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Symplectic neural surrogate models for beam dynamics

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The self-consistent nonlinear dynamics of a relativistic charged particle beam interacting with its complete self-fields is a fundamental problem underpinning many of the accelerator design issues in high brightness beam applications, as well as the development of advanced accelerators. A novel self-consistent code is developed based on a Lagrangian method for the calculation of the particles'radiation near-fields using wavefront/wavelet meshes via the Green's function of the Maxwell equations. These fields are then interpolated onto a moving mesh for dynamic update of the beam. This method allows radiation co-propagation and self-consistent interaction with the beam in 2D/3D simulations at greatly reduced numerical errors. Multiple levels of parallelisms are inherent in this method and implemented in our code CoSyR [1] to enable at-scale simulations of nonlinear beam dynamics on modern computing platforms using MPI, multi-threading, and GPUs. Our simulations reveal the slice emittance growth in a bend and the interplay between the longitudinal and transverse dynamics that occurs in a complex manner not captured in the 1D longitudinal static-state coherent synchrotron radiation model. Finally, we show that surrogate models with symplectic neural networks can be trained from simulations with significant time-savings for the modeling of nonlinear beam dynamics effects.

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Footnotes

[1] C.-K. Huang et al., Nucl. Instruments Methods Phys. Res. Sect. A, vol. 1034, p. 166808, Jul. 2022.

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