ISBN: 978-3-95450-206-6 doi:10.18429/JACoW-FLS2018-WEA2WD03

ANALYSIS OF ELECTRON TRAJECTORIES IN HARMONIC UNDULATOR WITH SCILAB'S MODEL BASED DESIGN CODES

H. Jeevakhan, S. Kumar, National Institute of Technical Teachers' Training and Research, Bhopal,India

G. Mishra, Physics Department, Devi Ahilya University, Indore, India

Abstract

Scilab's X-cos model-based simulation blocks have been used to simulate the trajectories of an electron traversing through a Harmonic undulator. The **trajectory** of electron along X direction has been simulated from Numerical and analytical methods. Analysis given in the present paper is compared with the other codes. Parallel simulation of Harmonic undulator magnetic field along with trajectories of electron is given in the present analysis.

INTRODUCTION

Fourth generation X-Ray Free electron laser (XFEL) light source is the state of art technology and have number of applications in cutting edge multidisciplinary research areas [1]. Spectral properties of out coming radiation in FEL depend upon numbers of parameters such as beam quality, magnetic structure, seed laser, trajectory of electron traversing in undulator and many more. Simulation software such as Radia and Poison are often used to design Undulator and calculate the magnetic field at on and Off axis. The raw data of magnetic field profile obtained from the simulation or measurements by Hall Probe method can be analysed to determine electron trajectories, intensity of spontaneous radiation, FEL gain in stimulated emission.

Model-based development (MBD) is a paradigm shift in software development. It's mainly focuses on executable models of the systems of equations. These models allow a wide range of analysis. Compare to traditional design flow, model-based design condensed development time. The main factors that contributed to the substantial reduction in development time is achieved by using model-based design: clocking, defect discovery, and component interfaces [2].

Scilab/Xcos an open source technology [3] had been used for number of applications such as remote control lab, real time experiments, and CDMA modelling [4-6]. Scilab/Xcos based simulation models for analytical solutions of electron trajectory equations have been presented with some limitations by H Jeevakhan etal [7]. In present analysis X-cos based on model based design has been employed to find the trajectory of the electron moving in the Harmonic undulator, variation of magnetic field along the axis of undulator. We have also presented a model to analyze trajectory in the magnetic field profile given by real undulator measurements and simulated by RADIA software.

PRESENT SIMULATION-UNDULATOR FIELD

Planar undulator magnetic field with additional small harmonic field is considered for simulation and is given by [8-9]

$$B = [0, a_0 B_0 (sink_u z + \Delta sink_h z), 0] \quad (1)$$

Where, $k_u = \frac{2\pi}{\lambda_u}$ and $k_h = \frac{2\pi}{\lambda_h}$ where k_u and k_h are undulator and harmonic undulator wave number respectively , λ_u is undulator wave length and $\lambda_h = h\lambda_u$, h is harmonic integer, B_0 is peak magnetic field, $\Delta = \frac{a_1}{a_0}$, a_0 and a_1 controls the amplitude of main undulator field and additional harmonic field respectively

The velocity and trajectory of electron in 'x' direction are deduced by using Lorentz force equation reads as

$$\beta_x = -\frac{K}{\gamma}\left[\cos(\Omega_u)t + \Delta\frac{\cos(h\Omega_u)t}{h}\right] \quad (2)$$

$$\frac{x}{c} = -\frac{K}{\gamma}\left[\frac{\sin(\Omega_u)t}{\Omega_u} + \Delta\frac{\sin(h\Omega_u)t}{h\Omega_u}\right] \quad (3)$$

Where γ is relativistic parameter, $K = \frac{a_0 e B_0}{\Omega_u m_0 c}$ is the undulator parameter, m_0 is rest mass of electron, and $\Omega_u = k_u c$

SIMULATION PARAMETERS

Analytical solution of trajectory along 'x' direction is simulated with the magnetic field given in Eq.(3) and Eq.(1) respectively. Table 1 gives the parameters of simulation used in the analysis. SCILAB's Model based simulation model using Xcos tool boxes has been designed for Eq.(3) and Eq.(1) . Each parameter in Table 1 is identified by a block in the simulation model. The parameter values can be changed by selecting the relevant block and alteration can be done.

