# NLC Electron Injector Beam Dynamics

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**Abstract**. The Next Linear Collider (NLC) being designed at SLAC requires a train of 90 electron bunches 1.4 ns apart at 120 Hz. The intensity and emittance required at the interaction point, and the various machine systems between the injector and the IP determine the beam requirements from the injector. The style of injector chosen for the NLC is driven by the fact that the production of polarized electrons at the IP is a must. Based on the successful operation of the SLC polarized electron source a similar type of injector with a DC gun and subharmonic bunching system is chosen for the NLC.

## INTRODUCTION

There will be two electron injectors on the NLC: one for the collision and another for the positron production electrons. The collision electron injector will have a polarized electron gun while the electron injector for positron production will have a thermionic gun at least initially. The low energy transport portion of both injectors will be identical to provide the flexibility of replacing the thermionic electron gun with a polarized gun in case of future upgrades where two polarized electron sources are needed for $\gamma$-$\gamma$ collisions.

Our goal is to design an injector such that it can produce the required beam parameters for both phase 1 and phase 2 of the Next Linear Collider (NLC). Thus it needs to produce a 126 ns trains of bunches 1.4 ns apart. The beam parameters at 200 MeV for phase 1 and phase 2 are listed in table 1. To assure reliable uninterrupted operation at these parameters, a 20% intensity overhead is designed into the low energy transport system of the injector.

The baseline approach for the NLC injector will be a conventional system with a DC polarized gun, and 714 and 2856 MHz bunching system. The RF gun injector

approach will be studied in parallel to take advantage of the extremely low

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emittances achievable with them but at this point the technology of producing polarized electrons with RF guns is a very high risk option. The conventional subharmonically bunching injector approach [1] chosen for NLC is a proven, mature technology, used on injectors around the world, including at the Stanford Linear Collider (SLC).

Table 1. NLC Polarized Electron Source requirements up to the DR

| | NLC - I | | | NLC - II | | | Overhead 20% |
|---|---|---|---|---|---|---|---|
| N at IP [$10^{10}$] | 0.65 | 0.75 | 0.85 | 0.95 | 1.1 | 1.25 | 1.5 |
| N at Gun[$10^{10}$] | 1.2 | 1.4 | 1.6 | 1.75 | 2.0 | 2.3 | 2.8 |
| N at In. jit. ap. [$10^{10}$] | 0.95 | 1.15 | 1.3 | 1.4 | 1.63 | 1.85 | 2.2 |
| Ipeak at gun [Amp] | 2.8 | 3.3 | 3.7 | 4.0 | 4.7 | 5.3 | 6.4 |
| N at 100 MeV [$10^{10}$] | 0.83 | 0.97 | 1.1 | 1.2 | 1.4 | 1.6 | 1.9 |
| Iave at 100 MeV Amp] | 0.95 | 1.11 | 1.26 | 1.37 | 1.58 | 1.8 | 2.2 |
| N at DR entr. [$10^{10}$] | 0.75 | 0.88 | 1.0 | 1.1 | 1.28 | 1.45 | 1.7 |
| Intensity Jitter [%] | 0.5 | | | | | | |
| Bunch $W_{edge}$ [ ps] | 22 | | | | | | |
| $\varepsilon_{n,rms}$ @ 40 MeV[$10^{-4}$m] | 0.5 | | | | | | |
| $\Delta E/E_{edge}$ DR entr. [%] | $\pm 1$ | | | | | | |

# NLC Injector Baseline Design

The design for the various sections of the NLC including the injector are continually evolving. The injector described in this section is shown in figure 1 and is the most up to date version of the layout. The injector has a 120 KV DC gun which produces a long 126 ns train of bunches 1.4 ns apart and 700 ps wide at the base with as much as 2.8 x $10^{10}$ e- in each bunch. The pulse format from the gun is determined by the polarized source laser for the collision electrons and by the thermionic gun pulser for the e+ production electrons. A vacuum isolation chamber and a 20° bend protect the polarized electron gun from the downstream environment. An intensity jitter limiting aperture approximately 24 cm downstream of the bend is used to reduce the incoming jitter from the gun to unmeasurable amount at the expense of scraping away some 20% of the charge. Two 714 MHz standing wave subharmonic bunchers and an S-band buncher and accelerator section compress the beam from the gun such that 90% of the charge is captured in 18° of S-band or 17.5 ps. The simulations are carried out to the end of the first accelerator section where the beam energy is 38.8$\pm$ 2.2 MeV. After accelerating the beam to 2 GeV, we expect an energy spread of $\pm$0.6%.

