STATUS OF THE ILC MAIN LINAC DESIGN*

A. Saini†, V. Kapin, N. Solyak, Fermi National Accelerator Laboratory, Batavia, USA

Abstract

The International Linear collider (ILC) is a proposed accelerator facility which is primarily based on two 11-km long superconducting (SC) main linacs. In this paper we present recent updates on the main linac design and discuss changes made in order to meet specification outlined in the technical design report (TDR).

INTRODUCTION

The ILC is a proposed accelerator facility for the study of high energy physics via electron-positron collisions at center–of-mass energy between 200 GeV and 500 GeV. A schematic of the ILC facility is shown in Fig. 1.

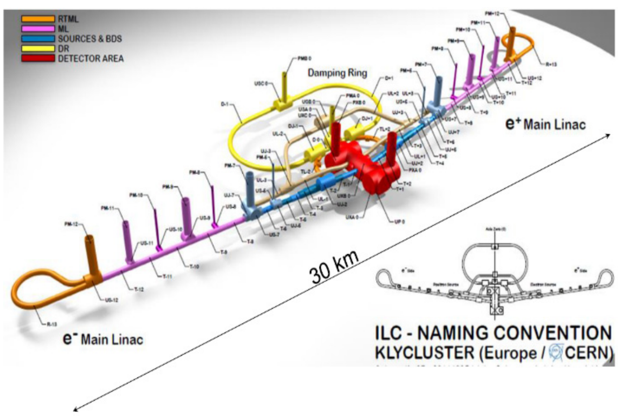

Figure 1: A schematic of ILC facility. All the main sections are presented in different colours.

The heart of the ILC facility is two SC main linacs that accelerate electron and positron from 15 GeV to their final collision energy ranging between 100 to 250 GeV. The ILC technical design report (TDR) [1] establishes technical aspects of the main linac such as geometry, cryogenic segmentation, RF distribution etc. In this paper we present a baseline configuration of the main linac that meets the TDR specifications and discuss the main linac optics.

MAIN LINAC ARCHITECTURE

Each main linac consists of approximately 7,500 nine-cell standing wave niobium cavities operating at frequency of 1.3 GHz. These cavities are installed in two variants of cryomodules named Type-A and Type-B cryomodule. Type-A cryomodule accommodates nine cavities while a Type-B cryomodule consists of eight cavities and a magnet package at the center which is comprised of a quadrupole magnet, a steering corrector magnet and a beam position monitor (BPM). Both cryomodules are approximately 12.6 m long. An arrangement of cryomodules in sequence of type-A type-B type-A forms an RF unit (also called ML unit) and therefore, two successive RF units form a FODO cell. There are 285 (282) ML units in electron (positron) linac. A group of three RF units with a 2.5m cold box at the end makes a cryo string. A periodic arrangement of cryo string is interrupted due to insertion of a 7.5m long warm section. Number of cryo strings between two successive warm sections form a cryo unit. It is comprising of between 11 to 21 cryo strings, with the final cold box being replaced by a 2.5m service box. The length of drift space between the last cryo string of a cryo unit and the first cryo string in following cryo unit is equal to a cryomodule length. Figure 2 shows a segmentation scheme in the main linac.

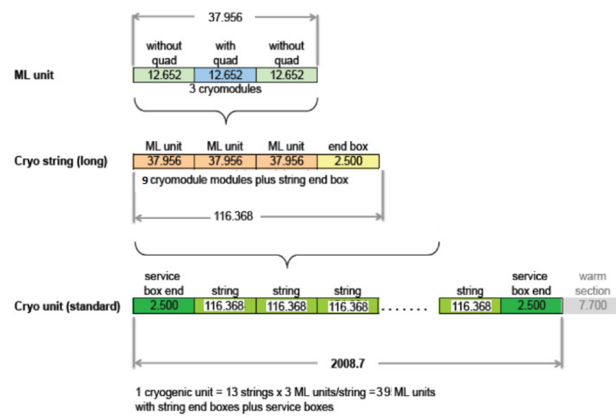

Figure 2: A block diagram of structural segmentation of the main linac.

RF power to the main linac is delivered using the Distribution Klystron Scheme (DKS) [2] which is more preferable choice over the Klystron Cluster Scheme (KCS) [3] for a mountainous topography such as the candidate sites in Japan.

