preaccelerator, and second compressor.

g) Tests of the betatron and dispersion matching of flat beams.

h) Check the influence of multiple bunches on compression.

## 8 Instrumentation

The instrumentation and techniques needed to study flat, low emittance beams with dimensions like those in the NLC linac and damping ring must be developed. Several adequate devices already exit (e.g. the wire scanner profile monitors and bunch length monitors), but they need testing. Others need development, such as the beam position monitors. Proper instrumentation of the bunch compressors and preaccelerator is very important for the this test and the NLC.

The basic control system for this facility would be incorporated into the existing SLC control system without a need for a new control room, thus concentrating efforts on needed advances.

Knowledge obtained:

a) Proven design of a profile monitor for flat beams and multiple bunches with NLC dimensions. Skewness monitored.

b) Adequate design of a position monitor for multiple bunches.

c) Jitter monitoring at the few micron level.

d) Short bunch lengths can be monitored.

## 9 Possible RF Test Area

Downstream of the second bunch length compressor, a straight section of about 50 m is available for potential RF tests. X-band structures complete with klystrons and RF pulse compression modules could be installed and tested with the NLC like bunches from upstream. The 50 m straight section allows the installation of an order of magnitude more RF structure than that of the presently planned NLCTA. The klystrons could be housed in the unused support building previously used for Sector 10 Maintenance or located in a new 'klystron gallery' above the north tunnel spur. AC power, cooling water, and other facilities are available along the linac at modest levels. With shielding in the accelerator housing at the entrance to the tunnel spur, access to the spur during normal linac running could be accommodated.

A spectrometer at the end of the transport line analyzes the energy and induced energy spread in the bunches as a result of RF acceleration.

Knowledge obtained:

a) Acceleration of proper NLC type bunches.
b) Accelerator tunnel tests of NLC x-band klystrons.
c) Accelerator tunnel tests of x-band RF power distribution.
d) Confirmation of the bunch length measurements.
e) Tests of the phasing system of the klystrons with damping ring beams.
f) Tests of RF kicks from x band RF structures.
g) Long term stability of the RF power plant.

## 10 RF Structure Test with Strong Wakefields

The NLC x-band linac will ultimately provide acceleration of 250 to 500 GeV. A complete test of the wakefield and alignment issues of that accelerator will most likely not be tested until the NLC is constructed. Nevertheless, a significant test of these issues should be performed to show that the scaling laws are experimentally correct. In the EDTA, a 50 meter straight section is available for tests of alignment and wakefields with multiple bunches with short bunch lengths. In order to make the tests significant, an unpowered x-band structure could be installed with iris diameters much smaller than those needed for the NLC, say 1mm or so. These structures could be built with the HOM dampers and the phase detuning slots appropriate for these chambers but using the design concepts used for the NLC. The iris sizes would be chosen so that the tolerances on the corrected trajectories of the bunches, the alignment of the structure and quadrupoles, the required instrumentation precision, the vibration damping, and the beam quality are exactly that required of a significant portion of the early region of the NLC main linac. The alignment stability of structures and beam based corrections could be studied from moment to moment, day to night, or week to week from environmental effects in an real tunnel under actual conditions.

Knowledge obtained:

a) Realistic test of NLC scaled wakefield effects.
b) Measurement of the bunch length through longitudinal wakefields.
c) Stability of beam based real time alignment.
d) HOM and dephasing suppression of transverse wakefields.
e) Environmental stability effects such as vibration and temperature changes observed and controlled directly.

## 11 Alignment

The alignment techniques to be developed for the damping ring, preaccelerator, and the 50-m x-band structure test section would provide valuable insight for those techniques needed for the NLC collider. The 50 m straight section is well suited for a fully designed alignment area containing stabilized quadrupole, BPM, and RF structure supports with remote readout and adjustment.

Knowledge obtained:

a) Adequate survey instruments and techniques.
b) Movable quadrupole, accelerator, and position monitor supports.
c) Adequate remote alignment procedures.
d) Inexpensive but adequate vibration damping.
e) Environmental and long term alignment changes.
f) Comparison of beam based and mechanical alignment techniques under NLC conditions.

## 12 Civil Construction

Little civil construction is needed for the proposed tests. Some concrete blocks are needed at the mouth of the tunnel spur to produce a radiation free area for the second half of the second bunch compressor, the 50 m straight, and the spectrometer region. Also, shielding is needed at the end of the spur. The exit of the spur is well below grade and the required shielding should be easy to provide. The only activity in the tunnel spur at present is an alignment calibration rail which, if care is taken, could remain in place, relatively untouched.

Furthermore, an extension of the spur by 45 m for a future upgrade (suggested by G. Fischer) would also not be difficult as the earth is already graded in this area. Covering the extended spur with dirt to bring it back to grade level would solve the shielding problem. With this extension, a ninety (90) meter straight section could be provided for expanded tests. A klystron housing above the tunnel spur is also possible with minimal difficulty.

