

Reference Manual for SPECTRA ver. 9.0

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1. Introduction

This document describes the instruction to use the free software *SPECTRA*, a synchrotron radiation (SR) calculation code developed at SPring-8, and is located in “[SPECTRA Home]/help”, where [SPECTRA Home] is the directory where *SPECTRA* has been installed.

All the pictures of the GUI windows in this document are those of the Microsoft Windows version, but other versions (Mac OS X and Linux) have similar appearances.

In this chapter, brief explanations on the software and numerical implementation of SR calculation are given with a simple instruction for how to get started.

1.1. Overview

SPECTRA is an application software to calculate optical characteristics of radiation emitted from various synchrotron radiation (SR) sources such as bending magnets (BMs) and insertion devices (IDs, i.e., wigglers and undulators). In addition, IDs with arbitrary magnetic fields are available by importing the magnetic field data prepared by users. This makes it possible to estimate the real performance of the SR source by using the magnetic field distribution actually measured by a field measurement instrument such as a Hall probe.

In order to calculate the optical characteristics to estimate the performances of SR sources, a lot of parameters are required to specify the accelerator performances, SR source configurations, and observation conditions.

SPECTRA is equipped with a fully graphical user interface (GUI) which helps the user to specify these parameters. In addition, a simple plotter is included to verify the results of calculation graphically. These graphical parts are written in C++ with the wxWidgets GUI tool kit library [2]. For visualization of results of several kinds of calculation, the OpenGL graphic library [3] is used. Thanks to portability of wxWidgets and OpenGL libraries, *SPECTRA* will run on most of the available platforms such as Microsoft Windows, Macintosh OS X (OS 9.x or earlier is not supported), Linux, and most unix-like operating systems. *SPECTRA* does not require any other commercial softwares or libraries.

The numerical part of *SPECTRA* is also written in C++ with the standard template library (STL). For wigglers and BMs, numerical implementation is based on the well-known expressions on SR [4]. As for SR emitted from an ideal undulator, the so-called far-field approximation can be used for fast computation. For more accurate evaluation, expressions on SR in the near-field region are used for numerical computation. In this case, characteristics of SR emitted from both the ideal- and arbi-

trary-field devices can be calculated. For details of numerical implementation, refer to [1], [5].

Before ver. 7.2, the magnetic field was assumed to be constant in the transverse (x - y) plane. In other words, only the dipole components were taken into account. This considerably simplifies the numerical algorithm not only in the trajectory calculation but also in the spatial integration to take into account the electron beam emittance.

In ver. 8.0, an arbitrary magnetic field has been supported to enable the evaluation of the effects due to quadrupole magnets between undulator segments and the undulator natural focusing, which would be significant for low-energy electrons.

In ver. 9.0, an arbitrary electron bunch profile (transverse and longitudinal) has been supported. The user can import the bunch profile data of the electron beam either in the projected profile or in the macroparticle coordinates in the 6-dimensional phase space, which is usually created by the start-to-end simulation for X-ray FELs.

1.2. Type of SR Sources

Two kinds of SR sources are available in *SPECTRA*. One is a built-in SR source with an ideal magnetic field profile (sinusoidal for undulators/wigglers and uniform for bending magnets). The other is a custom SR source with an arbitrary magnetic field distribution specified by the user. Refer to Selection of the SR Source Type (5.6) for details.

1.2.1. Built-in SR Source

A number of SR sources are available in *SPECTRA* without any special configurations: conventional undulators, helical undulators, wigglers, bending magnets, etc. Calculations based on the Far Field Approximation (1.3.1) are available for the built-in SR sources.

1.2.2. Custom SR Source

Beside the built-in SR sources described above, it is possible to specify an arbitrary magnetic field distribution and create a customized SR source. Note that the Far Field Approximation (1.3.1) cannot be applied. Thus, a longer computation time will usually be needed for this type of SR source.

1.3. Formulation of SR

In order to perform an effective numerical computation, formulae to express the SR characteristics should be simplified as much as possible. Roughly speaking, there are two methods to formulate the analytical expressions on SR, i.e., “near-field” and “far-field” expressions. In both methods, the electron is assumed to be relativistic. Let \mathbf{R} and \mathbf{r} be the vectors directing from the origin of the SR source to the observer, and to the electron moving in the magnetic field of the SR source, respectively.

1.3.1. Far Field Approximation

In the “far-field” expression, optical characteristics of radiation from SR sources are calculated with an assumption that $|R|$ is much larger than $|r|$. This also implies that the observation angle, i.e., an angle formed by the two vectors R and r , is kept constant. This significantly simplifies the expressions on SR and thus enables a fast computation. For most purposes, such as evaluation of the photon flux passing through a slit and heat load on optical elements, this method is recommended and in fact enough.

1.3.2. Near Field Expression

No approximation is made in this method besides an assumption that the electron is relativistic. In other words, the observation angle is a function of the electron position, i.e., it varies while the electron travels in the SR source. If the distance between the SR source and observer is comparable to the length of the SR source itself, the near-field effect would not be negligible. Especially, the off-axis spectrum will be considerably different from that observed at the point infinitely far from the SR source.

1.4. Getting Started

In order to quickly get started with *SPECTRA* for SR calculation, follow the steps below.

- (1) Open a parameter file by executing [File]-[Open Parameter File] command. You can also execute [File]-[Create New] command to start with a new parameter set.
- (2) Select a type of SR source from submenus in [Configurations]-[Light Source]-[Source Type].
- (3) Select a type of calculation from submenus in [Select Calculation]. The type of calculation is classified according to the main target (brilliance, power density, etc.) and dependence (energy, spatial, etc.).
- (4) Edit the parameters in the GUI windows if necessary.
- (5) Execute [Run]-[Start Calculation] command to start a calculation with current parameters shown in the GUI windows. Then a file-selection dialog box pops up. Enter a file name to save the calculation results. The output data are saved in a file with suffix depending on the type of calculation.
- (6) In order to perform more than one calculations, execute [Run]-[Create Process] command to create a “process”, which saves all the parameters in the configuration GUI windows to temporary memory and adds the created process to the current calculation list.
- (7) Repeat it until all the desired calculation processes are created. Then execute [Run]-[Start Calculation] command to start the calculations in series. You can also create a calculation process by scanning a parameter. Refer to Scanning a Parameter (2.4) for details.
- (8) A GUI window with a progress bar pops up to inform the user of the calculation status.

- (9) In order to verify the calculation results after completion of the calculation, execute [Open Utility]-[Simple Plotter] command, select the name of the output file and item(s) to check, and click [Plot] button to create a graphical plot. Refer to Visualization of Calculation Results (2.2) for details.

2. Instructions for Use

This chapter describes general instructions for use of *SPECTRA*.

2.1. Simple SR Calculation

This section describes a procedure to start a simple SR calculation.

2.1.1. Open a Parameter File

SPECTRA tries to load parameters from the parameter file that was opened last time. If successful, the parameters are shown in the GUI windows. If *SPECTRA* is run for the first time after installation, nothing will be shown. Open a *SPECTRA* parameter file by executing [File]-[Open Parameter File] command. In the initial setting, the parameter files are found in the directory “[SPECTRA Home]/prm” with a default suffix “prm”, where “[SPECTRA Home]” is the directory where *SPECTRA* has been installed.

2.1.2. Select Calculation Type

The type of calculation is selected by executing one of the submenus in [Select Calculation] on the main menu bar as shown in Figure 2.1. For details of each calculation type, refer to Calculation Type and Output Items (chapter 3).

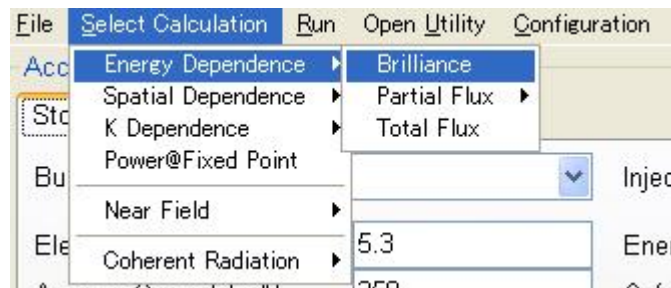


Figure 2.1 Selection of the calculation type.

2.1.3. Edit Parameters

Parameters necessary for SR calculation are edited in the configuration GUI windows. In general, there are several ways to specify a certain set of parameters. For example, the horizontal and vertical emittance values can be calculated if the natural emittance and coupling constant are specified, and vice versa. It is in principle possible to select either of the two parameter sets in order to express the electron-beam quality.

In *SPECTRA*, the natural emittance and coupling constant are specified by the user (input parameter), and the horizontal and vertical emittance values are calculated internally (output parameter). All the

input parameters are shown in the text entry boxes in the GUI windows and can be edited. Once they are edited, the related output parameters are calculated automatically and the values are updated. Also refer to Figure 2.2.

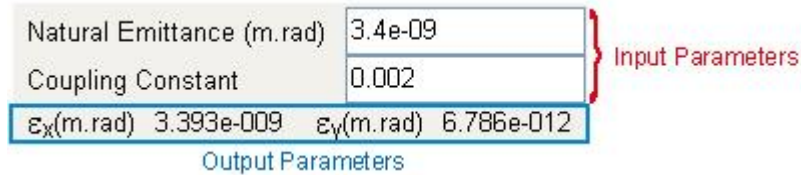


Figure 2.2 Input and output parameters shown in the GUI window.

2.1.4. Single Calculation

After completion of specifying the input parameters, execute [Run]-[Start Calculation] command to start a single calculation. Input a data name in the file-selection dialog box that pops up. A GUI window pops up to indicate the calculation status as shown in Figure 2.3. In order to cancel the calculation, click [CANCEL] button.

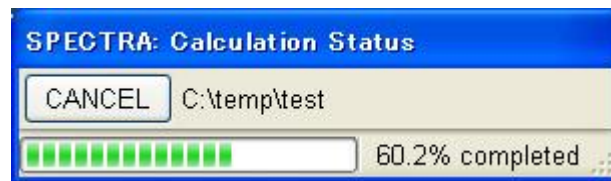


Figure 2.3 Progressbar to indicate the calculation status.

2.1.5. Successive Calculations

It is possible to specify a number of calculations with different sets of parameters. After completion of editing parameters, execute [Run]-[Create Process] command and input a data name in the file-selection dialog box that pops up. Then a GUI window pops up as shown in Figure 2.4 to show the calculation list currently saved in a temporary memory. Repeat it until all the calculations are specified.

Next execute [Run]-[Start Calculation] command. The calculations in the list are performed successively. The calculation status is indicated in the progress bar in the GUI window. Click [CANCEL] button to cancel the calculation currently in progress, or [CANCEL ALL] button to cancel all the remaining calculations.

Note that the created calculation process can be saved to a file. Click [Dump List] button and input a file name to save the data in the file-selection dialog box that pops up. The calculation processes saved in the file can be reproduced later, by executing [Run]-[Import List] command and specify the file location.

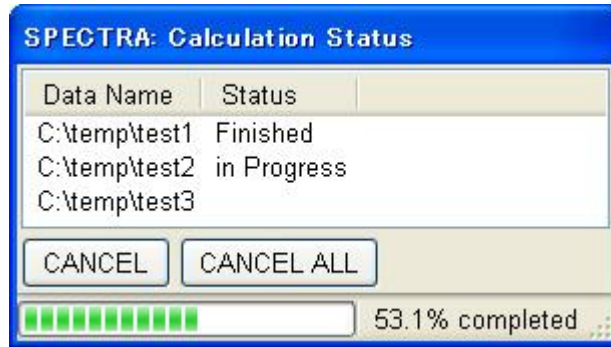


Figure 2.4 Progressbar to indicate the calculation list and status.

2.2. Visualization of Calculation Results

After completion of a calculation, the output data can be plotted graphically to verify the results. Configurations to plot the calculation results are available in the GUI window as shown in Figure 2.5, which pops up just after completion of calculation(s) (not in the Mac OS X version), or by executing [Open Utility]-[Simple Plotter] command.

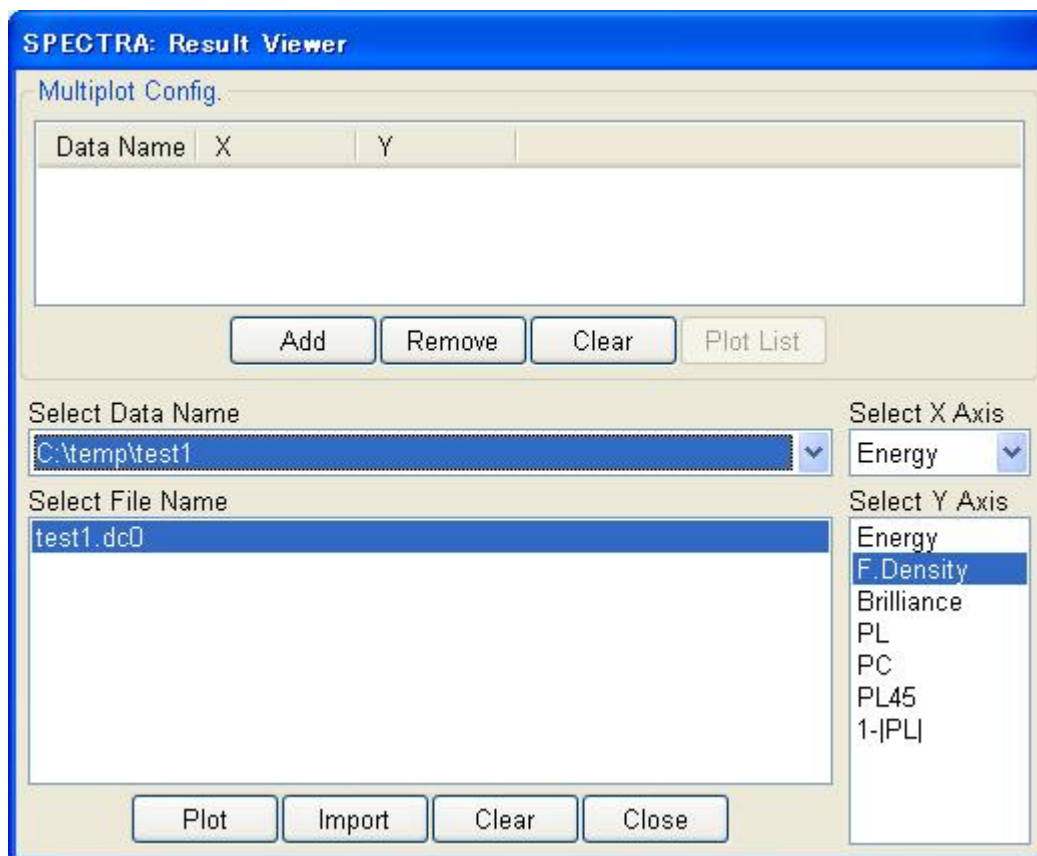


Figure 2.5 GUI window for configuration of plotting the calculation results.

2.2.1. Single Data Set

In order to plot the calculation results, specify the data name, file name and item(s) for X/Y axis in the GUI window. Refer to the followings for details.

Select Data Name

The data names, specified in the file-selection dialog box just before starting a calculation, are stored in this list. Select a desired one for plotting. The data name is automatically added to the list after completion of a calculation. It is also possible to add a data file manually. To do so, click [Import] button and select the file name in the file-selection dialog box that pops up.

Select File Name

In several types of calculation, a certain number of files are created to save the calculation results. For example, the spatial dependence along the x- and y- axes are saved in two files separately, i.e., “****.dtx” and “****.dty”, respectively, where “****” means a data name. Select desired file(s) for plotting.

Select X/Y Axis

In order to specify the abscissa (X Axis) and ordinate (Y Axis) of the plot, select an item from those in the lists. Multiple selections are allowed for Y Axis, which results in a multiple plot. If the calculation result is in a 3-dimensional (3-D) form (e.g., [Spatial Dependence]-[Cartesian Mesh] is selected), the X Axis list is disabled. Select one of the items in the Y Axis list.

After specification of the all the items above, click [Plot] button to create a graphical plot as shown in Figure 2.6. To clear all the data names in list, click [Clear] button.

2.2.2. Multiple Data Sets

Besides creating the plot with the single data set explained above, more than one data set can be plotted in a single window. To do so, click [Add] button after specifying all the items necessary to create a plot with a single data set. The contents of the plot are listed in the top box. After adding all the data sets, click [Plot List] button to create the plot with multiple data sets.

2.3. Editing the Plot

The graphical plot is created as a GUI window as shown in Figure 2.6. From version 8.1, a number of commands have been available to modify the appearance of the plot. In order to edit the plot, left- or right-click the plot window and execute one of the commands, which are explained in the following sections. Note that the type of command depends on the dimension of the plot (2-D or 3-D).

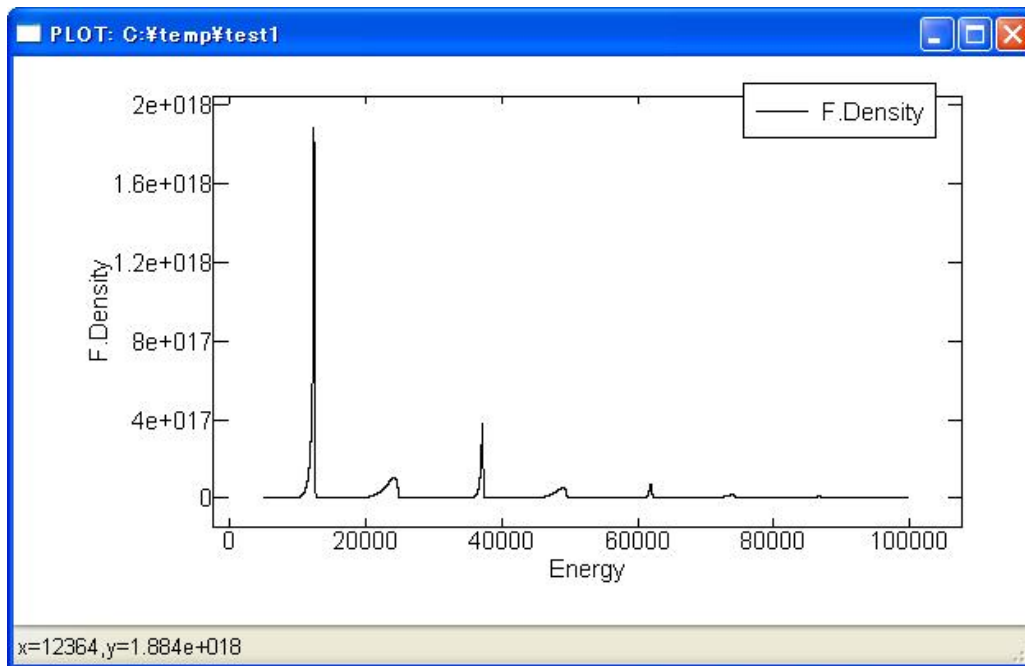


Figure 2.6 Example of a graphical plot to view the calculation result.