EARTH CURVEATURE IMPLEMENTATION

An essential feature of the ILC linac is that it follows Earth's curvature that simplifies transport of two-phase helium at 2K. A straight variant of the main linacs needs an expensive and complex cryogenic segmentation. In order to implement Earth's curvature in the main linac lattice, a same concept as discussed in [4] is utilized. Each cryomodule in the curved linac is aligned along a line perpendicular to Earth's radius at cryomodule center. It will result in a geometrical kink at the ends of cryomodule. This kink in the lattice is incorporated using a special element in LUCRETIA [5] named GKICK. However, this element is not supported by several optics codes including MAD8 [6]. Thus, a combination of the thin vertical correctors and the thin dipole with same but opposite kick is used to produce equivalent effect. The thin dipole changes both the beam trajectory and the reference frame while the thin corrector cancels out the trajectory change and therefore, leaves only

* Work supported by Fermi Research Alliance, LLC under Contracts No. De-Ac02-07CH11359 with the DOE, USA.
† asaini@fnal.gov

a change in the beam reference frame. A flag CURVE is implemented in the lattice to turn on or off (1/0) Earth's curvature. The beam trajectory is steered through the center of quadrupole using vertical correctors in the magnet package. Because quadrupoles are available only at every third cryomodule, there is systematic offset and angle between the cryomodule axis and the beam trajectory as depicted in Fig. 3. This feature can be switched on/off by setting STEER 1/0 in the lattice.

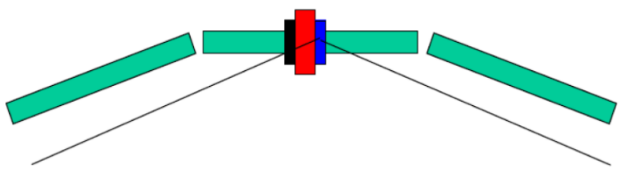

Figure 3: Implementation of curvature in lattice: Green blocks represents cryomodules, black block represents BPM while red and blue blocks represent quadrupole magnet and corrector respectively. Solid black line represents the beam trajectory.

Dispersion Matching

Ring to Main Linac (RTML) and bunch compressors do not follow Earth's curvature and therefore having zero dispersion. Similarly Beam Delivery System (BDS) after the main linac is also a straight section. This, in turn implies non-zero dispersion of the curved linac has to be matched to zero dispersion of the neighbouring sections at transitions. Furthermore, injected beam must be matched with periodic dispersion in the curve linac.

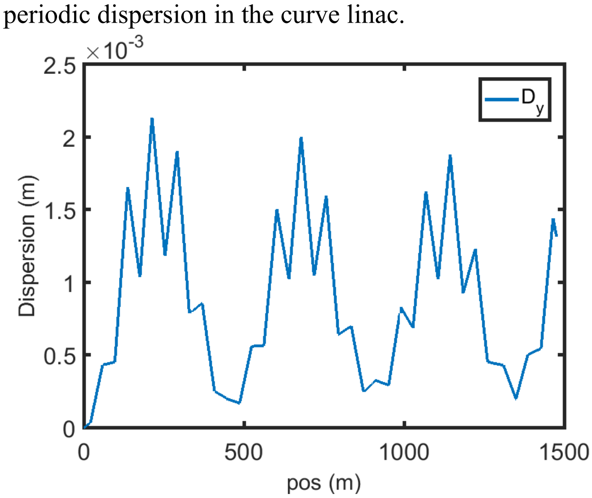

Figure 4: A zoomed view of vertical dispersion function along the first 1.5km of the linac.

The optimal periodic dispersion is achieved by minimizing its value at every defocusing quadrupole then dispersion matching and suppression at the beginning and end of the linac are achieved by supplying additional excitation to five correctors in "dispersion-bump". In order to reduce wakes effects and synchrotron radiation, beam orbit deviation is minimized during dispersion matching. Dispersion bump can be switched on (off) in the lattice by setting a flag "BUMP" to 1(0). Figure 4 shows a zoomed view of vertical dispersion in the curved linac. Figure 5 shows vertical and horizontal dispersion along the linac. It can be observed that there is no dispersion in horizontal plane. Figure 6 shows variation in dispersion derivative along the linac.

