USE of SCILAB BASED Xcos MODELLING FOR CALCULATION OF UNDULATOR RADIATION PARAMETERS

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ABSTRACT: The SCILAB Xcos model is designed to simulate the electron trajectories and intensity of planar undulator radiation using a numerical approach. The SCILAB 6.1.1 software was used to design the present model, which was designed to simulate the on-axis undulator radiation at various harmonics. A comparison of the results from this model with those obtained using the analytical method with the Bessel function is also given in this paper. The designed model can be modified for the numerical computation of the trajectories of the innovative and novel undulator schemes.

1. INTRODUCTION

Free electron laser (FEL) is a laser light source that is monochromatic, unidirectional, highly intense, coherent, tuneable, and highly brilliance and is available with ultra-high short pulses [1-2]. In the FEL system, a relativistic electron beam is transmitted via an undulator, which is an alternative magnetic field array that creates coherent electromagnetic radiation by performing wiggling motion. The path of electrons through an undulator determines the spectral characteristics of the radiation coming from it. The primary variables for consideration in FEL technology and applications are electron trajectories, which determine the radiation attributes [3-4]. There are various dedicated available FEL parameter simulation software such as Genesis, GINGER, and Spectra. The Genesis can be used for various FEL configurations and shows good agreement with experimental results [5-6]. In addition, GINGER is a useful software tool for assessing the FEL parameters, which is used to calculate the FEL parameters in the pulse regime [7]. This software has the facilities to simulate the FEL parameter for established undulator schemes used in FEL technology. The present study is an attempt to design a model for the simulation of electron trajectories and radiation properties by employing an open source software that can be used for innovative and novel schemes.

SCILAB is a free and open-source program for numerical calculations that has several applications in science and engineering [8]. SCILAB's Xcos tool boxes, which are analogous to MATLAB's Simulink, are used for model-based simulation. The goal of this study is to create simulation models that can be used to numerically calculate the amount of on-axis undulator radiation (UR) by a planar undulator. Hussain et al. developed and examined a numerically-based SCLAB Xcos simulation model in SCILAB 5.5.2 version for planar undulator radiation and compared the intensity calculation findings with analytical conclusions drawn from the use of generalized Bessel functions. [9]. This study is an extension of the simulation work related to the development of Xcos models for analytical solutions of electron trajectory equations in planar and harmonic undulators [10-11]. All the models developed in the previous reported work were in SCILAB version 5.5.2, which compares the analytical and numerical methods for calculating the brightness of an undulator [12].

As there are changes in the available software versions, the SCILAB 5 version has been upgraded to
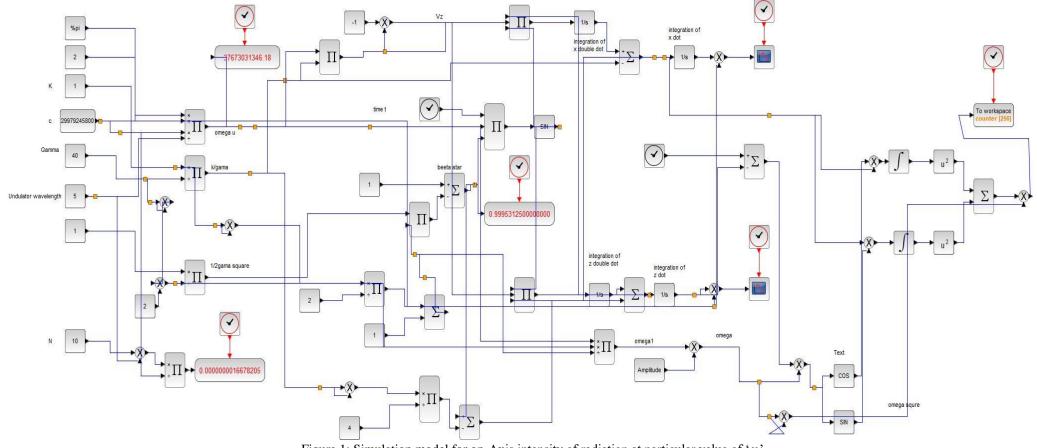
Figure 1: Simulation model for on-Axis intensity of radiation at particular value of 'ω'

SCILAB 6, and the presently available software version is SCILAB 2023. The previously designed model does not run on newer versions. The SCILAB Xcos model was redesigned in version 6.1.1 of the software and tested for SCILAB 2023. Proper care has been taken while designing the model such that it can easily identify the parameter that needs to be changed during simulations. A numerical technique was used to construct this model. The findings of this study contrast with the analytical conclusions obtained by applying the generalized Bessel function technique. The objective of the current study was to numerically determine the intensity variation with respect to the on-axis position of observation and to compare the results with those of earlier studies [13]. In earlier studies, more focus was on fundamental radiation, in this study, the spectral properties at emission odd harmonics are also included along with fundamental. As a result, the present model will be useful in determining the intensity of the on-axis radiation for novel schemes because the software [5-8] is suitable for well-known and widespread undulator schemes.

