ALIGNMENT TOLERANCES FOR VERTICAL EMITTANCE

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Abstract

A sensitivity analysis of the CLIC main damping ring lattice to magnet misalignments is presented. Misalignments considered included quadrupole vertical offsets and rolls, sextupole vertical offsets, and main dipole rolls.

Expectation values for the vertical emittance were calculated from theory.

Simulations of magnet misalignments were made in MAD-X, for 200 machines at each RMS misalignment. The lattice was found to be sensitive to betatron coupling as a result of sextupole vertical offsets in the arcs.

INTRODUCTION

The design of the linear collider damping rings calls for design horizontal emittances more than an order of magnitude lower than measured in existing storage rings. The few new collider projects are keen to leverage the operational experience of the many constructed storage ring light sources. The design pm rad vertical emittance has been achieved at only a single accelerator; the Australian Synchrotron storage ring [1]. This measurement is not at the IBS bunch density required of the CLIC damping rings - further investigation will be required to achieve this.

The goal of this research is to demonstrate the feasibility of design extracted transverse emittances for the CLIC main damping rings. Table 1 presents a summary of extracted beam parameters.

Table 1: Main damping ring extracted beam requirements

Parameter		Value	Units
Energy	E_b	2.86	GeV
Bunch population	N	4.1	10^9
Emittance, horizontal (norm)	$\gamma\epsilon_x$	480	nm rad
Emittance, vertical (norm)	$\gamma\epsilon_y$	4.5	nm rad

The required emittances include growth due to intra-beam scattering (IBS). It has been demonstrated that a zero-population equilibrium vertical emittance, $\gamma\epsilon_y = 3.7$ nm rad will be required to allow for growth due to IBS [2]. With the quantum limit of vertical emittance for such a ring approximately 0.7 nm rad, the specification is demanding.

A sensitivity analysis of the CLIC main damping ring lattice to magnet misalignments is presented. Misalignments considered included quadrupole vertical offsets and rolls, sextupole vertical offsets, and main dipole rolls.

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LATTICE

The CLIC main damping ring lattice is a wiggler-dominated racetrack lattice [3], with two-fold superperiodicity. The lattice design has matured significantly since the last estimate of alignment tolerances for vertical emittance [4]. The arc TME cell has been optimised for IBS [5], with FODO wiggler straights to achieve the design horizontal emittance.

The compact lattice design necessitates the use of extra windings as orbit and skew quadrupole correctors. We consider first the most conservative corrector pattern: horizontal and vertical orbit correctors on each arc sextupole (three per TME cell), as well as alternating horizontal and vertical steering correctors adjacent to wiggler straight quadrupoles (two per FODO cell). Additional steering is included in the matching sections.

Beam position monitors (BPMs) are positioned in arc cells at points of alternating high and low dispersion, as well as high and low beta functions. We consider BPM buttons with both horizontal and vertical position measurement. A summary of correctors and BPMs introduced in this study is presented in Table 2 below.

Table 2: Correctors and position monitors considered

Component	Plane	Total number
BPM	H&V	358
Corr	H&V	282
Corr	H	28
Corr	V	30

The corrector and BPM pattern used in this study for the arc cells is illustrated in Figure 1 below. Skew quadrupole correctors will be required for local correction of skew quadrupole components. These will be implemented as additional windings on sextupole assemblies. The advantage of including steering and skew quadrupole correctors in this arrangement is the orthogonality to the main sextupole field.