Table 1: Parameters used for Simulation

Parameter	Symbol	Values
Undulator parameter	K	1
Number of Undulator periods	N	10
Undulator wavelength	λ	5cm
Relativistic parameter	γ	20
Harmonic integer	h	3
Contribution of harmonic field	Δ	0, 0.1, 0.2, 0.4

ISBN: 978-3-95450-206-6 doi:10.18429/JACoW-FLS2018-WEA2WD03

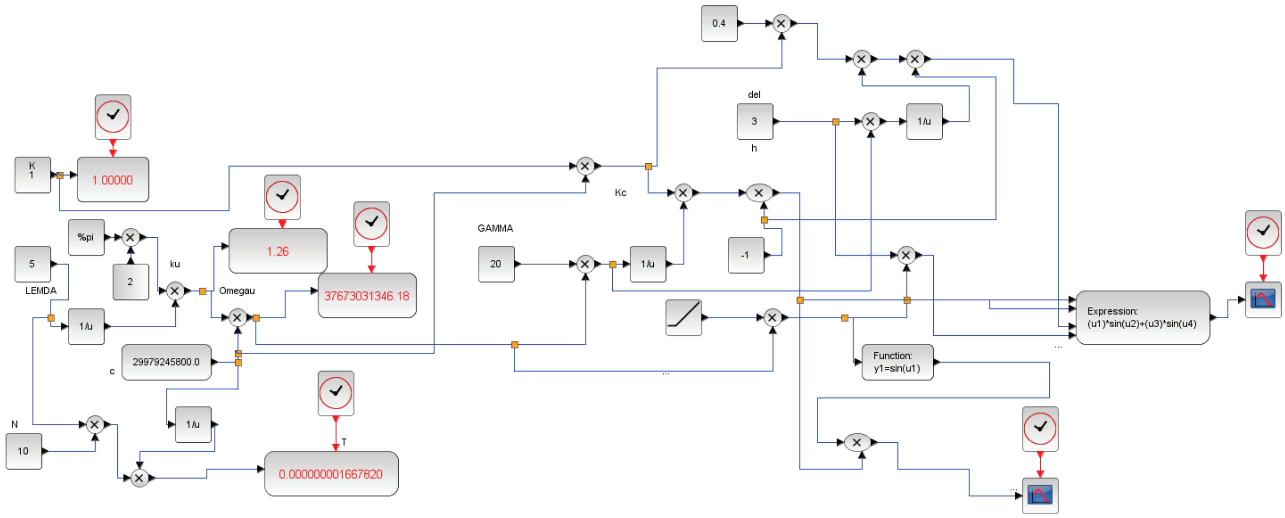


Figure 1: Simulation model of electron trajectory in planar and harmonic undulator.

