STATUS OF THE ILC MAIN LINAC LATTICE DESIGN*

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Abstract

The report describes the present design of the ILC Main Linac lattice. The topics covered include basic element layout, optical functions, and issues centered around the linac following of the Earth's curvature.

INTRODUCTION

Detailed understanding of the transverse beam dynamics in the ILC Main Linac is one of the critical components for the entire project. The main linac should accelerate particles up to the top energy of the collider while preserving the small transverse emittances. Emittance dilution during propagation of the beam through machine may be caused by dispersion and wakefields originating from various misalignments of focusing quadrupoles and cavities. Multiple algorithms have been developed for tuning the linac in order to minimize impact of both static misalignments and ground motion on the beam emittance [1].

The ILC Baseline Configuration Document [2] established that the main linac should follow curvature of the Earth's surface unless dictated otherwise by beam dynamics issues or site-specific limitations. Several studies of static alignment methods (see e.g. [5]) compared their performance for the cases of curved and straight linac. No significant differences were revealed by these studies thus allowing further development of the curved configuration.

The ILC Reference Design Report [3] determined various technical aspects of the project including basic geometry of the main linac and layout of cryogenic components. The RDR envisages that subsequent advances in beam dynamics studies should include start-to-end simulations where propagation of the beam through the chain of systems is considered.

These factors together with the demand from the international community for a common base for simulations necessitated the development of a comprehensive set of ILC lattice files.

In this report we describe the design of the main linac lattice, covering the following major topics:

- Basic element layout.
- Matching of the main linac optics to the adjacent systems
- Issues related to implementation of the linac curvature, including synchrotron radiation.

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BASIC LINAC LAYOUT

The basis for the development of the main linac lattice is the layout of cryogenic components. The lattice described in this report is based upon the so-called 9-8-9 configuration dated December, 28, 2006 by T. Peterson [4]. The basic unit of periodicity of this structure is a 37.956m long RF unit consisting of three cryomodules (CM). The two outermost modules have 9 RF cavities each, while the center module has 8 cavities and a quadrupole package at the center. The quadrupole package consists of a quadrupole, BPM and a dipole corrector. Thus, the linac has one quadrupole per three cryomodules and two RF units form a FODO cell. Four RF units and a 2.5m cold end box make a standard string. There are also two short strings having 3 RF units. Besides this, the periodicity is disturbed by warm drift spaces which separate criogenic units. The length of the warm drift together with adjacent cold service endboxes is equal to that of one cryomodule. The electron linac consists of 5 cryogenic units with 282 RF units and an undulator insert between cryounits 3 and 4 (Fig. 1). This includes 4 RF units which are needed to compensate for energy loss due to synchrotron radiation in the undulator. The positron linac has 278 RF units.

Phase advance per FODO cell is 75/60 degrees in the horizontal/vertical plane which, together with the distance between quadrupoles of about 38m, makes the maximum beta-function values 120/140m.

Main linac lattice files (later also referred to as decks) were created in XSIF format [6] which can be parsed by many accelerator optics and tracking codes. Figure 2 shows beta-functions in the electron linac with the undulator insert. Spikes in the beta-functions occur due to matching across the warm straight sections and to/from the undulator.

CURVATURE IMPLEMENTATION

An essential feature of the main linac is its curvature. With the curvature radius of the Earth's surface of $\sim$ 6400 km and the linac length of $\sim$ 12 km the maximum trajectory sagitta is about 2.8m. Vertical dipole correctors located next to quadrupoles are used to deflect the beam. The nominal kick angle is $\sim 5 \times 10^{-6}$ radian. Each cryomodule is aligned along the perpendicular to the Earth's radius at the center of the CM, i.e. the beam line is kinked at the ends of cryomodules. Because the beam trajectory is steered through the centers of quadrupoles only at every third cryomodule, there is systematic offset and angle between the orbit and the cryomodule axis (Fig. 3). The maximum offset is $\sim$ 40 μm which is small compared to the expected installation misalignments. Misalignment of the

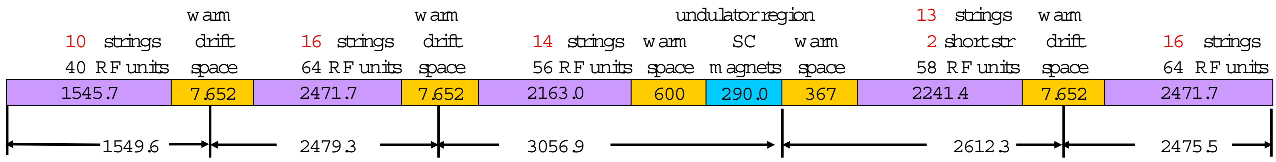

Figure 1: Layout of cryogenic components.