ANALYTICAL EMITTANCE ESTIMATE

The formalism for estimation of flat-beam vertical emittance follows closely the work of Raubenheimer [6]. The mean square vertical dispersion arises from five main contributions:

- Vertical dipole kicks;

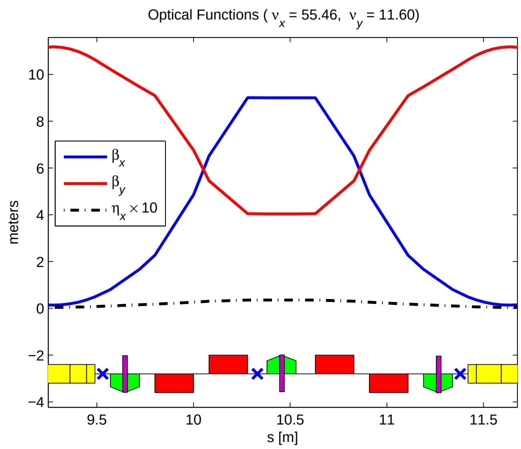

Figure 1: BPMs and correctors considered for TME arc cell. Steering correctors are shown in purple as additional windings on sextupoles, and BPMs indicated as blue crosses.

  – Main dipole rolls;
  – Quadrupole vertical offsets;

- Quadrupole transverse rolls;
- Sextupole vertical offsets;
- Function of the errors giving rise to a non-zero closed orbit;
- Orbit amplification factor (correlation function).

Contributions to the vertical emittance arising from betatron coupling are also considered.

- Quadrupole transverse rolls;
- Sextupole vertical offsets;
- Closed orbit.

The reader is referred to Raubenheimer's work for details of calculation of individual emittance contributions. In this work, the relevant individual contributions are evaluated, as presented in Figure 2. The sum of individual components is presented in Figure 5 as an analytical estimate of vertical emittance growth.

MISALIGNMENTS

Simulations of vertical emittance growth in the CLIC damping rings were made in MAD-X [7]. Lattice elements were seeded for RMS misalignments, in a Gaussian distribution truncated at 2.5 σ. For each misalignment magnitude considered, 200 machines were seeded. Vertical offsets were applied to quadrupoles and sextupoles, and longitudinal rolls were considered for quadrupoles and main dipoles. Misalignments were not considered for the damping wigglers.

Emittances were calculated using the method of Chao [8]. Vertical emittance growth was considered for both the uncorrected and corrected lattice. Results from the uncorrected lattice can represent the lattice sensitivity to misalignments.

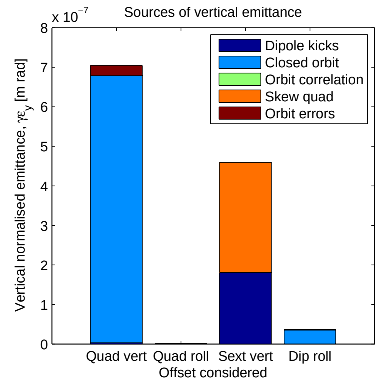

Figure 2: Contributions to vertical emittance. Uncorrected lattice, 100 μm, 100 μrad RMS misalignments.

CLOSED ORBIT

Figure 3 shows the RMS vertical closed orbit resulting from the four families of misalignments considered.

Orbit correction was undertaken using the MAD-X module. The correction algorithm used was singular value decomposition (SVD). All singular values were included in the correction.

Global corrections of tunes, chromaticity and energy were made. Beta-beating was uncorrected.

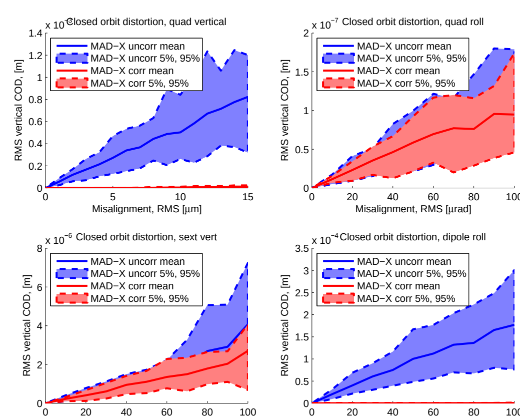

Figure 3: Closed orbit distortion under random misalignments. Uncorrected orbits shown in blue, corrected in red.

