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Linac, Beam Dynamics

Beam Dynamics in Curved ILC Main Linacs - 2

(following the earth curvature)

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2005.12.22 K.KUBO

This report includes corrections of the report on 2005.12.01, ILC-Asia Note 2005-23

Simulation of curved ILC Main Linac-2

- All Quad-magnets are aligned along the earth curvature, and accelerating cavities are aligned along the straight lines between quads.
- Optics is FODO as shown in Fig. 1. From 5 to 250 GeV beam energy.
- In the simulation, thin (zero-length) bending magnet is inserted at the middle of each quad.
- Strength of the bending magnets are set making the beam goes through the centers of the all quad-magnets.
- The initial dispersion (η and η') is adjusted to minimize the final 'Linear Dispersion Corrected Emittance' (see page 4), using SAD. The dispersion calculated by SAD are shown in Fig.2.
- Particle tracking with this designed linac (no error) was done using SLEPT. Initial vertical emittance, $\varepsilon\gamma 0$=2E-8 m and initial energy spread 2.8%. Fig. 4 shows vertical 'Projected Emittance' along the linac. Fig. 5 shows vertical 'Linear Dispersion Corrected Emittance' along the linac. 'Linear Dispersion Corrected Emittance' increase is very small (1%).
  - The same calculations and tracking had been done using SAD with zero initial dispersion (no initial dispersion adjustment). The results were shown in Fig. 4 of the previous report, reference [2]. It had large dispersion and 55% emittance increase.
  - (Dispersion matching was suggested by N. Walker and P. Tenenbaum.)
  - Special orbit, which was suggested by the reference [2], was turn out to be not necessary.
- Simulation using SLEPT including alignment errors and orbit correction was done. The results were compared with simulation of a laser straight linac. There was no significant difference. See Fig. 5.

Simulation of curved ILC Main Linac-2 (continued)

- Effects of magnet strength fluctuation were also checked. Vertical beam position and angle changes were calculated using SLEPT, due to magnet strength errors. Fig. 6a shows change of beam center, average of 100 random seeds.
- Random strength error should be less than 0.002% to keep the average beam offset less than 0.14 σ (Jy/e < 0.14^2), which corresponds to luminosity reduction of about 3%. This is relevant only for jitters faster than orbit feedback.
- Fig. 6b shows expected (average of 100 random seeds) emittance increase due to magnet strength error, simulated using SLEPT. To make the average of $\Delta\varepsilon/\varepsilon_0$ less than 0.063, the strength error should be less than 0.4%, which corresponds to luminosity reduction of about 3%. This is relevant for jitters or drifts faster than emittance corrections in the main linac.

Reference:

[1]: “Following Earth Curvature”, talk by N.Walker, in 2nd ILC Workshop, Snowmass, 2005,

