TUNING ALGORITHMS FOR THE ILC DAMPING RINGS*

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Abstract

Emittance preservation is an important aspect in the design and running of the International Linear Collider (ILC) with a direct consequence on the luminosity of the machine. One major area of concern is in the damping rings, where the extracted emittances set the effective lower limits for the rest of the machine. Algorithms for tuning this system have been investigated, and simulations have been performed to understand the design and implementation issues. The different algorithms have been applied to the current reference damping ring design, and the effectiveness of each algorithm has been assessed. A preliminary recommendation of tuning algorithm, and its effectiveness under various conditions, is given.

INTRODUCTION

The ILC Damping Ring is the dominant emittance damping mechanism in the ILC. The design of the damping rings for both the electron and positron sides of the ILC sets the lower limit on achievable emittance, and so luminosity, for the entire machine. For this reason it is essential that the damping rings be able to create the lowest emittances possible, thus relieving downstream systems of tight tolerances on errors. The target extracted normalised vertical emittance from the damping ring is 20nm-rad.

The damping rings, of course, have internal error sources that fight to increase the achievable emittances at extraction. These include, but are not limited to: collective effects; single-bunch effects; closed-orbit errors leading to linear and non-linear aberrations; extraction errors; coupling errors. Instabilities can be minimised by good design, where-as errors caused by dynamic effects such as closed-orbit errors and coupling errors must be corrected in the working machine. Extraction errors can be corrected in downstream systems such as the Ring-To-Main-Linac turn-around section.

The error sources leading to closed-orbit effects and coupling effects can be from natural sources such as ground motion, artificial sources such as cultural noise, or from initial alignment errors due to finite precision instruments. Correction of these errors can be performed in several manners. Of course, one would prefer to minimise the extent of such errors, rather than just correct them. This can partly be achieved through good lattice design and correct siting of the machine. Siting the machine in a geologically stable and culturally quiet position will minimise these two error sources, though not eliminate them.

It should be noted that the ILC luminosity is strictly dependant on achieving a small vertical emittance, and, within reason, the horizontal emittance is un-important. Correction of the damping ring error sources is therefore generally designed to decrease the achievable vertical emittance. In general correction of the closed orbit is enough to reduce the horizontal emittance to within tolerable limits in any case.

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SOURCES OF EMITTANCE DILUTION

As stated previously, correctable emittance dilution effects include vertical dispersion, linear coupling and closed-orbit effects. Linear optics tells us that the dominant source of these errors are respectively: rotated horizontal dipoles and vertically displaced quadrupoles; rotated quadrupoles and vertically offset sextupoles; rotated dipoles, transverse errors in quadrupoles.

There are three major sources leading to these three emittance dilution effects:

Alignment Errors

Alignment errors are static errors generated during alignment of the machine. They generally affect every degree of freedom of the relevant magnet, but are generally randomly Gaussian distributed with small sigma. Due to this low correlation random distribution the dominant effect of alignment errors is to cause large corrector requirements.

Ground Motion

Due to its large size, differential motion of the damping ring due to motion of the underlying ground can be quite significant. In general we can model the ground motion as an ATL like motion, where the mean square differential ground motion is proportional to both the distance over which it is measured and the time scale over which it is observed. In terms of dynamic effects within the damping ring complex, it is only differential motion that is important, however effects due to absolute motion related to other sections of the machine will also limit the achievable emittance as seen at the IP.

In general it is not the individual magnets but their girder support systems that move. This provides a correlated effect, and helps to minimise the aberrations caused by long wavelength ground motion.

Cultural Noise

The dominant source of motion above a few Hertz is from cultural effects. This includes, but is not limited to, traffic noise, noise from ancillary equipment such as cryo-pumps, electrical noise, noise due to water flow in cooling pipes etc. Often this cultural noise occurs at well defined peaks in the spectrum of motion, for example the 50/60Hz noise from electrical equipment.

EMITTANCE TUNING ALGORITHMS

Correction of three major emittance dilution effects can be performed in a variety of ways. The generally used methods for each error source are:

Closed-Orbit Correction

Closed-orbit correction generally requires the use of dipole magnetic fields to kick the beam into a minimum orbit as measured at a set of beam position monitors. These dipole fields can be achieved using dipole magnets (dedicated or as extra windings on other magnets, though this may reduce the available field quality) or through transverse motion of quadrupole magnets. Quadrupole correctors require the use of magnet movers on a large fraction of the quadrupoles in the machine. Accuracy of the movers is likely to be less than dedicated dipole magnets, and mechanical effects such as backlash may limit the effective correction.