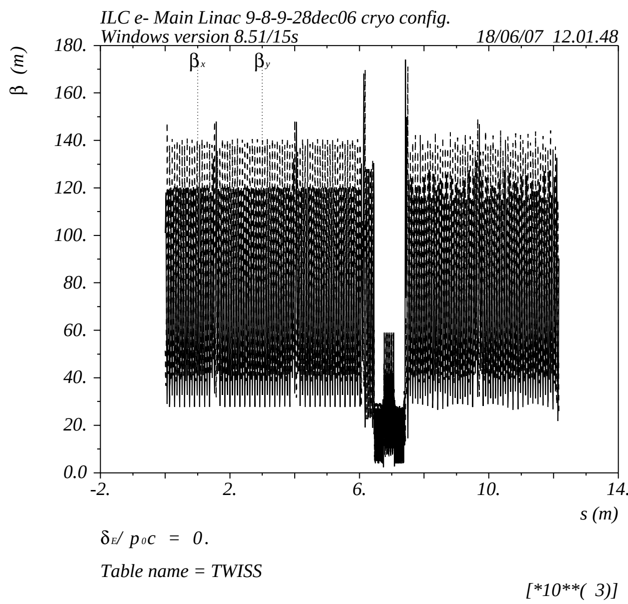

Figure 2: Beta-functions in the electron linac.

cavities within cryomodules will have the r.m.s. of 300μm.

In the decks the beamline curvature can be implemented using two approaches. The first employs a special element GKICK to perform the beamline geometry kink. However, not all optics codes (notably MAD) support this element. Hence, the same effect can be reached by combining a thin corrector and a thin dipole of the opposite sign. The thin dipole changes both the beam trajectory and the reference frame while the corrector cancels out the trajectory change. Thus only the reference orbit is kinked which is equivalent to the action of GKICK.

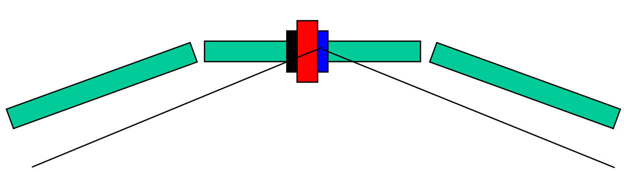

Figure 3: Curvature implementation. Green blocks are cryomodules, black block is the BPM, red - quadrupole, blue - corrector, black line is the beam orbit.

DISPERSION MATCHING

The beam injected into the main linac must be matched to the periodic dispersion in the curved lattice in order to avoid emittance dilution. First, the optimal periodic dispersion is found by minimizing the chromatic invariant. For the ILC main linac the design dispersion was found to be about 1mm. The bunch compressor, undulator, and beam delivery systems do not have curvature, thus having zero vertical dispersion. This means that non-zero dispersion has to be matched to zero at transitions between the machine systems.

The general approach uses the dipole correctors to create closed orbit bumps which generate dispersion. This can be achieved by fitting a minimum of four parameters to satisfy conditions for dispersion, orbit and their derivatives. However, it is desirable to minimize the orbit deviation because large transverse offset may generate strong wakefields. Besides, bending the electron beam at high energy generates significant synchrotron radiation. Because of this a more careful dispersion matching procedure should be used taking advantage of the fact that the phase advance in the vertical plane is 60 degrees. One can select two correctors which are 180 degrees apart to create a symmetrical dispersion matching bump [7].

Figures 4 and 5 show the vertical orbit and dispersion in a curved electron linac with the dispersion matching bumps. The orbit goes through the centers of quadrupoles and deviates by about -40 μm between them. The four peaks in the orbit are the dispersion matching from the bunch compressor, to and from the undulator section and to the beam delivery system.

SYNCHROTRON RADIATION

Because of the extremely high energy of the beam the synchrotron radiation in a curved linac may present some problems and sould be considered. The major limitation may come from the high power load on cryogenic components. Present specification says that for a single cryomodule the extra dissipated power should not exceed 2W. Given the fact that synchrotron radiation is emitted into a narrow cone and beam bending angle is small, special means of protection can be envisaged. However, they are not included in the present technical development thus limiting the tolerable bending angle.

