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A FAST SIMULATION TOOL TO CALCULATE SPECTRAL POWER DENSITY EMITTED BY WIGGLERS AND SHORT INSERTION DEVICES

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Abstract

The analysis of thermal stress of beamline components requires a comprehensive determination of the absorbed power profile. Consequently, accurate calculations of beam power density and its dependency on the photon energy are required. There exist precise tools to perform these calculations for undulator sources, like several methods available in the OASYS toolbox [1] considering, for example, the contribution of the different harmonics of the undulator radiation or using ray-tracing algorithms [2]. This is not the case for wiggler sources, in particular for short insertion devices that are used as source for the bending magnet beamlines in some upgraded storage rings like the ESRF-EBS. Wiggler radiation is incoherent and although it is possible the use of undulator methods for calculating it, this is very inefficient. In this work, we describe a tool that performs fast calculations of spectral power density from a wiggler source. The emission is calculated starting from a tabulated magnetic field and computes the power spatial and spectral density. It uses concepts inspired from Tanaka's work [3]. It is implemented in a user-friendly widget in OASYS and can be connected to widgets to calculate absorbed and transmitted power density along the beamline components. The accuracy of the method is verified by calculating three examples and comparing the results with ray-tracing. The three insertion devices simulated are: the EBS-ESRF-3PW (see results in Figure 1), the ESRF W150 (a high power wiggler) and the 3PW for the BEATS project [4] at the SESAME synchrotron source.

INTRODUCTION

Currently, there are some synchrotron facilities that are implementing short insertion devices (IDs) as suitable photon sources that fits the demands of different beamlines. For example, in the new ESRF-EBS storage ring, all the 16 bending magnet beamlines have been upgraded with 3-pole wigglers, 2-pole wigglers or short bending magnets [5]. Another example is at SESAME, where a 3-pole wiggler is planned to be used at the BEAmline for Tomography at SESAME (BEATS) [4]. Therefore, in order to perform analysis of thermal stress of components of beamlines with this kind of sources, there is a demand of accurate and efficient tools to calculate the spectra power density distribution of these type of IDs. In this work, a new fast algorithm implemented as a user-friendly widget in OASYS [1] is presented.

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CALCULATION METHOD

The goal is to calculate the emitted flux by a wiggler F as a function of the horizontal and vertical coordinates (x, y) of a screen plane perpendicular to the propagation direction (optical axis) and located at a distance D from the center of the wiggler. The flux distribution is calculated for a grid of photon energies E, therefore $F(x, y, E)$.

We do not restrict to conventional wigglers with sinusoidal field, but use a numerical map of the magnetic field in the vertical direction $B_y(z)$. This allows us to simulate short IDs like the ones used at EBS-ESRF in the bending magnet photon sources, namely 3-pole wigglers (3PWs), 2-pole wigglers and 1-pole wigglers (or superbendings).

Contrary to the conventional method to calculate the differential emission at any coordinate point (x, y) for then averaging to the pixel size, we use a top-to-bottom method, first calculating the emission spectrum (integrated over an infinite size) for then distributing each integrated intensity for a given photon energy $F(E)$ over its spatial distribution calculated ad-hoc. This method is explained in this section.

We assume (like in [3]) that i) the wiggler emission is fully incoherent (emission at every position of the electron trajectory are superimposed incoherently); ii) the electron emittances (finite size and divergence of the electron beam) are neglected, because they are usually smaller than the average sizes and divergences of the photon beam emitted by a single electron (or filament beam); and iii) the emission at a given point of the electron trajectory is the same as the Bending Magnet emission.

The calculation of the electron trajectory and emission spectrum follows the model implemented in SHADOW ([2]) and XOPPY ([1]).

Calculation of Electron Trajectory Under a Magnetic Field

Let us start with the wiggler magnetic field, that for a conventional wiggler has only a vertical component ($\vec{B} = (0, B_y, 0)$ and is given by tabulated values $B_y(z)$, with z the wiggler direction centered at the middle of the wiggler. An electron entering in this magnetic field will have a transversal velocity β_y (in c units) given by the integral of the magnetic field

$$\beta_y(z) = -\frac{c10^{-9}}{E_e[GeV]} \int_{z_1}^{z} B_y(s) ds. \tag{1}$$

The electron trajectory is in the horizontal plane and is given by the integral of the velocity,

$$x(z) = \int_{z_1}^{z} \beta_y(s) ds. \tag{2}$$

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The local curvature (or inverse of the local radius) is also calculated, because the local emission corresponds to that of a bending magnet of that curvature. It is proportional to the second derivative of the trajectory, therefore proportional to B_y

$$R^{-1}(z) = \frac{e}{\gamma m_e c} B_y(z), \quad (3)$$

with e the electron charge, m_e the electron mass and γ the electron energy in units of $m_e c^2$. Each curvature has associated a bending magnet critical energy given by

$$E_c(z) = \frac{3}{4\pi} \lambda \gamma^3 R^{-1}(z), \quad (4)$$

with λ the photon wavelength.