2.3.1. 2-D Plot

The 2-D plot has many items to be configured, which are explained in detail in the followings.

Zooming

In order to expand or shrink the plot, drag the region of interest. Then in the pop up menu, execute [Zoom In] to expand, and [Zoom Out] to shrink.

Specify and Read a Point

In order to get the coordinate of a certain point in the plot, click the pixel near that point. Then, the X (abscissa) and Y (ordinate) coordinates are indicated in the format $x=****$, $y=****$ in the status bar located on the bottom of the plot.

Log/Linear Scale: X/Y Axis

The scale of the abscissa or ordinate can be changed from logarithmic to linear, or vice versa.

Initialize Scale

Changes the plotting range to the original one.

Edit Options

Open a dialog window to edit the details of the plot. Refer to Plot Options (2.3.2) for details.

Line/Symbol/Line+Symbol

Selects the method of how to indicate and connect the points in the plot.

2.3.2. Plot Options

The details of the plot, such as the color, symbol type, plotting range, offset, and status can be specified in the dialog box shown in Figure 2.7.

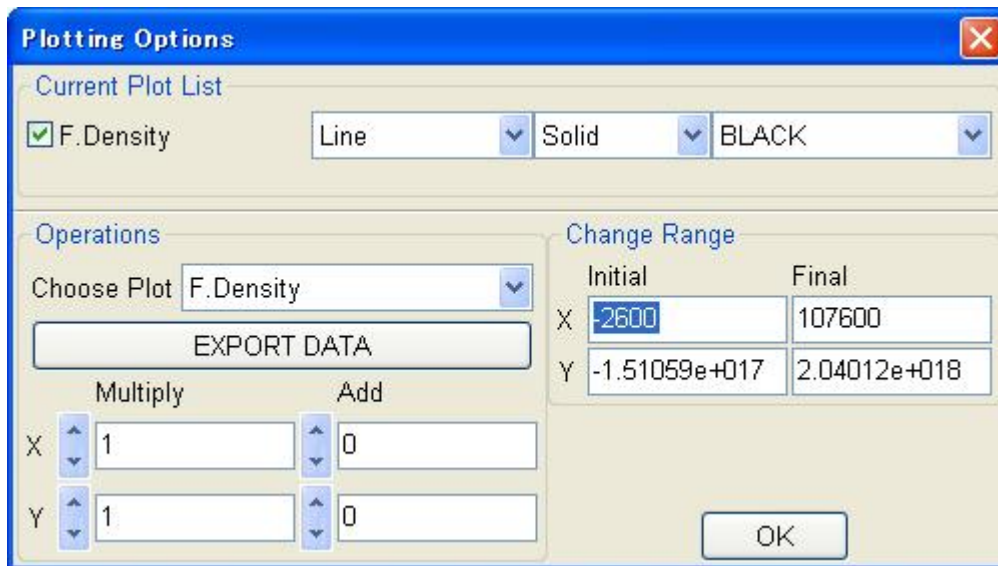


Figure 2.7 GUI window to edit the details of the plot.

Current Plot List

Configures the appearance of the plot. The checkbox in the left side specifies if the plot is shown or hidden. In the three choice boxes in the right side, the plot type, the symbol type and the plot color are specified.

Operations

In order to improve the appearance of the plot, especially to compare more than one plot, arithmetic operations are possible. To do so, choose the plot in the top choice box, and input the offset to be added and coefficient to be multiplied.

EXPORT DATA

Exports the numerical data currently chosen in the [Choose Plot] list box. Input a file name to save the data in the file-selection dialog box that pops up.

Change Range

Specifies the plotting range of interest.

2.3.3. 3-D Plot

Selection of the plot type (Surface, Contour, or Contour+Surface) is the only operation available in the 3-D plot. Choose the desired one in the pop up menu, which is available by right-clicking the plot.

2.4. Scanning a Parameter

Besides the Successive Calculations (2.1.5) scheme described previously, it is possible to specify a lot of calculation processes by scanning a certain parameter.

In order to scan a parameter, select the text entry box showing the parameter to be scanned in the GUI panels and right-click it. Select [Scan This Parameter] command in the popup menu. Then a dialog pops up to specify the parameters for scanning as shown in Figure 2.8.

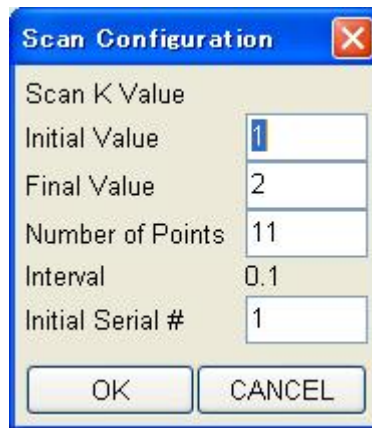


Figure 2.8 Configuration window to create a scanning process.

Enter the initial and final values and number of points for scanning. For some parameters to be specified by an integer, scanning interval should be specified instead of the number of points. In order to create the scanning calculation process, click [OK] button. Input a data name in the file-selection dialog box that pops up. Then the specified parameters are saved in a temporary memory and the scanning calculation process is saved in the calculation list (Figure 2.4). Execute [Run]-[Start Calculation] command to start the scanning calculation.

The calculation results are saved as follows. First, a directory with the data name specified in the file-selection dialog box is created. Each output file is saved in this directory with a serial number being attached. For example, if “[Data Directory]/test” is selected as the data name and “Scanning Points” and “Initial Serial #” parameters are set to 10 and 1, respectively, then output files with the names from “[Data Directory]/test/test-1[.suffix]” to “[Data Directory]/test /test-10[.suffix]” are created, where [.suffix] is the suffix defined by the selected type of calculation.

Besides the above output files, a header file containing the scanning condition is created in the parent directory of the data directory where the output files are saved. In the above example, a file with the name “[Data Directory]/test.hdr” is created. This file can be used to create an animation file from the output files as described in the next section.

2.5. Visualization of Scan Calculation

Because the output-file format of the scanning calculation is identical in terms of the target items and dependency, it is possible to create an “animation” by creating a graphical plot for each output file as a slide of the animation. In order to create an animation from the scanning calculation results, execute [Open Utility]-[Visualization of Scan Results] command to open a GUI window as shown in Figure 2.9. Then, follow the instructions below.

2.5.1. Single Window

First, import the header file (“***.hdr”) that contains the scanning conditions by clicking [Import] button in the [Select Scan Configuration File] group box, and specify its location in the file-selection dialog box. If all the scanning conditions are loaded successfully, they are indicated in the [Scan Condition] group box. In some cases, selection of items in the sub category ([Select File Type]) is required. Next, select the item to be plotted in [Select Item to Plot] group box and click [Single Window] button to create Animation GUI Window (2.6) that visualizes the output files as an animation.

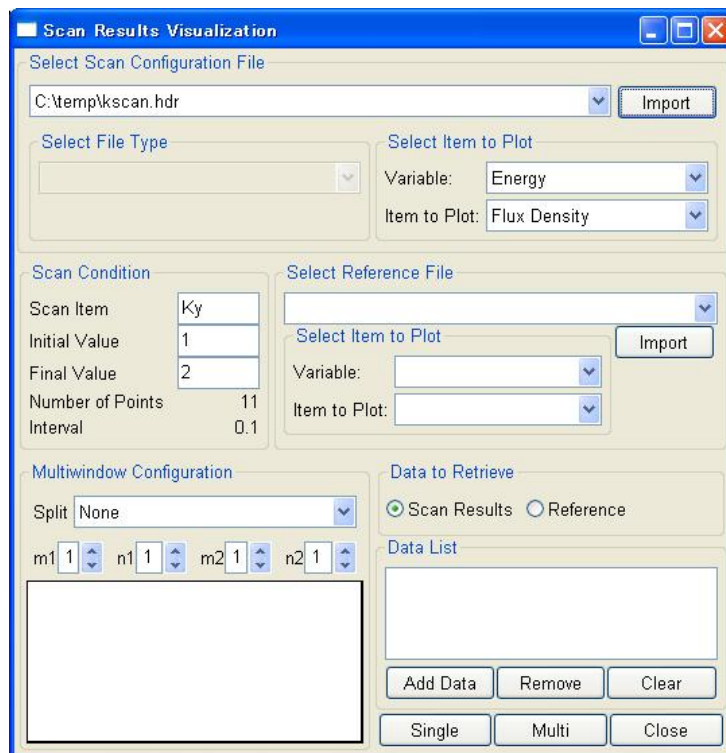


Figure 2.9 Configuration window to create an animation from scanning results.

Besides the scanning results, a simple calculation result (referred to as [Reference Data]), which is obtained by a single calculation but not by the scanning option, is also plotted. To do so, click [Import] button in the [Select Reference File] group box and specify the file location. In the same manner as that described above (using the header file), you can set up the plot by selecting the item to be plotted. Make sure that you have chosen [Reference] in the [Data to Retrieve] group box to plot the [Reference Data], before creating the plot.

2.5.2. Multiple Window

The above procedure creates a single-plot window. It is also possible to create more than one graphical plot in a single GUI window to see the behavior of several items simultaneously. The configurations are specified in [Multiwindow Configuration] group box. The instructions to create the multi-plot window are given in the following sections.

How to Partition the Window

In order to create a number of graphical plots in a single GUI window, the client area should be partitioned, which is performed according to [Split] option and [Matrix Size] parameter. The [Split] option determines how to divide the client area into two divisions that can be resized, while the [Matrix Size] parameters determine the number of columns and rows in each division.

In Figure 2.10, “Horizontally” is selected as [Split] option and [Matrix Size] parameters are set as $m1=1$, $n1=2$, $m2=2$, and $n2=3$, respectively. In this case, the client area is split by the horizontal sash, which can be dragged to resize the divisions. The divisions are further divided into subdivisions, according to the matrix size ($m1$, $n1$ for subdivision 1 and $m2$, $n2$ for subdivision 2). The subdivisions cannot be resized and regularly arranged inside the division.

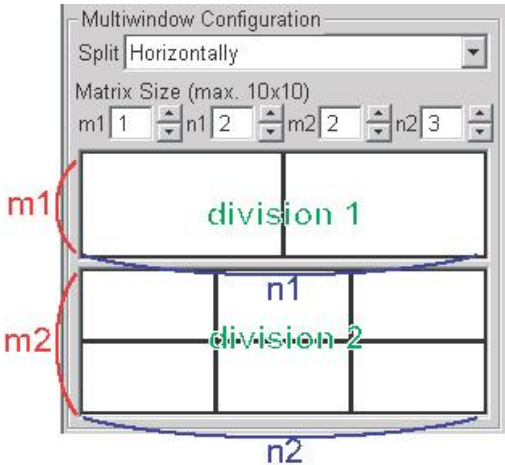


Figure 2.10 Configuration of the multiplot using [Split] option and [Matrix Size] parameter.

Data Allocation and Data Dump

After partitioning the client area, animation data should be allocated to each subdivision. In order to do so, right-click the area of desired subdivision, then a popup menu appears. Select [Allocate current parameter set here] menu to allocate the animation data to the selected subdivision with the parameters (Data File, Sub Category, and Items for X,Y,Z Axes) currently selected. If successful, the area of the selected subdivision is painted gray. If [Clear] is selected from the popup menu, all the data allocations are released.

After allocating the animation data to all the subdivisions, click [Multi] button to start to dump the data and create the Animation GUI Window (2.6).

2.5.3. How to Create Multiplot

The above procedure describes how to create a [single plot], namely, a plot containing a single set of data. In order to create a [multiplot], namely a plot containing more than one sets of data, click [Add Data] button in the [Data List] group box, then the data name is stored in the list box. After specifying all the data to plot, click the [Single Window] button. Note that even after creating the multiplot, the plot data list remains in the list box. In order to create a single plot afterwards, click [Clear] button to clear the data list.

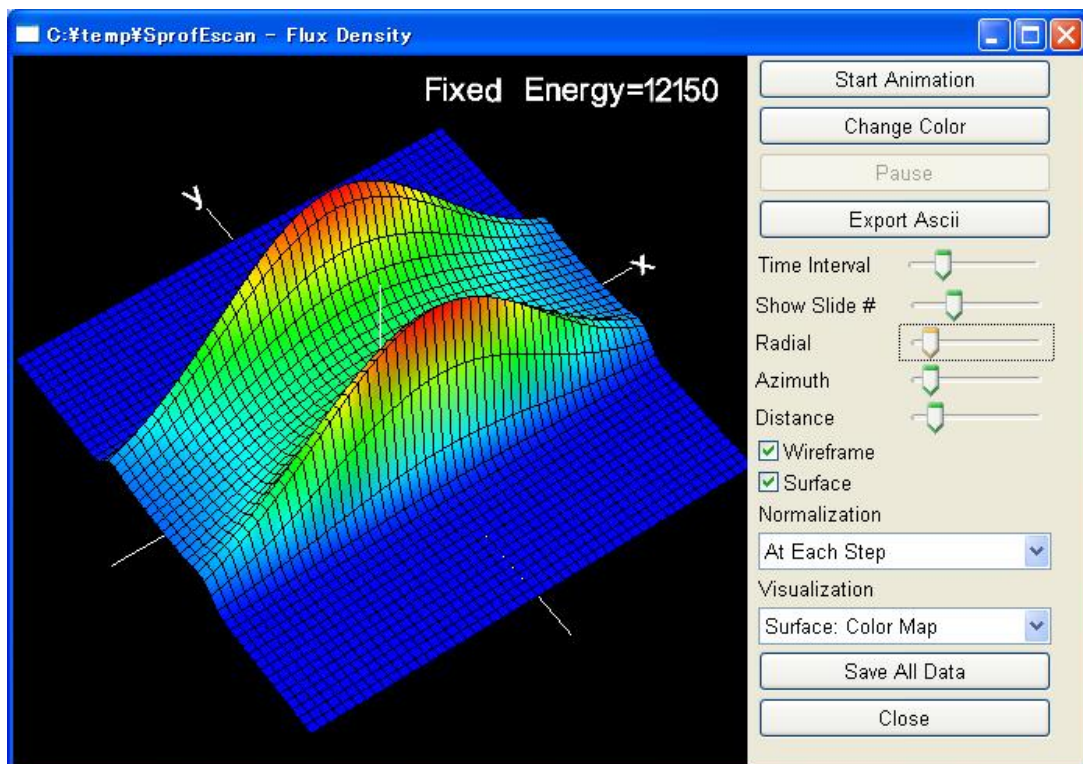


Figure 2.11 An animation GUI window to visualize the scanning results.

2.6. Animation GUI Window

Figure 2.11 shows a GUI window to show the animation, which also allows various operations of the graphical plot using the GUI controls located in the right panel, the details of which are explained in Table 2.1.

Table 2.1 Functions of GUI controls in the animation GUI window. *Functionally in the 3-D plot.

GUI Control	Function
Start Animation	Starts the animation. Disabled while it the animation in progress.
Pause/Resume	Stops or resumes the animation. Enabled only while the animation is in progress.
Change Color	Opens the color-selection dialog box to change the plot color.
Export Ascii	Exports the current graphical plot as numerical data to an ascii file. Specify the file name in the file-selection dialog box that pops up.
Time Interval	Specifies the time interval between slides. Increasing this value makes the animation slower. The actual time interval is dependent on the computer environment such as the platform and CPU.
Show Slide #	Shows the graphical plot corresponding to the selected slide number.
Radial, Azimuth, Distance*	Changes the direction of the plot or the distance from the viewpoint to the plot origin
Wireframe*	Shows a wireframe on the plot.
Surface*	Shows a surface plot.
Normalization	Selects the method to normalize the plot. [At Each Step] means that the item is normalized by the maximum value in the current plot (slide), while [By Maximum Value] means that the items is normalized by the maximum value among the whole data.
Visualization*	Specifies the appearance of the 3-D plot.
Save All Data	Saves the current data and settings to a file. The animation can be reproduced later by executing [File]-[Open SPECTRA Output]- [Visualization File] command.
Terminate	Terminates the animation. Enabled only while the animation is in progress.

2.7. Parameter Set

The “Parameter Set” is a group of input parameters, configurations and options bundled together. There are four types of parameter sets in *SPECTRA*.

2.7.1. Accelerator Parameter Set

The parameter set to specify the accelerator performance. Detailed descriptions on each item are given in Accelerator Specification (Chapter 4).

2.7.2. Light Source Parameter Set

The parameter set to describe the SR source. Detailed descriptions on each item are given in Light Source Description (Chapter 5).

2.7.3. Calculation Control Parameter Set

The parameter set to configure the calculation conditions. Detailed descriptions on each item are given in Calculation Configurations (Chapter 6).

2.7.4. Beamline Parameter Set

The parameter set just to bundles the above 3 parameter sets to specify a “beamline” in a SR facility.

2.7.5. Operation of the Parameter Set

The parameter sets loaded from the *SPECTRA* parameter file are listed in the submenus in [Configuration] menu. By selecting one of the submenus, a new parameter set is selected and the parameters in the GUI windows are updated with the parameters in the selected parameter set. The submenus in [Configuration] menu have three menu commands related to operation of the parameter set, which are explained in the following sections.

Duplicate

A new parameter set is created by executing [Duplicate] command as a copy of the current parameter set.

Change Name

The name of the current parameter set is changed by executing [Change Name] command. Input a new name in the text entry dialog box.