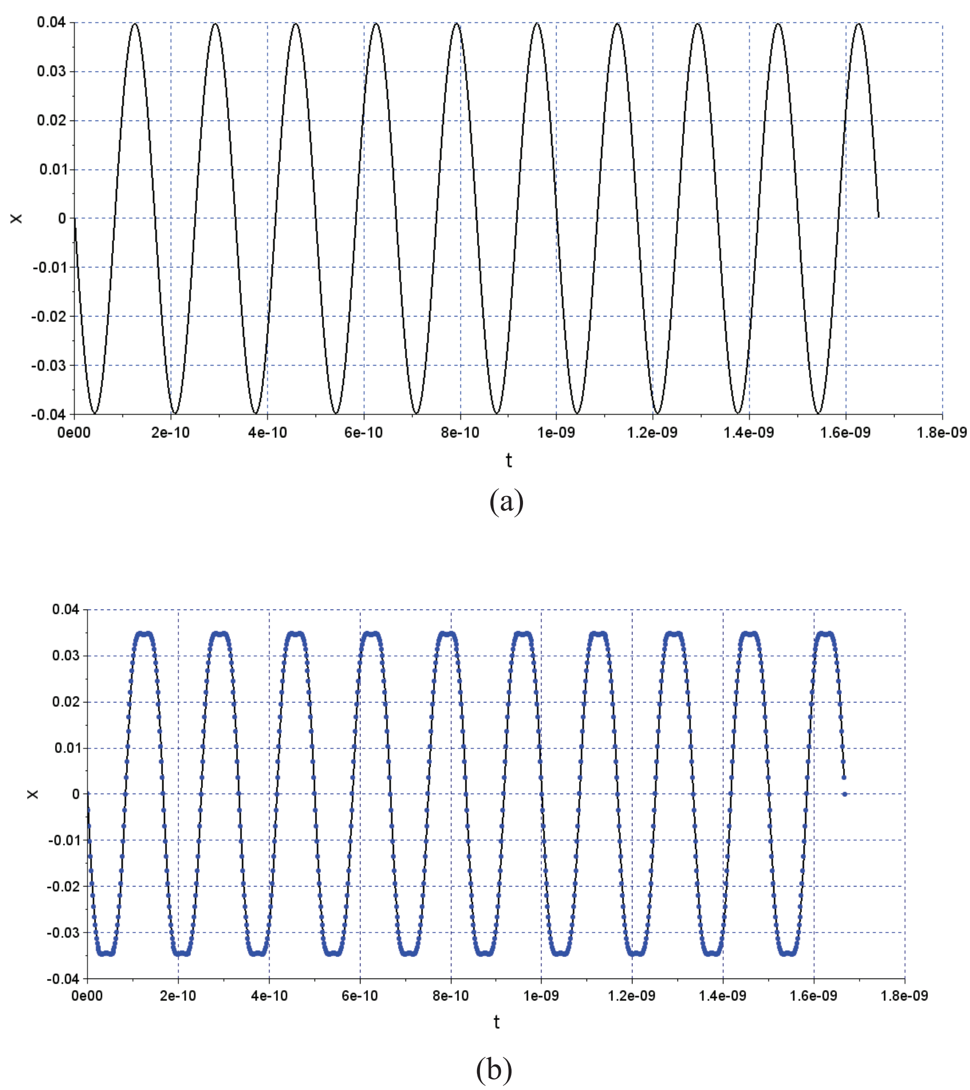


Figure 2: Trajectory of electron along ‘x’ in cm v/s time in seconds in planar and harmonic undulator.

ISBN: 978-3-95450-206-6 doi:10.18429/JACoW-FLS2018-WEA2WD03

Figure 1 represents the simulation model for equation (5) by using Scilab X-cos tools box and gives electron trajectory along 'x' direction. The total simulation time is 'T' for which the simulation has to be run is set according to the time of electron travel in insertion device. In present case it comes as 1.667 x 10^{-8} sec. In the preceding work the time interval from '0' to 'T has been set. The final value of trajectories has been stored in workspace and plot has been done in the command window of Scilab. In present model the time variation has been modelled as ramp block and figures have been plot along with the execution of the program. Figure 2a. and Figure 2 b display the parellel simultion for trajectory of electron in 'x' dire in plannar undulator without harmonic content and with harmonic content (Δ=0.4) respectively. Figure (2) b also displays the same simulation done by Fortram code by '.', the overlapping of two simualtion data asserts the correctness of the model desinged.

The advantages of using such simulation blocks instead of designing codes is that we dont have to remmeber the codes and same simulation block can be used for number of simulation parameters. In case to simulate Eq. (1).There is addition or deletion some blocks in the model given in Fig. 1 for simulation of Eq. 1. Figure 3 dspalys the simulation model for plannar and harmonic field. In Fig. 4 the planar undulator field simulataneously simulated with and without harmonic field (Δ=0.2).

