Numerical Modeling of the Optical Stochastic Cooling Experiment at IOTA

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Introduction

Overview

Optical stochastic cooling (OSC) is a process which reduces the phase-space of a particle beam over many turns ina storage ring. Particles traveling in a ring first pass through a kicker undulator where they produce radiation. They are then separated and recombined downstream in the kicker undulator where the radiation applies a corrective kick relative to each particle's deviation in momentum. Due to its nature, the change in a particle's momentum due to a single corrective kick is very small so the process occurs over many millions of turns. This has made full-tracking simulations of OSC time consuming. However, purely analytical models make it hard to study the effects of error and other parameters that vary over the lifetime of the beam

ELEGANT

ELEGANT

ELEGANT is an open-source particle-tracking program capable of simulating many beamline elements of storage rings and linear accelerators [1]. Its tracking capabilities and flexibility make it a perfect tool for out simulations.

We implemented a custom element which uses a semi-analytic model of OSC to simulate the process inside ELEGANT. It is based on an existing feedback element which uses a paired pickup and driver to apply a kick relative to the beam parameters recorded at the pickup. We replaced the FIR filter with a simple one-dimensional transit-time model of OSC where the longitudinal-momentum kick applied in the kicker is given

$$\Delta p = -\kappa \sin\left[\omega(t_0 - t_i) + \phi\right]$$

Parallel ELEGANT

The parallel capabilities of ELEGANT allowed us to dramatically improve the run time of the OSC simulation using thehigh-performance computing cluster at NIU

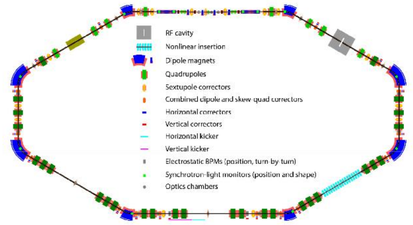
We are capable of tracking 10k particles through 10k turns around the IOTA ring undergoing the effects of OSC in about two hours.

IOTA Simulation

IOTA Lattice

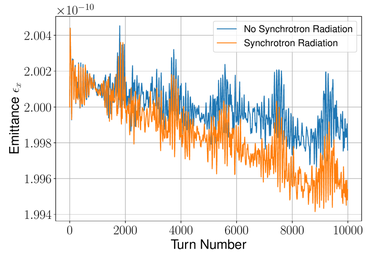
The IOTA ring is a 40m in circumference storage ring used to study advanced accelerator concepts.

Elegant is capable of simulating and tracking particles through the entire ring including effects of synchrotron radiation and optical stochastic cooling.



Synchrotron Radiation

Synchrotron Damping is a process by which particles traveling in a storage ring lose energy through synchrotron radiation in dipoles and are replinished by the rf system. This causes a decrease in emittance as particles lose transverse momentum. This effect is well understood and can be used to benchmark our Elegant simulation to the IOTA ring.



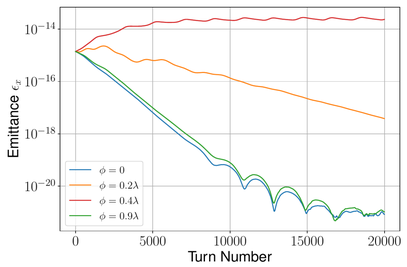
OSC Simulation

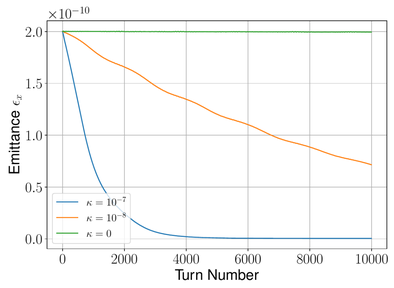
Strength and Phase

The cooling rate of OSC is related to the strength of the corrective kick. The model of OSC has two user defined paramters, k which is the strength (or amplification) of the kick, and phi which is the phase of the radiation at the point it is recombined in the kicker undulator with the beam.

We expect to see stronger k values produce faster cooling rates.

We may also vary the radiation phase and examine the cooling range. The cooling range is an important consideration in the stability of the cooling process. Several factions of a wavelength were simulated and as expected, radiation arriving closer in phase produces the strongest cooling whereas radiation beyond a quarter wavelength produces heating.