Delete

The current parameter set can be deleted by executing [Delete Parameter Set] command. At least one parameter set should be left.

Sort

Sort the parameter set alphabetically.

3. Calculation Type and Output Items

There are a lot of characteristics that denote the performance of SR, e.g., wavelength, source size and angular divergence, electric field amplitude, polarization, radiation power, and so on. In principle, there are an infinite number of formats to output these characteristics as numerical data. However, there should be a format appropriate for the purpose of SR calculation.

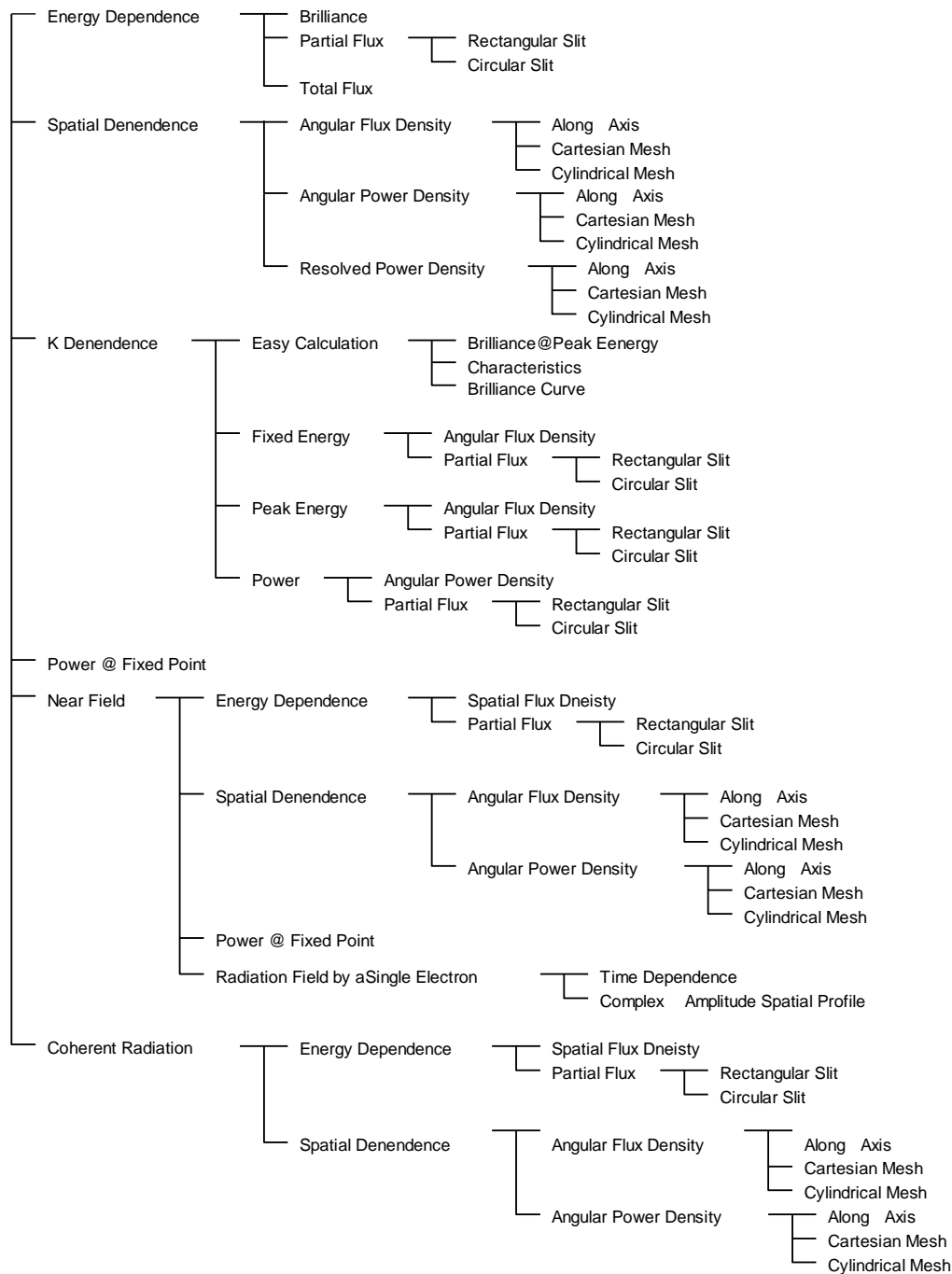


Figure 3.1 Available calculation types classified by the dependency and main item.

SPECTRA has several ways of SR calculation, which can be classified into several types according to the method for Formulation of SR (1.3), main target of SR calculation, and “dependency” of the target. The user is required to select the calculation type with an output format appropriate to the purpose of calculation.

The “dependency” represents a variable that is scanned over a certain range, and the main target (and related SR characteristics) is calculated as a function of that variable. Besides the dependency and main target, there are several items that specify the type of calculation such as the shape of the slit to extract the photon beam, and the mesh type for the calculation of spatial dependence.

All the calculation types available in *SPECTRA* are diagrammatically shown in Figure 3.1. Figure 3.1 Available calculation types classified by the dependency and main item. Submenus in [Select Calculation] have the same structure as in this figure, and each calculation type can be selected from one of the submenus with the same titles as the calculation type.

Calculations in the [Near Field] and [Coherent Radiation] categories are performed with the Near Field Expression (1.3.2) on SR, while the others use the Far Field Approximation (1.3.1). The details of each calculation type are explained in this chapter. Refer to Terms on SR (9.1) for the meanings of SR characteristics described in the following sections.

3.1. Energy Dependence

In the [Energy Dependence] category, SR characteristics summarized in Table 3.1 (except for [Characteristics]) are calculated as functions of the photon energy.

Table 3.1 SR characteristics calculated in the [Energy Dependence] category.

Item	Remarks
Brilliance	Available if [Brilliance] is selected as the main item.
Angular flux density	
Spatial flux density	Available if [Spatial Flux Density] is selected as the main item.
Partial flux	Available if [Partial Flux] is selected as the main item.
Total flux	Available if [Total Flux] is selected as the main item.
PL(s1/s0)	Available in any main item.
PC(s3/s0)	
PL45(s2/s0)	
1- PL	

According to the observation condition, this calculation is further classified into 3 types.

3.1.1. Brilliance/Spatial Flux Density

The characteristics of SR observed at a certain point, i.e., SR passing through an infinitely small slit, are calculated. It should be noted that the brilliance in this case is roughly estimated by dividing the angular flux density by the effective source size, unlike the method used in Characterization in Phase Space (chapter 7). The transverse observation position can be specified either in angle (θ_x, θ_y) or in transverse coordinate(x, y), the definitions of which are shown in Figure 3.2

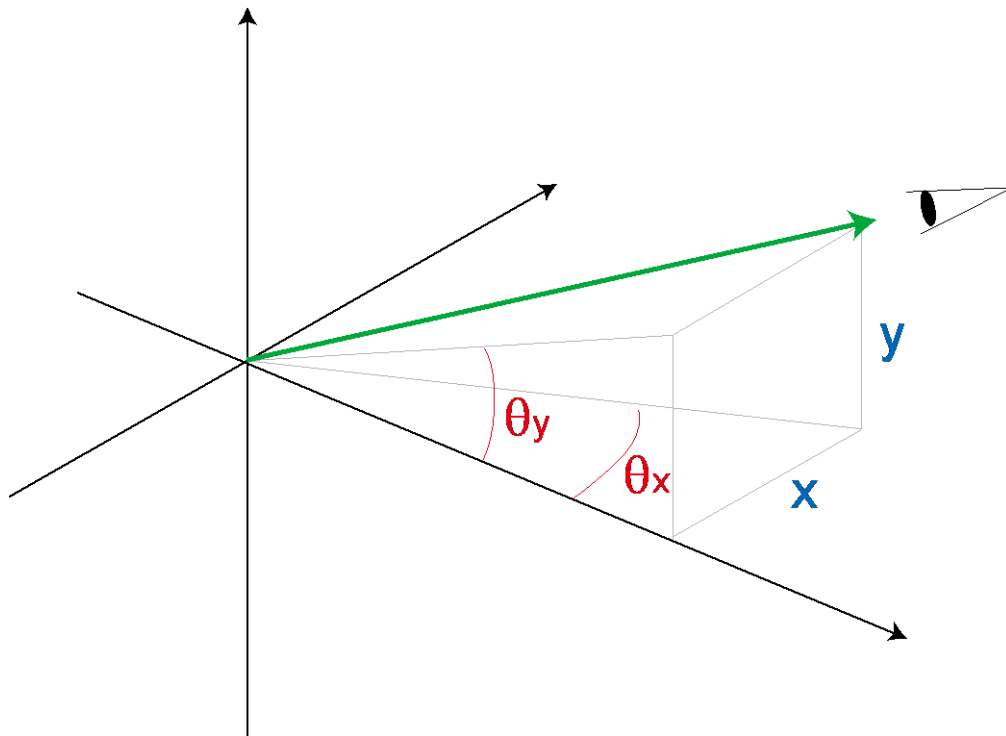


Figure 3.2 Observation of SR at a certain observation position.

3.1.2. Partial Flux

The characteristics of SR passing through a slit are calculated. According to the shape of the slit, this calculation is further classified into 2 types.

Rectangular Slit

A rectangular-shaped slit is located at a certain distance from the SR source as shown in Figure 3.3(a).

Circular Slit

A circular slit or a doughnut-shaped slit is located at a certain distance from the SR source as shown in Figure 3.3. Figure 3.3 Schematic illustration of the (a) rectangular slit and (b) circular slit. (b). The parameter r_1 denotes the radius of the inner area intercepting the photon beam. If this parameter is set to 0, the slit reduces to a simple circular slit.

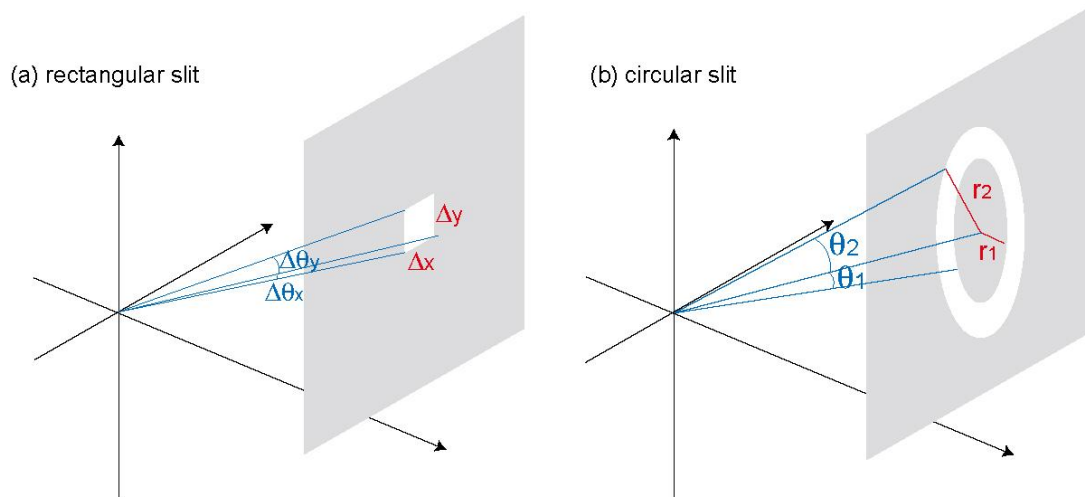


Figure 3.3 Schematic illustration of the (a) rectangular slit and (b) circular slit.

3.1.3. Total Flux

Characteristics of SR emitted over a whole solid angle (4π) are calculated. Not available in wigglers and BMs. For these SR sources, [Energy Dependence]-[Characteristics] (section 3.1.4) is available instead.

3.1.4. Characteristics

Characteristics to denote the performance of the SR source, such as the brilliance, total flux, source size and angular divergence are calculated. Not available in undulators. Select [K Dependence]-[Easy Calculation] instead.

Table 3.2 SR Characteristics calculated in the [Energy Dependence]-[Characteristics] category.

Item	Remarks
Brilliance	
Angular flux density	
Total flux	Unit bandwidth is indicated in 0.1%b.w. or eV
Integrated flux	
Integrated power	
Horizontal/Vertical size	Horizontal/Vertical effective source size
Horizontal/Vertical angular divergence	Horizontal/Vertical effective angular divergence

3.2. Spatial Dependence

In the [Spatial Dependence] category, SR characteristics summarized in Table 3.3 or Table 3.4 are calculated as functions of the transverse observation position.

3.2.1. Angular/Spatial Flux Density

SR characteristics observed at a fixed energy are calculated as a function of the observation point.

Table 3.3 SR Characteristics calculated in the [Spatial Dependence]-[Flux Density] category.

Item	Remarks
Angular flux density	Available if [Angular Flux Density] is selected as the main item.
Spatial flux density	Available if [Spatial Flux Density] is selected as the main item. ([Near Field] calculation)
PL(s1/s0)	
PC(s3/s0)	
PL45(s2/s0)	
1- PL	

3.2.2. Angular/Spatial Power Density

The angular (far field) or spatial (near field) power density of SR is calculated.

3.2.3. Resolved Power Density

The resolved power density represents the power contained in a specific harmonic. In addition, it can be also resolved into two polarization states, namely, horizontally and vertically polarized states. Note that this calculation is available only for undulator sources under the far-field approximation.

Table 3.4 SR Characteristics calculated in the [Spatial Dependence]-[Power Density] category.

Item	Remarks
Angular power density	Available if [Angular Power Density] is selected as the main item.
Spatial flux density	Available if [Spatial Power Density] is selected as the main item. ("Near Field" calculation)
Filtered Power	Power density of SR after transmitting a filter (optional).

3.2.4. How to Scan Observation Position?

Besides the target SR characteristics, the [Spatial Dependence] category is further classified into 3 types according to how to scan the observation point.

Along Axis

The observation position is moved along the horizontal (x) or vertical (y) axis as shown in Figure 3.4. In this case, two output files are created.

Cartesian Mesh

The observation position is moved in a rectangular area determined by the observation range (x_{max} , etc) as shown in Figure 3.4.

Cylindrical Mesh

The observation position is moved in a sectoral area determined by the observation range (r_{max} , etc) as shown in Figure 3.4.

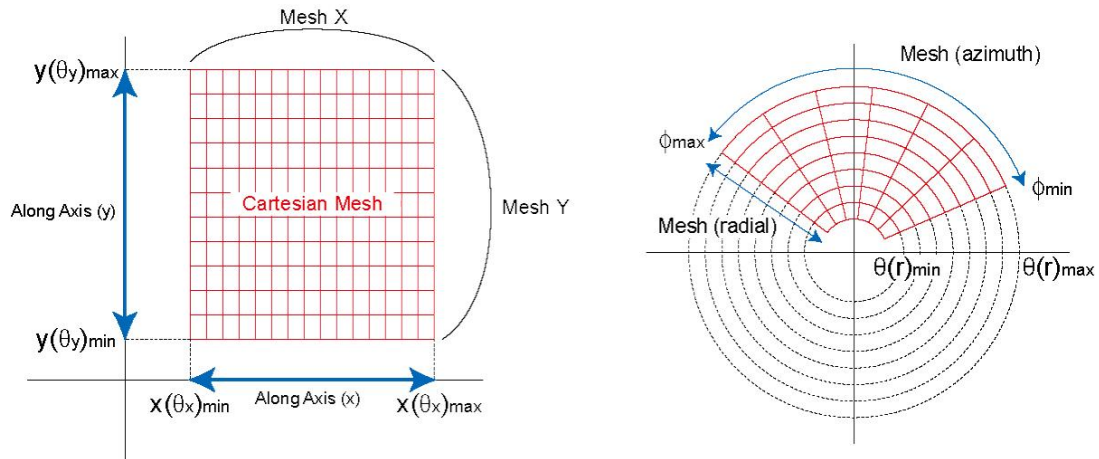


Figure 3.4 Scanning the observation position in [Along Axis] and [Cartesian Mesh] (left) and [Cylindrical Mesh] (right).

3.3. K Dependence

In the [K Dependence] category, the target SR characteristics are calculated as functions of the K value. This calculation type is available only for undulators, but not for wigglers and BMs.

3.3.1. Common Items to be Calculated

The items summarized in Table 3.5 are always calculated in the [K Dependence] category.

Table 3.5 Common items to be calculated in the [K Dependence] category.

Item	Remarks
Gap	Available if the Gap-Field Table (5.3) is enabled.
Peak energy at each harmonic	Not available in the [Fixed Energy] category.
Kx value	If the undulator has a horizontal magnetic field component, Kx (horizontal K value) is calculated as a function of Ky. If Gap-Field Table (5.3) is not enabled, the ratio of Kx and Ky is kept constant.

3.3.2. Easy Calculation

Various SR characteristics, such as the on-axis brilliance, total flux, source size and angular divergence, are calculated as functions of the peak energy at a certain harmonic. In this calculation, rigorous numerical computations are not performed, thus the output values are approximate ones. The user should specify the range of harmonics. A number of output files are created according to the specified harmonic range.

Brilliance@Peak Energy

SR characteristics such as the brilliance and total flux are calculated as functions of the peak energy at each harmonic. In addition, the total radiation power and on-axis angular power density are also calculated to indicate the performance of undulator as a SR source. This calculation is convenient to create a graphical plot that shows the performances of various SR sources.

Table 3.6 SR Characteristics calculated in [K Dependence]-[Easy Calculation]-[Brilliance@Peak Energy].

Item	Remarks
On-axis brilliance	
On-axis angular flux density	
Total flux	
Total power	
On-axis angular power density	Available if [Power Density Calculation] option is enabled.

Characteristics

SR characteristics that are important for optics designs such as the source size and angular divergence are calculated.

Table 3.7 SR Characteristics calculated in [K Dependence]-[Easy Calculation]-[Characteristics].

Item	Remarks
Natural size and divergence	Identical in both x and y directions.
Horizontal effective size and divergence	
Vertical effective size and divergence	
Coherent flux and power	

Brilliance Curve

This function has been added in ver. 9.0 to calculate the best performance of SR in terms of the brilliance, flux density and total flux as a function of the photon energy. In this calculation, *SPECTRA* looks for the maximum values of these physical quantities among the possible harmonic numbers at a given photon energy, and repeat it for different photon energies to create a curve that shows the best

performance in the specified energy region. In addition, the coherent fractions in the both directions are also calculated.