Vertical-Dispersion Correction

Vertical dispersion is caused mainly by dipole fields in the horizontal plane of the machine. They can be corrected both by introducing correction dipole fields, or through skew quadrupoles. In the case of dipole correction, this must be integrated into the correction of the closed orbit. There must therefore be a weighting of the contributions from the closed orbit and the vertical dispersion in the correction procedure. The vertical dispersion correction can be an integral part of the closed-orbit correction, or as an additional closed-orbit and vertical dispersion correction afterwards. Using skew quadrupoles to correct the vertical dispersion, means that it must be integrated with the coupling correction, and again optimised weightings between the two quantities must be defined. Generally, closed-orbit effects cause an increase in both vertical dispersion and coupling effects, and so it can be argued that separating these two errors from the closed-orbit correction could be advantageous.

Coupling Correction

There are several methods for correcting the linear coupling in the damping rings. In this paper, only one is explored. This is the minimisation of cross-plane response matrices. Coupling in the damping ring, should cause horizontal motion of the beam to be transferred into the vertical plane. This additional motion in the vertical plane is directly proportional to the amount of coupling in the machine. Minimisation of this coupling signal is performed using skew-quadrupoles. The coupled motion is excited by horizontal kickers, and the vertical motion on a set of BPMs analysed to determine the relative amount of coupling. The choice of horizontal kickers affects the coupling signal seen.

SIMULATION SET-UP

The latest ILC damping ring reference lattice, arbitrarily titled “RDR-1”, has been used throughout the simulation studies. Analysis of previous designs was also performed, but will not be noted here. The RDR-1 lattice was implemented in the *Mathematica* based MADInput MAD-interface code. This allows rapid designs of correction algorithms and simplifies large scale simulation runs of the system.

Additional elements, needed for tuning of the machine, were added to the reference design. This included BPMs, dipole correctors and skew-quadrupoles. They are all assumed to be zero-length elements at this early design stage, but clearly an engineering design will need to be performed. BPMs and dipole correctors were placed at every quadrupole magnet in the lattice, and skew-quadrupoles at every sextupole. 4 horizontal kickers for coupling correction were used in the simulations. 2 were spaced with a phase difference of $\pi/2$, the other 2 with a phase sum of $\pi/2$.

Alignment errors are assumed to be randomly Gaussian distributed within 2 sigma. A set of nominal alignment tolerances, in both transverse planes and as rotations about the s-axis, are given in Table 1.

Table 1 Alignment Tolerances

	Δx (μm)	Δy (μm)	$\Delta\Psi$ (mrad)
Quadrupole	30	30	0.3
Sextupole	30	30	0.3
BPM	100	100	20

The analysis of ATL-like ground motion was performed in the *Mathematica* code using the method described in [1]. The current design lattice has no cohesive girder design, so for these studies some simple girders were assumed, for example all damping wigglers are assumed to be one girder/unit and small FODO cell structures were assumed to be on girders. BPM, corrector and quadrupole groups as well as skew-quadrupole and sextupole groups were also assumed to be on the girders.

For all of the cases studied, correction for each aberration was performed using inversion of the relevant response matrices. Where required, weighting was used to normalise the resultant inverse response matrix to adequately correct both terms. The matrix inversion was performed using Singular Value Decomposition, both due to its inherent robustness and the ability to remove smaller Eigenvalues and optimise the correction .

DISPERSION CORRECTION

As outlined above, there are two different methods for correction of the vertical dispersion: using dipole correctors or using skew quadrupoles. A comparison is made between the two, using the alignment tolerances given in Table 1, with no coupling correction but two previous orbit correction steps. This is shown in Figure 1, where the results is given as a tolerance on the alignment values, and a higher tolerance is better.

Clearly skew quadrupole correction gives superior results compared to dipole correctors, it must be noted, however, that the relative weight between orbit and dispersion correction in this simulation was not fully optimised and further improvement may be possible.

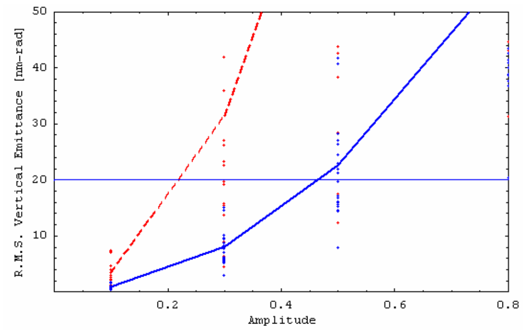

Figure 1 Comparison between dispersion correction using dipoles (red, dashed) or skew quadrupoles (blue, solid)

ALIGNMENT TOLERENCES

The tolerance on the normalised magnitude of the alignment tolerances in Table 1 is shown in Figure 2.

