Study of the NLC Linac Optics Compatible with a Low Energy Scenario ¹

Y. Nosochkov and T.O. Raubenheimer
Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309

Abstract

We explore the NLC linac optics compatible with a low energy scenario where initially only part of the full linac is installed. Optics modification suitable for a low energy beam running and upgrade to the nominal energy is discussed. Linac parameters and beam tolerances in the modified lattice are compared to the nominal design.

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1 Introduction

We consider a scenario where the NLC [1] is initially built for a lower beam energy than in the nominal design. The advantage is an earlier start of machine operation at a lower cost since only part of the full linac may be initially installed. However, the linac design has to be compatible with the low energy operation and upgrade to the nominal energy. A modification of the linac lattice suitable for the low energy option is discussed. Parameters of the modified lattice and ground motion tolerances are compared with the nominal design (based on linac version May 2000).

2 Optics

NLC linac optics (version May 2000) and β functions for a 500 GeV beam are shown in Fig. 1. The linac has three sectors consisting of FODO cells with accelerator rf-structures placed between quadrupoles. Compensation of wakefield effects requires stronger focusing at the low beam energy. This is achieved using short FODO cells in the first sector where each half-cell contains three accelerator structures. Cells in the second and third sectors are longer and contain six and nine structures per half-cell, respectively. Phase advance per cell along the first and second sectors is gradually decreased to take into account reduced wakefield effects with energy.

Let's consider a scenario where the NLC is initially built for a lower beam energy than in the nominal design. To reduce the initial machine cost, only the last part of the nominal linac may be installed for the low energy operation. We assume that injection can be provided at the beginning of the shorter linac. A schematic of the nominal (500 GeV) and low energy (125 GeV) linacs is shown in Fig. 2. In this scenario, the low energy linac would occupy part of the third sector of the full linac where the nominal cells are long. But for a wakefield compensation the low energy cells have to be about three times shorter, as in the first sector of the linac. It is also desirable to keep the same lattice for the low and nominal energy operations to reduce the cost of upgrade.

A compromise between the low and full energy optics can be achieved by a simple modification of the nominal cell in the third sector. The original long cell which is described schematically as

$$F - 3rf - 3rf - 3rf - D - 3rf - 3rf - 3rf, \quad (1)$$

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Figure 1: NLC main linac (version May 2000).

Figure 2: Schematic of the nominal (dash+solid) and low energy linac (solid).

where F and D are focusing and defocusing quadrupoles, can be modified by placing a quadrupole after every three accelerator structure module (3rf) to generate either three identical short cells for a low energy linac:

$$F - 3rf - D - 3rf - F - 3rf - D - 3rf - F - 3rf - D - 3rf, \quad (2)$$

or one long cell for the nominal energy beam:

$$F - 3rf - F - 3rf - F - 3rf - D - 3rf - D - 3rf - D - 3rf. \quad (3)$$

Although the same physical quadrupoles are considered for both regimes, their strengths will be different at low and high energy. Cells in the second sector may be modified similarly, if needed.

Modifications (2)-(3) add flexibility to the linac optics, but require many more quadrupoles. Based on the original design, it is clear that the modified short cell (2) is acceptable for the low energy beam since it's practically identical to the nominal cell in the first sector. The modified long cell (3) for the full energy beam is similar to the nominal long cell (1) except that F and D quadrupoles are split in three pieces. The quadrupole splitting increases the combined quadrupole strength KL and slightly reduces the maximum β functions.

An example of the nominal and modified long cells in the third sector is shown in Fig. 3 and 4, where the cell phase advance of 90 degrees is used. The maximum β functions are about 10% lower in the modified cell (3) in Fig. 4, but the combined quadrupole strength KL is up $\sim 60\%$ compared

Figure 3: 90 degree long FODO cell.

Figure 4: 90 degree FOFOFODODODO cell.

to the nominal cell. The individual quadrupoles in (3) are a factor of two weaker and therefore may be as twice as short (for the same K) compared to the nominal quadrupoles. Linear chromaticity $\frac{1}{4\pi} \sum \beta K L$ in the nominal and modified cells is about the same: -0.318 and -0.310, respectively.

