NEW ABILITIES OF COMPUTER CODE DECA

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Abstract

In the paper the status and new abilities of computer code package DeCA (Design of Cyclic Acclerators) are described. The main efforts of the code developers were aimed at creation of software capable to simulate intrabeam scattering effect and Compton scattering. Addition modules for calculation of the second order dispersion and momentum compaction factor were developed.

INTRODUCTION

The DeCA (Design of Cyclic Acclerators) code has being used for more than ten years [1-3] to investigate electron beam dynamics in cyclic accelerators. During these years the package was under permanent development and possessed a several new calculating capabilities such as oscillation coupling coefficient calculation [4], lattice fitting and others. DeCA was expended with new functional block devoted to synchrotron radiation parameters calculations. DeCA version for IBM PC was issued. Despite traditional FORTRAN structural programming DeCA demonstrates the main its traits were claimed in the very beginning in [1]. Namely, there are module principle and machine independence. It makes possible modernization and development of the code. More recently, there has been substantial interest in developing a tool that would provide simulation capabilities of Compton scattering (CS) incorporated in an electron storage ring and intrabeam scattering (IBS). Such interest was stipulated by our investigations aimed at construction of a new type of X-ray generator called laser electron storage ring (LESR). New version of the code was produced and feasibility of the new type of X-ray generator was shown [5]. Today DeCA is the unique tool for complex design and beam dynamic investigations in LESR.

In the paper we describe the changes were made to DeCA in order to permit such complex calculations and present a few examples.

COMPTON SCATTERING SIMULATIONS

Model of interaction

A relativistic electron e_i with initial coordinates (x_0, y_0, z_0) and pulse $\bar{p}_0$ moves in laboratory coordinate frame *(X, Y, Z)* and interacts with a photon cloud. The cloud has a Gaussian density distribution in coordinate frame (X_{ph}, Y_{ph}, Z_{ph}) turned to angle α_0 relatively Z axis of laboratory coordinate system (Fig. 1). Photon bunch moves along Y_{ph} axis towards the electron.

Then photon coordinates in the laboratory coordinate frame *(X, Y, Z)* are:

$$x_{ph}(s) = -xCos\alpha_0 - ySin\alpha_0$$
$$y_{ph}(s) = xSin\alpha_0 - yCos\alpha_0 - s$$
$$z_{ph}(s) = z$$

and the photon bunch density for the *i* th electron e_i with coordinates *(x_{0ei}, y_{0ei}, z_{0ei})* in the electron bunch is:

$$f_{ph}(x_{0ei}, y_{0ei}, z_{0ei}) =$$
$$\frac{N_{ph0}}{(2\pi)^{3/2} R_{ph}^2 l_{ph}} \exp\left\{-\frac{1}{2}\left(\frac{z_{0ei}^2{}_{ph} + (x_{0ei}Cos\alpha_0 + (s + y_{0ei})Sin\alpha_0)^2}{R_{ph}^2} + \frac{(x_{0ei}Sin\alpha_0 - s - (y_{0ei} + s)Cos\alpha_0)^2}{l_{ph}^2}\right)\right\},$$

where N_{ph} is photon number in the photon bunch, R_{ph} and l_{ph} are transversal and longitudinal size of the bunch.

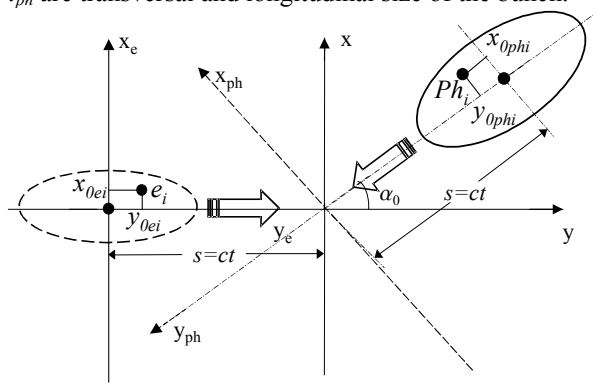

Figure 1. The layout of an electron-photon interaction.

Algorithm of calculations

We developed an algorithm of a relativistic electron passage trough a moving under arbitrary angle photon cloud (Fig. 1.) using the Monte Carlo method. The process consists of the following steps:

1. Formation of a table of the correspondence of scattered photon energy to random number uniformly distributed within number interval [0,1], taking into account CS cross section $\sigma(\varepsilon_\gamma)$ [5] and basic Monte Carlo method theorem

$$\int_0^{\varepsilon_\gamma} \frac{d\sigma(\varepsilon_\gamma)}{\mathrm{d}\, y} d\varepsilon_\gamma \Big/ \int_0^{\varepsilon_{\gamma m}} \frac{d\sigma(\varepsilon_\gamma)}{\mathrm{d}\, y} d\varepsilon_\gamma = RND ,$$

where RND is a number within interval [0,1], ε_γ is photon energy, $\varepsilon_{\gamma m}$ is maximal photon energy, $y = \varepsilon_\gamma/E_0$ is photon energy normalized to electron beam energy E_0 and dependence of CS cross section on E_0.