We use the following basic formulae to calculate the

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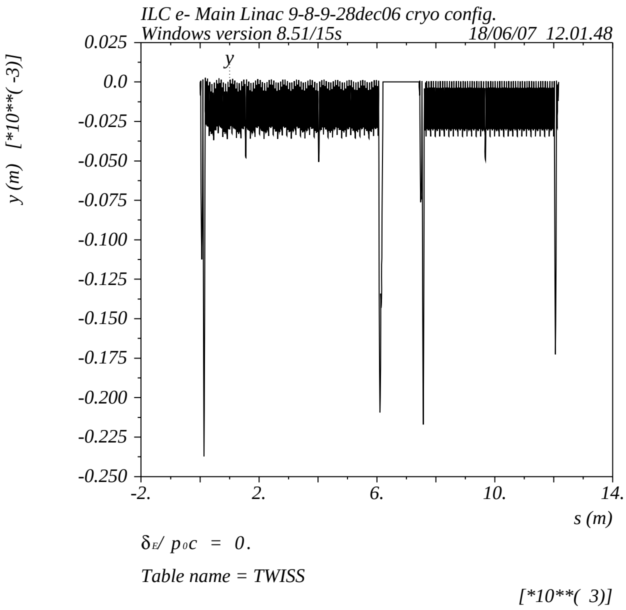

Figure 4: Vertical orbit in the curved linac.

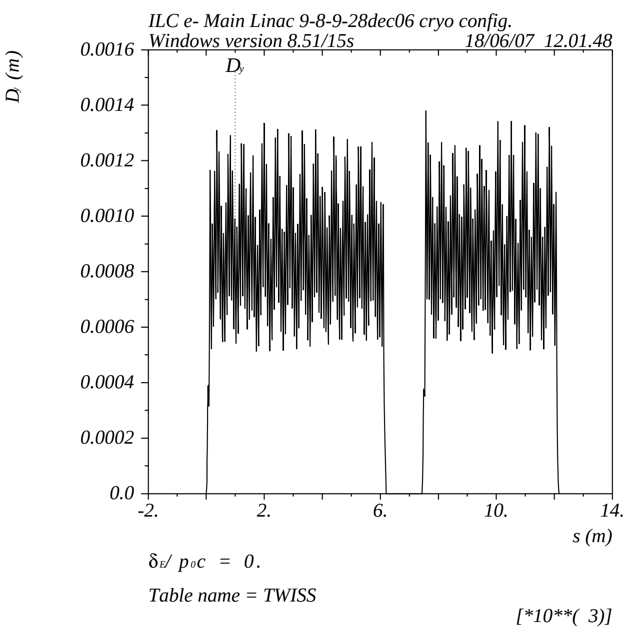

Figure 5: Vertical dispersion in the curved linac.

power radiated in a single dipole corrector:

$$U = 8.85 \times 10^4 E^4 \frac{\alpha^2}{L}, \ \ P = U \cdot I$$

where U is the particle energy loss in eV, E is the particle energy in GeV, α is the bending angle, L is the magnet length in m, P is the SR power in W, and I is the average beam current in A. Table 1 summarizes synchrotron power losses for $L = 0.335$m and $I = 4 \cdot 10^{-5}$A at different values of bending angle. Note that $5 \cdot 10^{-6}$ is the nominal angle for steering along the Earth's curvature. Calculations show that at the energy of 250GeV operation is possible at the bending angle not exceeding $7 \cdot 10^{-6}$ and at 500GeV the present steering scheme produces synchrotron radiation which is above the limit without protection system.

Table 1: Parameters of synchrotron radiation.

α	$U, P(E = 250)$	$U, P(E = 500)$
$5 \cdot 10^{-6}$	26, 1.1	413, 18
$1 \cdot 10^{-5}$	100, 4.5	1650, 72
$5 \cdot 10^{-5}$	2600, 110	41300, 1800

SUMMARY

The lattice of the ILC main linac has been developed based on current cryogenic layout. Various features resulting from the linac following the Earth's curvature have been considered, including orbit steering, dispersion matching, and synchrotron radiation. Dispersion matching bumps were optimized in order to minimize orbit excursion and bending angle. The lattice decks in XSIF format are published in the FNAL lattice repository at http://lattices.fnal.gov in the section *ilc_linac*.

REFERENCES

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