Table 3.8 SR Characteristics calculated in [K Dependence]-[Easy Calculation]-[Brilliance Curve].

Item	Remarks
On-axis angular flux density	Maximum values among possible harmonics
On-axis brilliance	
Total flux	
Horizontal/Vertical Coherent Fraction	Calculated for the harmonic number to maximize the brilliance

3.3.3. Fixed/Peak Energy

SR characteristics observed at a certain photon energy are calculated. In the [Fixed Energy] category, the photon energy is fixed, while the fundamental photon energy is changed by scanning the K value.

In the [Peak Energy] category, *SPECTRA* looks for a peak energy at which the photon flux (flux density or partial flux) becomes maximum and characteristics at the peak energy are saved to the output file.

In terms of the practical setting in the SR beamline, the undulator gap is varied to change the fundamental energy in both calculation conditions, while the monochromator angle is fixed in the [Fixed Energy] case and varied in the [Peak Energy] case to follow the variation of the fundamental energy.

According to the observation condition, this calculation is further classified into several types. Refer to [Brilliance] (3.1.1) and [Partial Flux] (3.1.2) in the [Energy Dependence] category.

Table 3.9 SR Characteristics calculated in the [K Dependence]-[Fixed/Peak Energy] category.

Item	Remarks
Peak energy	Available in [Peak Energy] category.
Angular flux density	Available if [Spatial Flux Density] is selected as the main item.
Partial flux	Available if [Partial Flux] is selected as the main item.
PL(s1/s0)	
PC(s3/s0)	
PL45(s2/s0)	
1- PL	Fraction of non-linear polarization

3.3.4. Power

Characteristics on the radiation power of SR are calculated. According to the observation condition, this calculation is further classified into several types. Items available in this category are summarized in Table 3.10.

Table 3.10 SR Characteristics calculated in the [K Dependence]-[Power] category.

Item	Remarks
Angular power density	Available if [Angular Power Density] is selected as the main item.
Partial power	Available if [Partial Power] is selected as the main item.
Total power	This does not depend on the observation condition and is calculated just for reference.

3.4. Power@Fixed Point

In the [Power@Fixed Point] category, characteristics on the radiation power of SR are calculated under the current condition.

After selecting [Select Calculation]-[Power@Fixed Point], you will find [Specify Item] choice box at the right side of GUI Window for Calculation Configurations (chapter 6). Select a desired item and click [Calculate] button. Then Calculation Progress GUI Window (Figure 2.3) pops up. When the calculation is completed, the result is printed with an appropriate unit.

3.4.1. Power Density

The angular power density observed at an angle (θ_x, θ_y) or at a position (x, y) is calculated.

3.4.2. Partial Power: Rectangular Slit

The partial power of radiation passing through the Rectangular Slit (Figure 3.4) is calculated. The slit center is located at an angle $(\theta_{xslit}, \theta_{yslit})$ or at a position (x_{slit}, y_{slit}) .

3.4.3. Partial Power: Circular Slit

The partial power of radiation passing through the Circular Slit (Figure 3.4) is calculated. The slit center is located at an angle $(\theta_{xslit}, \theta_{yslit})$ or at a position (x_{slit}, y_{slit}) .

3.5. Near Field

All the calculations in the [Near Field] category are performed using the Near Field Expression on SR (1.3.2).

3.5.1. Calculations Common to Far Field

There are 3 calculation types that are common to the far-field calculation: [Energy Dependence] (3.1), [Spatial Dependence] (3.2) and [Power@Fixed Point] (3.4). Refer to each section for details. Note that all the calculations in this category take much longer computation time than those with the Far Field Approximation.

3.5.2. Radiation Field by a Single Electron

The calculations in the [Radiation Field by a Single Electron] category are performed with an assumption that a single electron is injected in the SR source.

Time Dependence

The electric field of SR emitted by a single electron is calculated as a function of observer's time, which is measured in the laboratory frame but not in the rest frame of electron. Both the vertical and horizontal components of the electric field vector are calculated.

Complex Amplitude Spatial Profile

The complex amplitude of the electric field of SR, which is obtained by a temporal Fourier transform of the electric field generated by a single electron injected in the SR source, is calculated as a function of the transverse observation position. The real and imaginary parts of the complex amplitude are calculated for both the horizontal and vertical polarization components. The output data can be used for the Characterization in Phase Space (chapter 7).

3.6. Coherent Radiation

All the calculations under the [Coherent Radiation] category are performed using the Near Field Expression on SR with the temporal and spatial coherence taken into account. As in the case of spontaneous radiation, convolution with the electron beam is required to accurately evaluate the SR characteristics. The temporal convolution is done just by multiplying the bunch-factor spectrum (Fourier transform of the bunch profile of the electron beam). On the other hand, the spatial convolution is, if no approximation is made, quite time-consuming because 4-fold integration in the 4-D phase space spanned by (x, y, x', y') is required. In *SPECTRA*, a numerical method is implemented to reduce the computation time under an assumption that the electron beam spatial profile is a slowly varying function of the longitudinal coordinate, which is in most cases valid.

3.7. Abbreviations and Their Meanings in the Output File

In the output file that saves the calculation results, a line composed of abbreviations to denote the SR characteristics and other related quantities is printed at the top of the file or below the information header (section 6.7.1). The meanings of these abbreviations are summarized in Table 3.11 together with units used in the output file.

Table 3.11 Abbreviations to denote SR characteristics and related quantities used in the output file.

Abbreviation	Meaning	Unit
1- PL	Fraction of non-linear polarization	-
Av.Density	Averaged flux density	photons/sec/0.1%b.w./mm ² or /mrad ²
Brilliance	brilliance	photons/sec/mm ² /mrad ² /0.1%b.w.
Coh.Flux	Coherent flux	photons/sec/0.1%b.w.
Coh.Power	Coherent power	W
Div.x,y	Effective source divergence in x and y axes	rad
E.Field.x,y	Electric field in x and y axes	V/m
Energy	Photon energy	eV
F.Density	Spatial or angular flux density	photons/sec/0.1%b.w./mm ² or /mrad ²
Filtering	Filtered power	same as the unit before filtering
Flux	Total or partial flux	photons/sec/0.1%b.w.
Flux.eV	Total flux in 1-eV bandwidth	photons/sec/eV
Gap	Magnet gap of an ID	-
Horiz.Dens	Flux density of horizontally polarized component	-
I_Flux	Integrated flux	photons/sec
ImField.x,y	Imaginary part of complex amplitude of radiation field	V.sec/m
I_Power	Integrated power	kW
K_Value	K value of an ID	-
Kx,Ky	K values of an ID in x and y axes	-
Nat.Div.	Natural source divergence	rad
Nat.Size	Natural source size	m
ObserverTime	Observer's time	fsec
P.Density	Spatial or angular power density	kW/mm ² or kW/mrad ²
P.Energy	Peak photon energy	eV

Abbreviation	Meaning	Unit
Power	Partial power	kW
PC	Degree of circular polarization, s_3/s_0	-
PL	Degree of linear polarization, s_1/s_0	-
PL45	Degree of 45-deg. linear polarization, s_2/s_0	-
phi	Azimuth angle of observation	degree
r	Radial position of observation	mm
ReField.x,y	Real part of complex amplitude of radiation field	V.sec/m
Size.x,y	Effective source size in x and y axes	m
theta	Radial angle of observation	rad
theta_x,y	Observation angles in x and y axes	rad
Tot.Power	Total power	kW
x,y	Observation positions in x and y axes	mm
Vert.Dens	Flux density of vertically polarized component	-

4. Accelerator Specification

In this chapter, instructions to manipulate the parameters specifying the accelerator performance such as the electron energy, beam current, emittance and twiss parameters, are presented. After opening a *SPECTRA* parameter file, all the parameters related to the accelerator performance are indicated in the dabbed GUI panel that appears in a group box named [Accelerator Specification] located on the top of the main GUI window.

In ver. 9.0, the [Bunch Profile] option has been implemented so that calculation of SR emitted from the electron beam with an arbitrary bunch profile in the 6-D phase space is available.

Storage Ring					
Bunch Profile:	Gaussian	Injection Condition:	Default		
Electron Energy (GeV)	8	Energy Spread	0.001		
Average Current (mA)	100	$\beta_x(m)$	22.58	α_x	0
Circumference	1435.95	$\beta_y(m)$	5.61	α_y	0
Bunches	2436	$\eta_x(m)$	0.11	$\eta_{x'}$	0
σ_z (mm)	5.99685	$\eta_y(m)$	0	$\eta_{y'}$	0
Peak Current (A)	3.92212	$1/\gamma(\mu rad)$	63.8749		
Natural Emittance (m.rad)	3.4e-09	$\sigma_x(\mu m)$	297.9	$\sigma_{x'}(\mu rad)$	12.26
Coupling Constant	0.002	$\sigma_y(\mu m)$	6.170	$\sigma_{y'}(\mu rad)$	1.100
$\epsilon_x(m.rad)$	3.393e-009	$\gamma\sigma_{x'}$	0.1919	$\gamma\sigma_{y'}$	0.01722
$\epsilon_y(m.rad)$	6.786e-012				

Figure 4.1 GUI window for configuration of [Accelerator Specification]. [Storage Ring] is selected as the accelerator type in this figure.

4.1. Description of Parameters

Table 4.1 shows an example of the GUI panel for the parameters to specify the accelerator performances. The meanings and units of the parameters are summarized in Table 4.1.

4.2. Accelerator Type

The accelerator type can be selected by executing one of the two submenus in [Configuration]-[Accelerator]-[Accelerator Type]: [Linac] or [Storage Ring]. The difference between the two in *SPECTRA* is the method to specify the average current: it is directly specified by the user in the storage ring, while the pulse repetition rate and bunch charge should be specified in the linac (linear accelerator).

Table 4.1 Descriptions of parameters that belong to [Accelerator Specification].

Notation	Meaning	Unit	Remarks
Electron Energy	Energy of the electron beam	GeV	
Average Current	Average current of the electron beam	mA	Not editable in Linac (automatically calculated)
Pulses/sec	Electron beam repetition rate	1/sec	Not available Storage Ring
Bunch Charge	Total charge in a single bunch	nC	
Circumference	Circumference of the storage ring	m	Not editable in Linac
σ_z	Bunch length (r.m.s.)	mm	
Peak Current	Peak current of the electron beam	A	
Natural Emittance	Natural emittance of the electron beam	m.rad	
Coupling Constant	Coupling constant (ϵ_y/ϵ_x) of the electron beam	-	
ϵ_x, ϵ_y	Horizontal & Vertical emittance	m.rad	
Energy Spread	Energy spread of the electron beam expressed in r.m.s.	-	
β_x, β_y	Betatron function	m	Input the value at the center of the SR source
α_x, α_y	Lattice function to denote the slope of the phase ellipse of the electron beam	-	
$\eta_{x,y}, \eta_{x',y'}$	Dispersion function	m, rad	
$1/\gamma$	Inverse of the Lorentz factor of the electron beam	μrad	
σ_x, σ_y	Electron beam size	μm	
$\sigma_{x'}, \sigma_{y'}$	Electron beam divergence	μrad	
$\gamma\sigma_{x'}, \gamma\sigma_{y'}$	Electron beam divergence normalized by $1/\gamma$	-	

4.3. Bunch Profile

Usually, *SPECTRA* assumes Gaussian profiles for the electron beam distribution functions in the 6-D phase space. If the user needs to specify a customized electron-bunch profile, select [Customized Distribution Function] or [Import Macroparticle Data] from the [Bunch Profile] choice box. In the former option, the projected transverse and longitudinal profiles of the electron beam are required, while in the latter, the macroparticle data in the 6-D phase space are required. For details, refer to Bunch Profile (4.6) or Particle Data (4.7).

4.4. Injection Condition

When the SR source contains non-ideal field components such as the dipole field error and field offset as explained in Special Magnet Setup (section), or [User-Defined] is selected as the SR source type, the position and slope of the electron averaged over the length of the SR source are not necessarily zero. In such a case, the observer located at the beamline axis observes off-axis radiation. In fact, such trajectory errors can be corrected by steering magnets in front of the SR source. In other words, the position and slope of the electron beam when injected to the SR source are adjusted to eliminate the trajectory errors. The user is required to specify the injection condition from the options described as follows.

4.4.1. Default

An appropriate injection condition suited to respective SR source is selected. This is recommended in most cases.

4.4.2. Align Axis at Entrance, Center, Exit

The electron beam axis is adjusted to coincide with the axis of observation at the entrance, center, or exit of the SR source.

4.4.3. Custom

In case the user needs to adjust the injection condition, select this option. Then [Injection Condition] panel appears as shown in Figure 4.2. Input the initial conditions in position (x,y) and slope (x',y') at the entrance of the SR source. In order to apply the conditions described above (Default & Align Axis) to be computed by *SPECTRA* and evaluate the parameters, select one of them and click [Apply Condition] button. The injection parameters are automatically computed and indicated in individual entry boxes.

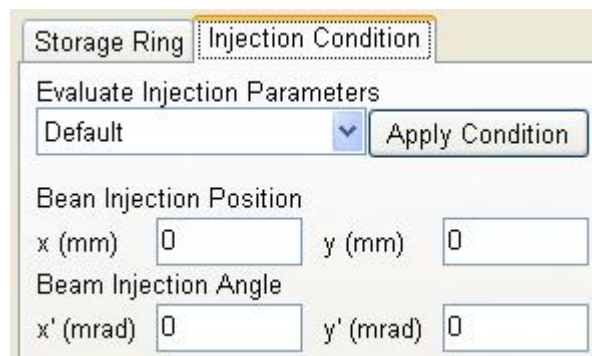


Figure 4.2 GUI window for the configuration of injection conditions.

4.5. Plot betatron Functions

In order to check the betatron function as a function of the longitudinal coordinate, execute the command [Configuration]-[Accelerator]-[Plot betatron Functions] after specifying the arrangement of the SR source and focusing magnets and the twiss parameters at the center of the SR source. This command is useful when focusing magnets are inserted in the SR source to make sure that the betatron functions is kept appropriate over the length of the SR source.

4.6. Bunch Profile

If [Customized Distribution Function] is selected as [Bunch Profile], the GUI panel named [Bunch Profile] appears, in which the numerical data for the bunch profile of the electron beam is manipulated. An example of the GUI panel is shown in Figure 4.3

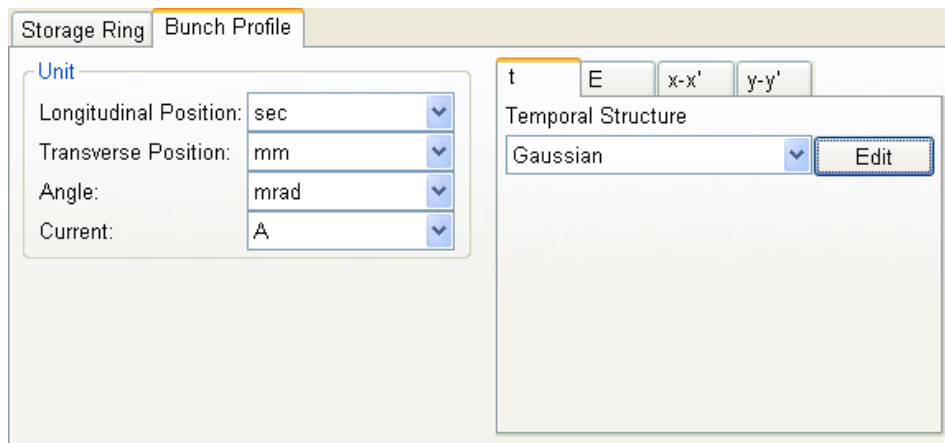


Figure 4.3 GUI panel to specify the customized bunch profile. By clicking [Edit] button, a popup menu appears to indicate the commands to manipulate the bunch-profile data.

Four types of profile data can be imported in the tabbed window located at the right side of the GUI panel. The titles “t”, “E”, “x-x’”, “y-y’” mean the type of the profile data. The first two data are the temporal and energy profiles having 1-D form, while the last two data are the horizontal and vertical profiles in the 2-D phase space and should have the 2-D form. In order to import the profile data, click [Edit] button in each tabbed panel and run the [Import] command. The data format is explained in the following sections.

The units for the profile data can be selected in the choice boxes located at the left side. A number of bunch-profile data sets can be saved in a *SPECTRA* parameter file. The names of these data sets are stored in the choice box at the right of the panel and the user can select one of them.

4.6.1. Format of the 1-D Data

The format of 1-D data set (“t” or “E”) should have the format as indicated below (e.g., temporal profile):

Time	Current
-5.5E-13	0.07
-4.5E-13	54.3
-3.5E-13	554.5
(omitted)	
1.35E-12	0.8
1.45E-12	0.1
1.55E-12	0.1

4.6.2. Format of the 2-D Data

The format of 2-D data set (“x-x” or “y-y”) should have the format as indicated below (e.g., x-x' profile):

x	x'	Intensity
-1	-1	0.001
-1	-0.9	0.0011
-1	-0.8	0.0012
(omitted)		
1	0.8	0.0012
1	0.9	0.0011
1	1	0.001

The 1st and 2nd column means the grid-like position of the x and x' coordinates, while the 3rd column means the electron beam intensity at the position specified by x and x'. For example, this kind of data is created by a computer program with the source as follows (in C language)

```
for(i = 1; i <= nx; i++){
    for(j = 1; j <= nxp; j++){
        printf("%g %g %g\n", x[i], xp[j], I[i][j])
    }
}
```

Note that the unit of the intensity is arbitrary; it is automatically normalized by *SPECTRA*. In order to check if importing the profile data is successful, run one of the submenus in [Configuration]-[Accelerator]-[Plot Bunch Profile] to graphically plot the imported data.

4.6.3. Selection of the Unit

After importing the bunch-profile data, the unit for each variable should be selected: mm, m, cm, sec or psec is available for the Longitudinal Position; A or kA is available for the Current, mm or m is available for the Transverse Position; mrad or rad is available for the Angle.