An example of correspondence table is shown in Fig.2.

2. Determination of the free path length of the electron in the photon cloud.

3. Selection of the scattered photon energy according to the table of the correspondence if the free path length is less than thickness of the cloud. In another case the

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history of the particle is supposed to be finished till next turn. Simulation code turns to the next element of a lattice.

4. Calculation of a scattering angle of the photon and the electron.

5. Selections of scattering angles of the photon and the electron on a cone of a solid angle $2\pi\theta_\gamma$, $2\pi\theta_e$ respectively. Calculations of the scattering angle projections in *XY* and *ZY* planes.

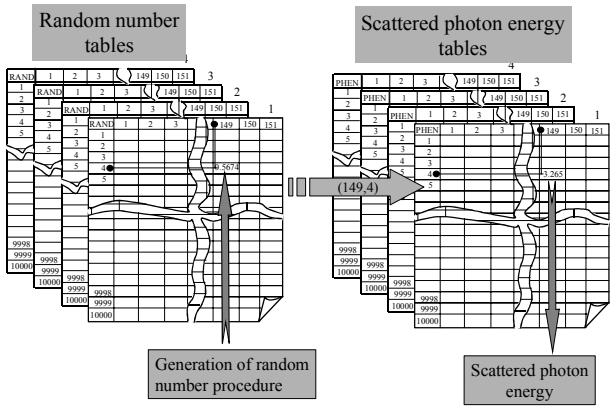

Figure 2. An example of tables of correspondence.

Data handling

According to the general DeCA strategy the control of the code is realized with two controlling files of *MOS* and *CMM* types. For CS simulation handling one new lattice element type and one new controlling command were introduced in the code.

Lattice element *LF* (Laser Flash) with parameters *LFL* (Length of Laser Flash, m), *A* (Power of laser plash, J), *LFV* (Transversal size of laser flash, m), *LFE* (Photon energy in the flash, eV), *ANGX* and *ANGZ* (Angles of the laser installation, deg) is used in MOS type file for setting of a laser flash parameters. It is possible to install up to four different laser flashes in the investigated lattice.

Controlling command *CMPT* with parameters *NENG* (Number of photon energy points in CS cross section in correspondence tables), *NESP* (Number of electron energy points in correspondence tables), *ESPR* (Electron beam energy spread value) is used for CS simulation parameters setting and switching. It is possible to set up to 5000 points on photon energy and 151 points on electron energy.

Code testing

For testing of developed model adequacy calculations of CS in a lattice of NSC KIPT X-ray generator NESTOR [6] were carried out. Simulations were done for electron beam with Gaussian density distribution and with energy of 50 *MeV*. The angle of the interaction was assumed equal to α_0=0.0. Calculations were carried out for Nd: YAG laser with photon energy equal to 1.17 *KeV* and with pulse length equal to 5 *nc*.

As an illustration results of a testing calculations for laser beam intensity equal to 0.001 *J* are presented. Calculations were done for 10000 electrons distributed in 3D ellipsoid with the following semi-axes lengths: *X* – 50×10^{-6} *m*, *Y* - 0.5×10^{-3} *m*, *Z* - 50×10^{-6} *m* and for photon beam with the following sizes: R_{ph} – 50×10^{-6} *m*, Y_{ph} - 1×10^{-3} *m*. Testing calculation duration was of about 26.5 million turns. As a result of simulation 4311 acts of scattering were registered. Calculations by analytical formula gave 4257 acts of scattering. Results of numerical simulations and analytical estimations are depicted in Fig. 3 and 4.

Fig. 3 shows distribution of photon scattered in all directions versus scattered photon energy. It is clear that results of simulations and analytical estimations are in a quite good agreement. The same result one can observe in Fig. 4, where dependence of scattered photon number in scattering plane is displayed.

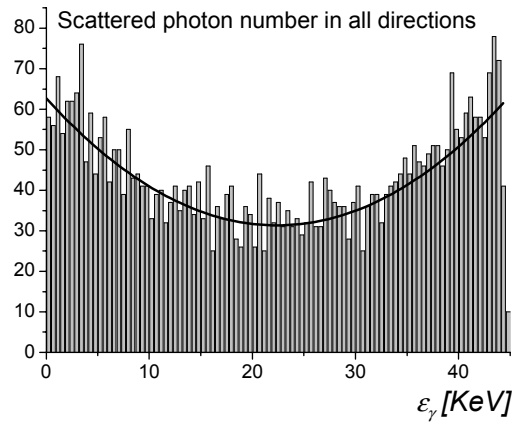

Figure 3. Number of scattered photons versus photon energy. Solid line – analytical calculations. Column – numerical calculation results.