Phase-Space Control

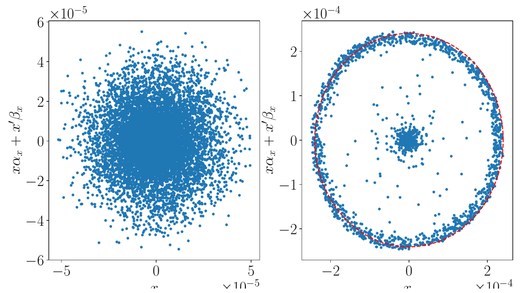
Phase-space

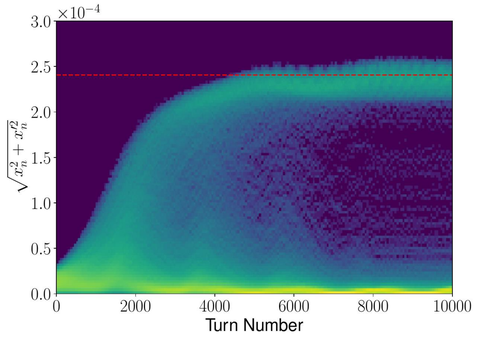
The ability to track particles throughout the entire ring allows us to investigate the phase-space evolution of a beam undergoing OSC. The particle coordinates are transformed to produce a normalized coordinate system under:

$$x_n = x \ , \quad x'_n = \alpha_x x + \beta_x x'$$

Heating

One aspect of OSC we observed in the ELEGANT simulation is the effect of heating on the beam. Particles are pushed away from the reference particle and toward another attractor which forms a ring in the normalized phase space





Acknowlegements

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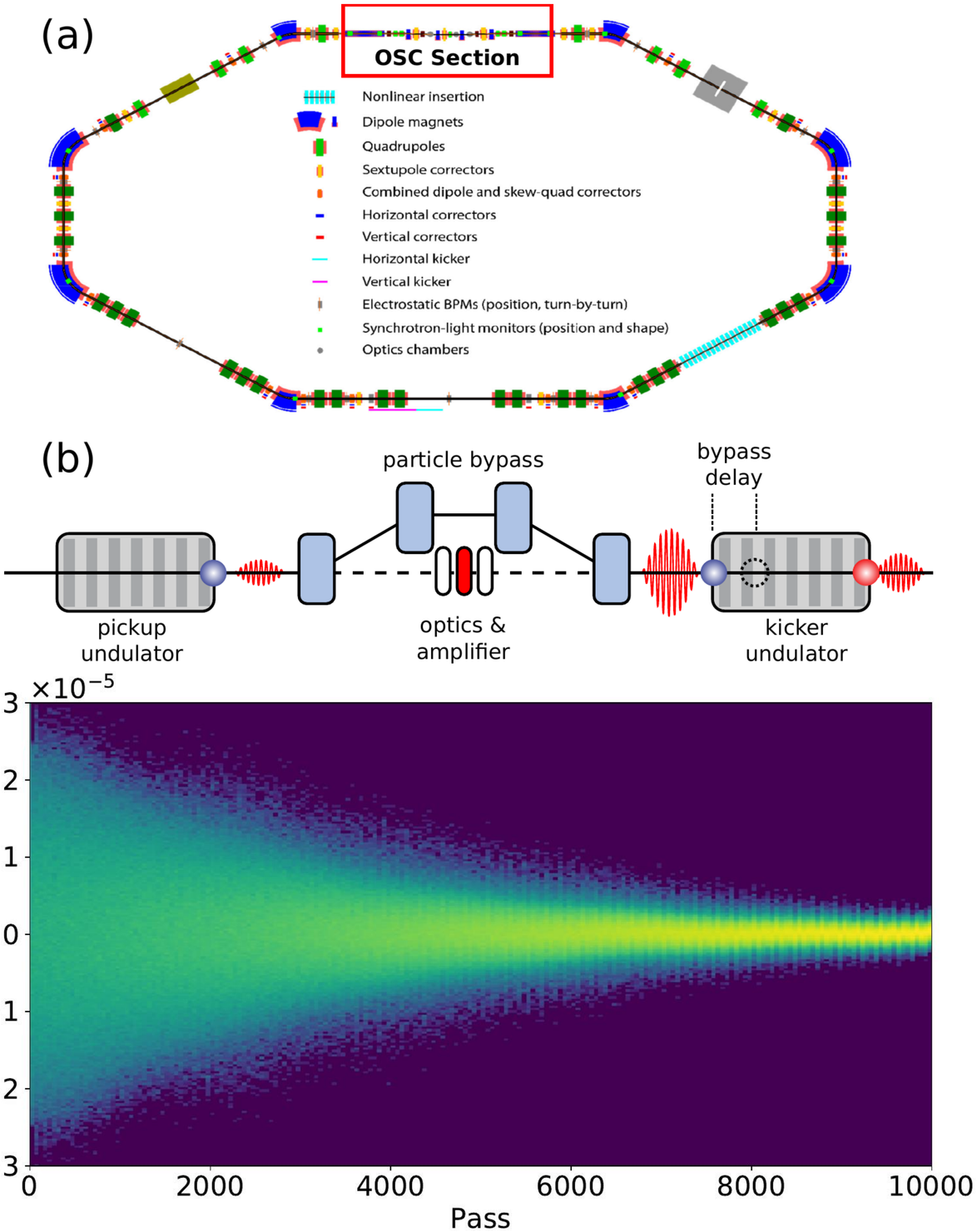