4.7. Particle Data

If [Import Macroparticle Data] is selected as [Bunch Profile], the GUI panel named [Particle Data] appears, in which the numerical data for the macroparticle of the electron beam is manipulated.

In this option, a data file containing information on the macroparticle distribution in the 6-D phase space is required. Such a data file is probably obtained by using other codes to simulate the electron beam dynamics in the accelerator components such as the bunch compressor. *SPECTRA* accepts an ascii file composed of lines containing the coordinates of each macroparticle.

In order to specify the file for the macroparticle data, click [BROWSE] button and specify the location of the file in the file-selection dialog box that pops up. Then a dialog box as shown in Figure 4.4 pops up. In the right, contents of the input data file are shown, while configuration of the input data is done in the left. Each line of the input data file should be composed of 6 coordinates, time (t), position (x,y), angle (x',y') and energy (E). Specify the data arrangement in the [Index] column of the [Data Structure] group box, and the unit of each coordinate in the [Unit] column.

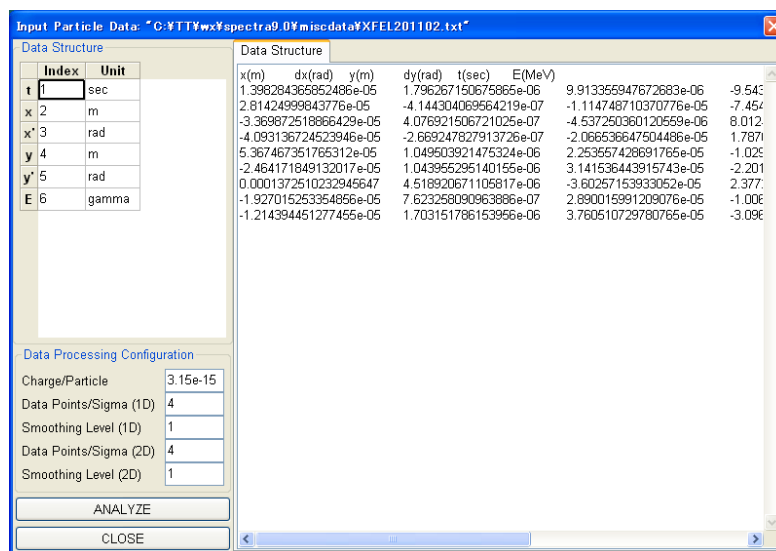


Figure 4.4 GUI window to show the results of analysis on the imported macroparticle distribution.

In order to analyze the input data, edit parameters in the [Data Processing Configuration] group box. Input the charge per macroparticle, the number of data points, and the smoothing level (higher values mean smoother processing) to be used in the calculation of the bunch profile. After that click [ANA-

LYZE], then temporal profile, energy distribution, and profiles in the x-y real space, x-x' phase space and y-y' phase space, are calculated and shown in the tabbed window with graphical plots. After checking these data and plots, click [CLOSE] to complete the data import. Note that the data file should not be deleted even after the above processing because *SPECTRA* saves only the name of the data file specified.

5. Light Source Description

In this chapter, instructions to manipulate the parameters describing the SR source such as the magnetic field strength, periodicity, and device length, are presented. After opening a *SPECTRA* parameter file, all the parameters specifying the SR source are shown in the tabbed GUI panel that appears in a group box named [Light Source Description] located on the bottom of the main GUI window. In addition, approximate photon beam characteristics are also indicated.

5.1. Description of Parameters

Figure 5.1 shows an example of the GUI panel for the parameters to describe the SR source. Depending on the SR source type and selected options, up to four tabbed windows appear: the main window for magnetic configurations, Gap-Field Table (5.3), Segmented Undulator (5.4) and Special Magnet Setup (5.5). Refer to the following sections for details.

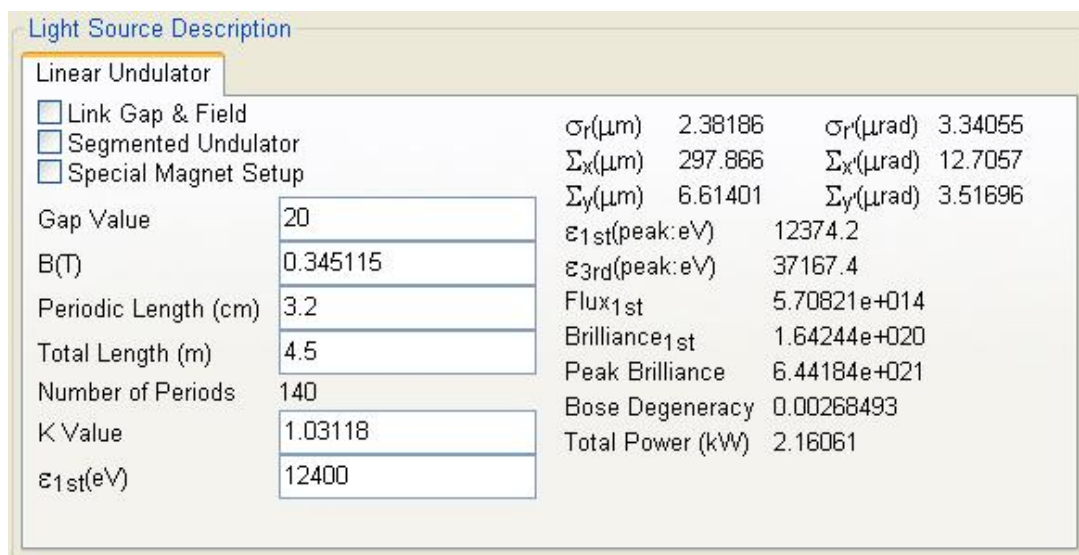


Figure 5.1 GUI window for configuration of [Light Source Description].

5.2. Main Window for Magnetic Configurations

The magnetic configurations for the Built-in SR Source (1.2.1), such as the field strength and periodicity, are indicated in the main panel with a title indicating the source type currently selected. The meanings and units of the parameters in the main panel are summarized in Table 5.1. The configurations for custom SR sources (sections 5.6.2, 5.6.3, 5.6.4) are different from those in Table 5.1. Refer to sections from Multipole(5.6.2) to User-Defined Source (5.6.4).

Table 5.1 Descriptions of parameters that belong to [Light Source Description]. *The values are approximate ones and available for undulators.

Notation	Meaning	Unit
Gap Value	Gap of the ID	-
$B_{x,y}$	Peak magnetic fields in the x and y axes.	T
B	Magnetic field in the principal direction. Peak for IDs and uniform for BM.	T
Radius	Radius of the electron orbit. Available for BM.	m
Periodic Length	Periodic length of the ID	cm
Number of Periods	Number of periods of the ID	-
Total Length	Total length of the ID	m
$K_{x,y}$	K Values in the x and y axes	-
K	K Value	-
$\epsilon 1^{st}$	Energy of the 1st harmonic	eV
σ_r, r'	Natural size and divergence of the photon beam at $\epsilon 1^{st}$.	m,rad
* $\Sigma_{x,y}, \Sigma_{x',y'}$	Effective beam size and divergence of the photon beam at $\epsilon 1^{st}$.	m,rad
* $\epsilon 1^{st}, 3^{rd}$ (peak)	peak energy for the 1st and 3rd harmonics	eV
*Flux 1st	Total flux at $\epsilon 1^{st}$.	photons/sec /0.1% b.w.
*Brilliance 1st	Brilliance at $\epsilon 1^{st}$.	photons/sec/mrad ² /mm ² /0.1% b.w.
*Peak Brilliance	Brilliance at $\epsilon 1^{st}$ at the peak current of the electron bunch.	photons/sec/mrad ² /mm ² /0.1% b.w.
*Degeneracy	Bose degeneracy.	-
Total Power	Total radiation power. Not available for BM.	kW
Critical Energy	Critical energy corresponding to the vertical magnet field. Available for wiggler and BM.	eV
Total Power /Revolution	Total power emitted over the whole ring. Available for BM.	kW
Linear Power Density	Linear power density emitted by the electron beam	kW/mrad

5.3. Gap-Field Table

In general, the magnetic field of a SR source is tuned by changing the gap between the top and bottom magnet arrays. The relation between the field strength and gap value is thus important. *SPECTRA* links the magnetic field with the gap value according to the relation specified by the user. In order to enable this option, tick the [Link Gap & Field] check box. Then, the tabbed window with the title [Gap-Field Table] appears as shown in Figure 5.2.

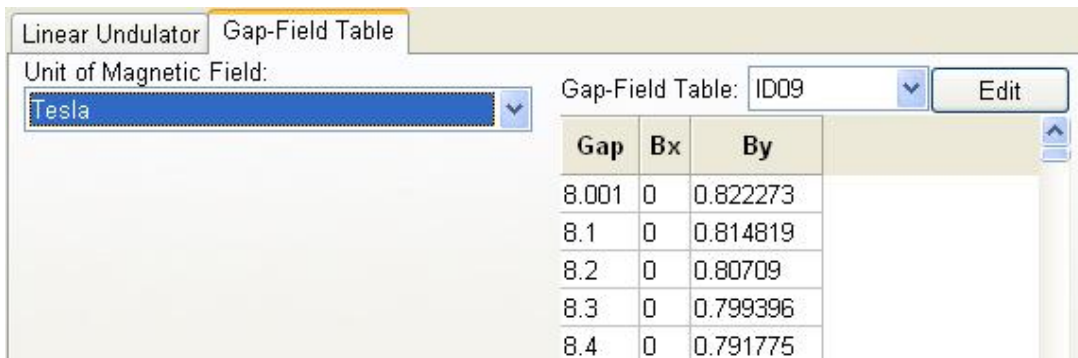


Figure 5.2 Tabbed window that shows the gap-field relation.

The spread sheet shows the relation between the gap and field. Select the desired data from the choice box. In order to import a new table, prepare an ASCII file with the format

Gap	Bx	By
50.0	0	0.0284231
48.9	0	0.0312138
47.9	0	0.0339968
(omitted)		
6.26	0	1.11445
6.13	0	1.12545
6.0	0	1.13648

The 1st column means the gap value, while the 2nd and 3rd mean the horizontal and vertical magnetic field amplitudes that is used to calculate the K values. Then click [Edit] button and execute [Import Gap-Field Table] command. Specify the location of the above file in the file-selection dialog box. The spreadsheet at the right side shows the contents of the imported table. Select the correct unit for the magnetic field from the choice box at the left side.

5.4. Segmented Undulator

Undulators are sometimes divided into several segments. If SR emitted from individual segments is coherently superimposed, the optical characteristics strongly depend on the undulator type and optical phase $\Delta\phi$ (determined by the length of the electron path) between segments. *SPECTRA* is equipped with functions to calculate optical properties of such segmented undulators. Tick [Segmented Undulator] check box in the main GUI panel, then the tabbed panel named [Segmented Undulator] appears as shown in Figure 5.3.

The parameters in the panel are divided into two groups. One is to specify the details and method of segmentation, while the other is to specify the field error due to segmentation.

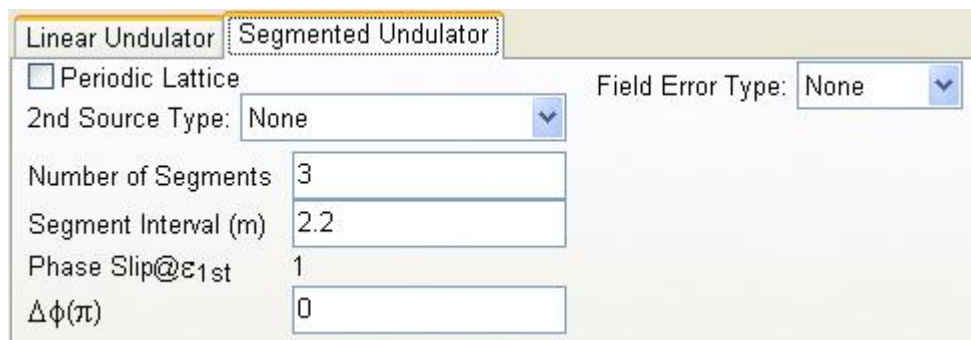


Figure 5.3 GUI panel for configuration of the segmented undulator.

5.4.1. Segmentation Details

In general, $\Delta\phi$ should be set to an integer multiple of 2π to obtain the maximum photon intensity. Contrary to this, there are several schemes to improve optical characteristics of SR that take advantage of undulator segmentation. One is to intentionally introduce a mismatched phase between segments to suppress the higher harmonic intensity [6].

Another application of undulator segmentation is to control the polarization of SR [7]: in this case, an undulator configuration composed of two types of undulator segments is adopted, which is schematically shown in Figure 5.4.



Figure 5.4 Segmented undulator scheme for polarization control.

In *SPECTRA*, several types of undulator segmentation are available ([2nd Source Type]) and the optical phase between segments ([Relative Phase]) can be specified, the details of which are explained in the followings.

2nd Source Type

Type	Meaning
None	The type of all segments and relative phase between them are identical.
Swap Bx and By	Swap Bx and By. The vertical and horizontal fields are swapped in the 2nd source type, i.e., if the 1st type is a conventional linear undulator, then the 2nd type is a vertical undulator.
Flip Bx (By)	Flip Bx (By). Flip the polarity of the horizontal (vertical) field in the 2nd source type, respectively. This makes nothing if the 1st source is a linear undulator, while the helicity of the 2nd source is flipped if the 1st source is a helical (elliptic) undulator.
Custom Setting	Specify the details of each segment Refer to Customizing the Segment (section) for details.

Relative Phase

Notation	Contents
$\Delta\phi$	Optical phase between segments when [None] is selected as [2nd Source Type]
ϕ_1	Optical phase between $(2n-1)$ -th and $(2n)$ -th segments. (e.g., 1-2, 3-4, ..)
ϕ_2	Optical phase between $(2n)$ -th and $(2n+1)$ -th segments.(e.g., 2-3, 4-5, ..)

5.4.2. Customizing the Segment

If [Custom Setting] is chosen for the [2nd Source Type], the user is required to specify the details of each undulator segment. In order to do so, click [Edit] button and execute [Create New Data Set], then a new spreadsheet appears. In the sheet, edit the specifications for each segment. The meanings of each column are summarized as follows.

Column	Contents
Type	Specify the type of the undulator. [Default] means the same undulator type as that currently specified in [Configuration]-[Light Source]-[Source Type] menu. For other types, refer to 2nd Source Type.
N-Ndef.	Difference in the number of periods from the default value. If the number of periods is the same for all the segments, 0 should be input here.
Phase	Phase between segments in the unit of π

5.4.3. Periodic Lattice

When the number of undulator segments is large and the total length is quite long as in the case of X-ray free electron lasers, focusing magnets are usually installed between undulator segments to keep the betatron function appropriate. In such a case, the betatron function is periodic with a periodic

length of the segment interval. In order to specify such a situation, tick the [Periodic Lattice] checkbox, then *SPECTRA* automatically arranges the focusing magnets to realize the lattice.

In this case, the betatron values (β_x, β_y) specified in [Accelerator Specification] are assumed to be those at the undulator center. If non-zero values are specified for the alpha parameters (α_x, α_y), then it is assumed that alpha values at the center of the odd-integer segments are equal to α_x, α_y , while those of the even-integer segments are equal to $-\alpha_x, -\alpha_y$.

5.4.4. Specification of Field Errors by Undulator Segmentation

The undulator segmentation gives rise to three intrinsic field errors: K-value Discrepancy, Phase Mismatch, and Kick Errors at the drift section between segments. In order to investigate the impacts of these field errors on the optical properties of SR, *SPECTRA* offers functions to generate a magnetic field distribution containing such field errors. Two options are available from [Field Error Type]. One is [Random] and the other is [Custom]. In the former case (Random), the field errors are generated by a random number generator with a certain integer as a seed. In the latter case (Custom), the user should specify the error at each segment.

Random

Column	Contents
Random Number Seed	A positive integer as a seed for the random number generator. By scanning this parameter (refer to Scanning a Parameter (2.4) for details), it is possible to repeat the calculations with different error models.
K-value Discrepancy	Maximum error in the K-value discrepancy. To be specific, the K value at the i -th segment (K_i) is given by $K_i=K(1+dr_i)$, where dr_i denotes the K-value Discrepancy parameter and uniform random number (form -1 to +1) at the i -th segment, respectively.
Phase Mismatch	Maximum phase error in the unit of π .
Kick Error X,Y (G.cm)	Maximum kick error in G.cm.

5.4.5. Custom

In the [Custom] error option, the user should specify the error values at each segment. In order to do so, click [Edit] button and run [Create New Data Set] command. Input any name in the dialog box that pops up. Then click again [Edit] button and run [Add New Segment] command. Input the segment number you need to add in the dialog box that pops up. You will find 4 or 8 columns according to the 2nd Source Type. The parameters in the 1st to 4th columns have the meanings identical to the [K-value Discrepancy], [Phase Mismatch], and [Kick Error X, Y] parameters in the Random option except that these parameters define the actual error values, but not the amplitude for the random error.

The parameters in the 5th to 8th columns, to be enabled if necessary, correspond to the 1st to 4th columns, except that they are for the 2nd source segments (which are thus the even-number segments).

5.5. Special Magnet Setup

In addition to the options on SR sources described so far, *SPECTRA* offers a number of magnet configurations useful for various purposes such as the focusing effect in the periodic field, magnetic tapering, field offset, and (additional) multipole components. In order to enable these configurations, tick [Special Magnet Setup] checkbox in the main GUI panel to show the tabbed panel named [Special Magnet Setup].

5.5.1. Natural Focusing

It is well known that a periodic magnetic field has a focusing effect on the electron beam in the direction of the magnetic field. In order to enable/disable this effect, tick/untick [Bx/By Natural Focusing] check box. Note that enabling [Bx Natural Focusing] for the linear undulator has no effect because no horizontal field exists. This is effective only for the SR source with the horizontal field component such as the helical and figure-8 undulators.