Calculation of Spectrum of the Wiggler Full Emission

Once calculated $E_c(z)$ we compute the number of photons emitted per mrad at each z point (using the equations of the bending magnet). This result is multiplied by $(R(z)10^{-3})^{-1}$ to get the number of photons emitted along each trajectory arc step, and then multiplied by $\sqrt{1 + (\beta_x(z)/\beta_z(z))^2}$ to account for the projection of the arc on the axial length Δz. A final integration in z results in the total number of photons at that photon energy.

Calculation of Screen Illumination at a Given Photon Energy

Consider a plane at a distance D from the center of the ID. We want to determine the flux as a function of the coordinates (x, y) and energy E. A first step is to define automatically the window that will receive the full radiation. For that, we consider $\sigma' \approx (0.597/\gamma)\sqrt{\max(E_c)/\min(E)}$ the maximum angular deviation of the emitted photons in a bending magnet approximation (after first equation in page 43 of [3]). The angular interval to be consider in horizontal is $\Delta x' = 2n_p\sigma' - \min(\beta_x) + \max(\beta_x)$ with n_p a "passepartout" coefficient to enlarge the window (by default $n_p = 3$). In vertical, $\Delta y' = 2n_p\sigma'$. The spatial points (x, y) at a distance D from the source are in the window $(D\Delta x', D\Delta y')$. Each point (x, y) subtend angles $(x/D, y/D)$ with the center of the ID.

For each photon energy E, we calculate the 1D intensity profiles $I_x = I(x, 0)$ and $I_y = I(0, y)$. The 2D map is constructed making the outer product of I_x and I_y. The vertical profile I_y corresponds to the bending magnet emission with an averaged critical energy $\bar{E}_c$. We recall that each point of the trajectory has a different curvature and therefore a different critical energy. We compute

$$\bar{E}_c = \frac{\int E_c(z) I(z) dz}{\int I(z) dz}, \quad (5)$$

where $I(z)$ is the local intensity emitted at the z coordinate. In vertical, each point y sees the emission with an approximated angle y/D as there the electron trajectory is in the (x, y) plane. However, in horizontal the situation is different, as each trajectory point emits with an angle $\beta_x(z)$. The function $I(\beta_x)$ is multivalued, therefore intensity at a given coordinate angle x/D is originated from different trajectory points with $\beta_x \approx x/D$. By doing a mutivalued interpolation we can obtain the intensity at coordinate x/D. It has then to be convolved with the bending magnet emission (using here critical energy $\max(Ec(z))$ as suggested in [3]) to obtain the profile I_x.

Evaluation of the $F(x, y, E)$ Stack

Having the intensity distribution $I(x, y)$ (normalized such as $\int dx \int dy I(x, y) = 1$) for each photon energy E, the spectral flux $F(E)$ is then multiplied by I to obtain the spectral flux density $F(x, y, E)$.

EXAMPLES

SHADOW ray tracing and the new OASYS widget Wiggler Radiation have been used to get the power density distribution at 30 m from the source. Calculations were done using 100 eV steps withing 0.1 keV to 100 keV photon energy range. ESRF-3PW are shown in Fig. 1, ESRF high power wiggler W150 in Fig. 2 and BEATS source in Fig. 3.

CONCLUSION

A new algorithm has been developed that allows a fast and accurate calculation of the spectral power density emission of Wigglers, with particular application on short wigglers and not periodical magnetic fields wigglers. It is implemented as an OASYS widget, representing an useful tool for heat-load calculations in beamline components, especially those found in the beamline front end. For that purpose, the new widget can be connected to the beamlime elements (slits, mirrors, crystals) under study.

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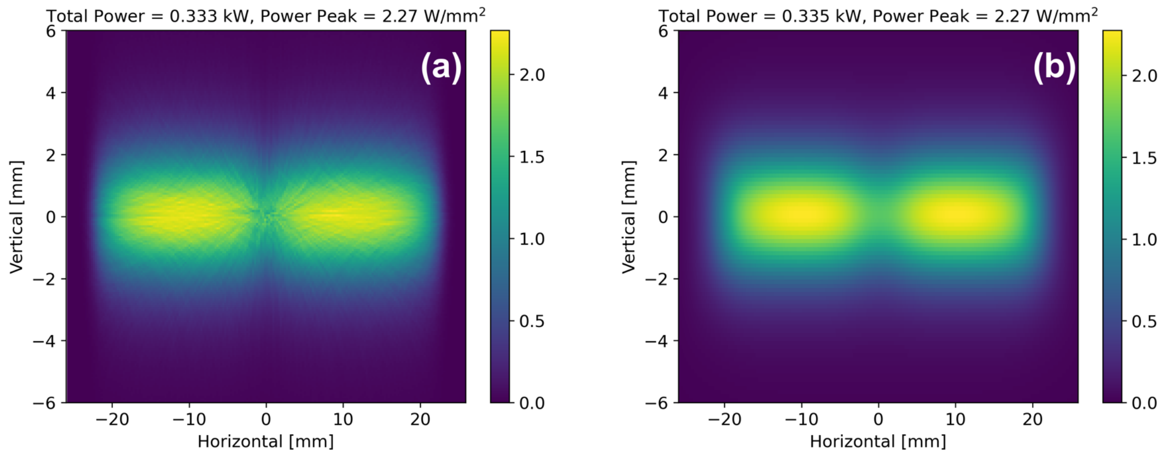

