ILC-Asia-2005-08
May 16, 2005
Linac, Beam Dynamics

Tolerances of Misalignment of Quads and Cavities of ILC Main Linac

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This report will be available as
http://lcdev.kek.jp/~kkubo/reports/MainLinac-simulation/lcsimu-20050516.pdf
This report follows “Emittance dilution due to misalignment of quads and cavities of ILC main linac - 20050325”, [1],

References

[1], http://lcdev.kek.jp/~kkubo/reports/MainLinac-simulation/lcsimu-20050325a.pdf

- For beam energy 250 GeV, two optics for 35 MV/m; (a) ‘weaker focus’ and (b) ‘stronger focus’, were tested in some caes as shown in Fig. 1, as smame as the previous report.
- Tracking simulation was done using SLEPT. Beam parameters were; single bunch, 2E10 particles/bunch, bunch length 0.3 mm (rms), initial energy 5 GeV, initial uncorrelated energy spread 2.8%(rms), initial normalized emittance 2E-8 m.
- Offset misalignment of quads, offset misalignment of cavities, tilt misalignment of cavities, quad-BPM offset (unknown error of BPM offset with respect to the field center of quad) and BPM resolution (measurement by measurement error) were set as gaussian random.
- Only single bunch effects were considered and short range wakefunctions in TESLA-TDR were used.
- Average of vertical emittance at the end of the linac over 100 different random seeds is presented for each condition.
- Fig. 2 shows emittance as function of cavity offset, quad offset and cavity tilt, without any corrections. The results will give rough tolerances for fast movement (in time scale faster than corrections in the main linac and slower than orbit feedback at IP); Quad offset: a few tenth of microns, Cavity offset: a few hundred microns, Cavity tilt: a few microns. Since the length of the cavity is about 1 m, tolerance of tilt error is tighter by two order than offset error.
- Steering Correction is described in page 4, as same as the previous report [1]. Every quad was assumed to have a BPM and a steering. This correction is combination of 1-to-1 correction (the orbit goes through the center of every quad) and a correction which makes kicks at quads (kicks by quad field and steering) minimum. Because this correction is not effective for cavity tilt, another method was tested as follows
- “Tilt Compensation + Steering Correction” is described in page 5 and 6. Transverse kick due to cavity tilt is compensated by steering near the cavities. RF cavities in a short section should be turned off to measure the orbit change due to the tilts in the section. Ten downstream BPMs are used for measurement of the orbit change and two steerings in the section are used for the compensation. Magnet strength and accelerating voltage in he relevant region should be scaled to the changed beam energy for accurate measurement. One FODO cell is chosen as this “section” and there were 142 sections in the simulated cases. Several iterations of “Tilt Compensation” and “Steering Correction” (here, four times) are needed to obtain good results.

- Fig. 4 shows emittance as function of cavity tilt angle, in the cases with "Tilt Compensation + Steering Correction" and with only Steering Correction. Quad offset 300 micron, Cavity offset 300 micron Quad-BPM offset error 20 micron and BPM resolution 3 micron were assumed. Only "weaker focus" optics was tested. This will give tolerance of static (in time scale slower than the correction) misalignment. Tilt Compensation makes the tolerance of cavity tilt significantly relaxed. The tolerance will be, roughly speaking, a few hundred micro-radian.
- Fig. 5 shows emittance as function of cavity tilt angle, in the cases with "Tilt Compensation + Steering Correction". Quad offset 300 micron, Cavity offset 300 micron Quad-BPM offset error 20 micron and Cavity tilt 300 micro radian were assumed. BPM resolution of a few micron will be good enough.
- As a summary of the previous report and this report, rough alignment tolerances will be as in the Table 1.
- The results also give a requirement for stability of accelerating voltage. If there are static tilt errors of the cavities, fast jitter of the accelerating voltage will have the same effect of the fast tilt movement. Since the estimated tolerance of fast tilt movement is a few micro-radian, the tolerance for RF voltage jitter will be about 1%, if the static tilt is a few hundred micro-radian.

Table 1, Rough tolerances.