5.5.2. Tapering

In order to broaden the spectral bandwidth, tapering the magnetic field is effective. The user is required to input the fraction of tapering in m^{-1} . For example, tapering of 0.1m^{-1} means that the magnetic field strength varies by 10% over the length of 1 m.

5.5.3. Field Offset

The magnetic field offset can be brought by mis-calibration of the Hall probe or the geomagnetic field, and causes a bend in the electron trajectory. The user is required to input the offset field in T.

5.5.4. Multipole Components

In addition to the main field of the SR source (sinusoidal fields in IDs, uniform field in BMs), the multipole components can be superimposed. Refer to “How to Specify Multipole Components?” (5.6.2) for details.

5.6. Selection of the SR Source Type

The SR source type can be selected by executing one of the submenus in [Configurations]-[Light Source]-[Source Type], which are explained in Table 5.2

Table 5.2 Type of SR sources available in SPECTRA.

Notation	Explanation	Field Profile
Linear Undulator	Conventional linear undulator for horizontal polarization.	Sinusoidal
Vertical Undulator	Undulator with horizontal field for vertical polarization.	Sinusoidal
Helical Undulator	Undulator for circular polarization with the horizontal and vertical K values being identical.	Sinusoidal
Elliptic Undulator	Undulator for elliptic polarization: the horizontal and vertical K values are not necessarily the same.	Sinusoidal
Figure-8 Undulator	Undulator for horizontal and vertical polarization with low heat load.	Sinusoidal
Asymmetric Figure-8 Undulator	Modified type of figure-8 undulator for circular polarization.	Sinusoidal
Wiggler	Conventional wiggler.	Sinusoidal
Elliptic Multipole Wiggler	An elliptic multipole wiggler for elliptic polarization in the high energy region.	Sinusoidal
Bending Magnet	Conventional bending magnet.	Uniform
Multipole Field	Refer to section 5.6.2	Custom
Field Mapping	Refer to section 5.6.3	Custom
User Defined: Periodic	Refer to section 5.6.4	Custom (but periodic)
User Defined		Custom

5.6.1. SR Sources with an Ideal Field Profile

In the build-in sources, the magnetic field is assumed to be sinusoidal (undulators and wigglers) or uniform (bending magnet), and calculations with the Far Field Approximation are possible to save the computation time. The difference between the undulator and wiggler is that the photon beam is coherent (undulator) or not (wiggler).

5.6.2. Multipole

Besides the undulators and bending magnets described in the preceding section, the electron can emit light when passing through other magnetic devices such as the quadrupole and sextupole magnets. In *SPECTRA*, multipole components up to the decapole can be specified as the SR source.

How to Specify Multipole Components?

Figure 5.5 shows the GUI panel for configuration of the multipole data.

Multipole Data: FODO

Type	Order	z(m)	L(m)	G(T/m)
Normal	Quadrupole	-1.1	0.1	10
Normal	Quadrupole	1.1	0.1	-10

Figure 5.5 GUI panel for configuration of the multipole data.

In order to specify the multipole components, click [Edit] button and execute [Create New Multipole Data] command. Enter a desired name in the dialog box that pops up. Then, a new spreadsheet appears. The meaning of each column is as follows:

Column	Contents
Type	Select [Normal] or [Skew] as the type of the multipole..
Order	Select the order of the multipole. Up to the decapole is available.
z(m)	Enter the position of the magnet.
L(m)	Enter the effective length of the magnet.
G(T/m ⁿ)	Enter the gradient of the magnet in T and m. If Quadrupole is selected, then the unit is T/m, and so on.

In order to add multipole components, click [Edit] button and execute [Add New Magnet] command. Enter the number of magnets to add in the dialog box and click [OK]. Then new lines appear in the spreadsheet. Select the type and order of the multipole components, and input the numerical data to specify them.

5.6.3. Field Mapping

In order to calculate the electron trajectory in the SR source, it is necessary to specify the magnetic field distribution, i.e., the magnetic flux density vector as a function of the 3-dimensional coordinate ($\mathbf{B}(\mathbf{r})$). [Field Mapping] is the SR source specified by the numerical data on $\mathbf{B}(\mathbf{r})$.

In order to select this source type, first prepare an ascii file that contains the magnetic field components at 3-dimensional grid points with the format as follows:

0.2	0.3	0.5	11	13	421
1.23456e-1	2.3456e-1	3.4557e-1			
2.23456e-1	3.3456e-1	6.4557e-1			
	(omitted)				
4.23456e-1	5.3456e-1	8.4557e-1			
2.23456e-1	3.3456e-1	6.4557e-1			

The 6 numbers in the first line indicate the grid interval in mm and number of grid points along the x, y, and z axes. In the above case, the magnetic field components are given at 11x13x421 grid points with the x, y, and z intervals of 0.2 mm, 0.3 mm, and 0.5 mm, respectively. From the 2nd line, the magnetic field components (B_x , B_y , B_z) at each grid point are given. The grid point should be moved first in the z direction, next y direction, and finally x direction. For example, such data arrangement will be created by a computer code like this (in C language):

```
for(i = 1; i <= nx; i++){
    for(j = 1; j <= ny; j++){
        for(k = 1; k <= nz; k++){
            printf("%g %g %g\n", Bx[i][j][k], By[i][j][k], Bz[i][j][k])
        }
    }
}
```

Next, select [Field Mapping] as the SR source type. To show the GUI panel as shown in Figure 5.6. Then click [BROWSE] button and select the data file for the magnetic field distribution with the format described above. In order to check if the data format is correct, execute [Configuration]-[Light Source]-[Magnetic Field Distribution]-[Plot Orbit] command and verify the electron trajectory. Before starting the SR calculation, appropriate units should be selected from the choice boxes at the left of the GUI panel.



Figure 5.6 GUI panel for configuration of [Field Mapping] source.

5.6.4. User-Defined Source

In most cases, it is not necessary to specify all the information on the magnetic field distribution to calculate the SR properties. Transverse components of \mathbf{B} measured along the z axis at the origin of the xy plane ($B_x(0,0,z)$, $B_y(0,0,z)$) are necessary to approximately calculate the electron trajectory in the SR source. In *SPECTRA*, two SR source types based on this concept are available: [User Defined: Periodic] and [User Defined].

In the former case, the magnetic field is assumed to be periodic. The user is required to import the magnetic field data in a single period and specify the number of periods. This option is useful in the

case when the magnetic field distribution is far from a sinusoidal one such as the electromagnet undulators operated in a double-period (or more) mode.

In the latter case, the user is required to import the magnetic field data over the whole length, which is probably obtained by the field measurement of the actual device. Note that the Far Field Approximation is not available in the latter case.

Figure 5.7 shows the GUI panel for the [User Defined: Periodic] and [User Defined] sources. Select the appropriate unit for the magnetic field (Tesla or Gauss) and longitudinal position (mm, cm, or m). For the [User Defined: Periodic] source, also specify the number of periods.

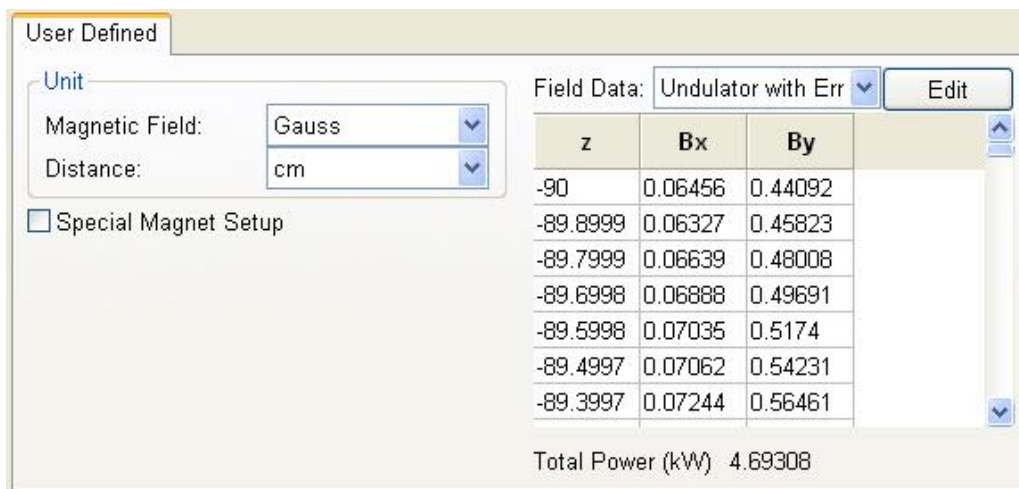


Figure 5.7 GUI panel for configuration common to the [User Defined: Periodic] and [User Defined] sources. In [User Defined: Periodic], several other parameters to specify the periodicity are shown in the left panel.

In order to import the magnetic field data, prepare an ASCII file that contains the field-distribution data:

Z	Bx	By
-8.959978e-01	5.174e-05	7.035e-06
-8.949972e-01	5.423e-05	7.062e-06
-8.939967e-01	5.646e-05	7.244e-06
(omitted)		
8.979989e-01	4.801e-05	6.639e-06
8.989994e-01	4.582e-05	6.327e-06
9.000000e-01	4.409e-05	6.456e-06

where the 1st column means the position along the longitudinal direction (electron path), the 2nd and 3rd mean the horizontal and vertical magnetic fields, respectively. The title line is not compulsory, and more than one comment lines are accepted. Then click [Edit] button and execute [Import Field Data] command. Specify the location of the above file in the file-selection dialog box that pops up. *SPECTRA* loads the data from the specified file and shows it in the spread sheet with the data name (the name of the imported file without suffix) indicated in the choice box. Do not forget to execute [File]-[Save] command to save the imported data.

5.7. Checking the Electron Trajectory

If the SR source contains non-ideal magnetic fields, it is recommended to calculate the electron trajectory in the SR source in order to check if the data import in Custom SR Source (1.2.2) is successful and/or configurations in Special Magnet Setup (5.5) are correct. For this purpose, execute one of the submenus in [Configuration]-[Light Source]-[Solve Equation of Motion]. Refer to descriptions in Table 8.4.

6. Calculation Configurations

In this chapter, instructions to manipulate the parameters describing the calculation conditions such as the position of observation, photon energy range, numerical options, are presented. After selecting the calculation type, all these parameters are indicated in the tabbed GUI panel that appears in a GUI window titled [Calculation Configurations].

6.1. Description of Parameters

Figure 6.1 shows an example of the GUI window for the calculation configuration. The number and type of parameters are dependent on the calculation type, the details of which are explained in the following sections.

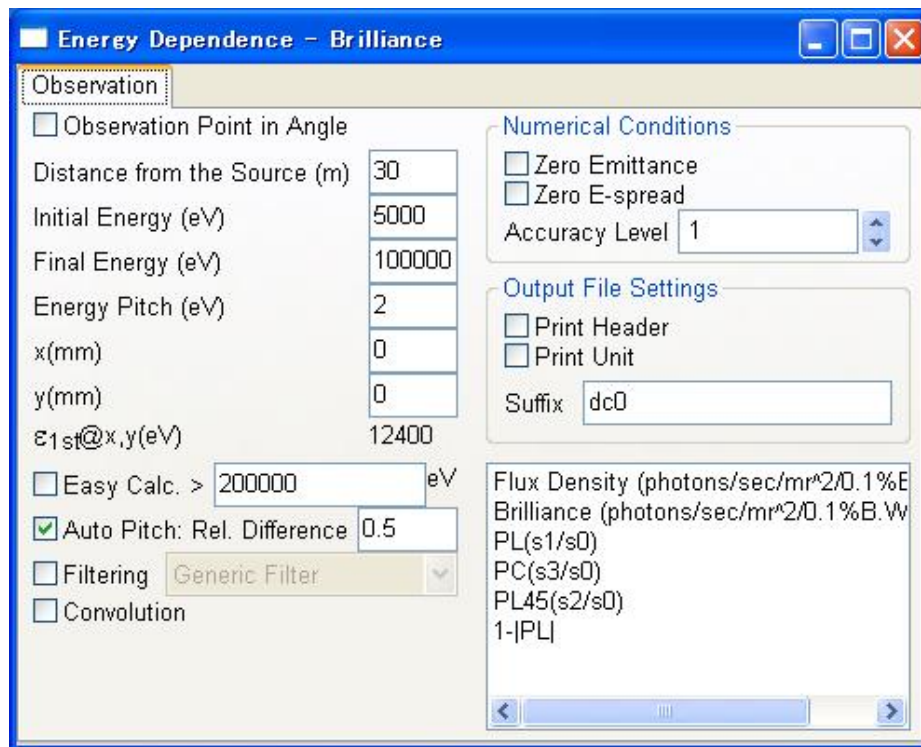


Figure 6.1 GUI window for the calculation configuration ([Spatial Dependence]-[Angular Flux Density]-[Along Axis] is selected in this case).

6.1.1. Parameters and Options Common to All Calculations

Table 6.1 summarizes the common items to the all calculation types.

Table 6.1 Options and parameters common to the all calculation types.

Notation	Remarks
Indicate Obs. Point in Angle	The transverse observation position can be specified either in transverse displacement (x,y) or in angle ($\theta_{x,y}$). If this option is selected, all the observation position are shown in angle.
Distance from the Source	Distance between the source and observation position in m.

6.1.2. Energy Dependence

The meanings and units of the parameters for the [Energy Dependence] calculation are summarized in Table 6.2

Table 6.2 Descriptions of parameters that belong to [Calculation Control] related to calculation types in the [Energy Dependence] category.

Notation	Meaning	Unit
Minimum Energy	Minimum energy of the calculation energy range	eV
Maximum Energy	Maximum energy of the calculation energy range	eV
Mesh (Energy)	Number of calculation points for the photon energy. Available for wigglers and BM	-
Energy Pitch	Energy pitch to scan the energy. If [Auto Pitch] option is enabled selected, this is a maximum value. Available for undulators.	eV
Relative Difference	Maximum ratio in the [Auto Pitch] option. Available for undulators.	-
x,y	Observation positions in x and y axes	mm
$\theta_{x,y}$	Observation angles in x and y axes	mm
xslit,y slit	Slit center positions in x and y axes	mm
$\theta_{xslit,y slit}$	Slit center angles in x and y axes	urad
$\Delta x,y$	Full width (x) and height (y) of the rectangular slit expressed in length (see Figure 3.3)	mm
$\Delta \theta_{x,y}$	Full width (x) and height (y) of the rectangular slit expressed in angle (see Figure 3.3)	urad
r1,2	Radial positions that specify the circular slit (see Figure 3.3)	mm
$\Delta \theta_{1,2}$	Radial angles that specify the circular slit (see Figure 3.3)	urad
$\epsilon_{1st@x,y(slit)}$	Energy of the 1st harmonic observed at (x,y) or (qx, qy). Available for undulators	eV

6.1.3. Spatial Dependence

The meanings and units of the parameters for the [Spatial Dependence] calculation are summarized in Table 6.3.

Table 6.3 Descriptions of parameters that belong to [Calculation Control] related to calculation types in the [Spatial Dependence] category. Also refer to definitions of section 3.2.4.

Notation	Meaning	Unit
Fixed Energy	Photon energy to be fixed. Available in [Flux Density]	eV
$\Sigma_{x,y}, (\Sigma_{x'},y')$	Effective size (angular divergence) of the photon beam at [Fixed Energy] at the observation position. Approximate value. For undulators, not valid if [Fixed Energy] is different from the peak energy of each harmonic.	mm (μ rad)
$\Sigma_{px,py}, (\Sigma_{px'},py')$	Effective size (angular divergence) of the radiation power at the observation position. Approximate value.	mm (μ rad)
Minimum or Maximum x,y ($\theta_{x,y}$)	Minimum or maximum position (angle) in x,y axis. Available in [Along Axis] and [Cartesian Mesh].	mm (μ rad)
Minimum or Maximum r (ϕ)	Minimum or maximum position (angle) in cylindrical mesh	mm (degree)
Mesh (x,y)	Numbers of calculation points for the observation position in x,y axis	-
Mesh (radial, azimuth)	Number of calculation points for the observation position in cylindrical mesh	-

6.1.4. K Dependence

The meanings and units of the parameters for the [K Dependence] calculation are summarized in Table 6.4.

Table 6.4 Descriptions of parameters that belong to [Calculation Control] related to calculation types in the [K Dependence] category.

Notation	Meaning
Minimum or Maximum Harmonic	Determine the harmonic range. Should be an integer or half-odd-integer for (asymmetric) figure-8 undulator, or integer for other IDs. In the former case, the harmonics to be calculated are $n_{min}, n_{min}+0.5, n_{min}+1, \dots, n_{max}-0.5, n_{max}$. In the latter case, only odd-integer harmonics are calculated. For example, only 3rd and 5th harmonics are calculated if $n_{min} = 2$ and $n_{max} = 6$.
Minimum or Maximum $K(K_y)$	Determine K -value range for calculation
Mesh (K Value)	Number of calculation points for the K -value
$\theta_{xslit,y slit}$	Refer to Energy Dependence (6.1.2)
$\Delta_{x,y}$	

Notation	Meaning
$\Delta\theta_{x,y}$	
$r_{1,2}$	
$\Delta\theta_{1,2}$	
$\varepsilon_{1st@x,y}(slit)$	

6.1.5. Power@Fixed Point

The parameters related to [Power@Fixed Point] are common to those explained in the Energy Dependence (6.1.2) and Spatial Dependence (6.1.3). Refer to each section for details.

6.1.6. Near Field

The parameters related to [Near Field]-[Energy Dependence], [Near Field]-[Spatial Dependence], and [Near Field]-[Power@Fixed Point] are common to those in Energy Dependence (6.1.2), Spatial Dependence (6.1.3), and Power@Fixed Point (6.1.5), respectively. Refer to each section for details. For other calculations in the [Radiation Field by a Single Electron] category, explanations are given in the following sections.

6.1.7. Time Dependence

The meanings and units of the parameters for the [Time Dependence] calculation are summarized in Table 6.5.

Table 6.5 Descriptions of parameters that belong to [Calculation Control] related to [Near Field]-[Time Dependence].