Figure 1: Power density distribution of ESRF-3PW: (a) Using ray-tracing and (b) New OASYS widget Wiggler Radiation.

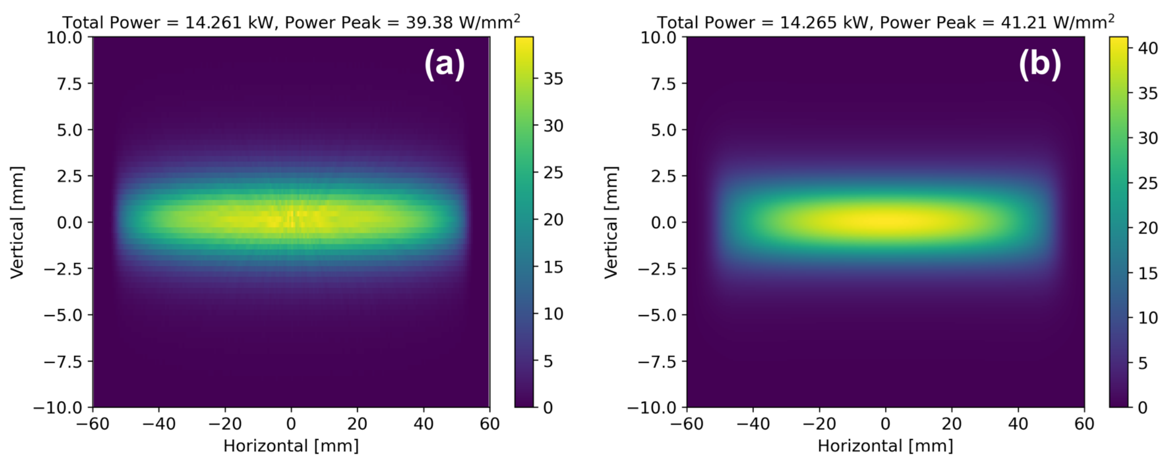

Figure 2: Power density distribution of ESRF-W150: (a) Using ray-tracing and (b) New OASYS widget Wiggler Radiation.

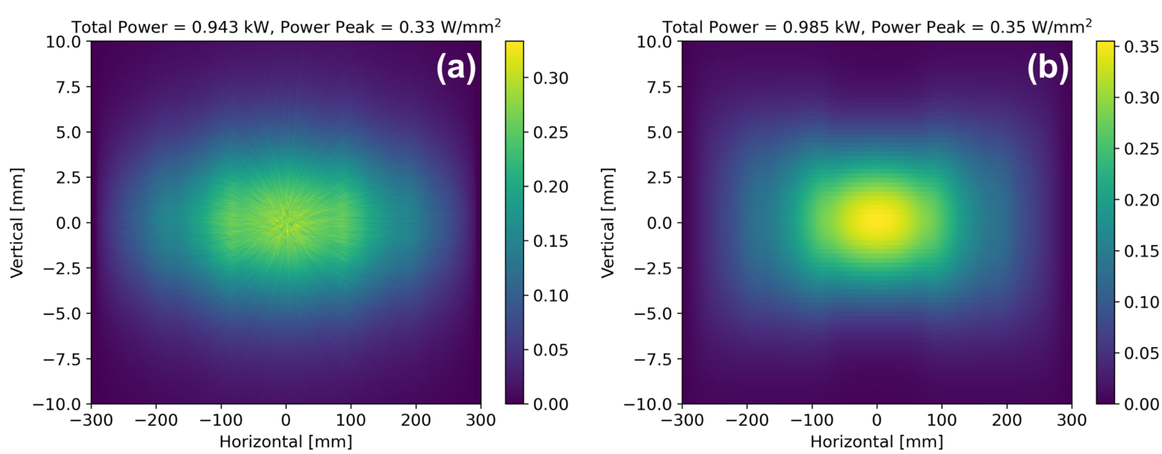

Figure 3: Power density distribution of BEATS project source: (a) Using ray-tracing and (b) New OASYS widget Wiggler Radiation.