Static misalignment (Slower than the correction in the main linac)	
Quad offset	A few 100 μm
Cavity offset	A few 100 μm
Cavity tilt	A few 100 μrad
Quad - BPM offset	A few 10 μm
Fast movement (Faster than the correction in the main linac but slower than the orbit feedback at IP)	
Quad offset	A few 0.1 μm
Cavity offset	A few 100 μm
Cavity tilt	A few 1 μrad
Mmeasurement by measurement	
BPM Resolution	A few 1 μm

Fig.1, Optics

Square root of beta-function of three models;
(a) 35 MV/m weak focussing
from 5 GeV to 125 GeV: 2 modules/quad
from 125GeV to 250 GeV: 3 modules/quad
(b) 35 MV/m strong focussing
from 5 GeV to 125 GeV: 1 modules/quad
from 125GeV to 250 GeV: 2 modules/quad

(a) Will be better

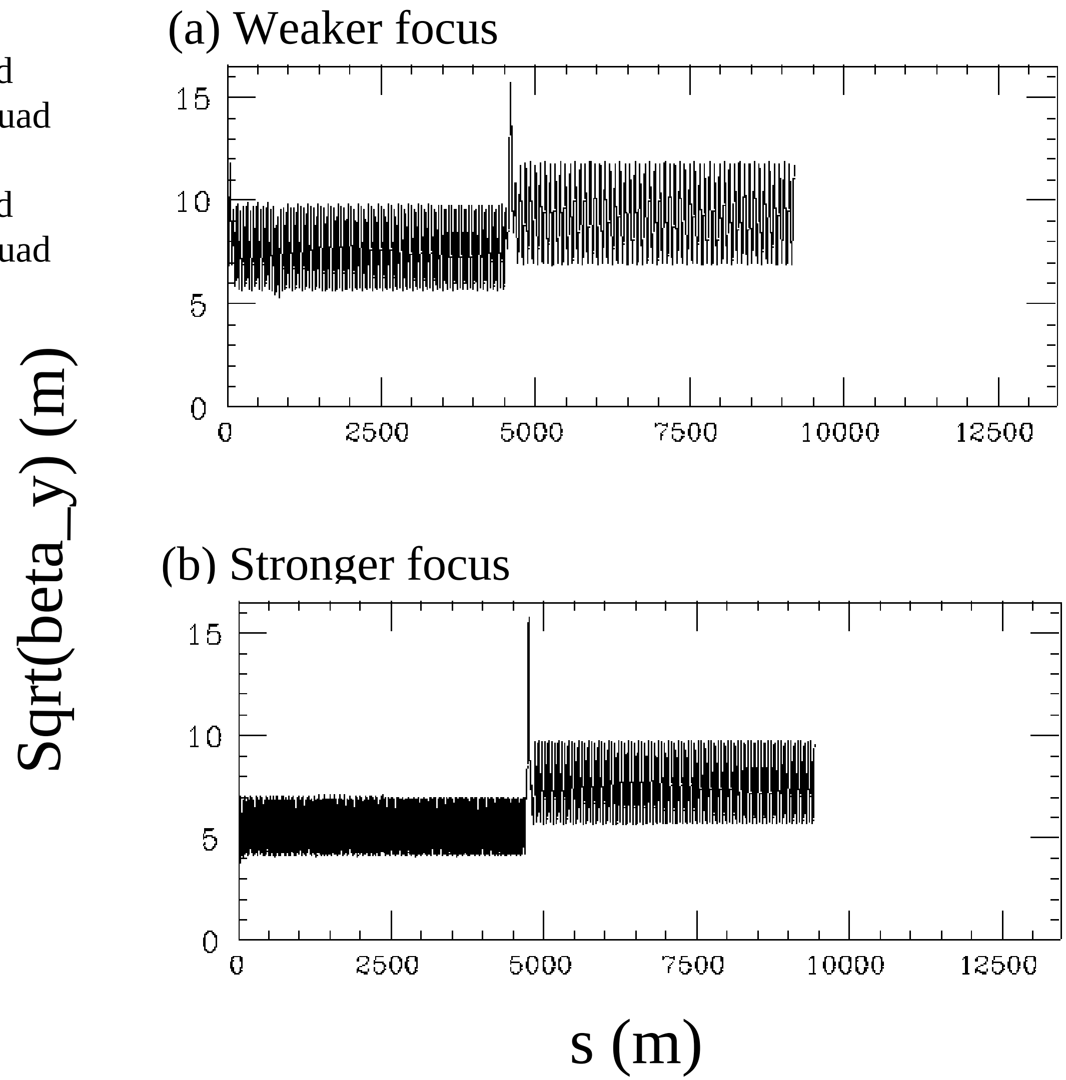
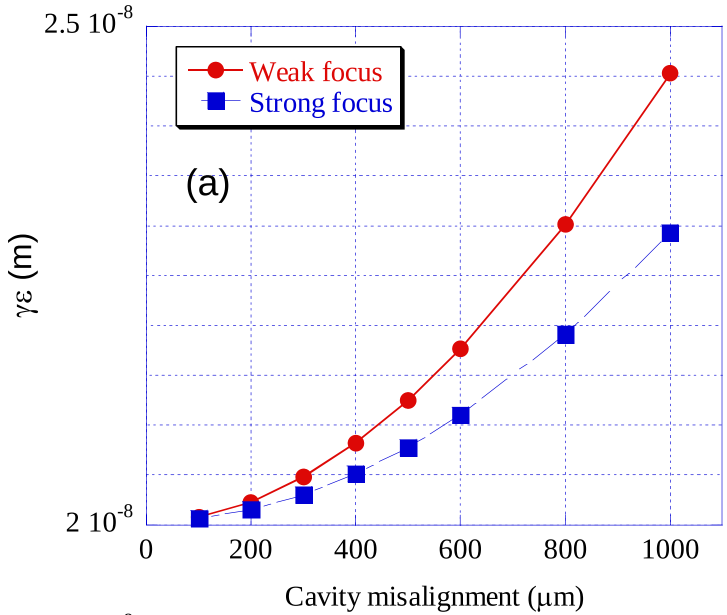
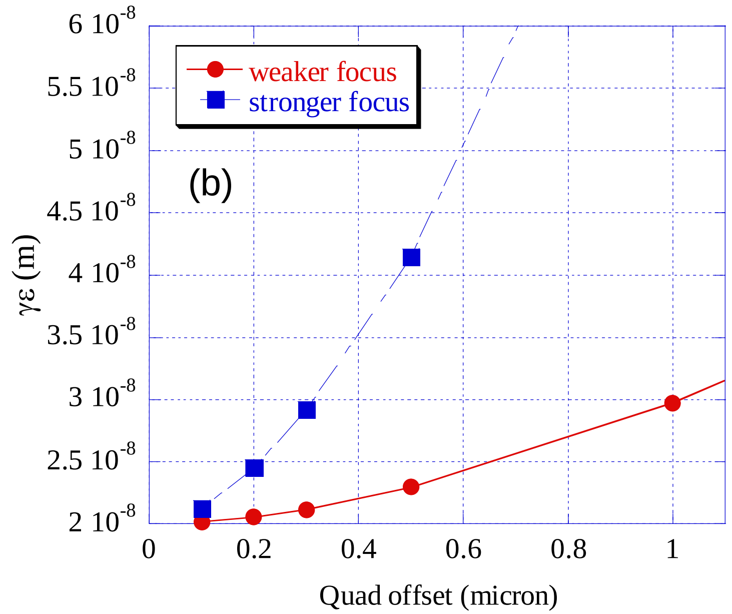
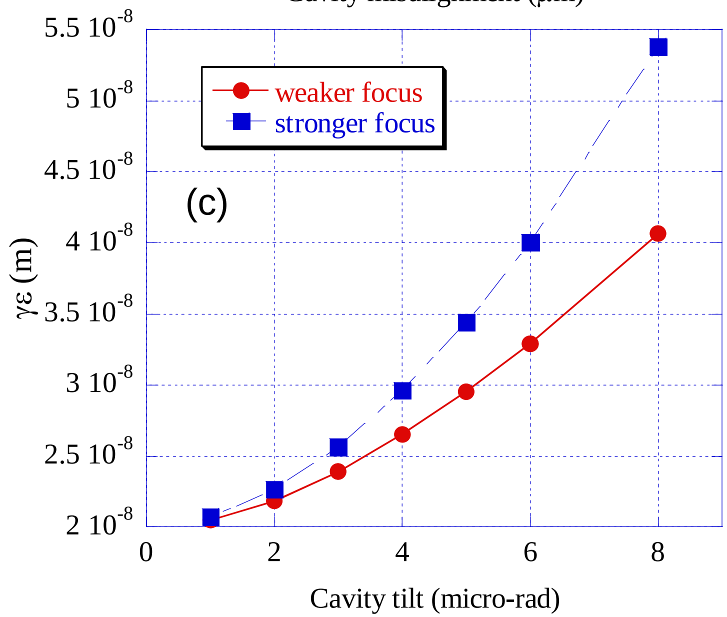