[2]: “Beam Dynamics in Curved ILC Main Linac”, by k. Kubo, ILC-Asia Note 2005-23

Fig. 1,
Beta function along the linac

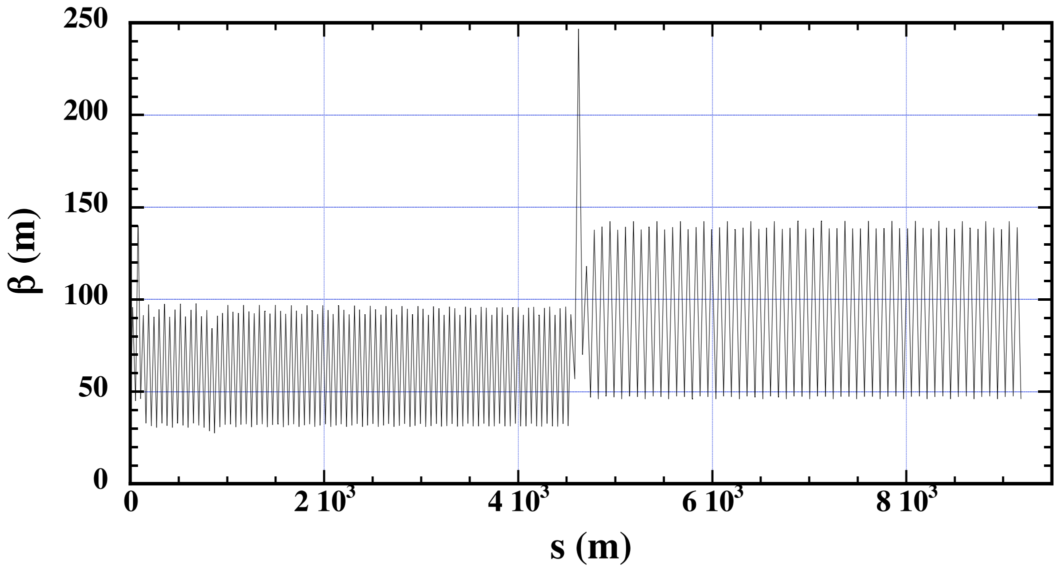
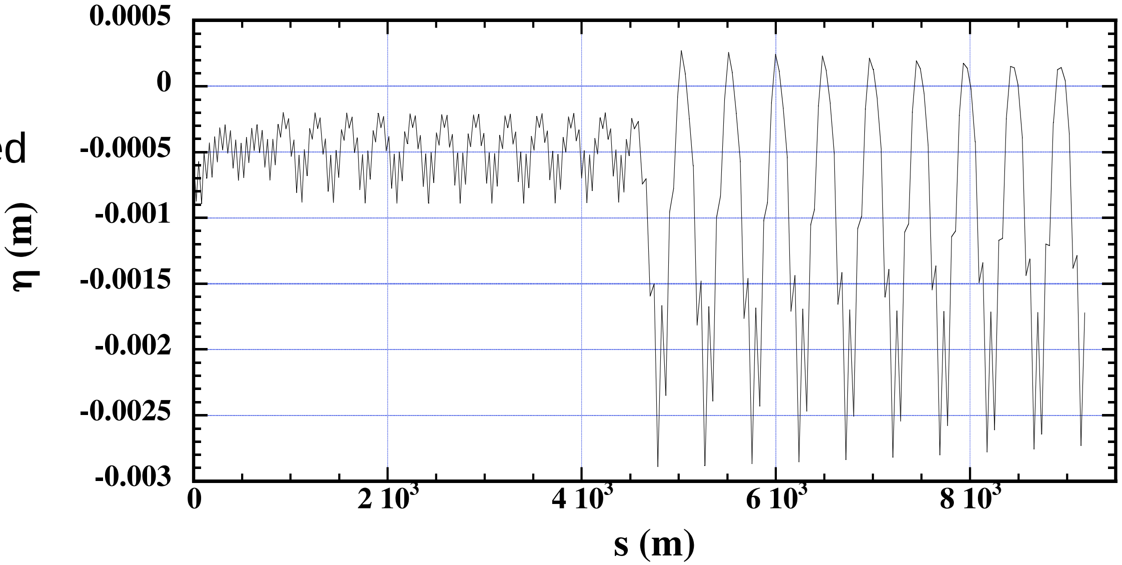


Fig. 2,
Dispersion along the linac
(Initial dispersion is optimized to minimize the emittance growth.)



Projected emittance and
Linear Dispersion Corrected emittance

Projected emittance

$$\equiv \sqrt{(<y^2> - <y>^2)(<y'^2> - <y'>^2) - (<yy'> - <y><y'>)^2}$$

Linear Dispersion Corrected emittance

$$\equiv \sqrt{(<(y-\eta\delta)^2> - <y-\eta\delta>^2)(<(y'-\eta'\delta)^2> - <y'-\eta'\delta>^2) - (<(y-\eta\delta)(y'-\eta'\delta)> - <y-\eta\delta><y'-\eta'\delta>)^2}$$

y: Vertical offset, y': Verticale angle

δ: Relative energy deviation

$\eta \equiv (<y\delta> - <y><\delta>)/(<\delta^2> - <\delta>^2)$, $\eta' \equiv (<y'\delta> - <y'><\delta>)/(<\delta^2> - <\delta>^2)$

$< >$: Average over all macro - particles

Fig. 3,
Projected emittance along the linac.

