

UNDULATOR RADIATION SIMULATION BY QUINDI

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Abstract

QUINDI, a code developed to simulate coherent emission from bending systems, has been upgraded to include undulators as a beamline element. This approach allows us to better model the radiation produced by a relativistic electron bunch propagating through such a device. Additionally, many new features have been added to the QUINDI post-processor, SpecGUI, which allow the user more sophisticated ways to manipulate and analyze the output from QUINDI.

INTRODUCTION

QUINDI was originally developed to provide a computational simulation for a chicane compressor experiment at the Brookhaven National Laboratory Accelerator Test Facility[1]. The code is unique in its ability to model the radiation spectrum of the bending electron bunch as seen by a detector placed somewhere in space.

The first paper published about the code describes the basic flow of processes (trajectory calculation, electric field calculation, and spectrum calculation) and compared our theoretical results to the experimental results of the ATF experiment[2]. It introduced SpecGUI, the QUINDI post-processor programmed in Matlab[3], which is the primary tool for analyzing the single HDF5[4] output file that is produced by running a QUINDI simulation.

The second paper published about QUINDI discusses the improvements that had been made up to that time[5]. These include 3-dimensional magnetic fields to better model edge radiation, improved particle tracking accuracy, the addition of the velocity field component to the Lienard-Wiechert potential[6], the ability to choose a logarithmic frequency scaling for the Fourier transform, and some improvements to SpecGUI, such as the addition of a rotatable polarizer.

In this paper, we explain the addition of an undulator beamline element to QUINDI, and the new additions to SpecGUI, which include individual frequency component selection, frequency range selection, and individual detector point spectral analysis.

UNDULATOR

We first tried to approximate an undulator by using the existing beamline elements, creating an undulator with a long series of alternating polarity bend magnets. While this does produce some degree of undulating effect, as seen in

figure 1, to more accurately reflect the true sinusoidal nature of the magnetic field, we had to develop an undulator as a discrete beamline element. In QUINDI, an undulator is currently limited to a 1-dimensional field in the x -direction, and is defined by the undulator wavelength λ_u , the z -position in the beamline, the peak magnetic field, and the number of periods. To prevent an overall y -direction drift of the particles inside of the undulator, we add a half-period half-strength magnetic field section to the beginning and end of the undulator. The magnetic field strength inside of the undulator is sinusoidal in position, but static in time, and this causes the particles to have a similarly sinusoidal trajectory with the expected correct amplitude.

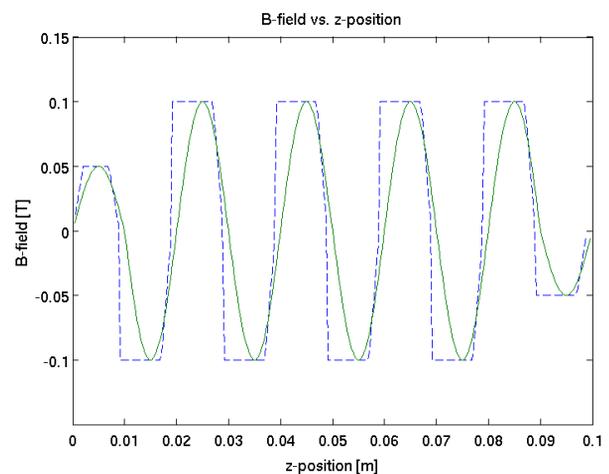


Figure 1: Comparison of magnetic field profiles for undulator vs. bends. The blue dashed line is the magnetic field for a series of alternating bend magnets, while the green solid line is the magnetic field for the undulator.

One major advantage to how undulators are used in QUINDI is that we calculate the field with the full Lienard-Wiechert potential formalism. This includes the near-field radiation in addition to the far-field, as well as all three components of the electric field vector. Further, in this approach QUINDI recalculates the particle's distance to the detector with every trajectory step thereby eliminating the ambiguity in the field calculation associated with the distance from the detector to the extended undulator source, which is a common problem unless the detector is many undulator lengths away. This allows the detector to be placed arbitrarily close to the end of the undulator in order to see all possible radiative effects within the desired frequency window. As undulators continue to increase in size, the

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chance of a diagnostic being placed in the near-field zone increases, and the influence of the near-field effects can no longer be ignored; therefore, to better model current and future generations of undulators, we have included this term.

BENCHMARKING

In order to test if the spectrum and intensity profiles computed by QUINDI are correct, we used Mathematica[7] to produce an analytical simulation directly from the standard undulator equations[8]. Despite the fact that these two methods of computation vastly differ in their approaches, they produce remarkably similar results.

