

CBDA - CYCLOTRON BEAM DYNAMICS ANALYSIS CODE

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Abstract

A need for intense cyclotron beam requires to minimize the particle losses during injection, acceleration and extraction from the machine. More importance is given to the computational tools that are needed to optimise the design. The 3D CBDA program has been prepared for this purpose. The basic features of this code are: 1) The accelerated beam axial motion with analysis of the particle losses at the limiting aperture surfaces to estimate the transmission efficiency of the beam through cyclotron; 2) Very detailed 3D electrical and magnetic field maps generated and introduced into the code; 3) Simulation of the space charge dominated beam acceleration; taking into account Coulomb repulsion of particles in the beam by PIC (FFT) and PP methods; 4) Enhanced post-processing of the results by means of MathCAD and AutoCAD/SolidEdge software. Some efforts were undertaken to provide user friendliness of the code, including initial documentation and its menu driven operation. Several cross checks of the CBDA simulation results (fields and beam dynamics) compared with other studies have been successfully performed. A number of applications of the code simulate the functionality and design of various cyclotrons is given. They are: VINCY Cyclotron (Belgrade) [1]; 1.747 MeV, 5mA, H⁻ Customs cyclotron [2]; RIKEN AVF cyclotron (Japan) [3] etc. The present status of the code allows to provide efficient and realistic beam dynamics analysis for the new cyclotron design and operational cyclotron upgrade.

STRUCTURE

Figure 1 shows the main window of the CBDA code. The “Pre-Processor” part of the code consists of six main blocks: “Particle”, “RF system”, “Injection line”, “Inflector”, “Cyclotron” and “Extraction”.

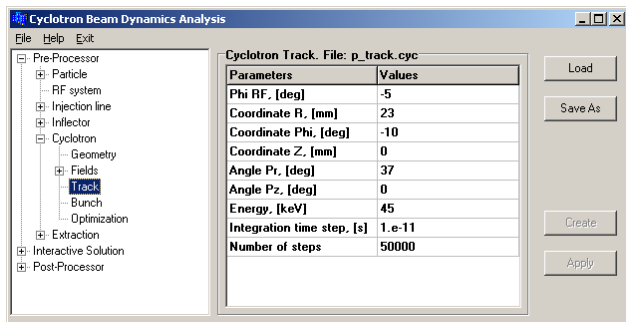


Figure 1: CBDA main window

The “Particle” block defines particle parameters and the selected method to take the beam space charge effects (SC) into account. The SC algorithm uses “PP” (Particle to Particle) and “PIC” (Particle In Cell with FFT application) methods. The “RF system” block defines

frequency of the RF system and flat-top system parameters.

The following blocks: “Injection line”, “Inflector”, “Cyclotron”, “Extraction” have a uniform structure. They are similar to “Geometry”, “Fields”, “Track” and “Bunch” blocks. The geometrical objects made in the graphical programs (AutoCAD, SolidEdge etc) are exported to the CBDA as 3DS format files. There are four 3DS files used totally. The block “Fields” defines the magnetic and electric fields needed for the beam dynamics calculations. Those fields may be in the form of the 3D map generated, for example, by TOSCA code. The analytical approximation also made by CBDA is available. The “Track” block defines the particle initial parameters: position, RF phase and momentum. The “Bunch” block generates the bunch object of four types.

The “Interactive Solution” block determines the “entrance point” and carries out the beam simulation itself (See Figure 2). The “Entrance point” means “Injection line”, “Inflector” etc.

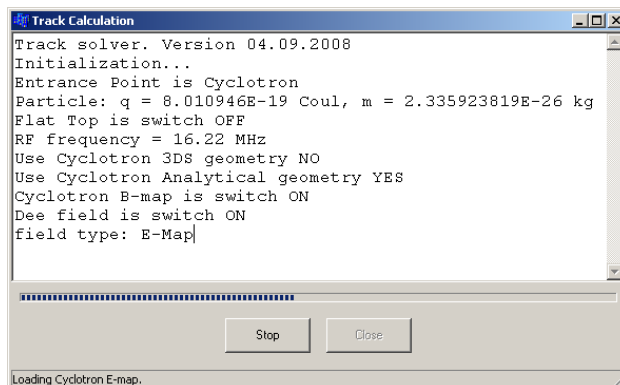


Figure 2: Solver window

Also this part specifies the “Monitoring planes” that register the particle hits at the locations. Each block has its own monitoring planes. The “Post-Processor” part visualizes the calculation results by MathCAD and AutoCAD (Figures 3-6 are examples). Besides, creation of the animation files, in the *.avi format are also feasible. The animation reflects the characteristic features in the results obtained to understand some essential aspects of the beam simulation.