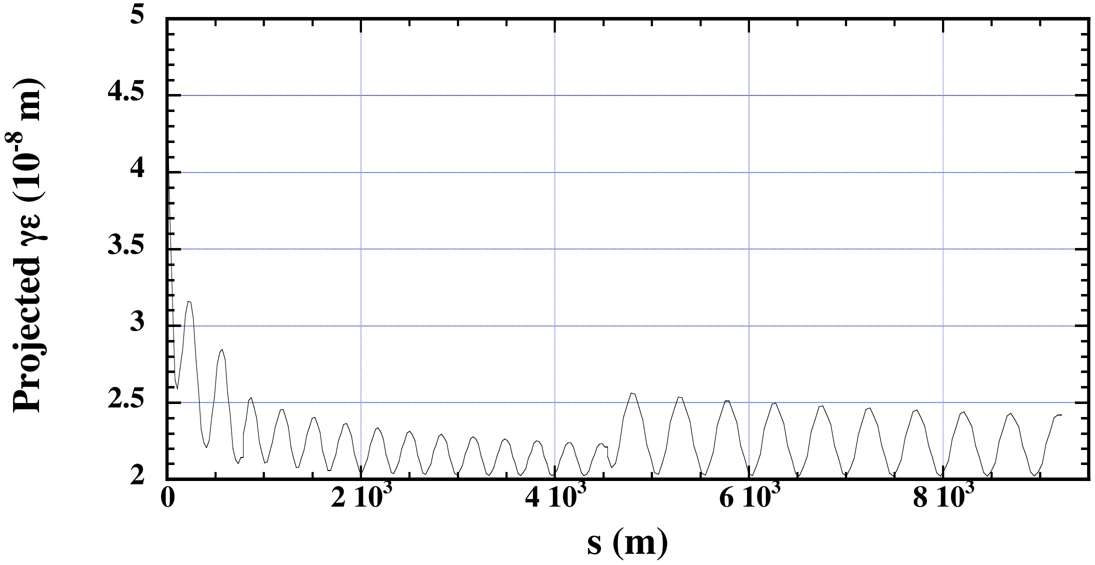


Fig. 4,
'Linear Dispersion corrected' emittance along the linac.