Fig. 2, Emitttance vs. cavity offset, quad offset and cavity tilt. No correction.







These give tolerances in time scale faster than corrections in the main linac and slower than orbit feedback at IP.

Steering Correction

Use steering, or correction coils of quads.
Every quad has a BPM and a correction coils.

$$\text{Minimize } \sum_i r^2 y_i^2 + \sum_i \left(\theta_i - k_i y_i\right)^2,$$

θ_i : kick angle of steering at i-th quad

y_i : BPM reading at i-th quad

k_i : K-value of the i-th quad

r : Weight ratio. $= 10^{-3}$

Not very effective for cavity tilt.

Tilt Compensation + Steering Correction

(1) Perform steering correction

(2) Turn off RF of cavities in one FODO cell (40 or 60 cavities for weaker focus optics), scale the strength of magnets and accelerating voltage of downstream RF cavities to the beam energy, and measure orbit difference from nominal orbit.

Then, set two steerings (at quad in the cell) to compensate the difference.

Perform this for every cell.

(3) Perform steering correction again keeping the compensation,

$$\text{Minimize } \sum_i r^2 y_i^2 + \sum_i \left(\theta_i - \theta_{ti} - k_i y_i\right)^2,$$

θ_{ti} : kick angle for cavity tilt compensation at i-th quad

(4) Iterate (2) and (3) four times for better compensation

Fig. 3, Tilt Compensation

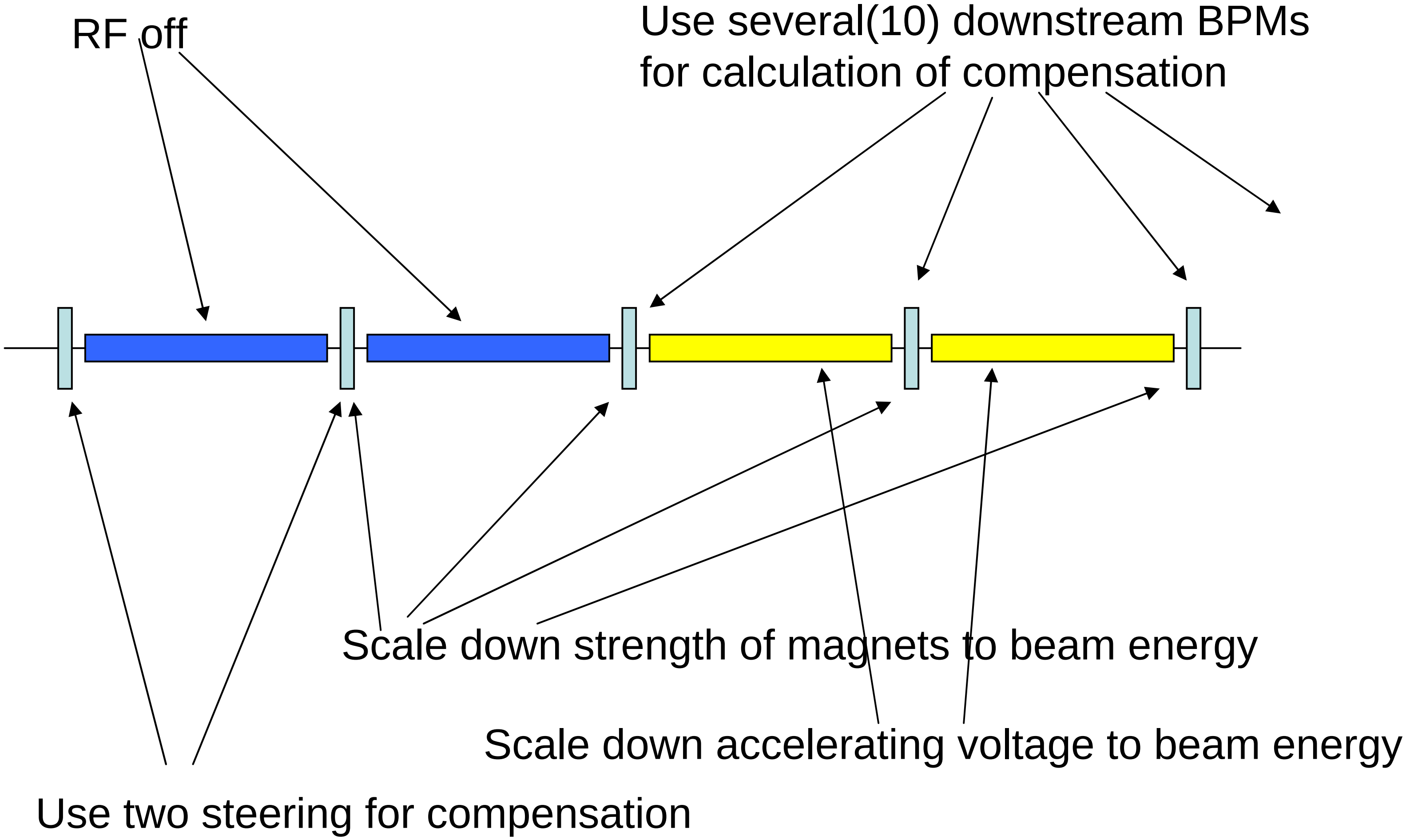
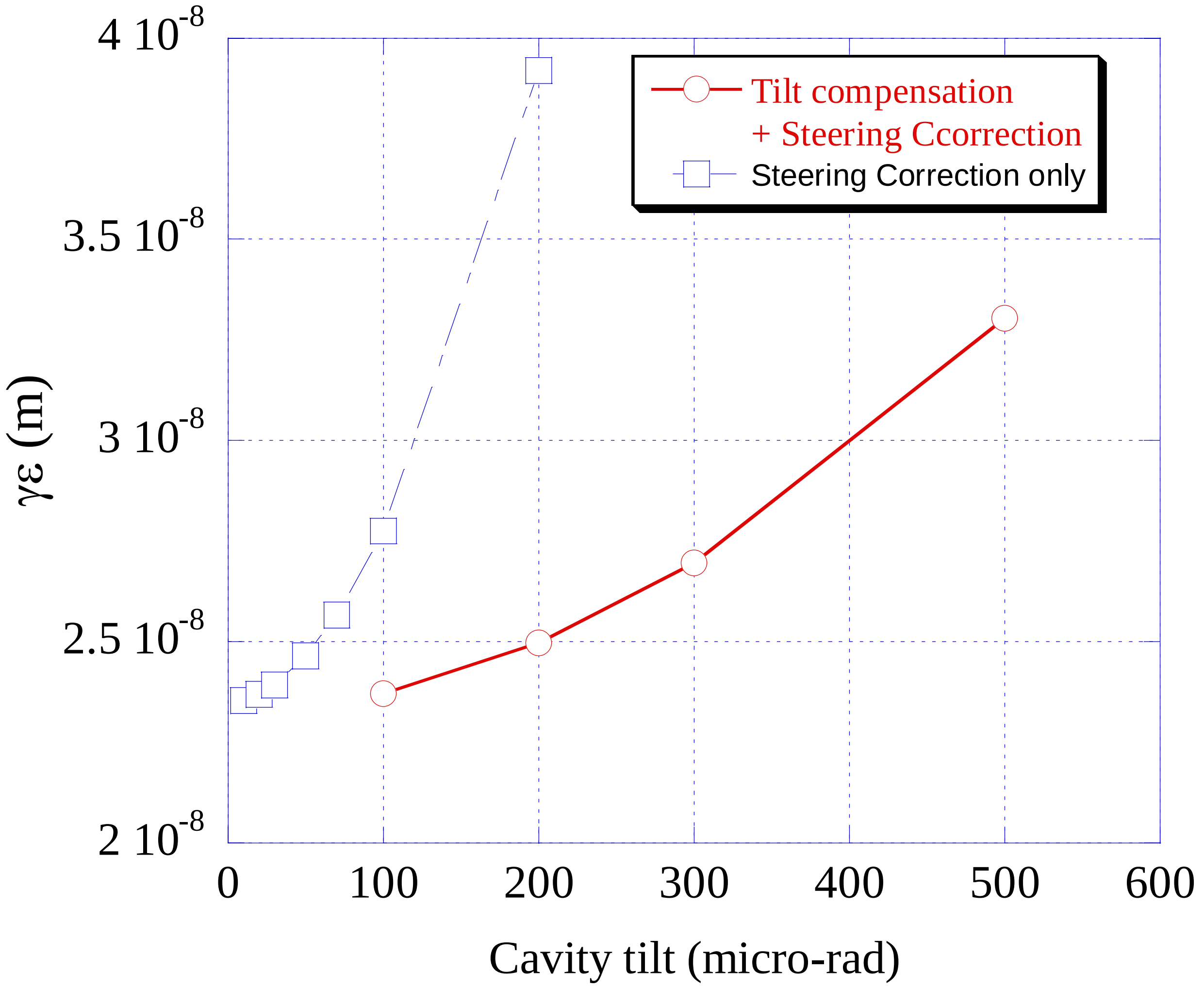


Fig. 4, Emittance vs. cavity tilt angle.
Quad offset 300 micron, Cavity offset 300 micron
Quad-BPM offset error 20 micron, BPM resolution 3 micron



Emittance vs. cavity tilt angle.
Quad offset 300 micron, Cavity offset 300 micron
Quad-BPM offset error 20 micron, Cavity tilt 300 micro-rad