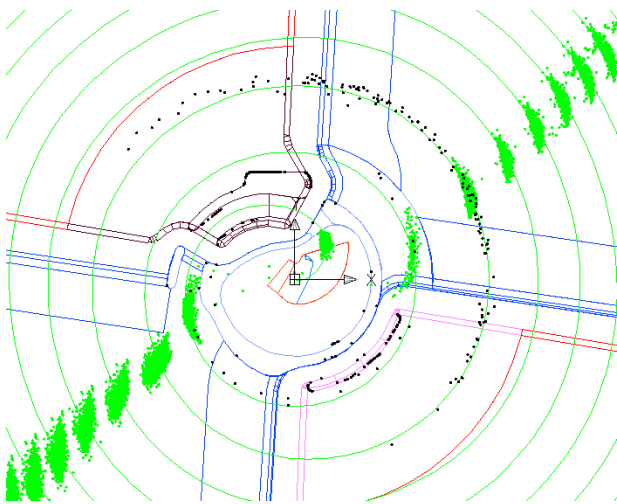


Figure 3: AutoCAD visualization. Cyclotron central region. Green colour – accelerated bunches; Black colour – losses particles.

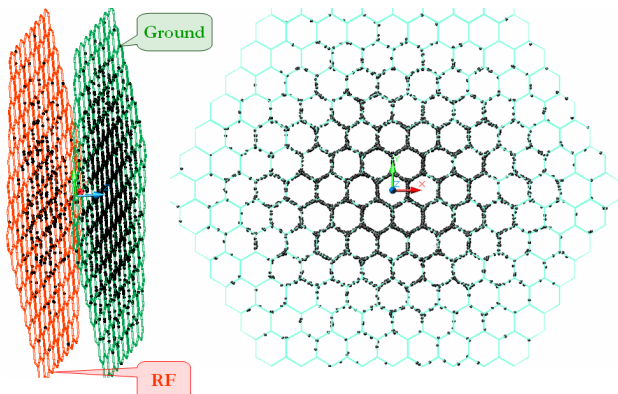


Figure 4: AutoCAD visualisation. Losses on the buncher grids. Black colour – lost particles.

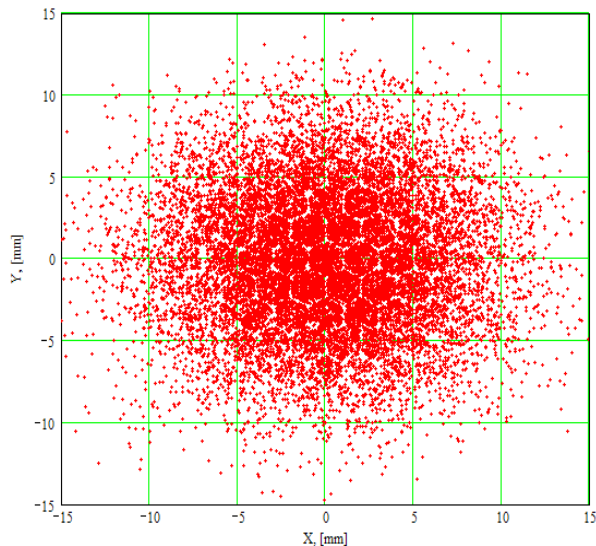


Figure 5: MathCAD visualisation. Bunch configuration space after buncher grids. Particle distribution sets on the grid structure.

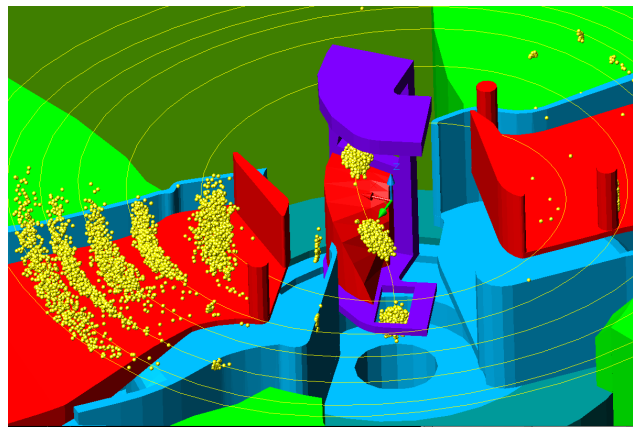


Figure 6: AutoCAD visualisation. 3D cyclotron central region. Bunches acceleration.

The “Cyclotron” block has an option called “Optimization”. It is a new feature for the optimal design of the cyclotron central region. The CBDA code can make a central electrode structure by optimizing a new backward tracking. This method is very powerful for the multi-particle central region.