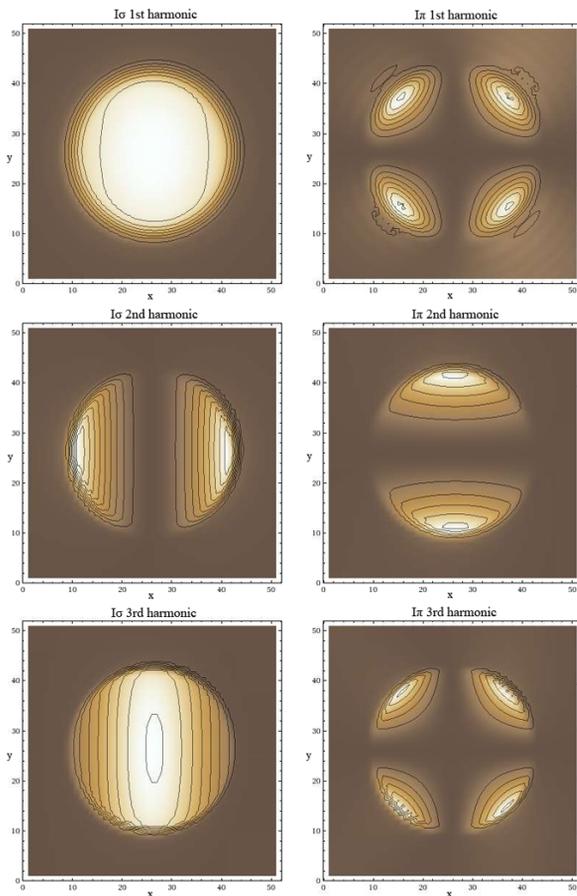


Figure 2: Comparison of π - and σ -modes for the first three harmonics. The underlying shading represents the computed QUINDI results and the contour overlays are the analytical Mathematica results.

In figure 2, we compare the analytical solutions from Mathematica to the computed QUINDI results for an electron with γ of 142, an undulator with 100 periods, λ_u of 2cm, a peak field of 1T, and the detector is 3cm^2 and placed on-axis 2m away from the end. The first three harmonics are shown in both σ - and π -modes, and they have been integrated over a frequency bandwidth of $\pm 2\%$ for both the computational and analytical results.

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The integrated frequency spectrum for this undulator is shown in figure 3. The second and third harmonics are at integer multiples of the fundamental frequency, as is expected with undulator radiation.

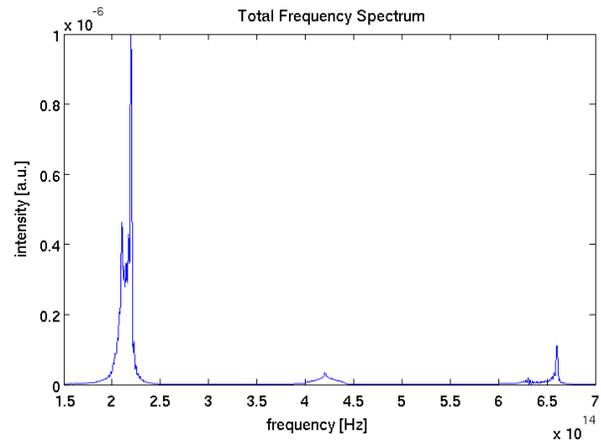


Figure 3: Integrated spectrum showing the first three harmonics for the benchmarking case.

UPDATES TO SPECGUI

QUINDI output files are best analyzed with the Matlab post-processor, SpecGUI. Many new features have been added to SpecGUI to help users better interpret the spectral data. Previously, a user could only see the frequency spectrum as integrated over the entire detector. Now, we have added the ability to choose a single detector point and view the spectrum at only that location, with the angle off-axis displayed in mrad. This allows the user to watch how the frequency spectrum changes as the location is moved off-axis, and it makes it easy to see the spectrum at various hot spots of intensity.

Another feature allows the user to cycle through the frequency cuts to see what the radiation looks like on the detector at each separate frequency. This makes it possible to see what individual frequency components are contributing to the total integrated spectrum, and by setting the limits of the plot to the limits of the most intense frequency slice, the user can easily see the relative strengths of each slice. Additionally, the user can select a range of frequency slices to integrate over in order to see what the detector intensity is for a wider bandwidth of frequencies.

