A USER-FRIENDLY CODE TO MODEL RADIATION OF HIGH BRIGHTNESS BEAMS*

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Abstract

The accelerator community has many codes that model beams and emitted radiation. One of the most important goals of simulations is to accurately model beam parameters and compare results to those obtained from real laboratory diagnostics. Many of these codes are specialized and often, as in start-to-end simulations, multiple codes are employed in a subsequent fashion. This paper describes the development of a user-friendly code that models the coherent radiation of high brightness beams, with a heavy emphasis on simulation of observables via laboratory diagnostics.

INTRODUCTION

The codes developed for the accelerator community tend to focus on either beam dynamics or radiation calculations. There are many robust codes which have been benchmarked to experiment but typically require effort to get from first principles to laboratory results. The code Rad-Track was developed by RadiaBeam Technologies, to accurately model diagnostic observables with an emphasis on modularity and a user-friendly interface. There are three main objectives of this code. First, it is built with a modular approach to increase its functionality and extend its range of addressable problems. Second, its visualization canvas is an intuitive tool that easily generates and displays important aspects of the simulation such as beam distributions and beamline lattices; it also provides near real time feedback to mitigate the errors associated with text-based input/output (I/O) files. Third, it incorporates an intuitive user interface that provides a front-end for the seamless management of start-to-end projects; the same interface can be used for quick calculations and/or for detailed design optimizations that require access to a computing cluster network. The goal of the code is to make complicated beam and radiation simulations more transparent and intuitive for the user, specifically to compare simulations to real laboratory results. The code has undergone preliminary user-testing and is ready to proceed into the second phase of development.

PARTICLE TRACKER AND FIELD SOLVER

The code calculates radiation emission of high brightness beams through bends using a modular approach. First,

the particle trajectories are calculated using Q-Tracker, a modification to the existing code QUINDI [1] which specifically allows for the dumping of the 6-dimensional phase space for each particle. The particle trajectories in Q-Tracker are determined by the Lorentz force law. Then the radiation fields are solved using a modified version of QUINDI for bends. The radiation emission is calculated using the Lienerd-Wiechert potentials [2]:

$$\vec{E}\left(r,t\right) = \frac{e}{\sqrt{4\pi\epsilon_0}}\left[\frac{\vec{n}-\vec{\beta}}{\gamma^2\left(1-\vec{\beta}\cdot\vec{n}\right)^3 R^2}\right]_{\text{ret}} +$$

$$\left[\frac{\vec{n}\times\left[\left(\vec{n}-\vec{\beta}\right)\times\dot{\vec{\beta}}\right]}{c\left(1-\vec{\beta}\cdot\vec{n}\right)^3 R}\right]_{\text{ret}}$$

where $\vec{n}$ is the unit vector pointing from the radiation point to an observation point and R is the distance to the observation point. The magnetic field is simply derived from

$$\vec{B}\left(r,t\right) = \left[\vec{n}\times\vec{E}\left(r,t\right)\right]_{\text{ret}}$$

The fields in the above relations are calculated at the retarded time $t' = t + R(t)/c$.

The modular approach of QUINDI is attractive because the separation of trajectory determination from field calculation allows the user to employ different codes for each function. For example, the user may use particle trajectories from other codes, like TREDI [3], in conjunction with the radiation solver QUINDI. Preliminary efforts are directed at including trajectories from PARMELA [4], EL-EGANT [5], and TREDI. Further efforts will enhance the support of other codes as well.

USER INTERFACE

A significant part of the development effort went into the graphical user interface. The user interface is separated into panels with distinct features. The panels include a beam distribution generator, a beamline lattice constructor, a radiation detector setup, a project management panel and a simple post-processor for the output of key information. The workflow of the program is intuitively designed.

Beam Distribution Generator

The first component of the simulation setup is handled in the beam distribution panel, where the user must define initial beam parameters. The user has two options for describing the initial beam: an externally generated distribution,

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such as one previously constructed in another program like PARMELA, may be imported, or the user may manually specify the 6-dimensional phase space distribution using either beam moments (averages and standard deviations, including arbitrary correlations, various degrees of noise, modulations with complex spectral density) or Twiss parameters via the user interface.

Another feature is available for imported beam distributions: the beam properties are analyzed and a summary of the imported beam is displayed (moments and Twiss parameters), allowing the user to quickly and visually confirm the properties of the beam distribution. The user has the option to adjust these parameters as desired to either rescale or regenerate the imported beam for further use (Figure 1).
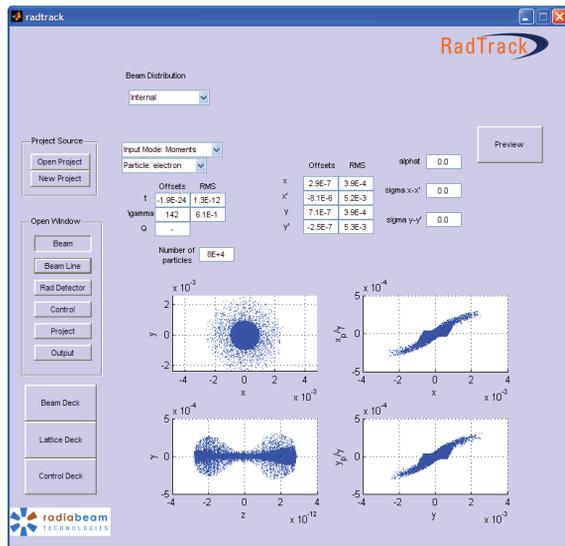

Figure 1: Screenshot of the graphical user interface displaying the beam distribution generator panel. In this panel, a beam distribution can be created or imported from another program.

