SIMULATION OF SINGLE PARTICLE DYNAMICS IN A COMPACT PLANAR WIGGLER

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Abstract

In this report a description of Radia particle dynamics simulation are presented. The single particle dynamics were investigated depending on the horizontal and vertical positions of the particles. The simulation was done for gaussian beam with divergence which moves in a short planar wiggler. The evolution of such a beam along wiggler central axis is shown.

INTRODUCTION

Nowadays there are a few particle tracking simulation software are freely available. The most famous of them are Parmela, Elegant and GPT. Recently a code was developed [1] with a new method which realise the fast and precise algorithm for simulation of electron trajectories in complex magnetic fields in order to design an advanced synchrotron radiation sources. At the present time there is no a project on the construction of modern accelerators facility which is not complete with a careful particle trajectories simulation. The comparison of the different beam dynamics simulation codes can be found in paper [2]. However, those codes are required quite a lot of time to study them. Also to start modelling with those tracking codes some advanced knowledge in programming is necessary. Radia code did not consider in this overview.

Here we present a simple approach how to simulate a single particle track inside a 3D magnetic field using Radia code [3]. Such a simulation maybe useful in order to briefly estimate in a short time the beam dynamics in the magnetic field produced by means of different types of the magnet devices. In contrast with previous mentioned codes written on C++ and FORTRAN to start work with Radia is much easier. Since Radia is the Mathematica add-on which based on the Wolfram Language (WL) some of this language knowledge is needed.

Radia is full three-dimensional magnetostatic code, where the 4th order Runge-Kutta method was implemented for the trajectory calculations. Recently we have already had an experience of simulation a planar wiggler magnetic field using Radia [4]. As an example, we will be used the same model of the wiggler which was created in the past work. There is one paper with Radia usage for particle tracking simulation with only one simple calculation of single electron trajectory, however, with comparison by means of pulse wire method [5]. Note that Radia was used for testing a new tracking code described in [1].

Our main goal is to show how such a simple free code maybe used for rather extended particle tracking simulation by means of WL.

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MODEL DESCRIPTION

In the simulation in a compact 30-cm planar wiggler [6] was used as a source of magnetic field. The scheme is depicted on Fig. 1. This wiggler produced almost periodic magnetic field with center peak from 0.09 to 0.4 T (K parameter equals 0.5 and 2.4 respectively). Due to we begin the tracking investigation of low energy relativistic electron (8.25 MeV), here we chose the widest possible gap with smallest peak field. Otherwise a deviation of particle trajectory in wiggler output becomes critical. For instance, with 0.4 T peak field which correspond 30 mm gap the maximum particle shift is more than 15 mm for the central initial particle position with speed along Y axis. Those calculations are not discussed in this report.

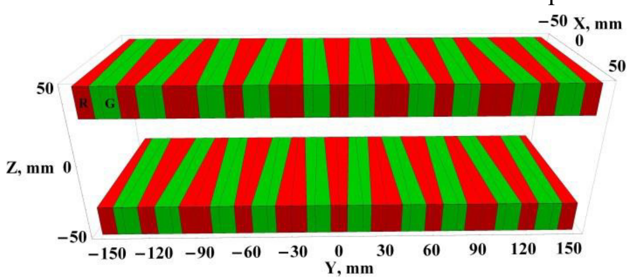

Figure 1: 3D wiggler model with 60-mm gap, where X is the horizontal axis and Z is the vertical axis, Y is the longitudinal axis. The origin is the center of the wiggler. Red (R) and green (G) blocks have a vertical and horizontal magnetization respectively.

All simulation parameter for wiggler and beam [7] are listed in Table 1. Note that we take into account only transversal bunch size. Energy was chosen for electrons right after RF gun without main accelerating.

Table 1: Simulation Parameter

Name	Value
Period length	60 mm
Number of periods	5
Magnet gap	60 mm
Nominal block size (Z, X)	20×100 mm
Center magnetic field	0.09 T
K parameter	0.5
Electron energy	8.25 MeV ($\gamma \approx 16$)
Transversal size (rms)	200 µm

In Radia there is only one function (radFldPtcTrj) which we can use to compute trajectory of a relativistic charged particle in the magnetic field created by the arbitrary object. This function returns a list of horizontal coordinate (x) and angle (x’) and vertical coordinate (z) and angle (z’) with longitudinal coordinates at given interval. All calculations were done for the -200…200 mm range along Y axis.

SIMULATION RESULTS AND DISCUSSION

First the single electron trajectory dependence in wiggler magnetic field on the initial horizontal coordinate and angle was investigated. These trajectories are presented on Fig. 2. As we see from this picture a beam will be defocused in horizontal plane moving along wiggler axis. For given on Fig. 2 parameters such broadening is occurred about 3 times. The dots are shown the trajectories with two different initial angles of movement.