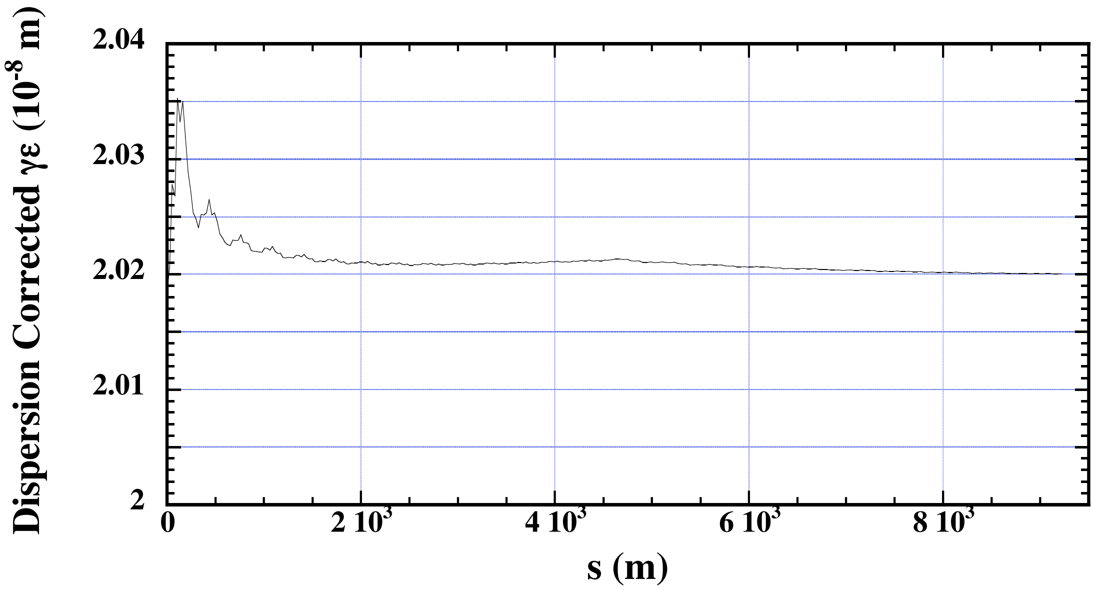
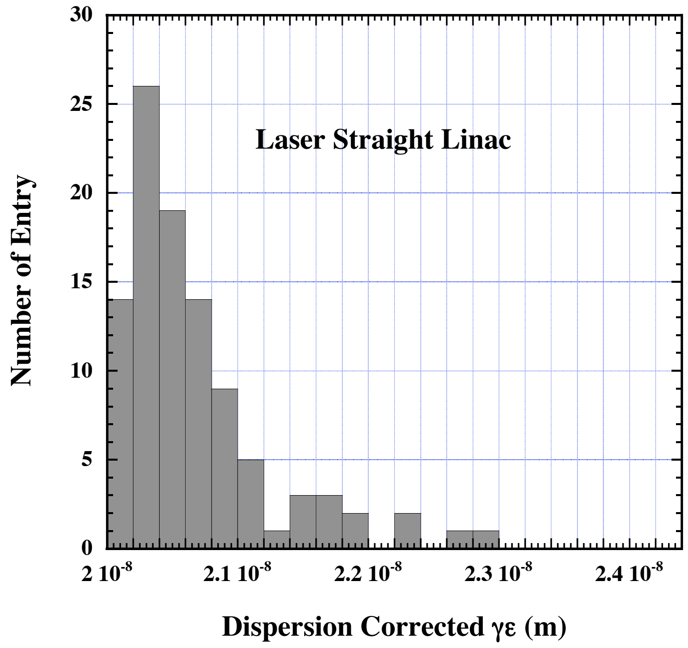
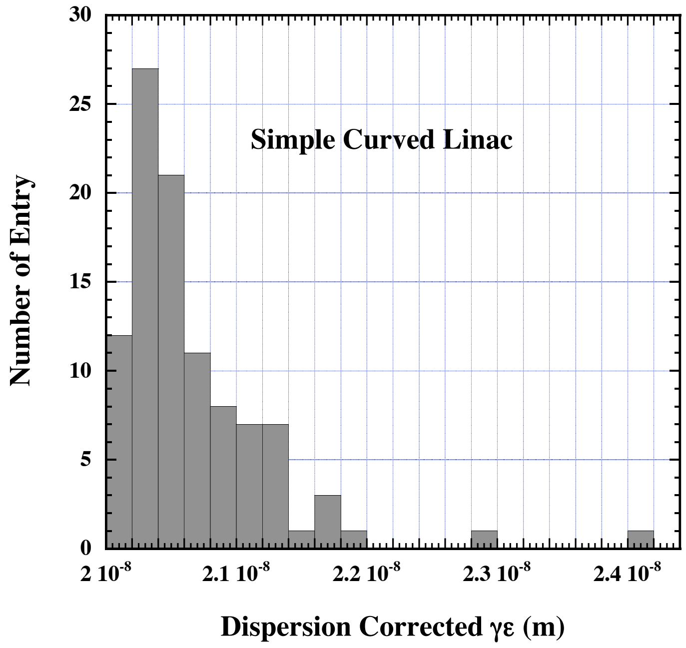


Fig. 5,
Distribution of emittance (simulated using SLEPT)

Quad and cavity misalignment (offset) 200 um
BPM-Quad offset 10 um,
BPM resolution 5 um

