Overview of the WARP Code and Studies of Transverse Resonance Effects

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Overview of the WARP Code and Studies of Transverse Resonance Effects*

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Abstract. Two papers presented at the Shelter Island workshop are very briefly summarized here, in view of recent publications elsewhere. The WARP code, developed for Heavy-Ion beam-driven inertial confinement Fusion (HIF) accelerator studies, combines features of a particle-in-cell plasma simulation and an accelerator tracking program. Its methods and architecture have been developed for efficiency both in detailed simulation of individual machine sections and in long-time beam tracking. The transverse "slice" model in the code has been applied to the study of transverse resonance effects associated with quadrupole strength errors. These simulations confirm that rapid passage through a resonance can reduce the associated mismatch and emittance growth. References to published details and to other sources of information are supplied.

WARP CODE OVERVIEW

WARP is a particle-in-cell (1,2) beam simulation code offering 3-D, axisymmetric (r, z), and transverse (x, y) geometries. The code was developed for Heavy-Ion beam-driven inertial confinement Fusion (HIF) accelerator studies (3-8). In this application, and particularly in the U.S. approach based on induction technology, space charge forces dominate over the beam thermal pressure.

WARP (9-14) incorporates detailed descriptions of various accelerator and beamline elements, and was designed to follow beams efficiently over long path lengths. A hierarchy of models affords increasing levels of detail in the description of the accelerator lattice. While some of these models are based on an expansion in powers of the off-axis separation, the code can use models which are good to "all orders" (such as field specification on a full 3-D grid) when sufficient knowledge of the field is available. Several Poisson equation solvers are available, optionally incorporating internal conducting elements from "first principles" with subgrid-scale resolution of the conductor boundary locations.

WARP uses time (rather than path length) as the independent coordinate for particle motion, this facilitates the treatment of longitudinally-extended beams. The code gets its name from its use of "warped" coordinates, that is, a sequence of Cartesian grid sections aligned with the local beamline (so that each lattice element is described in its own natural coordinate system) linked by sections of "polar coordinate" grid. Coordinate transformations account for the bends while preserving the symplectic nature of the underlying advance. The fields from neighboring elements can overlap, even when

those elements are separated by a bend and so are described with reference to different frames. The user specifies a coordinate system which describes the beamline as it is laid out "in the laboratory," and need not specify a reference orbit. In the 3-D and r,z models, no paraxial approximation is invoked.

The code offers an interactive, interpreter-driven user interface for code steering and scripting-language control. This capability allows significant changes in the code's operation to be effected by the user without requiring recompilation. It provides a rich simulation environment which offers ready access to the code's internal database, algebraic transformations, and interactive visualization. WARP has been parallelized to run on supercomputers, symmetric multiprocessors, and workstation clusters using message-passing techniques. While already quite capable, the code is still under development, it has not yet "settled down" to a version suitable for unlimited release.

TRANSVERSE RESONANCE EFFECTS

In the recirculating induction accelerator approach to an HIF driver (15,16), the beam is rapidly accelerated "through resonances" — it is "different on every lap" and errors add much as in a long linac. Beam steering is used to correct the centroid motion. In some RF linac / storage ring approaches, resonance crossing is driven by rapid bunching of the beam, which shifts the resonances as a result of the increasing space charge density and image effects. We are carrying out studies (17) of transverse resonance effects in rings with space charge. The beams we consider are highly space-charge-dominated, with an undepressed phase advance per lattice period of $\sigma_0 \sim 75^\circ$ reduced by the transverse self-fields to $\sigma \sim 15\text{-}20^\circ$. These parameters are similar to those of the "small recirculator" (16) under development at LLNL. We consider periodic quadrupole strength errors which can resonantly drive symmetric and antisymmetric mismatch oscillations of the beam core. Interactions with those core oscillations can drive particles into the halo and degrade the emittance. Using a 2D transverse "slice" model in the WARP PIC code, we study how aggressive acceleration or bunching, leading to rapid passage through a single applied resonance, affects the emittance. Power spectra are computed and their many features identified. We confirm that rapid passage through the resonance significantly reduces the attendant emittance growth. The growth rate is seen to be strongly correlated with the instantaneous degree of mismatch.

As part of this study, the convergence of the PIC method employed was investigated. Runs using 20,000 particles showed some jaggedness of particle orbits and enhanced emittance growth (resulting from the nonphysically-large collisionality associated with the small particle number), but were generally deemed reliable enough for studies such as these. Runs using 80,000 and 320,000 particles were well-behaved, and produced essentially converged results.

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