Using design lattice for a 500 GeV beam (version May 2000), we estimated linac length when quadrupoles are placed after every three structures (3rf). In this case, each 12.8 inches gap between 3rf modules in the nominal design is replaced by a quadrupole with 6.275 inches space on both

Figure 5: Modified 90 degree linac with a quadrupole after every three rf-structures.

sides. If the original quadrupoles are used, then the modified second and third sectors would be 77.7 m and 699.5 m longer, respectively, and the full linac would be longer by 777.2 m. However, if shorter quadrupoles are used in the modified lattice, the length increase could be reduced by a half.

To generate a 500 GeV linac with a quadrupole after every three structures, we used a specially written code: “Linac_05” [2]. It automatically generates matched lattice for a three sector linac with F-3rf-D-3rf cells in the first sector, F-3rf-F-3rf-D-3rf-D-3rf cells in the second sector, and F-3rf-F-3rf-F-3rf-D-3rf-D-3rf-D-3rf cells in the third sector, where realistic spaces between magnets and accelerator structures are used. For an estimate, we used phase advance of 90 degrees per cell in the modified lattice. Short 12.75 inches quadrupoles were used throughout the modified linac to minimize the total length. Some other linac parameters were updated as well compared to the original design. The resultant β functions are shown in Fig. 5.

Linac parameters for the original and modified lattices are listed in Table 1. The nominal linac in Table 1 also includes a 114 m post-linac diagnostic section while the modified linac does not. The main disadvantage of the modified lattice is that it requires a larger number of individual quadrupoles. However, Table 1 represents a conservative approach where both sectors 2 and 3 are modified. In principle, the nominal optics could be kept unchanged in the second sector and beginning of the third sector which would reduce the number of additional quadrupoles.

3 Tolerances at 500 GeV/beam

To compare alignment tolerances in the nominal and modified lattices for a 500 GeV beam, we computed effects of ground motion on beam emittance and beam jitter using the “Tolerance” code [3]. This code analytically calculates tolerances on quadrupole and rf-structure rms displacements for 6% emittance dilution and beam jitter amplitude of 25% of beam size. An approximation is used where the entire space between quadrupoles is filled with accelerator structures. This way, the total

Table 1: Linac parameters for the nominal and modified lattices for 500 GeV beam.

	Nominal	Modified
Initial / final energy, GeV	8 / 500	8 / 500
Total length, m	10257.924	10591.537
Total accelerator structures	4752	4977
Total length of accel. structures, m	8565.480	8975.522
Length of one accel. structure, m	1.8025	1.8034
Accelerator gradient, MV/m	57.440	54.816
Total quadrupoles	724	1660
Total quadrupole length, m	510.029	537.267
Total quadrupole strength, kG	420062	630325
Maximum quadrupole gradient, kG/m	1373.8	2021.0
Total x/y phase advance, $[2\pi]$	79.68 / 84.12	88.45 / 88.87

length of structures is slightly increased and the accelerator gradient is correspondingly reduced to maintain the same energy gain. The following beam parameters were used in the tolerance calculation:

- 3×10^{-6} and 3×10^{-8} m for x and y normalized emittance, respectively
- 1.1×10^{10} particles per bunch
- 150 μm for rms bunch length
- 1.29×10^{20} V/C/m³ for transverse wakefield slope in the structures.

The computed tolerances are shown in Table 2. One can see that difference between the nominal and modified linac tolerances are small. Therefore, the modified lattice is acceptable for running at the full beam energy. This lattice has more optical flexibility than the nominal lattice, but at the expense of using many more quadrupoles.

Table 2: Ground motion tolerances for the nominal and modified linacs for 500 GeV beam.

		Nominal	Modified
Quadrupole rms misalignment	x	80.79	78.22
for 6% emittance dilution, μm	y	8.11	7.79
Accel. structure rms misalignment	x	14.90	15.38
for 6% emittance dilution, μm	y	1.52	1.54
Quadrupole jitter for beam jitter	x	75.01	83.40
amplitude of 25% of beam size, nm	y	7.45	8.35

4 Summary

We described a modification of the NLC linac lattice suitable for initial low energy beam running as well as an upgrade to the nominal energy. In this lattice, the long cells in the last segment of the linac are replaced by shorter cells with quadrupoles placed after every three rf-structures. The

modification is optimal for the low energy beam running and provides acceptable ground motion tolerances at the nominal energy. The main disadvantages of the modified optics are a larger number of quadrupoles needed for a full energy beam and up to 4% longer linac.

References

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- [3] T.O. Raubenheimer, unpublished.