ALGORITHM

The Runge-Kutt fourth order method is applied to calculate motion of particles in the CBDA code. There are two solvers to do this: “Track” solver and “Bunch: solver. The integration time step specifies the accuracy of the calculation. The simulations in each of the blocks (“Injection line”, “Inflector” etc.) can be performed in any combination of the blocks in sequence.

CROSS-CHECK

The operation of the CBDA parts was tested against various analytical solutions and applications like TRACE3d/2d [4] and SPUNCH. Figure 7 illustrates the RIKEN AVF cyclotron (Japan) [3] axial injection line model simulated by CBDA. In the case of an infinitively small transverse size of the beams the cross check CBDA vs SPUNCH code, was performed [5]. The main goal of this calculation was to estimate the longitudinal SC effect. The SPUNCH code uses analytical formula for assessment of the beam electrical field. The CBDA code uses the PIC (with inclusion of the FFT procedure) method. Figure 8 presents the phase portrait images at monitoring planes. The SPUNCH and CBDA codes give very close results in this case.

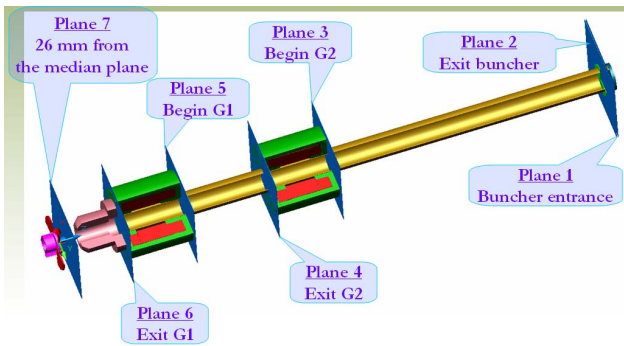


Figure 7: Injection line model. Monitoring plane positions.

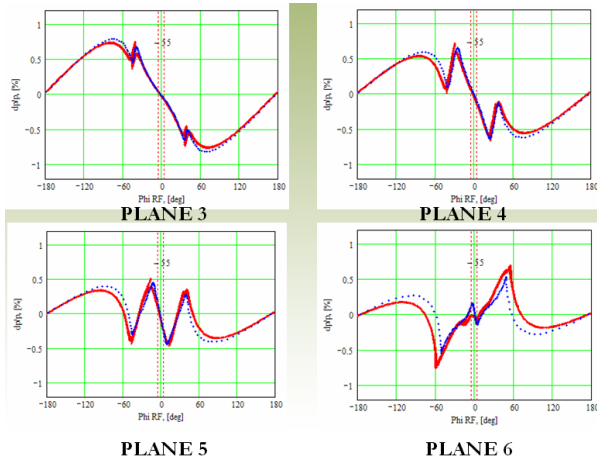


Figure 8: Comparison SC effect calculated by SPUNCH (blue) vs CBDA (red) code.

Figure 9 illustrates the motion of the CW beam through the injection line calculated by CBDA code. Figure 10 illustrates the same results obtained by TRACE2d code. These results are in good agree if the Glazer lens fringe field defined with the necessary level of approximation in the TRACE2d code. In some cases of a rather short lens a sequence of the solenoids is required in the TRACE2d to obtain an accurate enough result of calculation.

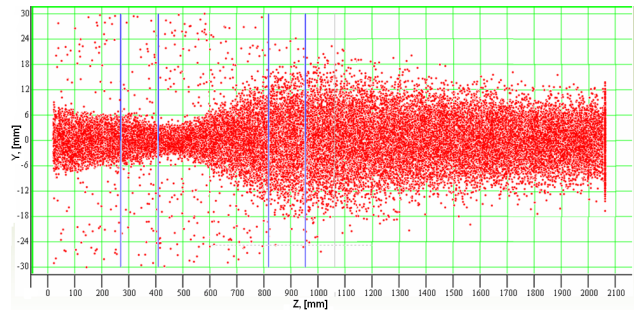


Figure 9: Beam motion through the injection line by CBDA

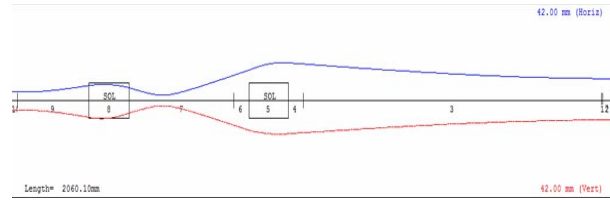


Figure 10: Beam envelopes obtained by TRACE2d.

REFERENCES

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- [5] A. Goto. "Beam injection and extraction of RIKEN AVF Cyclotron". CNS-RIKEN Workshop on Upgrade of AVF Cyclotron, CNS Wako Campus, 3-4 March 2008.