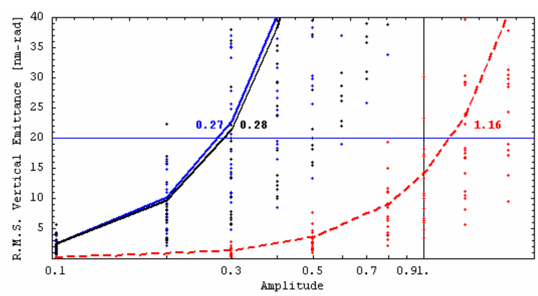

Figure 2 Normalised alignment tolerances in the 3 correction scenarios.

It is clear that closed orbit and dispersion correction alone does not provide adequate emittance correction.

A histogram of tuned vertical emittances is given in Figure 3.

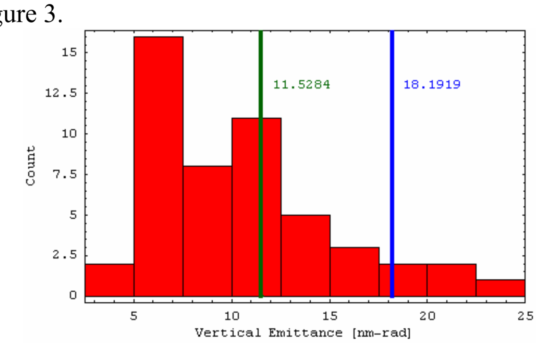

Figure 3 Tuned vertical emittance values, showing the r.m.s (green) and 90% confidence limits (blue).

TOLERENCES

Tolerances are given for the quadrupole and sextupole errors in the lattice. Results are presented only for the case of no correction (*None*), 2 iterations of orbit correction with dipoles (*CO*), and 2 iterations of orbit correction with dipoles and 2 iterations of coupling+dispersion correction using skew quadrupoles (*Full*). The tolerances are presented in Table 2.

Table 2 Magnet Tolerances

Error	Quadrupoles			Sextupoles		
	None	*CO*	*Full*	*None*	*CO*	*Full*
ΔY (μm)	9.1	108	380	81	100	3548
ΔΨ (mrad)	0.084	0.085	2.81	~		

ATL GROUND MOTION

Analysis of the effects of ATL-like ground motion is presented. The ground is assumed to have an A coefficient of 100μm/10m/Year. The results are presented for two different cases, with and without emittance tuning.

The simulation is initially seeded with the alignment tolerances given in Table 1. The ring was then allowed to move under the influence of ATL motion. In the corrected case full emittance tuning was applied once every 6 days. The evolution of the vertical emittance in both cases is shown in Figure 4, over a period of 4 months. Emittance tuning every 6 days is sufficient to maintain the vertical emittance below the target of 20nm-rad over the 4 period.

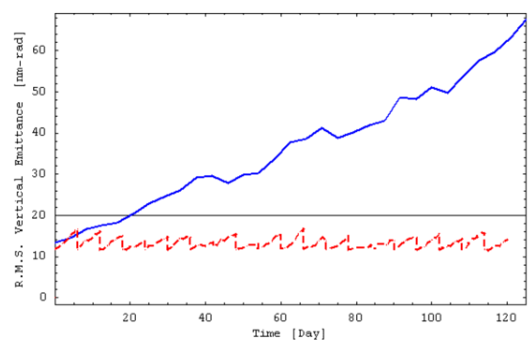

Figure 4 R.M.S. Vertical emittance evolution with full tuning (red, dashed) and without (blue, solid)

With only initial emittance tuning, the vertical emittance exceeds the specification after 20 days. These values are dependant on the final chosen site. This simulation does not take into account any localised ground motion such as that simulated in [2].

CONCLUSIONS

The latest ILC damping ring reference design has been analysed in terms of its emittance tuning properties. Results show that the design is robust and easily tuneable, with generally relaxed tolerances. Initial simulations of the effects of correlated ground motion show good results. The next steps are to increase the number and variety of error sources in the machine and to attempt to characterise and understand the requirements on diagnostics for the system.

REFERENCES

[1] Andrzej Wolski, Nicholas Walker, "A Model of ATL Ground Motion for Storage Rings", PAC'03, Portland, May 2003.

[2] James Jones, "Slow Ground Motion Modelling Of Diamond", PAC'03, Portland, May 2003.