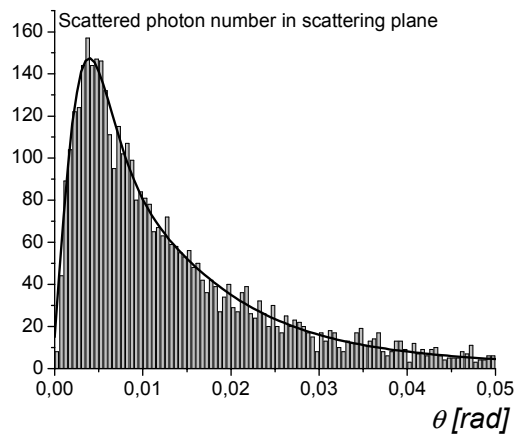

Figure 4. Scattered photon number versus scattering angle in scattering plane. Solid line – analytical calculations. Column – numerical calculation results.

INTRABEAM SCATTERING SIMULATIONS

Algorithm of calculations

We simulate the IBS by using the following algorithm:

- the growth rates τ_y^{gr}, $y = \{x, z, \delta\}$ are computed before simulation over estimated range of the beam emittances;

- the simulating element is incorporated in a ring lattice and angular coordinates and momentum deviation of the

particle are changed in this element by using of matrix transformations

$$y_{fin}' = y_{ini}'*(1 + T_{rev} / \tau_y^{gr}),\ y' = \{x', z', \delta).$$

During simulation the growth rates are corrected in accordance to the beam emittances.

Data handling

Lattice element *IBS* (Intra Beam Scattering) with parameter *STP* (Step of beam size recomputation, number of turns) is used in MOS type file for setting of IBS calculation regime.

Code testing

If correction time is much less than growth rate we get the beam emittances coinciding well with analytical estimations. The results of the IBS simulation in storage ring NESTOR are presented in Fig. 4.

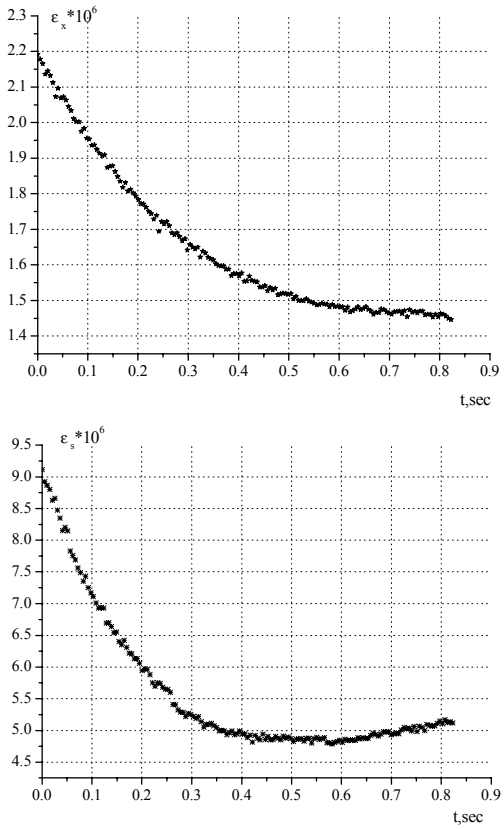

Figure 4. Behavior of horizontal and longitudinal beam emittances involving both radiation damping and IBS.

The simulation parameters were following:

- electron beam energy E_0 = 75 MeV;
- particles number N = 400;
- stored bunch current I_{stor} = 10 mA;
- coupling coefficient κ = 0.05.

The coupling of the transversal oscillations is simulated with skew quadrupole lens. The horizontal and longitudinal damping times at simulation energy are equal to 1.36 s and 0.7 s, respectively, analytical estimations of the steady-state emittances are equal to $\varepsilon_x = 1.54*10^{-6}$ and $\varepsilon_s = 6.69*10^{-6}$.

SECOND ORDER VALUES CALCULATIONS

For the LESR design and investigations it is badly needed to calculate the second order machine values such as the second order dispersion function and the second order momentum compaction factor.

For this purpose an algorithm described in [7] was realized in the DeCA code. Controlling command *FFSL* was extended with the algorithm. The results of the second order dispersion function calculations for storage ring NESTOR are shown in Fig. 5.

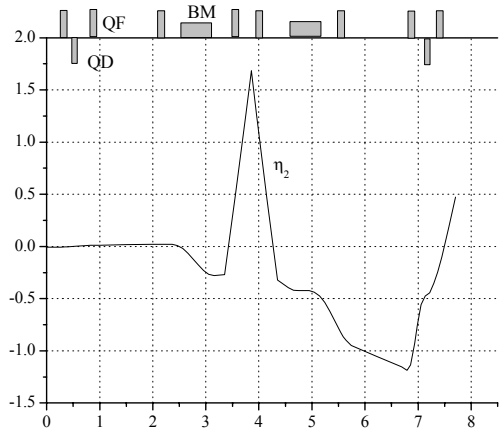

Figure 5. The second order dispersion at half of ring lattice.

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