We plan to use an intensity jitter limiting aperture between the 20° bend and the first subharmonic buncher to reduce the electron beam jitter from the gun due to the incoming laser intensity jitter on the photocathode.

Figure 1.  NLC electron injector low energy transport beamline.

## ELECTRON GUN OPTICS

The plan is to use a modulated laser to extract an electron bunch train from the photocathode. The electron beam energy from the gun will be 120 KeV, a comfortable operating point for the polarized electron source. The proposed gun for the NLC polarized electrons has a large, 3 $cm^2$ cathode to offset the photocathode charge limit problem [2]. The electrodes are shaped to minimize emittance for 4.5 A bunch current and reduce the electric field gradients near the cathode to avoid arcing in this region. We used EGUN to simulate the beam from the gun. Figure 2 shows the ray-trace of the beam from the cathode to 12 cm downstream. The normalized edge emittance is $6 \times 10^{-6}$ m-rad and the beam envelope radius is 1.2 cm at the tip of the anode.

Figure 2. Beam envelope from the NLC electron gun.

## INTENSITY JITTER LIMITING APERTURE

A scenario for reducing the electron intensity jitter is to locate a fixed aperture in the 120 KeV beamline at a location where the beam size is proportional to space charge. With this method we hope to reduce the intensity jitter by scraping more charge when more charge is produced at the gun and less charge when less charge is produced at the gun. For the proposed NLC injector design such a location exists 24 cm downstream of the 20° bend. Using a 1.05 cm aperture we can reduce the intensity jitter at the gun to be immeasurable in the bunched beam, while losing 20% of the charge in the aperture. Since this loss occurs after the gun vacuum isolation chamber and the 20° bend, it should not cause any damage to the photocathode based on various gun test experiences on the SLC polarized source. Figures 3 show the correlation of charge per bunch in the downstream part of the injector with the charge produced at the gun.

Figure 3. Intensity jitter reduction using a 1.05 cm aperture, 24 cm downstream of the 20° bend.

## BUNCHING SYSTEM

As shown in figure 1 two 714 MHz standing wave subharmonic bunchers are located 74 cm apart downstream of the intensity jitter limiting aperture. The S-band buncher is a 4 cavity $\beta = 0.75$ traveling wave section and is located 42 cm downstream of the second subharmonic buncher. Immediately following the S-band buncher is a $\beta = 1$, 3 m S-band accelerator section which acts as a further buncher in the first meter. This bunching system compresses the beam such that 90% of the charge is captured in 18° of S-band or 17.5 ps. Given that 20% of the beam is lost in the intensity limiting aperture, we expect to have $1.5 \times 10^{10}$ e- in 18 ps per bunch if $2.0 \times 10^{10}$ e- per bunch is produced at the gun. Figure 4 a, b, c, d show the bunch charge distribution profile in time, transverse particle distribution, longitudinal particle distribution, and the energy spread profile respectively at the end of the first accelerator section. With similar capture efficiency as the simulated case this system will be able to produce the $1.9 \times 10^{10}$ e- per bunch at 200 MeV with $2.8 \times 10^{10}$ e- at the gun.

At the end of the first accelerator section the beam normalized rms emittance is $4.5 \times 10^{-5}$ m-rad. Figure 5 shows the normalized rms emittance growth from the gun up to the end of the first accelerator section.

The beam energy at the end of the first accelerator section is $38.8 \pm 2.2$ MeV. The $\pm 2.2$ MeV energy spread largely results from the fact that when the beam reaches the speed of light and the bunching process is completed it does not end up on the crest but some 20° ahead of it. This energy spread is linearly correlated with bunch length and can be removed by properly phasing the beam in the next accelerator section. In addition there is a $\pm 0.2$ MeV uncorrelated energy spread. The total energy spread of the beam is determined by the sum of the energy spread due to a finite length bunch riding on the RF and the uncorrelated energy spread. For an 18° bunch riding on the crest of the RF the energy spread will be $\pm 0.6\%$ plus the uncorrelated energy spread whose effect diminishes as the beam accelerates. Thus for example at 200 MeV the uncorrelated energy spread will be $\pm 0.2$ MeV/200 MeV or $\pm 0.1\%$ and the total energy spread will be $\pm 0.7\%$.