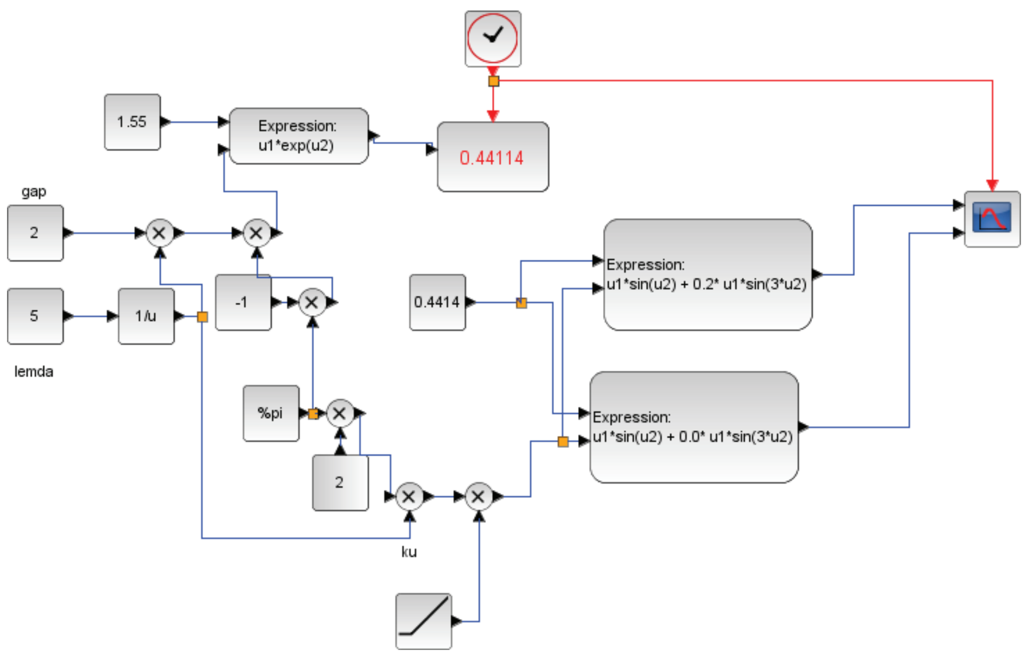


Figure 3: Simulation model for planar and harmonic undulator field in Xcos.

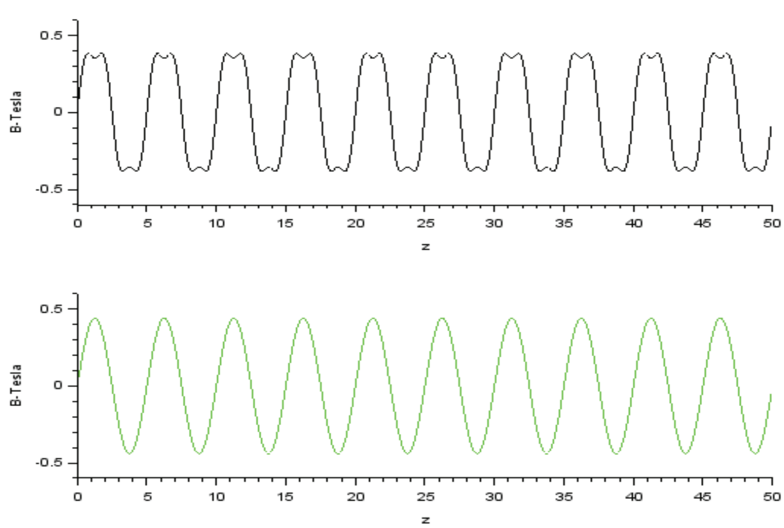


Figure 4:. On axis planar undulator magnetic field with and without harmonic content.

ISBN: 978-3-95450-206-6 doi:10.18429/JACoW-FLS2018-WEA2WD03

We have extended the present work to determine the the trajectory of electron in real undulator devices. Figure 5 displays the model degined for the analysis of trajectory along the undulator with real data of magnetic fields. The trajectory has been determined by product of $e/m_0\,\gamma c$ with double integration of magnetic field data. We have taken the data for magnetic field of proposed superconducting undulator by DAVV Lab, Indore [10] by radia codes. Figure 6 (a) displays the data for double integration with present model and in the same figure, the data for double integration from Mathematica code has also been displayed. Figure 6 (b) gives the trajectory along 'x' direction, simulated in the same model.

