Lattice Sensitivity and Tuning Studies for Linear Collider Damping Rings

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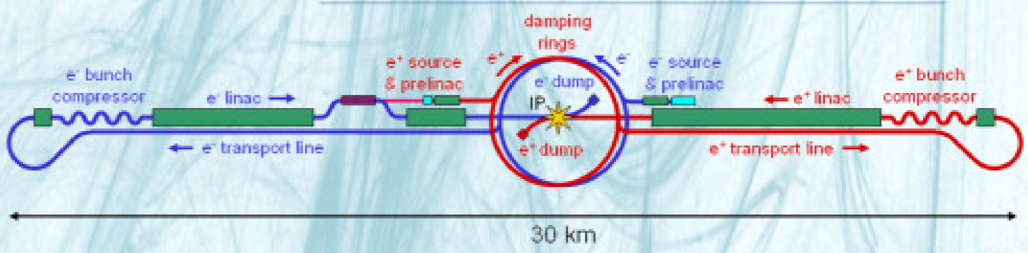
The Basic Idea of Accelerators

The higher the energy of the accelerator the smaller the fragments of matter we are likely to obtain. These fragments and their trajectories are then reconstructed and studied by particle physicists in order to verify existing theories and/or create new ones.

An accelerator smashes particles . Depending on the type of particles to be accelerated different types of accelerators are designed and built.

Suggested Design of a Linear Collider



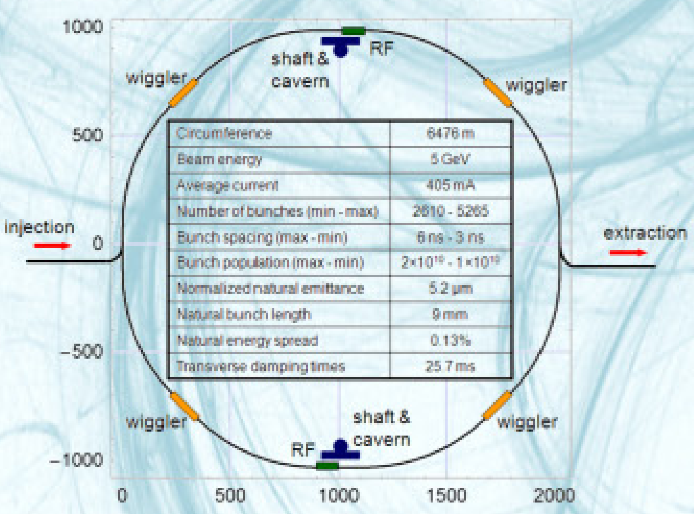
- In reality, accelerators are far more complicated than a hammer and designing and operating one often push technology and engineering to the absolute contemporary limits.
- A Linear Collider is a proposed facility that will help the advancement of research in fundamental particle physics by providing answers to questions about the origin of mass, dark matter in the universe and folded dimensions.
- The global particle physics community agrees that a precision machine of this kind will help us gain a better understanding of what the universe is made of and provide exciting new insights into how it works.
- Critical components in such a machine are the Damping Rings, which serve the task of increasing the beam quality in order to achieve the desired high luminosity.

Project Objectives

This project addresses the various issues that affect the beam quality in the damping rings of a linear collider:

- **Characterization of the machine sensitivity to errors of various kinds.**
- **Optimization of the design to minimize sensitivity to different types of error.**
- **Testing of various tuning procedures and algorithms, taking into account performance of the diagnostics.**
- **Specification of alignment tolerances, diagnostics performance, and tuning and correction procedures.**

The ILC Damping Rings Baseline Configuration

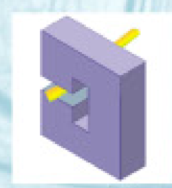


Circumference	6476 m
Beam energy	5 GeV
Average current	405 mA
Number of bunches (min - max)	2610 - 5265
Bunch spacing (max - min)	6 ns - 3 ns
Bunch population (max - min)	2×10^{10} - 1×10^{10}
Normalized natural emittance	5.2 µm
Natural bunch length	9 mm
Natural energy spread	0.13%
Transverse damping times	25.7 ms

Types of Magnets used in a Damping Ring

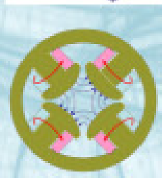
- **Dipole Magnets**

  These are used to bend the beam. The principle error here is the roll of the magnet around the beam axis, leading to the magnet steering the beam in the "wrong" direction.



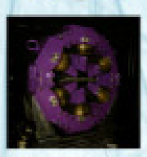
- **Quadrupole Magnets**

  Their purpose is to focus the beam. Roll of the magnet is a major concern here as well, as it leads to coupling between the vertical and horizontal beam sizes.

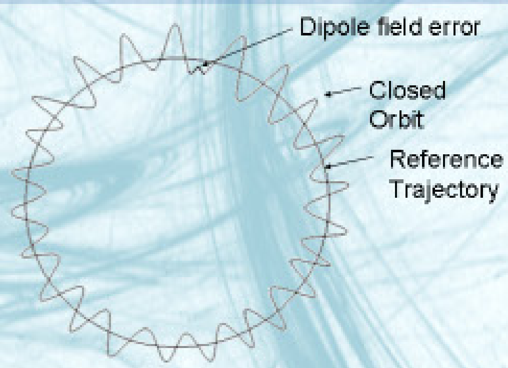


- **Sextupole Magnets**

  They are used to correct the chromaticity. Coupling between the vertical and horizontal beam sizes is the result of vertical sextupole misalignment.