Implementation in ELEGANT

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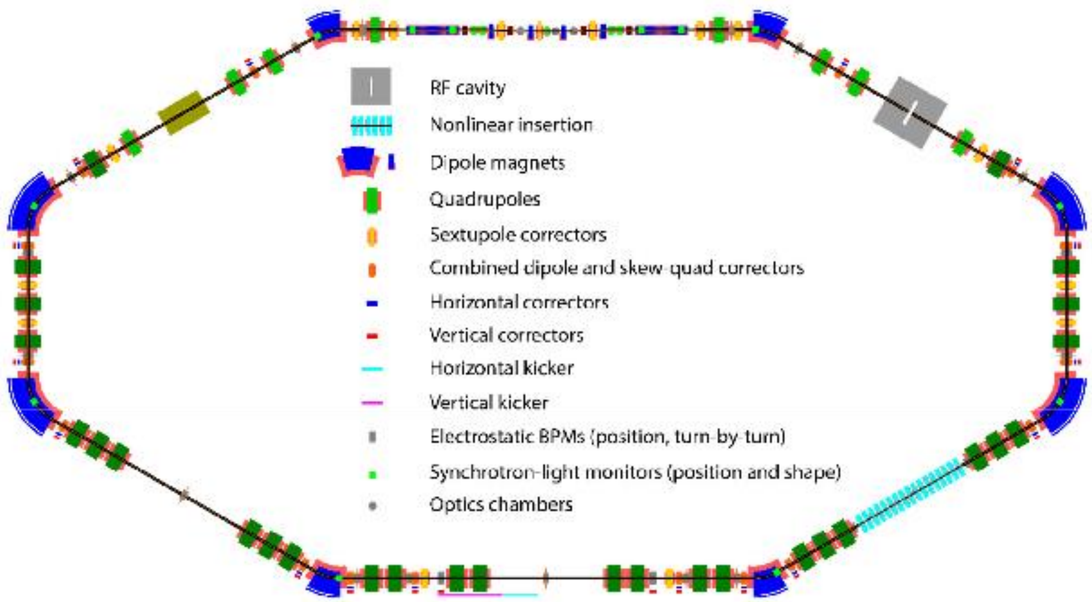

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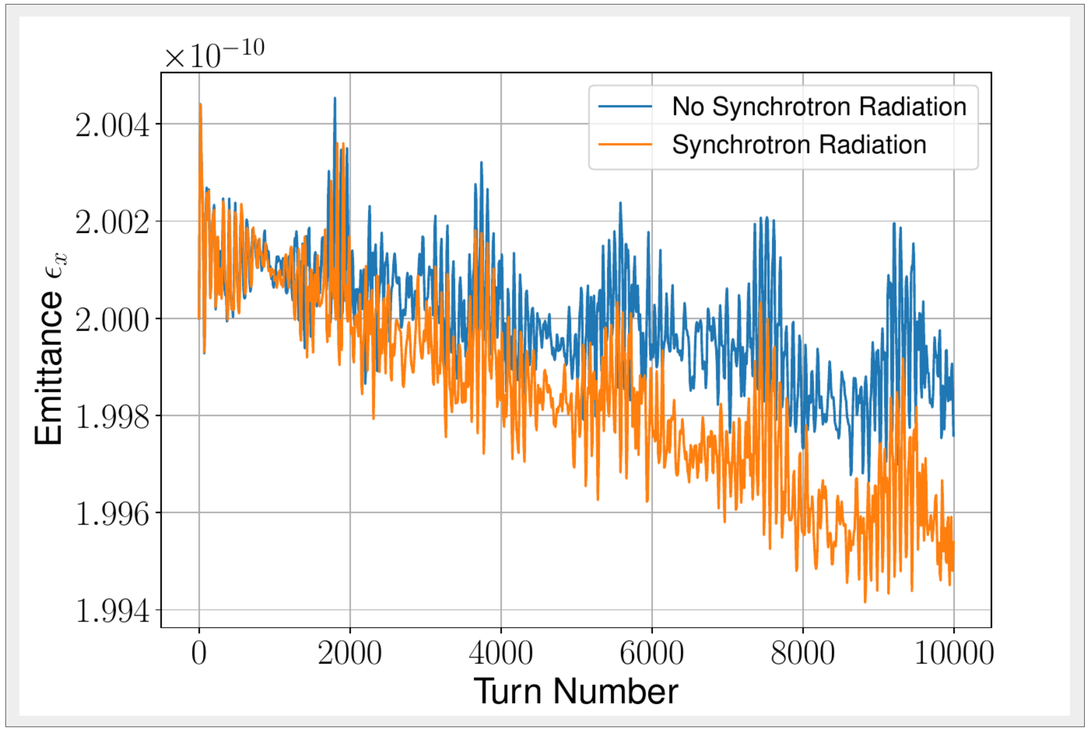