Notation	Meaning
x,y	Refer to Energy Dependence (6.1.2)
$\theta_{x,y}$	
$\varepsilon_{1st@x,y}(slit)$	
Mesh (Time)	Number of calculation points for the observer's time

6.1.8. Complex Amplitude Spatial Profile

The meanings and units of the parameters for the [Complex Amplitude Spatial Profile] calculation are summarized in Table 6.5

Table 6.6 Descriptions of parameters that belong to [Calculation Control] related to [Near Field]-[Complex Amplitude Spatial Profile].

Notation	Meaning	Unit
Fixed Energy	Refer to Spatial Dependence (6.1.3)	
$\Sigma_{x,y}$		

Notation	Meaning	Unit
$\Delta x,y/2$	Half calculation range in x and y axes. The calculation range is from $-\Delta x,y/2$ to $\Delta x,y/2$	mm
Mesh x, y (Half Range)	Number of observation positions in $\Delta x,y/2$	

6.1.9. Coherent Radiation

All the parameters related to the calculations under [Coherent Radiation] are common to those in the [Near Field] category.

6.2. Easy Calculation

The undulator radiation spectrum consists of several sharp peaks called Harmonic, Harmonic Number. This is a consequence of the fact the undulator radiation is coherent. However, such a peak structure is smeared in an energy region where high-harmonic radiation is dominant, due to finite emittance of the electron beam, finite angular acceptance of the beamline, and so on. Thus rough estimation of photon flux suffices for most applications in such a high-energy region. The [Easy Calculation] option enables the numerical algorithm for such rough estimation. The user is required to input a photon energy above which this algorithm is applied.

6.3. Auto Pitch

[Auto Pitch] is a numerical method for effective calculation of spectrum composed of sharp peaks such as undulator radiation. The energy pitch would be narrow around the sharp peak and wide at other energies. Refer to Fig. Figure 6.2 for details.

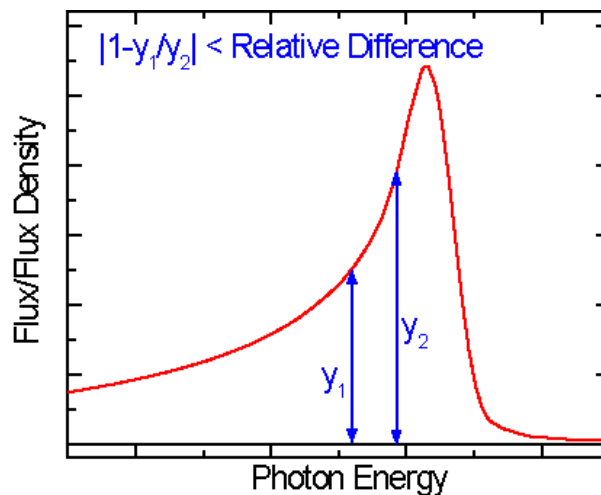


Figure 6.2 Explanation of [Auto Pitch]. When this option is selected, the energy pitch is set automatically so that the value of $|1-y_1/y_2|$ does not exceed the value of [Relative Difference]. Around the energy region where the profile is not steep, the energy pitch would become the maximum value (specified by [Energy Pitch]).

6.4. Filtering

If [Filtering] option is enabled, the characteristics of SR after transmitting an energy filter are calculated in addition to those before the filter. The user should select the filter type from choice box. Three kinds of filters are available: [Generic Filter], [Bandpath Filter], or [Custom Filter].

6.4.1. Generic Filter

[Generic Filter] means a general term for a slab or layer that attenuates the photon-beam intensity, which is usually found in x-ray beamlines of SR facilities, such as a beryllium window for vacuum seal and a layer of air in front of a sample to be irradiated. In *SPECTRA*, any kind of existing elements can be selected as a filter material.

Figure 6.3 shows a configuration window for the generic filter. The user can specify a material and thickness of a filter. The information on the filter material is shown in the [Material Information] group box, and the materials available are listed in the [Material Name] choice box. If the desired material is not found in the list, you can create it. Refer to Create New Material for details.

Material Name	Thickness (m)
Be	0.5

Atomic Number	Mass Ratio
2	1

Minimum Energy (eV)	1000
Maximum Energy (eV)	100000
Number of Points	1000

Figure 6.3 Configuration window for the generic filter.

In order create a new filter, click [Edit] button in the [Selected Filters] group box and execute [Create New Filter] command. Then a new spread sheet with a single row appears. Select the material name and input the thickness of the material in the spread sheet. In order to add new materials, click [Edit] button and execute [Add New Material] command. Input the number of materials you need, then new rows appear in the spread sheet for the new material.

Create New Material

In order to create a new material for filters, click [Edit] button in the [Material Information] group box and execute [Create New Material] command. Input the name of the material in the dialog box that pops up. Input the atomic number and its mass ratio in the spread sheet. In order to add new elements, click [Edit] button and execute [Add New Element] command. Input the number of elements you need, then new rows appear in the spread sheet for the new elements.

Plot Transmission Rate

In order to check the transmission rate of the specified filter, input the energy range and number of plotting points in the [Plot Transmission Rate] group box, and then click [Plot] button. A GUI window pops up to show the graphical plot of the transmission rate as a function of the photon energy.

6.4.2. Bandpass Filter

In *SPECTRA*, three types of bandpass filters are available: Gaussian, Lorentzian and Boxcar. For each bandpass filter, the central energy, width (FWHM or full), and maximum transmission rate should be specified. Meanings of these parameters are explained in Figure 6.4.

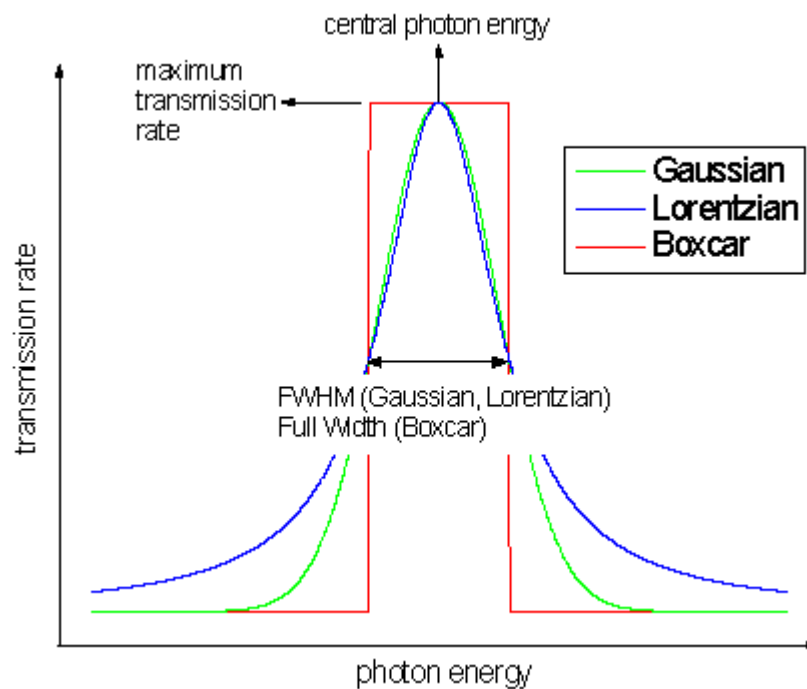


Figure 6.4 Schematic illustration of the three types of bandpass filters available in *SPECTRA*, and parameters that specify the profile of the transmission rate.

6.4.3. Custom Filter

Besides the above two filters, *SPECTRA* accepts a filter that is defined by the user. The input file should have a format indicated below.

Energy	Filtering
58071.5	2.261E-4
49680.1	7.972E-4
41482.5	0.0012
(omitted)	
3298.2	0.07375
3123.85	0.06741
2963.5	0.0626

In order to import the above file, click [Edit] button and execute [Import Transmission Data] command. Specify the location of the above file in the file selection dialog box that pops up. After importing the data, do not forget to save the parameter file, otherwise the imported data is discarded when opening another parameter file or quitting *SPECTRA*. In order to verify the imported data, click [PLOT Transmission Rate] button to create a graphical plot of the transmission rate.

6.5. Convolution

The energy spectrum measured with a photon detector is in general different from the original spectrum of SR due to a finite energy resolution of the detector, which can be estimated with this option. The resolution of the detector is assumed to be a function of the photon energy with the form

$$[\sigma(\omega)]^2 = a + b\omega$$

where σ is the energy resolution, ω is the photon energy, and a and b are the parameters dependent on the type of the photon detector and electronic circuit.

In *SPECTRA*, the energy resolution at two different energies should be specified. Then the parameters a and b are automatically calculated and used for the convolution calculation.

6.6. Numerical Conditions

In the group box titled [Numerical Conditions] located at the right of the [Calculation Configurations] GUI panel, a number of options are available to specify conditions concerning the numerical algorithm. The details are described in the following sections.

6.6.1. Zero Emittance and Energy Spread

The sharp peaks in the spectrum of undulator radiation are broadened by the effects due to the finite emittance and energy spread of the electron beam. In order to estimate SR characteristics without these broadening effects, [Zero Emittance] and/or [Zero Energy Spread] options can be selected instead of substituting 0 for Natural Emittance and Energy Spread parameter (section 4.1), to avoid numerical problems.

6.6.2. Fast Computation Using Swap Files

If the Periodic Lattice option (5.4.3) is enabled, the computation time tends to be very long. This is a consequence of the fact that the convolution of SR with the electron beam requires the 4-dimensional (or 6-dimensional) numerical integration in this case. *SPECTRA* makes use of the Monte Carlo integration method to reduce the computation time. Even so, it is required to repeat many times the calculation of the radiation property from a single electron. A new algorithm that can be applied to reduce the computation time has been developed at SPring-8, in which the total number of numerical operations is reduced drastically. The algorithm is implemented in *SPECTRA*, which is available by enabling this option. Note that a huge memory size is required during the calculation process, and in most cases, swap files are used for that. Specify the maximum size available for such swap files.

6.6.3. Fast Computation

This option is similar to that described in the previous section, but mainly is available for radiation power calculation. In this case, the memory requirement is not severe and thus the swap files are not necessary.

6.6.4. Accuracy Level

In general, a lot of numerical schemes are necessary to calculate SR characteristics, e.g., numerical integration, summation of an infinite series, Fourier transform, and so on. The parameter [Accuracy Level] determines the numerical accuracy of these schemes. It is represented by an integer with a default value of 1. Increasing this number results in a higher accuracy, and vice versa. Needless to say, a higher precision requires a longer computation time.

6.6.5. Numerical Method for Radiation Field

This option determines the numerical algorithm of how to calculate the complex amplitude of the electric field of radiation emitted by an electron moving in the SR source. Select one of the three algorithms: [Fast Fourier Transform], [Direct Integration], [Wiggler Approximation], and [Automatic].

Fast Fourier Transform

Uses a fast Fourier transform (FFT) algorithm to calculate the radiation field. This is always much faster than the [Direct Integration] method and gives correct results in most cases.

Direct Integration

Calculates the radiation field by means of a direct integration. When the radiation field is composed of pulses with a sharp peak as in the case of radiation from IDs with large K values, and edge radiation, the FFT algorithm is sometimes very time-consuming and less accurate. In such a case, this method is more effective.

Wiggler Approximation

Regards the device as a wiggler (i.e., incoherent source). This simplifies the method to calculate the radiation field and gives an approximate result for the flux of SR. Please keep in mind that this method gives incorrect results in the energy region where an undulator spectral profile (composed of sharp peaks) is dominant.

Automatic

SPECTRA automatically judges which algorithm (FFT or Direct Integration) is appropriate in order to reduce the computation time.

Examples

An example to compare the 3 methods described above is shown in Figure 6.5, where spectra for the undulator with error magnetic fields which are calculated with the three different methods are shown. Among them, the [Direct Integration] method takes much longer computation time than the other two.

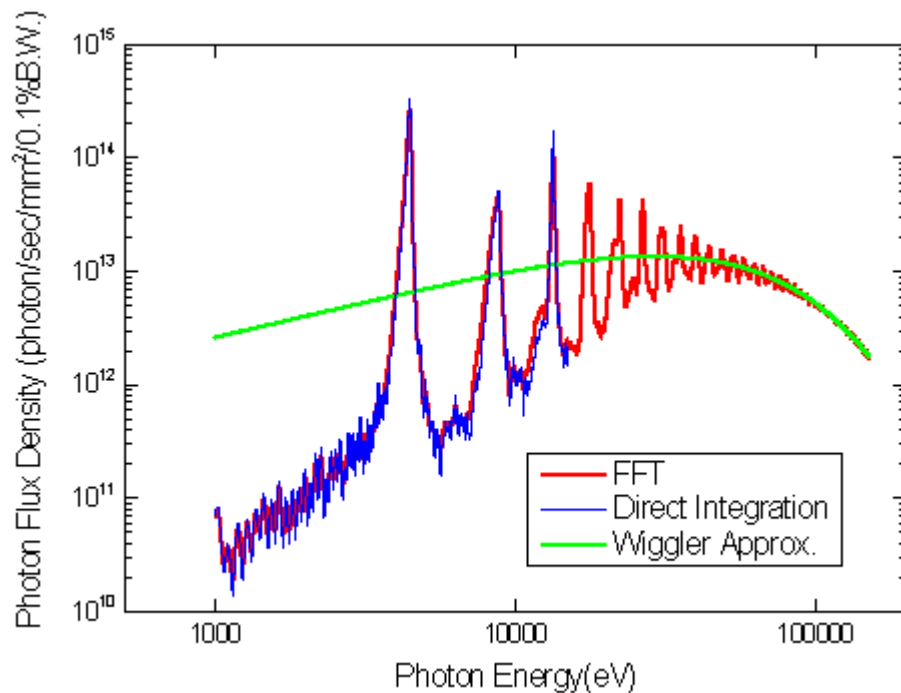


Figure 6.5 Examples to show difference between the 3 numerical methods to calculate the radiation field.

6.7. Options for the Output File

The output file that saves the calculation result can be configured in various ways. Detailed explanations are given below.

6.7.1. Print Header

If this option is enabled, the output file contains a header with information on the calculation conditions, such as the electron energy, emittance, K value, and number of magnetic periods.

6.7.2. Print Unit

If this option is enabled, the output file contains character strings that represent the unit for each item.

6.7.3. Suffix

The name of the output file is composed of a data name and suffix. The data name is specified in the file-selection dialog box that pops up after executing, e.g., [Run]-[Start Calculation] command. On the other hand, the suffix should be specified in this option. The number of suffices are dependent on the type of calculation. For example, the calculation [Spatial Dependence]-[Angular Flux Density]-[Along Axis] needs two suffices for the x and y axes.

Let us consider the case when “[Data Directory]/test” is selected as a data name, and character strings “.dtx” and “.dty” are specified as the suffices for x and y axes. Then two files “[Data Directory]/test.dtx” and “[Data Directory]/test.dty” will be created as the output files. It should be noted that several calculation types do not accept the user input for the suffix.

For example, the suffix for [K Dependence]-[Easy Calculation]-[Characteristics] has the format “.dmn”, where “mn” indicates the harmonic number (.d01=1st harmonic, .d03=3rd harmonic), and cannot be defined by the user.

7. Characterization in Phase Space

The photon distribution in the 4-D phase space (x, x', y, y') is important in designing optical components in the SR beamline. In general, Gaussian profiles are assumed as distribution functions along both position (x, x') and velocity (y, y') axes in the phase space. In the case of undulator radiation, the standard deviation is given by a simple formula, which is determined from the SR formulae under the far-field approximation, and the diffraction limit of light.

This is a consequence of the fact that undulator radiation is coherent. On the other hand, wiggler radiation is incoherent, which makes it impossible to express the standard deviation with a simple analytical formula. Instead, fitting functions have been proposed in [8] with adequate fitting parameters.

It should be noted, however, that these expressions for the standard deviation and the Gaussian-profile assumption are not exactly correct to evaluate the photon distribution in the phase space. In order to accurately characterize the photon distribution, an analysis should be made on the complex amplitude of radiation field.

7.1. Characterization Method

In *SPECTRA*, two methods are available for the source characterization.

7.1.1. Walther's Formula

The photon distribution in the 4-D phase space have been formulated by Walter [8] as

$$B(\mathbf{r}, \boldsymbol{\theta}) \propto \int d\mathbf{u} \langle E^*(\mathbf{r} - \mathbf{u}/2) \rangle \langle E(\mathbf{r} + \mathbf{u}/2) \rangle \exp(i\mathbf{k}\boldsymbol{\theta} \cdot \mathbf{u})$$

where \mathbf{r} and $\boldsymbol{\theta}$ are the position and angle variables in the phase space, E denotes an electric field of a single polarization component and thus is a scalar, and B is a quantity called brilliance that denotes the flux density in the 4-D phase space usually expressed in unit of photons/sec/mrad²/mm²/0.1%B.W.

It should be noted that B is real but not necessarily positive, and thus is not a physically measurable quantity. What is measurable in a real space is the angular flux density obtained by integration of B along \mathbf{r} , and the spatial flux density obtained by integration of B along $\boldsymbol{\theta}$.

7.1.2. Virtual Slit

Let us assume that a movable rectangular slit is placed at a certain position, and a screen that can measure the spatial profile of the photon intensity is located infinitely far from the slit position as shown in Figure 7.1. By scanning the slit and measuring the spatial profile at the screen, we can obtain the photon distribution in the 4-D phase space, which is a physically measurable quantity unlike that derived by the Walther's formulae.

It should be noted that the spatial profile is convoluted with a step function that denotes the slit profile, and the angular profile is convoluted with a “sinc” function ($\sin x/x$) that denote the diffraction effects. In other words, a small (large) slit results in a great change in the angular (spatial) profile due to convolution.