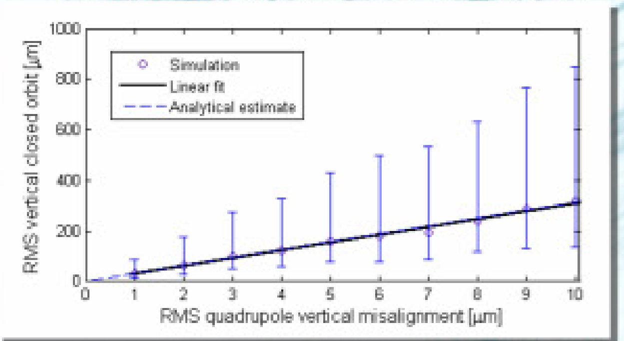
Particle Trajectory and Steering Errors



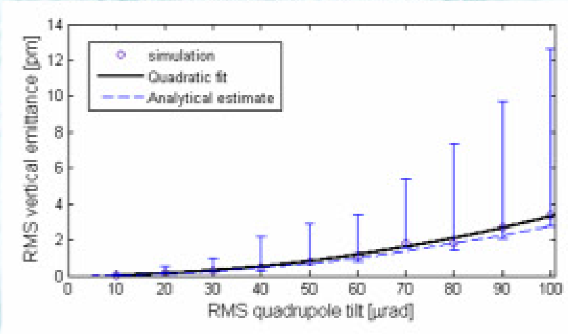
- Particles crossing a region with a dipole field error get a "kick": this distorts the closed orbit.
- Even a small error can lead to a large orbit distortion. This means that to operate the ring successfully, the alignment tolerances of magnetic components become very demanding.

Using simulation codes, we can model the response of the lattice to different kinds of alignment error…

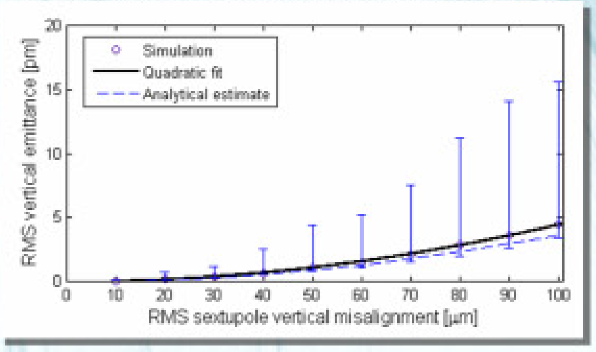
Sensitivity of closed orbit to quadrupole alignment



Sensitivity of emittance to quadrupole roll



Sensitivity of emittance to sextupole vertical alignment



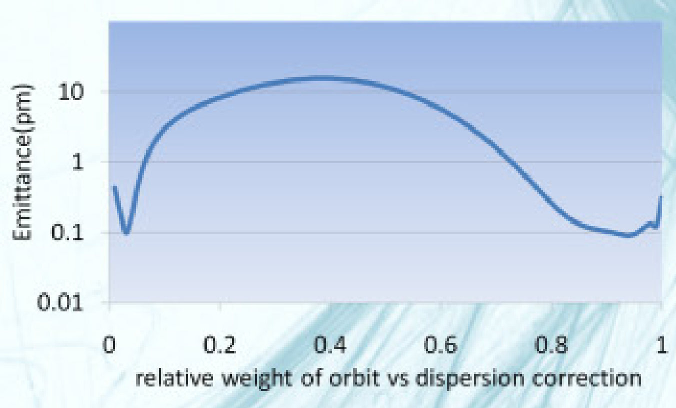
An analytical estimate of the sensitivity of the closed orbit to quadrupole alignment errors can be made from:

$$\langle y_{co}^2 \rangle \approx \frac{\langle \beta_y \rangle}{8 \sin^2 \pi \nu_y} \sum_{quads} \beta_y (k_1 L)^2$$

The dependence of the vertical emittance on quadrupole roll errors and on sextupole alignment errors can be estimated analytically. A similar formula for the dependence of the emittance on the sextupole alignment errors $\langle y^2 \rangle$ can be obtained by replacing k_1L with $k_2L/2$. The results can be confirmed using simulations, which also indicate the range of emittances expected for different seeds of alignment errors.

$$\frac{\varepsilon_y}{\langle \theta_{quad}^2 \rangle} \approx \frac{J_x (1 - \cos 2\pi\nu_x \cos 2\pi\nu_y)}{J_y (\cos 2\pi\nu_x - \cos 2\pi\nu_y)^2} \varepsilon_x \sum_{quads} \beta_x \beta_y (k_1 L)^2 + \frac{J_z \sigma_\delta^2}{\sin^2 \pi\nu_y} \sum_{quads} \beta_y \eta_x^2 (k_1 L)^2$$

…we can then devise the optimum correction method to achieve the best possible beam quality.



- Emittance (a measure of the beam size) depends on the beam orbit and the dispersion (the change in orbit with respect to energy).
- The graph (left) shows the results of a simulation of orbit and dispersion correction in the ILC damping rings.
- Since orbit and dispersion cannot each be perfectly corrected at the same time, we have to choose to weight one relative to the other.
- The aim is to find the optimum value for the weight factor (which is the value that minimizes the emittance).

Future Work

- Create a more realistic model of the ring where all possible types of errors come into play, and simulate their combined effects.
- Understand the dynamics of these effects and explain the observed simulated results.
- Optimize and test the tuning and correction algorithms.
- Ideally, take measurements from an existing machine to confirm the simulation studies.