Rough Estimation of energy spread produced in Final Focus line and effects to chromatic correction in ILC and ATF

201301018

minor change 201402

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Energy change after bend in FF affect chromatic correction

- Energy changes after bending magnet (for dispersion creation) in FF affect chromaticity correction [1]
- Energy dependent horizontal displacements at sextupole magnets deviate from design (smeared)

- For perfect chromaticity correction, energy of each particle should not change in designed dispersive (non-zero horizontal dispersion) region
- Beam size is expressed as

$$\sigma_y \approx \sigma_{y,0}\sqrt{1+\xi^{*2}\,\delta^2}$$

$\sigma_{y,0}$: beam size with perfect chromatic correction

$\xi^* = L^*/\beta^* \approx 10000$ (both in ILC and ATF2)

δ : rms of induced energy spread

- Relative energy change should be much less than 1E-4

Possible sources of energy change in FF

- Space charge
- Resistive wall wake
- Structure (discontinuities) wake
  - Crab cavity
  - Cavity BPM
- Synchrotron radiation
  - Incoherent (SR)
  - Coherent (CSR)

Each effect is (very roughly) estimated as follows.

Roughly estimated energy spread induced by each effect,
Relative to beam energy, which should be compared with

$1/\xi^* \sim 1\mathrm{E}-4$

	ILC BDS	ATF2
Space charge	7E-11	2E-9
Resistive wall wake	1.1E-5	2.4E-7
Incoherent SR*	1.5E-5	< 4.2E-7
Coherent SR	< 1.3.E-6	< 1.8E-6
Crab cavities wake	1E-6	- - -
Cavity BPM wake	1.4E-5**	5E-6

* This effect is included in ILC FF design

** If similar design of ATF, scaled ½, used

See next 8 pages for estimation of each effect

Space charge

Longitudinal electronic field is roughly [2],

$$E_s \approx \frac{2}{\gamma^2}\lambda'(z)\ln\frac{b}{a}$$

$\lambda(z)$: charge line density of bunch,

γ : energy factor,

b : radius of beam pipe,

a : radius of beam

$$\max.\lambda'(z) \approx \frac{qe^{-1/2}}{\sqrt{2\pi}\sigma_z^2}$$ for Gaussian bunch with charge q and length σ_z

	ILC BDS (E_b 100GeV)	ATF2
q (C) / σ_z (m) / γ	3.2E-9 / 3E-4 / 2E5	1E-9 / 7E-3 / 2.6E3
b (m) / a (m)	5E-3 / 1E-6	12E-3 / 1E-6
max. E_s (V/m)	5.5E-3	0.13
Relevant beamline length (m)	500	21
$\delta = eE_sL/(mc^2\gamma)$	7E-11 (for 100 GeV)	2E-9

Negligible

Resistive wall wake [2, 3, 4]

Standard deviation of energy loss of Gaussian bunch beam due to resistive wall wake is approximately

$$\delta E \approx 1.1 \times eq\kappa$$

where, κ is the loss factor which is approximately

$$\kappa = \frac{\Gamma(3/4) c Z_0^{1/2} L}{4\sqrt{2}\pi^2 b \sigma_z^{3/2} \sigma^{1/2}}$$

q : bunch charge
b : radius of beam pipe,
σ_z : rms bunch length
σ : conductivity of pipe wall
L : Length of beam pipe
Z_0 : vacuum impedance, $= 120\pi\ \Omega$
$\Gamma(3/4) \approx 1.225$

	ILC BDS (E_b 100GeV)	ATF2
q (C) / σ_z (m) / γ	3.2E-9 / 3E-4 / 2E5	1E-9 / 7E-3 / 2.6E3
b (m)	5E-3	12E-3
σ (Ω^{-1}m^{-1})	5.9E7 (Copper)	1.4E6 (Stainless)
κ/L (V/m/nC)	640	15
Relevant beamline length, L	500	21
$\delta E/E$	1.1E-5 (for 100 GeV)	2.7E-7

Incoherent SR

Energy spread increase in bending field is roughly,

$$\Delta E^2 \approx \frac{55e^2\hbar c}{24\sqrt{3}}\frac{\gamma^7 L}{\rho^3}$$

γ : energy factor

L : length of bending magnet

ρ : curvature radius

There are three different types of bending magnets.

	ILC BDS (E_b 250GeV)	ATF2
γ	4.9E5	2.6E3
ρ of bends (m)	2.0E4/2.4E4/6.7E4	min. 11.6
L of bends (m)	24/26.4/14.4	Total 1.8
Sqrt(ΔE^2) (eV)	3.8E6	< 5.4E2
δ ~ sqrt(ΔE^2)/($mc^2\gamma$)	1.5E-5	< 4.2E-7

(This effect is already included in ILC FF design.)