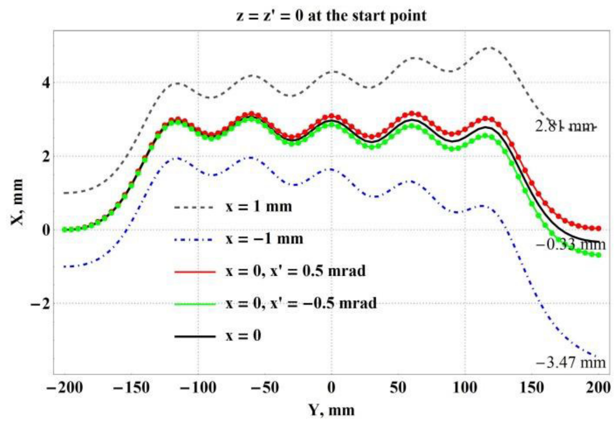

Figure 2: The electron trajectory in horizontal plane with different start point x = -1, 0 and 1 mm (curves) and x' = ±0.5 mrad (dots).

Second the trajectory dependence on the initial vertical coordinate was investigated. These trajectories are presented on Fig. 3. As we see from picture the wiggler has a focusing influence to the beam in vertical plane. However, if we take into account a beam divergence this focusing will be less expressed. This angle for divergence was chosen in order to have a visible difference of the simulation results.

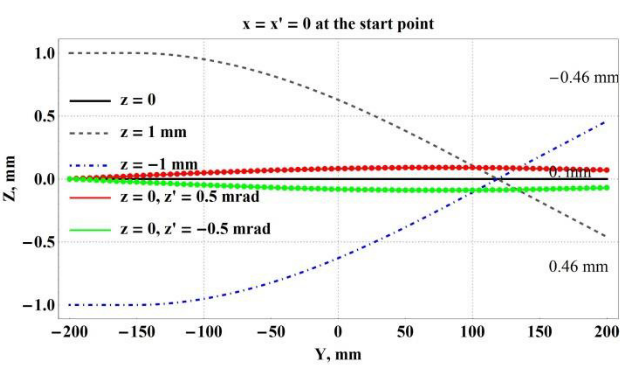

Figure 3: The electron trajectory in vertical plane with different start point z = -1, 0 and 1 mm (curves) and z' = ±0.5 mrad (dots).

Further we start to investigate an electron dynamics from the randomly distributed over 2-dimensional gaussian shape beam. The distributions of the beam without divergence in initial (up) and final (bottom) positions are shown on Fig. 4. From those pictures we may estimate the transversal beam profile changing.

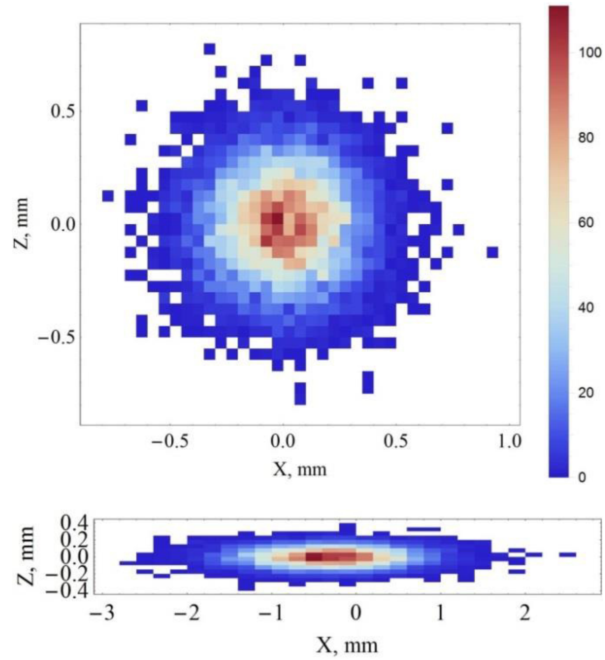

Figure 4: Example of random gaussian electron transversal distribution at start point (up, Y = -200 mm) and at end point (bottom, Y = 200 mm) with 10^4 particles. Both horizontal and vertical sizes are equal to 0.2 mm (rms) for upper picture. The legend is the same for both pictures.

At the end point of calculations the horizontal size of the beam became 3 times larger and vertical size became 2 times less. The beam center was shifted on 0.33 mm in horizontal plane. As we may clear see the distribution at the end point has the same gaussian shape like at the start point.

On Fig. 5 we may observe the transversal beam profile evolution both with and without beam divergence when electrons move along Y axis inside the wiggler. Central and halo points show us the case without and with divergence respectively. The initial transversal beam shape has a gaussian form with 0.2-mm (rms) size and for beam with divergence its distribution also has a gaussian form with 0.5-mrad (rms) angle. This picture of evolution shows us how the transversal beam profile changed (focused and defocused) during the movement. The arrows specify on the central position of the beam along horizontal plane (X) axis. As we may see the presence of the divergence significantly changes the motion dynamics of the beam along the wiggler axis especially in vertical plane (Z). However, it should be noted that simulation does not include a space charge effect. That's why the results on Fig. 5 do not take into account a broadening of the beam due to Coulomb repulsion.