Figure 4. Electron beam parameters at the end of the NLC injector as simulated with PARMELA: a) the microbunch pulse shape, b) the transverse and c) the longitudinal beam distribution, and d) the energy spread profile

Figure 5.  Charge transmission  and emittance growth from the gun through the first accelerator section at 40 MeV

# DIAGNOSTICS

The purpose of the diagnostics system is several fold: to aid in tuning the injector, to diagnose the beam parameters including jitter, and to be used for machine protection triggers. The diagnostics consist of Charge Monitors (CM), Beam Position Monitors (BPM), Bunch to bunch timing monitor, aperture/pepper pot insert, beam profile monitors, bunch length monitor (BLM), emittance measurement and energy spread measurement stations after 40 MeV

Most of the monitors at the gun and at the end of the first accelerator section need to have the ability to measure variation from bunch to bunch within the same bunch train. Measuring the variation between a group of bunches in 5 ns intervals would be sufficient, that is to say, it is not necessary to measure the charge within a single bunch.

The following is a table of the various diagnostics and their specifications.

**Table 2.** Injector Diagnostics and their Specifications

| Diagnostic | Total Bunch Train range | relative resolution | Bunchlet* range | relative resolution |
|---|---|---|---|---|
| Toroid charge monitors | 45 - 250 x $10^{10}$ e- | ±0.2% | 0.5 - 3 x $10^{10}$ e- | ±1% |
| Gap current monitors | | | | |
| charge | 45 - 250 x $10^{10}$ e- | ±3% | 0.5 - 3 x $10^{10}$ e- | ±3% |
| pulse width | 1 - 150 ns | ±1ns | ~200 ps | ---- |
| Streak Camera | 1 - 150 ns | ±1ns | 5 - 40 ps | 1ps |
| Beam loss monitors | 0 - $10^{8}$ e- | $10^{7}$ e- | ---- | ---- |
| Beam Position Monitors | 0 - 1 cm | ±20µ | 0 - 1 cm | ±20µ |
| Beam size monitors | | | | |
| !at the cathode | R=0 - 1.5 cm edge | ±1% | R=0 - 1.5 cm edge | ±1% |
| at 120 KeV | R=0 - 1.5cm edge | ±1% | R=0 - 1.5cm edge | ±1% |
| at 40 MeV | R=0.2 - 1cm edge | ±1% | R=0.2 - 1cm edge | ±1% |
| Energy | ~40 MeV | ±0.2% | ~40 MeV | ±0.5% |
| Energy spread at 40 MeV | ~20% | ±1% | ~20% | ±1% |
| Pepper pot | qualitative diagnostic | | | |
| Bunch length monitor | qualitative measurement for tuning by maximizing signal | | | |

*Bunchlet represents a group of bunches as close to a single bunch as possible. Some of the diagnostics may not be fast or sensitive enough to measure single bunch parameters but can measure a group of about 5 adjacent bunches and this would be sufficient. These diagnostics would require a timing gate width of about 3 ns, with a 0.5 ns rise time and 10 ps timing stability. Where applicable the specifications in the bunch to bunch column are normalized to a single bunch.

! A profile of the laser at a screen located at the image point of the cathode.

## CONCLUSION

The NLC polarized source injector will be a conventional injector employing subharmonic bunching to achieve the required bunch intensity and structure. Simulation results show that it is possible to capture 90% of the charge from the gun into 18 ps bunches when a train of bunches are produced from the gun which are 700 ps wide and 1.4 ns apart. The charge intensity jitter limiting aperture is able to reduce the incoming jitter to an immeasurable amount at the cost of losing 20% of the charge from the gun.

## REFERENCES


1. M. B. James, R. H. Miller, "A High Current Injector for the Proposed SLAC Linear Collider", IEEE Trans. Nucl. Sci., NS-28, (3), 3461, (1981)

2. H. Tang et. al., "Prospects for a Polarized Electron Source for the Next Generation Linear Colliders Based on a SLC-Type Gun", SLAC-PUB-6585, 1994

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Requirements

Design Philosophy

Injector low energy beam transport system

Simulation results

Conclusions

The injector for the collision electrons has to produce polarized electrons while the electron injector for positron production does not.

The beamline from gun to 2 GeV for both injectors is identical except for the fact that the polarized source will have two 40 MeV lines.

Our goal is to design an injector such that it can produce the required beam parameters for both phase 1 and phase 2 of the Next Linear Collider (NLC).

Thus it needs to produce a 126 ns trains of bunches 1.4 ns apart.

20% intensity overhead is designed into the low energy transport system of the injector to assure reliable and continuous operation.

The baseline approach for the NLC injector will be a conventional system with a DC polarized gun, and 714 and 2856 MHz bunching system.

The RF gun injector approach will be studied in parallel to take advantage of the extremely low emittances achievable with them but at this point the technology of producing polarized electrons with RF guns is a very high risk option.

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The charge intensity jitter limiting aperture is able to reduce the incoming jitter to an immeasurable amount at the cost of losing 20% of the charge from the gun.

Contact author for figures.