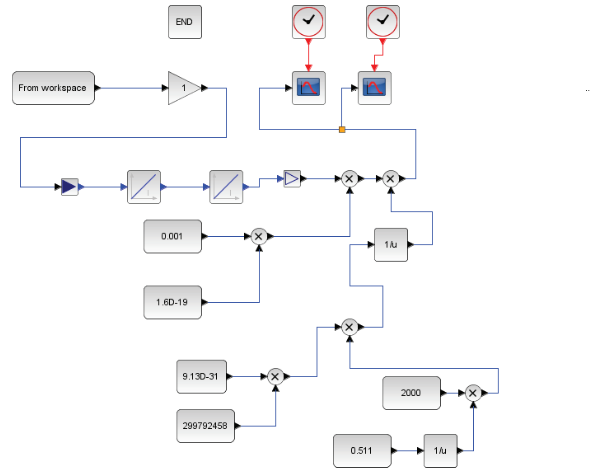
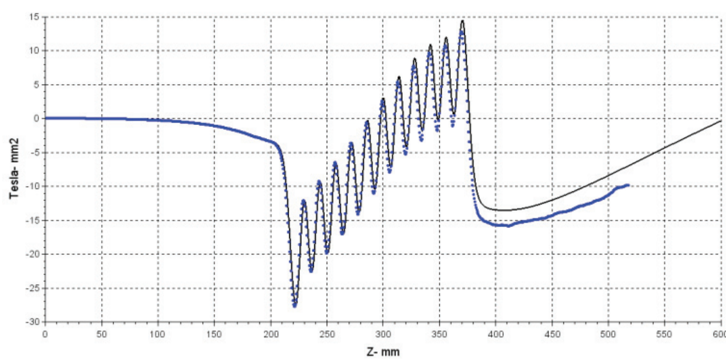
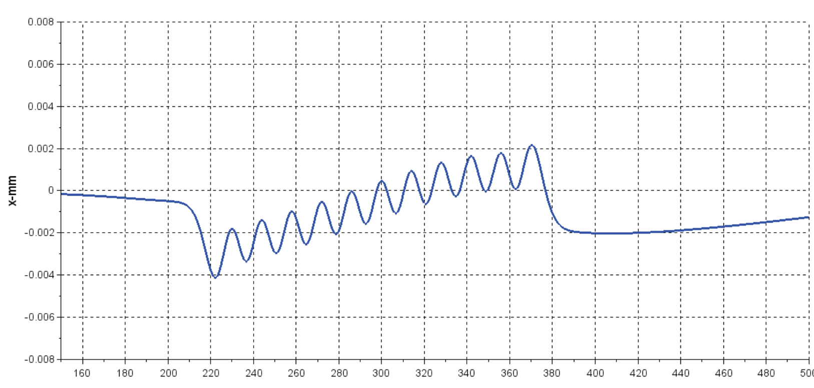


Figure 5: Simulation model for trajectory of electron using magnetic field data (measured by experiments/by simulation from codes).



(a)



(b)

Figure 6: (a) Displays the double integration of magnetic field and (b) Displays the trajectory of electron using model given in Fig. 5.

ISBN: 978-3-95450-206-6 doi:10.18429/JACoW-FLS2018-WEA2WD03

CONCLUSION

In the present paper Scilab Xcos based model has been used for electron trajectories and magnetic field. Electron trajectory along 'x' direction and variation of magnetic field along 'z' direction has been modelled and simulated for Planar and Harmonic undulator. Expression block and ramp block has been used for variation of data. In present simulation plot of output data has been done parallel to simulation and is part of execution of program. These models do not require a separate plotter tool. In our analysis we have also presented the model for determination of trajectory in real system or in simulation model given by other codes considering the factors of possible errors in planar undulator magnetic field. The above work can be extended as a model for trajector in 'x' and 'y' direction, along with the intensity of spontaneous radiation. The GUI interface for present model is also a future scope of the work.

REFERENCES

[1] W.A. Barletta et al. Nuclear Instruments and Methods in Physics Research A 618 (2010) 69–96.

[2] https://www.umsec.umn.edu.

[3] SCILAB, https://www.scilab.org/

[4] Zoltán Magyar et al, Proceedings of the 9th IFAC Symposium Advances in Control Education

[5] Zoltán Janík, IJOE – Volume 9, Issue 1, February 2013.

[6] Mouhamed Fadel Diagana et al, nt. J. Communications, Network and System Sciences, 2015, 8, 274-281.

[7] H Jeevakhan et al , Indian PAC 2018 proceedings, Jan 2018, ID 267

[8] G. Dattoli, et al, Lectures on FEL Theory and Related Topics, World Scientific, Singapore.

[9] G. Mishra, Mona Gehlot, Jeevakhan Hussain, Journal of Modern Optics, vol. 56, p- 667,2009.

[10] G Mishra et al, J Synchrotron Radiat. 2017 Mar 1;24(Pt 2):422-428. doi: 10.1107/S16005-77517001540. Epub 2017 Feb 16