On the base of Radia calculation results we may also plot the transversal phase diagrams of the beam. However, by limiting the studies to this relatively short paper these pictures are not presented here.

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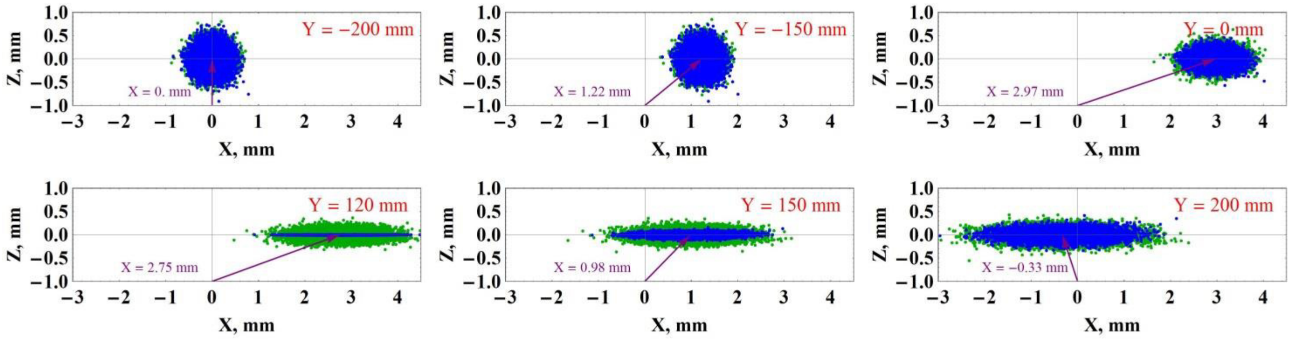

Figure 5: Transversal beam profile evolution along Y axis without divergence (blue central dots) and with divergence (green halo dots), where -150 and 150 mm are wiggler magnet edge, 120 mm is the maximum vertical focusing (see Fig. 3), -200 and 200 mm are the locations 50 mm far from both magnet edges.

CONCLUSION

We may conclude that:

- The numerical code was developed for electron tracking simulation using Radia and Wolfram Language. Code consists of 3 parts: creation the wiggler model, calculation of the electron trajectories (see APPENDIX for detail) and post processing of the simulation results. The calculation of the particle trajectories for Fig. 5 took about 3 minutes (4 cores).
- The particle dynamics have investigated with the simulation of the transversal beam profile evolution (the divergence was taken into account). The simulation was carried out for the low energy relativistic electrons which move inside the compact 30-cm planar wiggler produced about 0.1-Tesla magnetic field. Also the fast approximate estimation of transversal beam size along longitudinal wiggler axis was done.
- This wiggler defocuses the beam in the horizontal plane and focuses in the vertical plane.
- We can see that Radia may be applied for rather advanced particle tracking simulation. Note that in Radia it is needed to be very careful in coordinate axis location when you simulate the particle trajectories.
- Due to Radia is Mathematica add-on, on the one hand, this is a minus because of some WL knowledge is required; on the other hand, this is an advantage because of the great power of WL. However to start modelling in Radia with WL is much easier comparing with another C-based tracking simulation code, for example, [8].

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APPENDIX

For detailed help of function usage button F1 in Mathematica is essential. This is an example of Wolfram Language for trajectory calculations with 2-dimensional gaussian transversal beam distribution which moves along Y axis without any divergence:

```
(* user function *)
rdmGausBeamTrj[obj_, en_, num_, {bx_, bz_}, {yin_, yout_}, trjnum_] := Module[{rr2, mass2, trj, in, out},
(* massive of initial trajectory data with random hor. and vert. coordinate *)
mass2 = Table[Clear[rr2];rr2 =
Flatten@RandomVariate@BinormalDistribution[{0, 0}, {bx, bz}, 0];
(* Radia function for calculation for one particle *)
radFldPtcTrj[obj, en(*GeV*), {rr2[[1]], 0, rr2[[2]], 0}, {yin, yout}, trjnum],{num}];
(* massive of {x, z, y} coordinates *)
trj = Transpose[{mass2[[#, All, 2]], mass2[[#, All, 4]], mass2[[#, All, 1]]}] & /@ Range[num];
trj]
(*calculation of particle dynamics for given parameters, obj is the magnetic field source in Radia*)
trj = rdmGausBeamTrj[obj, 8.25*10^-3, 10000, {0.2, 0.2}, {-200, 200}, 41];
```

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