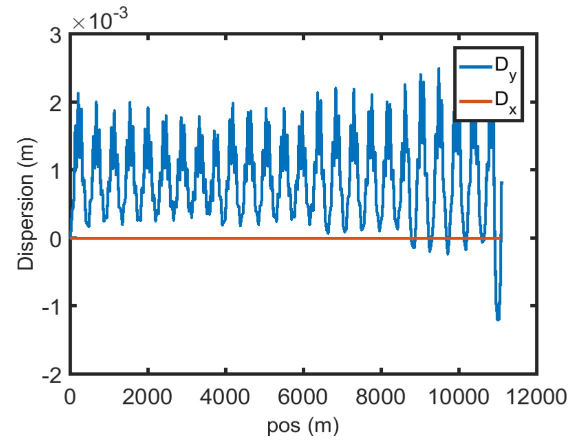

Figure 5: Horizontal (orange) and vertical (blue) dispersion functions along the main linac.

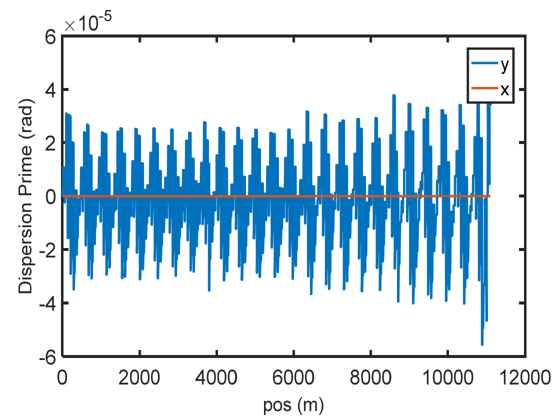

Figure 6: Dispersion derivative along the main linac.

BEAM OPTICS STUDIES

The main linac lattice is largely periodic except the interruptions imposed by warm sections between cryo units. It uses FODO optics to provide transverse beam focusing.

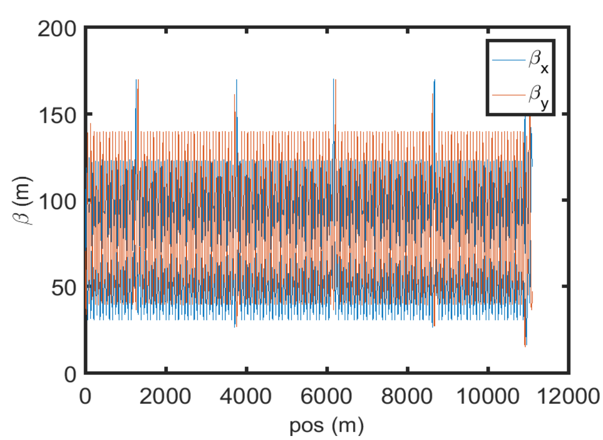

Figure 7: Lattice beta functions along the main linac.

It can be observed from Fig.7 that lattice beta functions do not vary systematically along the linac which implies that focusing strength is independent of beam energy. Average lattice beta functions are about 80m and 90m in horizontal and vertical planes respectively. Large abrupt changes in beta functions are due to perturbance in periodicity between two cryo strings. The mean phase advance per cell is 75^0 in horizontal plane and 60^0 in vertical plane.

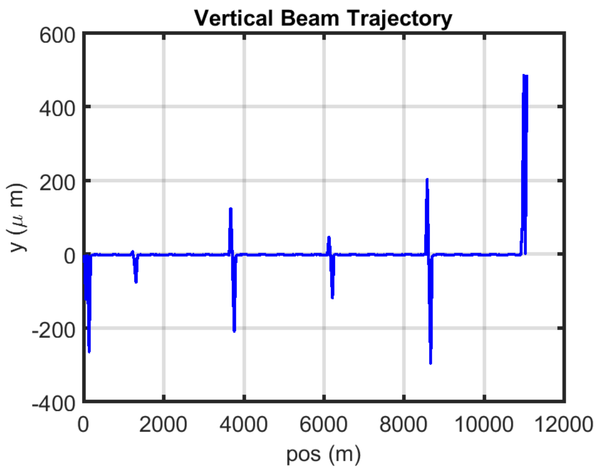

Figure 8: Vertical beam trajectory along the curved main linac.