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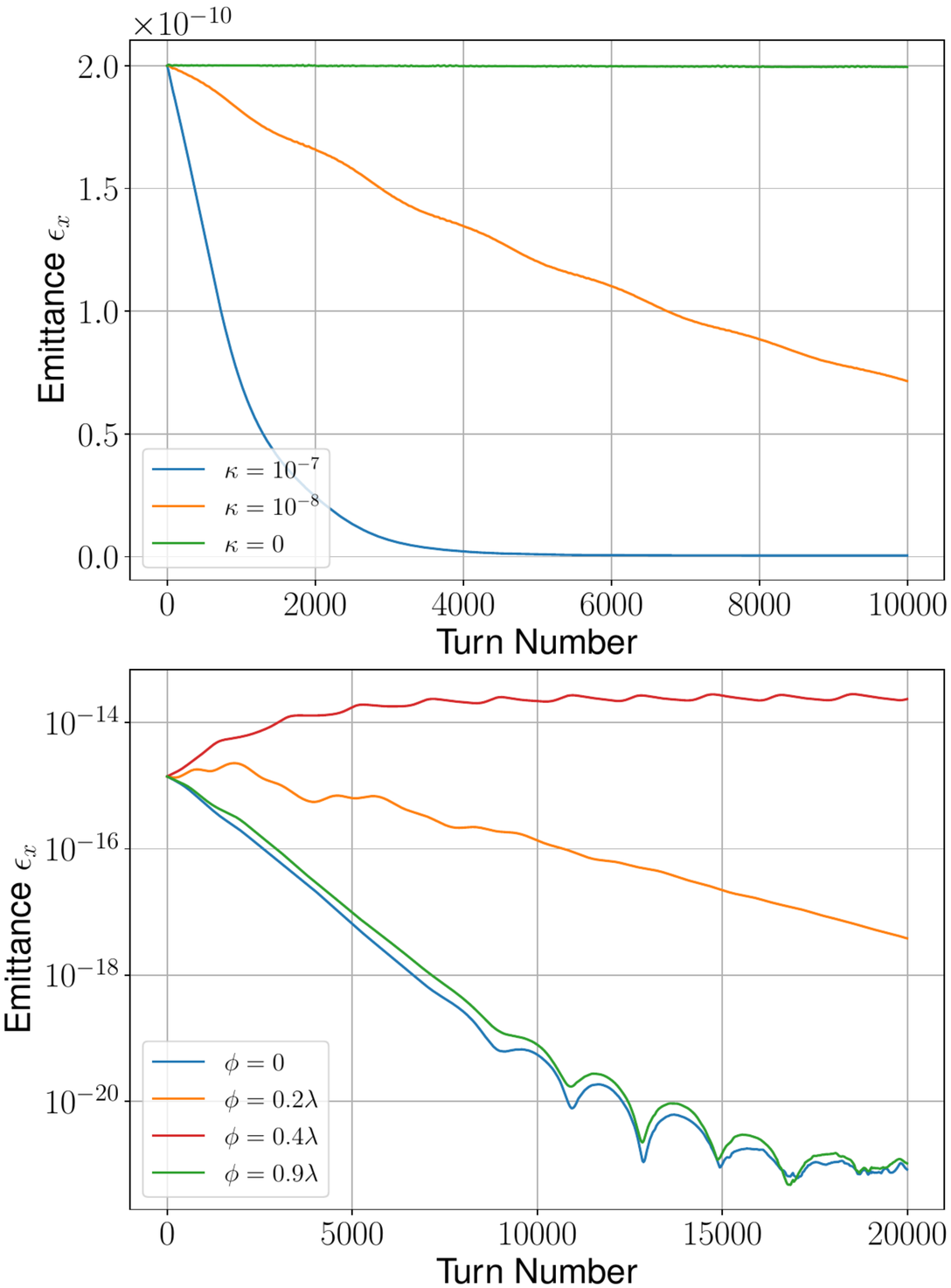

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