Coherent SR

The effect is expressed as a wakepotential, which is roughly [3],

$$W \approx \frac{Z_0 c}{4\pi\sigma_z^{4/3}\rho^{2/3}}$$

Z_0 : vacuum impedance

σ_z : bunch length

ρ : curvature radius

Energy change is wakepotential times bunch charge times length,

$$\Delta E \approx qLW$$

	ILC BDS (E_b 100GeV)	ATF2
q (C) / σ_z (m) / γ	3.2E-9 / 3E-4 / 4.9E5	1E-9 / 7E-3 / 2.6E3
min. ρ (m)	2E4	19
W (V/C/m)	6.1E11	1.3E12
Total bend length, L (m)	65	1.8
ΔE (eV)	< 1.3E5	< 2.3E3
$\delta \sim \Delta E/(mc^2\gamma)$	< 1.3.E-6	< 1.8E-6

Wakefield of structures, discontinuities

- Crab cavities (only in ILC BDS, not in ATF2)
- Cavity BPM
- Other discontinuities

Crab cavity in ILC BDS

- Loss factor of a crab cavity was estimated as 23.5 V/pC in the reference [5].
- There will be two cavities per beam, and for 3.2 nC bunch, energy change will be about 150 keV.
- Which is order of a 1E-6 of the beam energy.
- Not significant.

Cavity BPM – ATF2

ATF2

- Longitudinal wakepotential of a reference cavity of BPM system (aperture 16 mm) in ATF2 was calculated as about 0.7 V/pC
  - for 7 mm length bunch [6].
  - Scaling for dipole cavity (aperture 20 mm), $0.7 \times (16/20)^2 \sim 0.45$ V/pC
- Energy change in one BPM is about 0.45 keV for 1nC bunch.
- Total about 14 BPMs in the relevant beam line
  - energy change is about 6.3 keV, about 4.8E-6 of the beam energy.
- Not significant compare with 1E-4 (1/chromaticity)

Cavity BPM - ILC

ILC BDS (Rough Scaling from the ATF2 case)

- Assume similar BPM design, scaled by the aperture (~1/2), and similar number of BPMs, wakepotential scale as aperture^(-2),

  → factor 2^2

- Bunch length 0.3 mm, bunch charge 3.2 nC, assume proportional to line density,

  → factor (7/0.3)x(3.2/1)

- Beam energy ~100 times higher → factor 1/100
- Total factor is about 3 and relative energy change will be 1.4E-5
- It may have a small visible effect.
  - May use BPM with larger aperture.
  - Or may use stripline BPM for large beta locations.

Wakefield of other discontinuities

- Strength of additional Wake is expected to be comparable to or smaller than that of cavity BPM.
- In ATF2, it will not be significant.
- In ILC BDS careful design is required.

SUMMARY

- Energy change after the first bend in FF line can affect beam size at IP. Relative energy change should be much smaller than 1/chromaticity ~ 1E-4.
- Rough estimation of space charge, resistive wall wake, structure (crab cavity, cavity BPM) wake, incoherent radiation and coherent radiation are made.
- For ILC BDS FF,
  - Resistive wall wakefield (5 mm radius, 500 m long copper pipe) and Incoherent synchrotron radiation have some effects.

    $$\text{Resistive wall}: \xi * \delta \sim 0.11, \quad \text{beam size increase} \sim 0.6\%$$

    $$\text{Incoherent SR}: \xi * \delta \sim 0.15, \quad \text{beam size increase} \sim 1\%$$

  - Wakefield of cavity BPMs and other discontinuities may have some effects (~1% beam size increase, if simply scaled from ATF2 cavity BPM). Careful design required for BPMs and beam pipe.
  - Other effects will be small.
- For ATF2 FF
  - All effects are small.

References

[1] K. Oide, private communication.

[2] A. Chao, “Physics of collective beam instabilities in high energy accelerators”

[3] “Handbook of Accelerator Physics and Engineering” , ed. A. Chao, et.al..

[4] K. Yokoya, private communication.

[5] C. Adolphsen et al., “Design of the ILC crab cavity system,” EUROTEV-REPORT-2007-010 (2007), DOI: 10.2172/915387.

[6] A. Lyapin, http://atf.kek.jp/twiki/pub/ATF/Atf2Wakes/atfCrefWakeLBL7.pdf