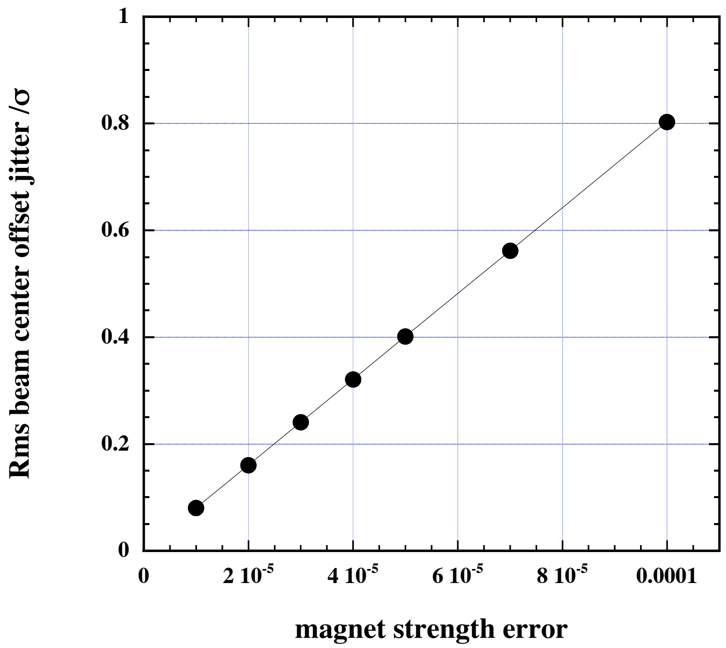
Laser Straight Linac (left) and
Curved Linac (right)



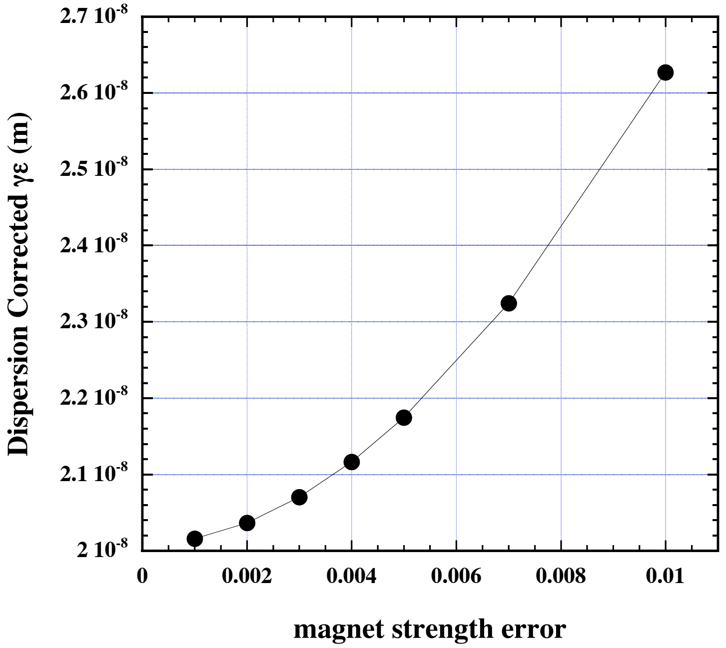


Effects of the magnet strength jitter. (simulated using SLEPT)
Fig. 6(a) Motion of the beam center and
Fig. 6(b) Emittance growth vs. relative magnet strength error.

(a)



(b)



Summary

- Simulations were done for a 5 GeV to 250 GeV beam energy linac, assuming all Quad-magnets are aligned along the earth curvature and accelerating cavities are aligned along the straight lines between quads. Initial dispersion adjustment ('matching') was assumed.
- Emittance increase was small without errors.
- Emittance increase with misalignments and orbit correction in the curved linac and the laser straight linac were almost the same.
- Special design orbit, which was suggested by the previous report (ref.[2]) was turn out to be not needed.
- Tolerance of random magnet strength jitter (magnet by magnet independent) for beam center offset less than 0.14 σ (about 3% luminosity reduction) will be about 0.0017%. (This is relevant only for jitters faster than orbit feedback.)
- Tolerance of random magnet strength jitter for emittance increase less than 0.063 ε_0 (about 3% luminosity reduction) will be about 0.4%.
- The results suggests: Curved Linac (following earth curvature) will be fine, if magnet strength can be stable enough.