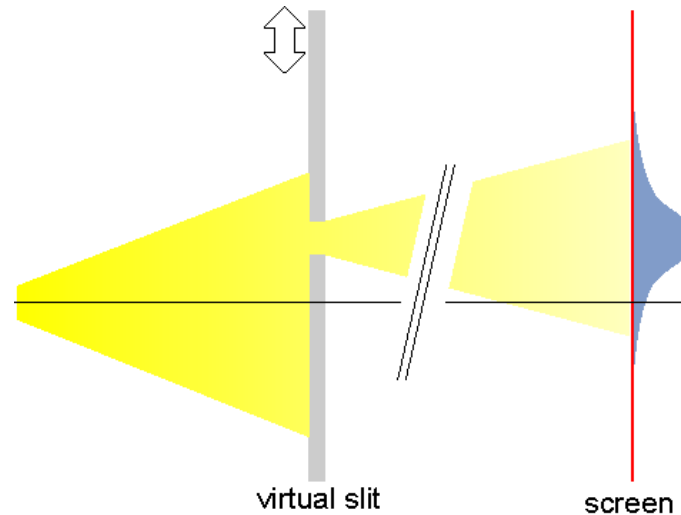


Figure 7.1 Schematic illustration of the virtual experiments to determine the photon distribution in the phase space.

7.2. Configuration for Source Characterization

In order to perform source characterization, a data file that contains a spatial profile of the complex amplitude of radiation field (amplitude data file) is necessary. In practice, it can be created using *SPECTRA* by executing the calculation, [Near Field]-[Radiation Field by a Single Electron]-[Complex Amplitude Spatial Profile]. Refer to Complex Amplitude Spatial Profile (6.1.8) for details.

After the calculation is finished, execute [Open Utility]-[Source Characterization in Phase Space] command to open the configuration GUI window as shown in Figure 7.2. Then click [Import] button and input the location of the data file in the file-selection dialog box that pops up.

In order to calculate the photon distribution in the phase space, it is necessary to specify the parameters given below:

- Radiation wavelength
- Spatial interval
- Angular interval
- Distance from the source to the observer
- Calculation range and fixed point

For the first two parameters, the values are specified at the time when the amplitude data file has been created, and indicated in the [Observation Condition] group box as $\lambda(m)$ and $\Delta x,y(mm)$. Other parameters should be specified by the user.

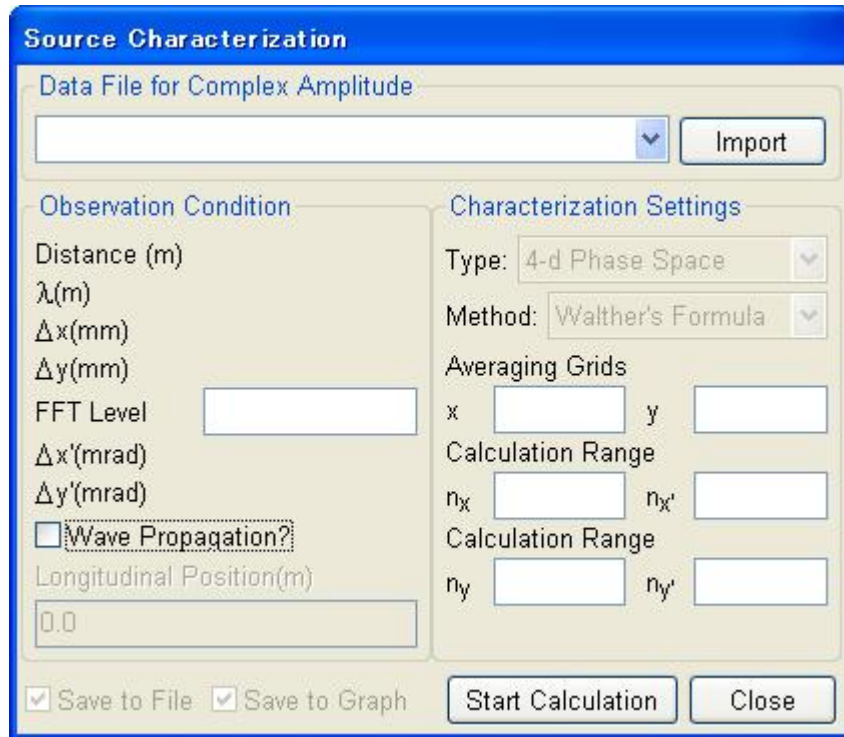


Figure 7.2 GUI window to configure the source characterization.

7.3. Type of Characterization

There are 5 types of methods for source characterization.

7.3.1. 4-d Phase Space

The photon distribution is calculated in the 4-D phase space spanned by x , x' , y and y' axes.

7.3.2. 2-d: x-x' Plane

The photon distribution is calculated on the plane spanned by x and x' axes.

7.3.3. 2-d: y-y' Plane

The photon distribution is calculated on the plane spanned by y and y' axes.

7.3.4. 2-d: x-y Plane

The photon distribution is calculated on the plane spanned by x and y axes. This is simply a spatial profile of photon intensity.

7.3.5. 2-d: x'-y' Plane

The photon distribution is calculated on the plane spanned by x' and y' axes. This is simply an angular profile of photon intensity. The Wave Propagation Option (7.5) is meaningless in this case.

7.4. Angular Interval

The spatial and angular profiles are related with each other by a Fourier transform, which is performed numerically by an FFT (Fast Fourier Transform) algorithm in *SPECTRA*. This implies that the angular interval ($\Delta x'$, $\Delta y'$) in the phase space is determined by the spatial interval (Δx , Δy) and the number of spatial points for FFT (N_x , N_y), and cannot be selected arbitrarily. Because Δx and Δy are fixed, N_x and N_y are the only parameters to be changed.

For the FFT algorithm to be applicable, N_x and N_y should be a power of 2 (FFT algorithm that does not need such a requirement also exists, which is not adopted in *SPECTRA* because of computation efficiency). The number of spatial data points (M_x , M_y) used to create the amplitude data file does not necessarily satisfy this condition. In such a case, N_x (N_y) is chosen to be a minimum number that exceeds M_x (M_y) besides being a power of 2.

This means that there are a certain number of data points where no data is allocated. Before starting calculation, these data points are filled with 0 for compatibility to the FFT algorithm.

In order to make the angular interval smaller, N_x (N_y) can be increased as long as it is a power of 2, namely $N_x = 2^{m+n-1}$, where n is the minimum number so that $N_x > M_x$ and m is a positive integer to determine the angular interval. The parameter m can be specified in [FFT Level] in the GUI window (refer to Figure 7.2).

7.5. Wave Propagation Option

Although the spatial profile of the complex amplitude is calculated at a fixed longitudinal position (z), it is possible to change the position where the source characterization is performed. In order to do so, the radiation field should be transmitted over a certain distance by Fresnel-Kirchhoff's diffraction theory [9] to denote the electromagnetic propagation in free space.

Input a desired longitudinal position (measured from the origin of the SR source) and tick [Wave Propagation?] to enable the wave propagation.

7.6. How to Specify Coordinates?

The coordinate for the calculation range and fixed point should be specified by an integer, i.e., $x = n_x \Delta x$ and $x' = n_x' \Delta x'$, where x and x' are the horizontal spatial and angular coordinates, and n_x and n_x' are input integers, respectively.

7.6.1. Fixed Grid in (x-x'), (y-y')

If [2-d: x-x] is selected as Type of Characterization (7.3), the observation position in the vertical direction (y,y') should be fixed at some position. Input an integer to specify the fixed point. This is also applied to the case when [2-d: y-y] is selected, in which the fixed point in (x,x') should be specified.

7.6.2. Calculation Range

The calculation range should be specified by a single integer for each direction (x, x', y and y'). For example, the range for the x direction is from $-nx\Delta x$ to $nx\Delta x$.

7.6.3. Averaging Grids

If [Walther's Formula] is selected as the characterization method, the results can be averaged over certain lengths along the x and y axes. This is for comparison with the [Virtual Slit] method, which inevitably averages the photon distribution over a region correspondent to the slit size. The averaging region in the x direction is from $(m_x-n_x)\Delta x$ to $(m_x+n_x)\Delta x$, where m_x is an integer that specifies the horizontal (x) observation position.

7.6.4. Slit Size

In order to apply the [Virtual Slit] method, the slit size at least larger than $\Delta x\Delta y$ should be specified. As in the above two cases, an integer should be input for each (x,y) direction. Then, the slit area in the x direction is from $(m_x-n_x)\Delta x$ to $(m_x+n_x)\Delta x$, where m_x is an integer that specifies the location of the slit center.

7.7. How to Manipulate Data?

The calculated characterization data can be manipulated in two ways. One is to save the data to a file and the other is to create a graphical plot similar to that shown in Figure 2.11. To enable the former and latter functions, tick [Save to File] and [Show Plot] checkboxes, respectively. Click [Start Calculation] button to start the source characterization and input a file name to save the data if necessary, then a GUI window pops up to show the status of calculation progress.

7.8. Unit of the Photon Intensity

The photon intensity to be calculated has a unit of “photons/d Ω /0.1%B.W./electron”, where d Ω means a unit volume of the 2-D or 4-D phase space, and an adequate unit will be selected from “mm²”, “mrad²”, or “mm²mrad²” according to Type of Characterization (7.3). The term “/electron” means that the photon intensity is for SR emitted by a single electron, which is a consequence of the fact that the amplitude data file is created by the calculation in the case when a single electron is injected in the SR source. Thus it is necessary to convolute the photon distribution with a function that denotes the electron-beam distribution in order to obtain the familiar quantity such as the brilliance.

8. Menu Commands

This chapter explains the contents of the menu commands.

8.1. File

The submenu commands in [File] menu are summarized in Table 8.1.

Table 8.1 Submenus in [File] menu.

Menu		Action
Create New		Closes the current parameter file and create a new set of parameters.
Open Parameter File		Opens a <i>SPECTRA</i> parameter file.
Import Parameter File		Reads parameters in an existing <i>SPECTRA</i> parameter file and add the parameters to the current parameters.
Open <i>SPECTRA</i> Output	Data File	Same as the [Import] command in Figure 2.5
	Scan Configuration File	Same as the [Import] command in Figure 2.9
	Visualization File	Creates the Animation GUI Window (2.6) with the data file created by the [Save All Data] command.
Save		Saves the current parameters.
Save As		Saves the parameters in another file. Input a new file name in the file-selection dialog box
Initialize Configuration		Initializes the configuration file. Useful in case the behavior of <i>SPECTRA</i> looks abnormal.
Exit		Quits <i>SPECTRA</i> .

8.2. Select Calculation

Selects the type of calculation. Refer to Chapter 3 for details.

8.3. Run

The submenu commands in [Run] menu are summarized in Table 8.2.

Table 8.2 Submenus in [Run] menu.

Menu	Action
Create Process	Saves the current parameters in the temporary memory and create a calculation process. Refer to Successive Calculations (2.1.5) for details.
Import List	Reads the parameter list in the file created previously. Refer to Successive Calculations (2.1.5) for details.

Menu	Action
Import Parameter File	Reads parameters in an existing <i>SPECTRA</i> parameter file and add the parameters to the current parameters.
Start Calculation	Starts the calculation. If no processes are created, a single calculation is started using the parameters currently shown in the GUI panels. Otherwise, the calculations in list are performed in series.

8.4. Open Utility

The submenu commands in [Open Utility] menu are summarized in Table 8.3.

Table 8.3 Submenus in [Open Utility] menu.

Menu	Action
Simple Plotter	Opens the configuration window to visualize the calculation results (Figure 2.5).
Visualization of Scan Results	Opens the configuration window for Visualization of Scan Calculation (2.5).
Source Characterization in Phase Space	Opens the GUI window for Characterization in Phase Space (chapter 7)

8.5. Configuration

The submenus in [Configuration] menu are for operation of the parameter sets. Refer to Parameter Set (2.7) for details. Besides the parameter set operation, several commands related to the configuration of the accelerator and light source are summarized in Table 8.4.

8.6. Help

Opens this document with a standard PDF viewer installed in your computer. If no standard viewer is found, a warning message is shown.

8.7. About

Show the dialog to show information on *SPECTRA*.

Table 8.4 Submenus in [Configuration] menu.

Menu		Action
Accelerator	Accelerator Type	Selects the accelerator type. Refer to Accelerator Type (4.2) for details.
	Plot betatron Functions	Plot the betatron functions over the SR source. Refer to Plot betatron Functions (4.5) for details.
Light Source	Source Type	Selects the type of SR source. Refer to Selection of the SR Source Type (5.6) for details.
	Solve Equation of Motion	Numerically solves the equation of motion of an electron moving in the magnetic field of the SR source. Select one of the submenus to specify the method and items to output the calculation result. If [Save Orbit Data] is selected, the user is required to input a file name to save the calculation result. Otherwise, the results are graphically plotted.

9. Glossary

9.1. Terms on SR

Here, brief explanations on terms on SR used in *SPECTRA* are given. It should be noted that the definitions here are only in the use of *SPECTRA* and other definitions may be given in other applications.

9.1.1. Angular Flux Density

Photons emitted per unit time, bandwidth, and solid angle. The unit used in *SPECTRA* is photons/sec/mrad²/0.1%B.W, indicating the number of photons emitted per second per 1mrad² in 0.1% bandwidth.

9.1.2. Average Flux Density

Flux density of SR transmitting through a slit averaged of the slit area. Given by the partial flux divided by the solid angle or area of the slit. The unit is the same as that used in the Angular Flux Density or Spatial Flux Density.

9.1.3. Angular Power Density

Radiation power emitted into a unit solid angle. The unit used in *SPECTRA* is kW/ mrad².

9.1.4. Average Power Density

Power density of SR transmitting through a slit averaged of the slit area. Given by the Partial Power divided by the solid angle or area of the slit. The unit is the same as that used in the Angular Power Density or Spatial Power Density.

9.1.5. Bose Degeneracy

The number of photons in the minimum volume of the 6-D (position:x,y, momentum:x',y', energy, time) phase space.

9.1.6. Brilliance

The photon density in the 6-D phase space. The unit used in *SPECTRA* is photons/sec /mrad²/mm²/0.1%B.W.

9.1.7. Coherent Flux

The flux of photons residing within a 4-D phase-space volume defined by full spatial coherence. Refer to [10] for details.

9.1.8. Coherent Power

Portion of the radiated power residing within a 6-D phase-space volume defined by full spatial coherence and a coherence length determined by the undulator period. Refer to [10] for details.

9.1.9. Critical Energy

The photon energy that divides the total-flux spectrum of BM radiation into two parts of equal power. In a more practical meaning, the photon-flux spectrum has its maximum near the critical energy.

9.1.10. Degree of Polarization (PL, PC, PL45)

Degree of polarization of light. There are 3 types of degree of polarization: linear (PL), circular (PC) and 45-degree linear (PL45) polarization. PL = +1(-1) means that the electric vector of the photon beam lies on the horizontal (vertical) plane. PC = +1(-1) means that the electric vector rotates clockwise (counterclockwise). PL45 = +1(-1) means that the electric vector lies on the plane tilted by 45 (135) degree from the horizontal plane.

9.1.11. Harmonic, Harmonic Number

The spectrum of undulator radiation has a sharp peak around an energy corresponding to an integer multiple ($=n$) of a certain energy (fundamental energy) determined by the electron energy, periodic length, and K value(s). SR at such an energy is called n -th harmonic and n is called a harmonic number.

9.1.12. Integrated Power, Flux

Radiation power and Total Flux of SR integrated from a certain target energy to infinity.

9.1.13. K Value

A dimensionless parameter that denotes the strength of the magnetic field of an ID. Deflection parameter in other words.

9.1.14. Linear Power Density

Power density integrated along the vertical axis.

9.1.15. Natural Size/Divergence, Effective Size/Divergence

Natural size (divergence) is the photon beam size emitted from a single electron (or zero-emittance electron beam) and effective size (divergence) is the photon beam size (divergence) emitted from a finite-emittance electron beam. The effective size (divergence) is given by convolution of the natural size (divergence) with the electron beam size (divergence).

9.1.16. Partial Flux

Photon flux of SR transmitting through a slit. The unit used in *SPECTRA* is photons/sec/0.1%B.W.

9.1.17. Partial Power

Radiation power of SR transmitting through a slit.

9.1.18. Spatial Flux Density

Photons emitted per unit time, bandwidth, and area. The unit used in *SPECTRA* is photons/sec/mm²/0.1%B.W., indicating the number of photons emitted per second per 1mm² in 0.1% bandwidth.

9.1.19. Spatial Power Density

Radiation power emitted into a unit solid area. The unit used in *SPECTRA* is kW/mm².

9.1.20. Total Flux

Photon flux emitted over the total solid angle (4π). The unit used in *SPECTRA* is photons/sec/0.1%B.W.

9.1.21. Total Power

Power emitted over the total solid angle (4π).

9.2. GUI Controls

Various controls are used in a GUI-based application as shown in Figure 9.1. Here, brief explanations are given for each control.

9.2.1. Check Box

Boolean to enable or disable the item concerned.

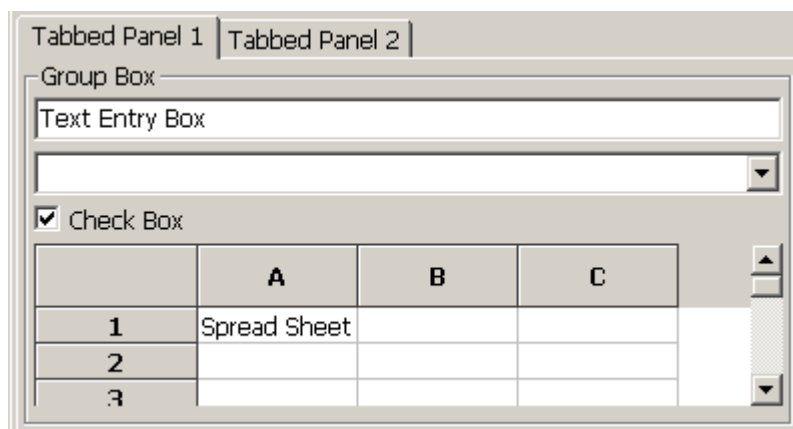


Figure 9.1 Typical GUI controls in a GUI-based application (older MS-Windows version).

9.2.2. Group Box

Group of GUI controls enclosed by a rectangular with a title to indicate the contents of the group.

9.2.3. Choice Box

Box to contain several items and select one of them.

9.2.4. Spread Sheet

Sheet that contains 2-dimensional matrix data.

9.2.5. Text Entry Box

Box where string characters can be input.

9.2.6. Tabbed Window

GUI window that contains a number of subwindows. A titled tab is attached at the top of each subwindow, which enables the user's selection.

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