2. SIMULATION MODEL FOR ON- AXIS RADIATION

The simulation model designed for the on-axis planar undulator radiation in SCILAB 6.1.1 is displayed in Fig. 1. Numerous blocks of the SCILAB-Xcos toolboxes were used to create this model. All the key parameters in this model, including the natural constants (or simulation block variables) and the number of undulator periods (N), relativistic speed (c), undulator parameter (K), energy relativistic parameter (γ), and undulator wavelength (K_u), are aligned on the left side of the model, which make this different from previous designed model[11]. By modifying the values in the box, it is simple to identify and change the values of the primary parameters. The interconnection of various blocks is decided by the equation 1 and 3, governing the trajectories and intensity of radiation respectively as given in the appendix. To obtain the values of the secondary parameters, several mathematical operators are used to link the outputs of the main parameters. After a single simulation of the model designed, secondary parameters, such as the undulator wave number (k_u) and total traversing time (T) of electrons in the undulator can be evaluated. These secondary parameters are the determining factors in simulations of electron trajectories and the intensity of undulator radiation for the undulator scheme, and they are shown in the corresponding *AFFICH_m* block. The model's overall simulation time is determined by T.

The model used to calculate the on-axis intensity of the planar undulator radiation is modified in the current model [9]. To determine the final simulation's secondary parameter values, the designed model is simulated once. The intensity values for various outgoing frequencies or harmonics are evaluated using the set context function of the Xcos model designer. The model is performed individually for each harmonic in the current calculation. The SCILAB 2023 version of this model also functions. In this study, for simulation, γ is kept at 40 and the remaining parameters are kept as given in a previously reported work [9]. For the present study the γ is kept as 20 and total number of periods is taken as 10. The traversing time T for simulation comes out as 1.66×10^{-9} second.

3. RESULTS

The Intensity of On-axis radiation calculated by present SCILAB-Xcos model for planar harmonic undulator is evaluated at K=1 for different odd harmonics. The results are shown in Fig. 2(a),(b) and (c) and depicts the On-axis intensity of radiation for 1st harmonic spectrum, 3rd harmonic and 5th harmonic respectively. Each figure displays the magnified view at each odd harmonic. The peak value of 1st harmonic observed at 1.02 and the peak value of 3rd harmonic observed at 2.96 and the peak value of 5th harmonic observed at 5.02.

On comparison with the results are observed from the analytical method and given in the Appendix A Fig.3 (a), (b) and (c). The peak value of 1st harmonic observed at 1 while in numerical approach it is shifted 0.02 ahead from 1 and the peak value of 3rd harmonic observed at 2 while in numerical approach it is shifted behind 0.04 from 3 and the peak value of 5th harmonic observed at 5 while in numerical approach it is shifted 0.02 ahead from 5. The peak intensity variation between the numerical and analytical results can be corrected by using correction parameter as discussed in previous paper [9].
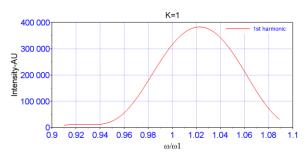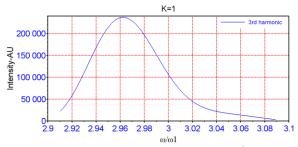
Figure 2(a) : Intensity of radiation at 1st harmonic

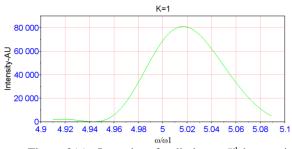Figure 2(b) : Intensity of radiation at 3rd harmonic

Figure 2(c) : Intensity of radiation at 5th harmonic

4. CONCLUSION

The present work presents designing of SCILAB Xcosmodel in SCILAB 6.1.1 version for simulating the intensity of On-axis planar undulator radiation. The numerical method's algorithm is used to design the model. The model designed in SCILAB 6.1.1 version can also be used in latest SCILAB 2023 version. The intensity results obtained from Xcos modelemploying numerical approach at different harmonics were compared with the results obtained from analytical method based on generalised Bessel functions. The model designed by SCILAB model-based works well in different versions. The presented model can also be modified to determine the On-axis radiation from novel undulator schemes such as asymmetric configuration and others by finding the trajectories of electron in the undulator magnetic field. The spectral properties off-axis undulatorradiation can also be determined by modification of the presented model