The closed orbit from quadrupole vertical displacements is seen to be orders of magnitude greater than the next leading contribution of dipole rolls. The uncorrected orbit amplification factor of 50 as shown in Figure 3 for quadrupole vertical misalignments, reduces to approximately 1 on orbit correction, as illustrated in Figure 4.

Orbit correction is seen to be effective in reducing emittance from quadrupole vertical displacements and dipole rolls, which represent vertical dipole kicks. Orbit correction is seen to be mildly detrimental for coupling from skew quadrupole terms.

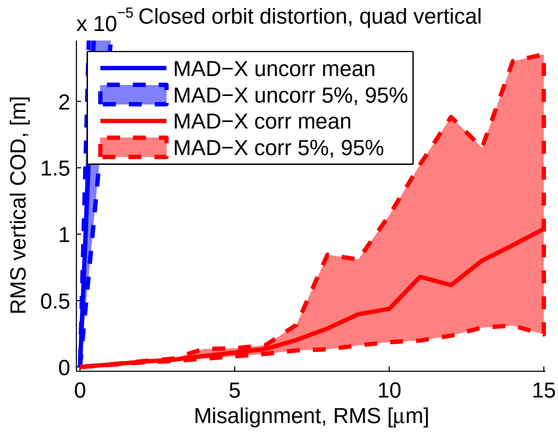

Figure 4: Closed orbit distortion (corrected), for quadrupole vertical displacements. Uncorrected (large) orbits shown in blue, corrected in red.

VERTICAL EMITTANCE

The equilibrium vertical emittance is summarised in Figure 5 below.

Orbit correction reduces the emittance contribution from random dipole kicks to acceptable levels. In the absence of a skew quadrupole corrector scheme, a vertical emittance of 5 nm rad is achieved with an RMS sextupole vertical misalignment of 6 μm. To allow realistic mechanical prealignment tolerances of approximately 50 μm, skew quadrupole correctors and an individual correction scheme will be required.

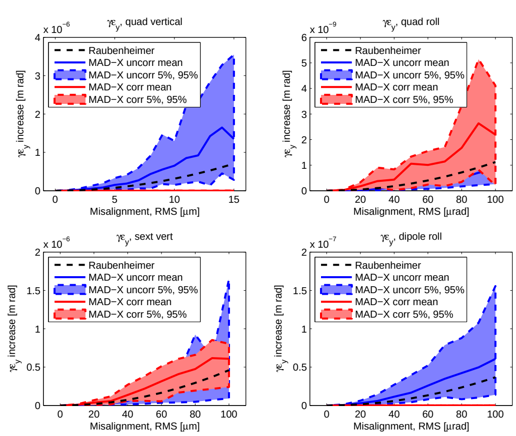

Figure 5: Normalised vertical emittance under random misalignments. Emittances of uncorrected orbits shown in blue, corrected in red, black curve shows analytical estimate of uncorrected emittance (not a quadratic fit).

DISCUSSION

Only relatively recently has low vertical emittance become a design specification of storage rings. The design emittance ratio of the Australian Synchrotron storage ring is and will remain 1%. Whilst many beam dynamics codes provide analysis of emittance growth arising from lattice imperfections, few codes provide a tool suitable for low vertical emittance correction requirements.

The benchmark code for storage ring lattice correction is LOCO [9] using orbit response matrices. MATLAB-based LOCO provides a convenient interface for iterative correction of a single ring. MAD-X features many useful modules for ring design and analysis, but as yet lacks a module for correction of coupling.

The author proposes to the community the inherent usefulness in implementing the LOCO algorithm as a MAD-X module, permitting analysis of many parallel seeded jobs.

CONCLUSION

In the absence of a skew quadrupole corrector scheme, a vertical emittance of 5 nm rad is achieved with an RMS sextupole vertical misalignment of 6 μm. This is not realistic, and an achievable sextupole distribution will require a skew quadrupole correction scheme. Large misalignments from dipole and quadrupole rolls of 100 μm are tolerable, and quadrupole misalignment of 50 μm acceptable.

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