These two features can be used independently or together to get a very complete picture of the spectrum and relative intensities between frequency cuts and detector location. The existing polarization feature can be used with these new modes, so that the user can view the detector intensity at different polarizations at only the frequency or frequency range of interest. Additionally, the polarizer can be used with the detector point selection mode, so that the frequency spectrum can be seen for a single detector point at a desired angle of polarization. Figure 4 is a screenshot

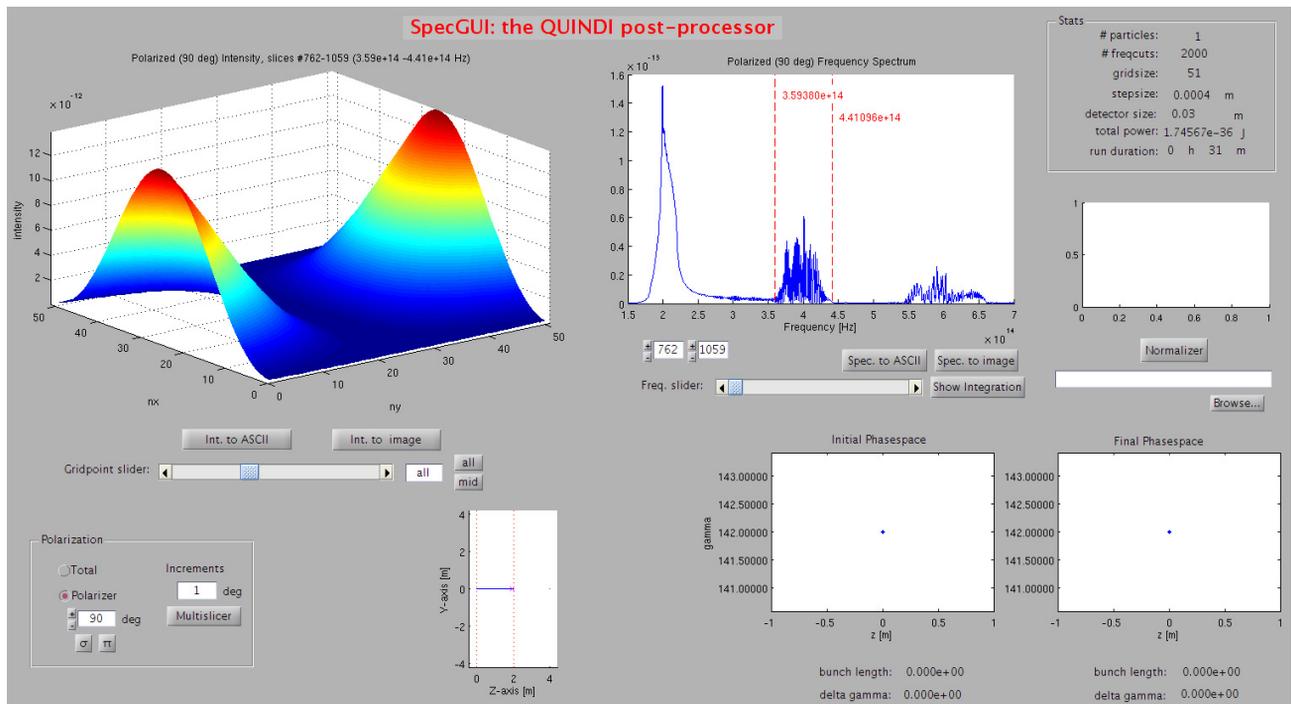


Figure 4: Screenshot of the newest version of SpecGUI

of the latest version of SpecGUI, showing the intensity on the detector within a narrow band of frequencies.

OUTLOOK

As always, we are looking to add new features to QUINDI. The most likely next addition is to allow an external electric field to be defined, and to extend our use of the Lorentz force to include an electric field component. This will provide the ability to model electron beam/laser interactions such as inverse Compton scattering, and additionally can work to model newer technologies such as laser and dielectric acceleration.

We intend to add more possible types of magnets to the collection of beamline elements, including quadrupoles and sextupoles; these are common elements and would provide the ability to model focusing. We would like the ability to be able to rotate beamline elements arbitrarily in space to match a wider array of experimental setups.

We have already implemented a rudimentary coherent transition radiation function, however, it only acts to slow down the particle to a stop by artificially reducing its momentum. While this does provide some useful results, we would like to improve on this functionality in order to better simulate the actual energy losses which occur as an electron slams into a target material.

QUINDI will continue to be developed in the future to be able to model more types of experiments involving relativistic electron beams.

REFERENCES

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