For the initial development, only Guassian distributions are supported. The Gaussian beam distribution is generated by a normalized Box-Muller transformation [6] of a uniform distribution. The final distribution is formed by dialation, rotation and shearing of the distribution. In future upgrades of the code, other distributions (such as waterbag, K-V, boxcar, etc.) will also be supported. In particular, the quiet start routine will be implemented. The quiet start [7] is important because it reduces the artificial microbunching in the distribution that leads to overestimates of the beam emittance.

Lattice Constructor

The second step in the simulation process is to define the beamline lattice. The beamline constructor panel is a graphical means of constructing a beamline (and lattice file) in RadTrack, independent of specific code language. The user selects an element to add and specifies the required, and optional, parameters. Element parameters can

be specified in different formats for flexibility. As elements are added to the beamline, a reference particle trajectory is calculated and plotted through the element for visualization aiding. Editing of individual element properties is permitted through the interface, as well as reordering of elements. When the beamline is complete, the user is left with a color-coded, scaled drawing of the lattice with an overlay of the reference particle trajectory and a text-based input deck.

One of the main objectives of the code is to model beam based radiation sources, including Compton sources, THz sources, and, specifically, radiation used by diagnostics. Modeling specific diagnostics necessitates a visually descriptive method for placing detector planes in the visualization canvas. For some radiation processes, this is relatively straightforward; for example, a transition radiation screen is placed directly along the beam path some distance from a beamline element. However, for bend radiation (dipole radiation), the detector is usually outside the beamline, and is further complicated by radiation emitted at frequencies which are difficult to detect traditionally. To account for this generality, arbitrary placement of the radiation detector is allowed in RadTrack. In order to place a detector, the user selects a reference element and specifies offsets from the beam as well as rotations of the detector plane in the form of Euler angles. Alternatively, the user may lock the detector to always view the line tangential to the beam (useful for bend radiation) or simply specify a point-vector-vector to place the detector plane. The detector is displayed on the visualization canvas, at an exaggerated size for ease of placement (Figure 2).
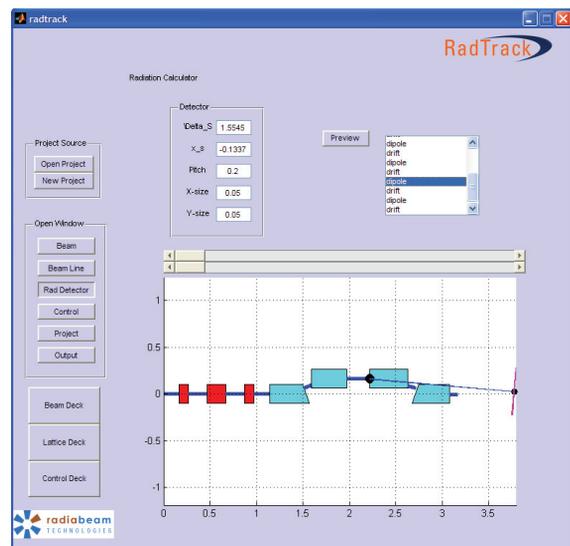

Figure 2: Screenshot of the graphical user interface displaying the radiation detector panel. In this panel a beamline lattice of the BNL ATF chicane compressor was created with a radiation detector surface area (represented in pink) exaggerated in dimension.

In future upgrades of the code, the visualization canvas will be enhanced to support drag-and-drop features, allow-

ing the user a more intuitive method of placing and rearranging beamline elements.

PROJECT MANAGER

Project management is necessary in any simulation effort and is built directly into the RadTrack framework. Components that fall under project management include a logging feature (which allows undo/redo functions), a project save/load feature and a file management scheme. The file management scheme consists of a simple method to track output files from multiple runs and to import previous data sets for new runs for example, if the code is being used to fine-tune a beamline, multiple configurations of the beamline can be saved and recalled without disrupting beam distributions or radiation detectors. All data is saved as binary files to conserve space; input decks are stored as text with the exception of beam files, which are optionally converted to text as requested.

One of the attractive features of the user interface, is the ability to run single paritcle calculations and highly detailed design studies, requiring the use of a cluster, using the same interface. The project management tool also allows for straightforward execution of start-to-end simulations with other available codes and file management. Start-to-end simulations have been used in many experiments as there is no singular code that can accurately model the beam form its inception to radiation emission. The project manager in the code sets up a framework which includes a file-format parser for certain codes. This feature is useful because the user will experience a consistent, undisturbed workflow while the code handles the necessary parsing and I/O interplay between the codes. Additionally, the file management of the various output files of each code are stored and organized by the software allowing for easy access as needed. As development on the code continues, the support for other external codes will grow as well.

CONCLUSIONS AND OUTLOOK

The user-friendly software, RadTrack, was successfully developed to model the emitted radiation from high brightness beams in bends. The initial development effort focused on using a modified version of QUINDI for the field solver. The user interface incorporates visualization aides that are useful for beamline lattice construction and post-processing. The novel project management tool allows the user intuitive access for the simulation control, including start-to-end file management, I/O handling, and computer cluster operations.

Future upgrades and improvements to the software include the comprehensive development of other physics modules. The primary effort in new module development is in the radiation transport module, to accurately model the phasefronts of the electromagnetic waves from formation to detection. The radiation transport module will include a limited library of components, specifically for the terahertz regime (as this regime is often overlooked by other such programs), and will attempt to benchmark a typical problem (such as the emitted coherent radiation used to study longitudinal beam profiles). Other improvements will include the calculation of self-fields in the particle tracker and enhancement of the beamline visualization canvas. The ultimate goal of the program is to establish a singular destination for complicated start-to-end simulations with intuitive visualization guides for the everyday accelerator beamline or radiation user.

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