A study is performed to analyse beam quality along the matched curved linac using a beamdynamics code LUCRETIA. A Gaussian distribution of 50k macro particles truncated at 3σ corresponding to bunch charge of 3.2nC is tracked through the main linac. Initial RMS bunch length and relative RMS energy spread are 0.3mm and 1.1 % respectively. The linac is perfectly aligned and implications of misaligned elements are excluded in this study. However, wakes fields effects are included in this simulation. Figure 8 shows vertical beam trajectory along the linac. One can observe abrupt changes in vertical beam trajectory at entrance of the main linac, transitions between cryo units and exit of the main linac.

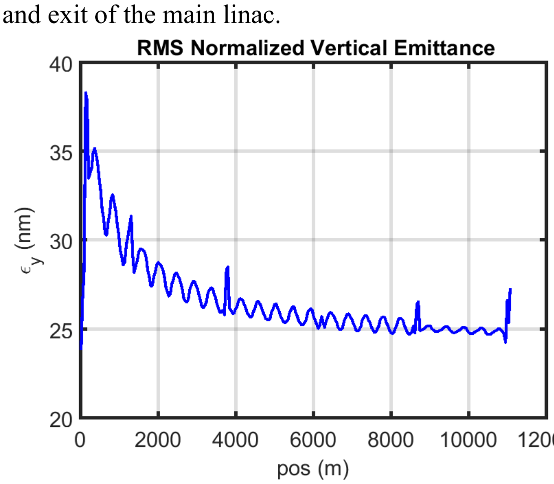

Figure 9: Projected vertical RMS normalized emittance along the curved main linac.

Horizontal and vertical normalized RMS emittance at the damping ring extraction are 8μm and 20nm respectively. An emittance budget of 20% growth in projected vertical normalized RMS emittance is allotted for bunch compressor. Thus, initial projected vertical emittance at the main linac is 24nm.

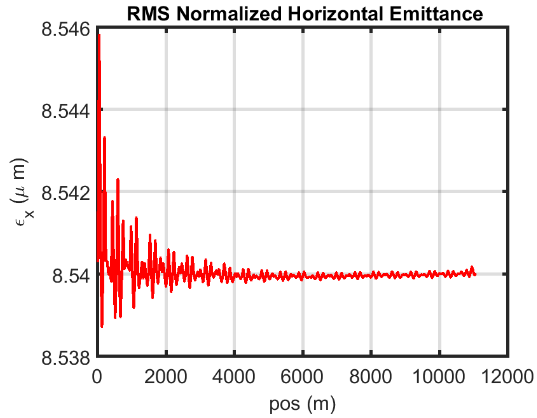

Figure 10: Projected horizontal normalized RMS emittance along the linac.

Figure 9 shows evolution of projected vertical normalized RMS emittance growth along the curved linac. Initial abrupt increase in emittance is due to dispersion matching at the entrance of linac. Similarly there is an emittance growth at the end due to a matching with following machine protection system collimator (MPSCOL) section. As shown in Fig. 10, there is no growth in horizontal emittance along the linac.

SUMMARY

A baseline configuration of the ILC main linac lattice that meets TDR specifications has been developed. Earth's curvature has been implemented in the lattice. Dispersion matching with adjacent straight sections and periodic dispersion of the curved linac have been optimized. A tracking study shows there are no significant growth in both horizontal and vertical projected emittances along the perfectly aligned linac.

REFERENCES

[1] C. Adolphsen, M. Barone, B. Barish et al., "The International Linear Collider Technical Design Report- Volume 3.1: Accelerator R&D".

[2] S. Fukuda et al., "HLRF scheme in ILC-Toward the TDR (Technical Design Report)," in Proc. 9th Annual meeting of Particle Accelerator Society of Japan, Tokoyo, Japan, Aug. 2012, pp 945-949.

[3] C. Nantista and C. Adolphsen, "Klystron Cluster Scheme for ILC High Power RF distribution," in *Proc. 23rd Particle Accelerator Conf. (PAC'09),* Vancouver, Canada, May 2009, paper WE5PFP021, pp 2036-2038.

[4] A. Valishev, N. Solyak and M. Woodley, "Status of the ILC Main Linac Lattice Design," in Proc. PAC'07, Albuquerque, New Mexico, USA, June 2007, paper THPMN109, pp 2966-2968.

[5] `http://www.slac.stanford.edu/accel/ilc/codes/Lucretia/`

[6] `http://www.slac.stanford.edu/accel/ilc/codes/mad8.51/`

ISBN 978-3-95450-169-4