## 13 Future Work

Many calculations must now be done to provide practical numbers for all the parameters from CID through the spectrometer. The project must also be scaled to the appropriate size and scope. After a set of self-consistent parameters are determined, cost estimates can be made. Then, a proposal for a full but practical experiment can be put forward for this stringent test of the accelerator physics of a full front end of an NLC collider.

The accelerator physics experiments from this test area can start immediately and occur continuously was soon as the project is approved. For example, the production of flat beams can be studied with no component changes. Emittance studies at low energies can also be started immediately. Studies of accelerated low emittance, flat beams can soon follow. The more complicated experiments requiring additional hardware would start as available.

## 14 Related Experiments

Several experiments have been proposed by independent interests which are separate but sufficiently related to the tests proposed here so that common beam time can be utilized. Some of these tests are (1) straight ahead multi-bunch tests to study beam breakup BBU [7], (2) VLEPP structure alignment tests [8], and (3) providing beam for the Final Focus Test Beam [3]. Operational resources can be combined to expedite all of these studies.

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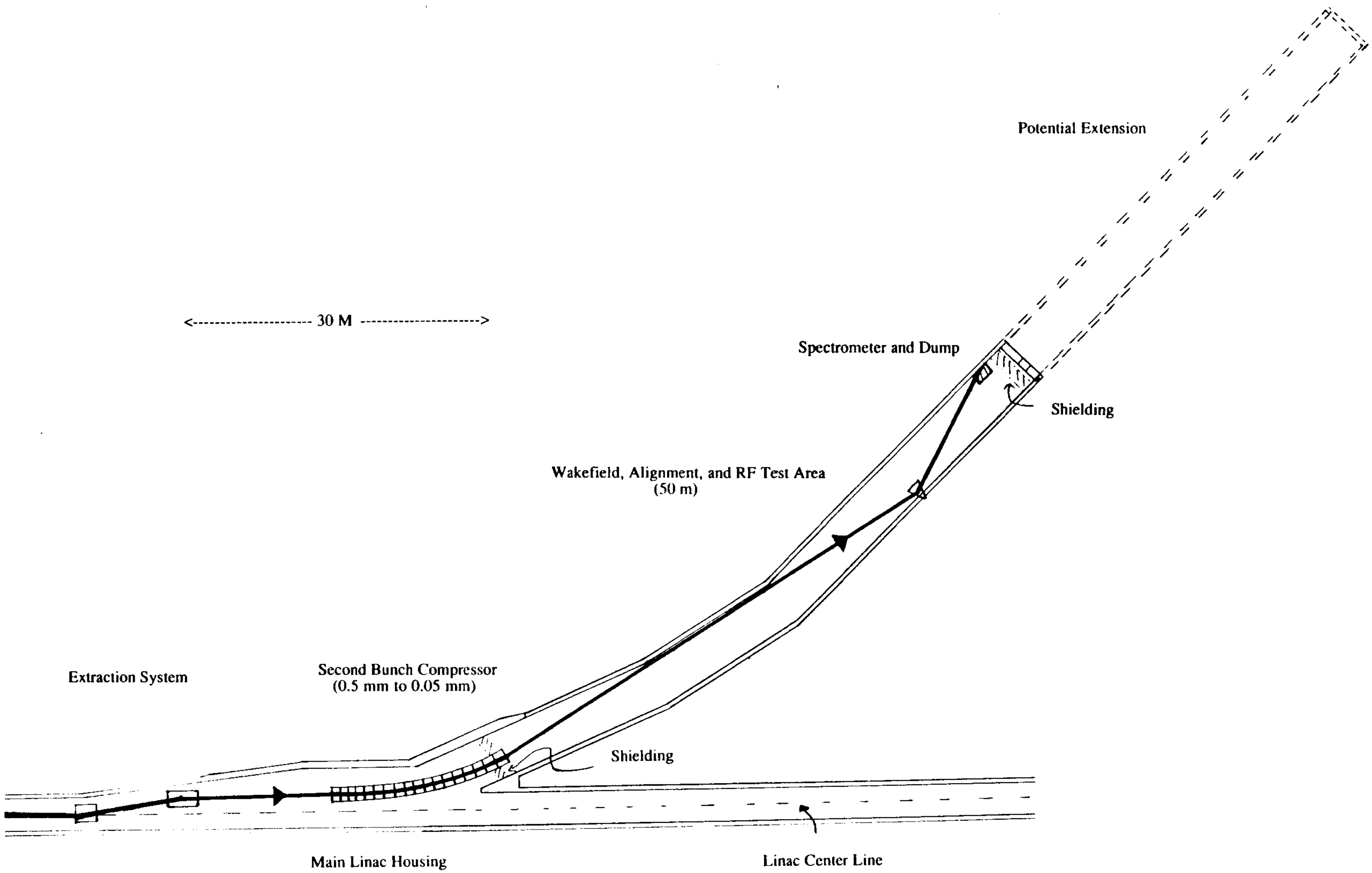


Figure 1 Schematic layout of the Emittance-Dynamics Test Area in the Sector 10 tunnel spur showing the second bunch length compressor and the test area for wakefield, alignment, RF, and bunch parameters studies. The dimensions are to scale as per SLAC D-501-335 S-5 (1963).