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APENDIX- A: numerical approach for intensity calculations

The Intensity of radiation *'I'* of electromagnetic radiation per unit solid angle '$d\Omega$' per unit frequency range '$d\omega$' of frequency 'ω' from accelerating electron of charge *'e'* given by Lienard - Wiechart integral and read as[14],

$$\frac{d^2I}{d\omega d\Omega} = \frac{e^2\omega^2}{4\pi^2 c}\left|\int_0^T \{\widehat{\beta_x}\}exp\left[i\omega(t-\frac{z}{c})\right]dt\right|^2 \quad (1)$$

In case of planar undulator Magnetic field as

$$\vec{B} = 0, B_y, 0 \quad (2)$$

The electron velocity, which can be integrated for trajectories can be read as [3-4]

$$\beta_x = -\frac{K}{\gamma}\cos(\Omega_u t) \quad (3)$$

$$\beta_z = \beta - \frac{1}{2}\left[\frac{K^2}{2\gamma^2} + \frac{K^2}{2\gamma^2}\cos(2\Omega_u t)\right] \quad (4)$$

Where

$$\beta_* = 1 - \frac{1}{2\gamma^2}\left(1 + \frac{K^2}{2}\right)$$

and γ is relativistic parameter, $K = \frac{eB_0}{\Omega_u m_0 c}$ is the undulator parameter, m_0 is rest mass of electron, $\Omega_u = k_u c$, $k_u = \frac{2\pi}{\lambda_u}$ is undulator wave number, λ_u is undulator wave length, B_0 is peak magnetic field and T is the total time for which the electron wiggle in undulator.

Eqs.1 can be solved analytically and given as [3-4]

$$\frac{d^2I}{d\omega d\Omega} = \frac{e^2\omega^2 T^2}{4\pi^2 c}\{|T_x^2|\}\left(\frac{sin(\frac{vT}{2})}{\frac{vT}{2}}\right) \quad (5)$$

Where, the intensity coefficient T_x in Eq. (10) is given in terms of generalized Bessel functions (GBF) as,

$$T_x = \left[\frac{K}{2\gamma}\{J_{m+1}(0,z_1) + J_{m-1}(0,z_1)\}\right]$$

Detuning parameter 'ν' is given by

$$\vartheta = \frac{\omega}{2\gamma^2}\left[1 + \frac{K^2}{2}\right] - m\Omega_u$$

Argument of Generalised Bessel Function is

$$z_1 = -\frac{K^2\omega}{8\Omega_u\gamma^2}$$

and 'T' is the total time for traversing of electron in an undulator. The analytical method uses generalised Bessel functions to calculate the intensity of undulator radiation. The analytical results are shown in figure 3 (a),(b) and (c).
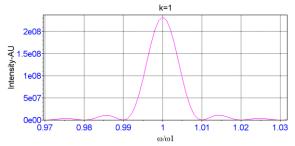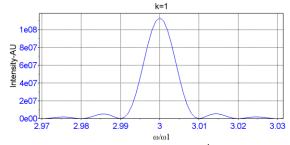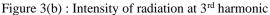

Figure 3(a) : Intensity of radiation at 1st harmonic
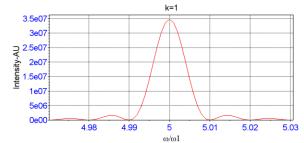

Figure 3(b) : Intensity of radiation at 3rd harmonic

Figure 3(c) : Intensity of radiation at 5th harmonic

For numerical calculations, the acceleration along the 'x' and 'z' directions can be evaluated by Lorentz force equation as

$$\ddot{x} = \frac{K}{\gamma}\Omega_u v_z\left[sin(\Omega_u\beta_* t)\right] \quad (6)$$

$$\ddot{z} = -\frac{K}{\gamma}\Omega_u v_x [sin(\Omega_u \beta_* t)] \qquad (7)$$

The Eqs. (6) and (7) can be integrated to get velocities and double integrated to get trajectories along corresponding directions respectively. These values can be put in the Eqs.(1), to get intensity at a frequency.Corresponding initial values read as,

$$\beta_{x,t=0} = -\frac{K}{\gamma} \qquad (8)$$

$$z_{t=0} = 0 \qquad (9$$