PROGRAM PACKAGE FOR 3D PIC MODEL OF PLASMA FIBER

PETR KULHÁNEK, DAVID BŘEŇ

Department of Physics, Faculty of Electrical Engineering,
Czech Technical University,
Technická 2, 162 00 Prague, Czech Republic

A fully three dimensional Particle in Cell model of the plasma fiber had been developed. The code is written in FORTRAN 95, implementation CVF (Compaq Visual Fortran) under Microsoft Visual Studio user interface. Five particle solvers and two field solvers are included in the model. The solvers have relativistic and non-relativistic variants. The model can deal both with periodical and non-periodical boundary conditions. The mechanism of the surface turbulences generation in the plasma fiber was successfully simulated with the PIC program package.

1. Introduction – PIC implementation

A fully three-dimensional PIC code [1] was developed for the simulations of the plasma structures in various situations.

The fields are solved via FFT solver or Multigrid solver MUDPACK 5 developed in the UCAR (University Corporation for Atmospheric Research) was used [3]. The time evolution is treated on similar considerations as in the Boris-Buneman particle scheme [4]. Electric and magnetic fields are calculated separately from the Laplace-Poisson equations.

There are implemented five particle solvers in the PIC package (Newton-Euler, Boris-Buneman, Leap-Frog, Runge-Kutta and Canonical) [4]. Both non-relativistic and relativistic variants are incorporated in the model [7].

There are several types of particles included. Initial coordinates of the particles are generated randomly. In the computational area two beams and surrounding particles can be present. The initial particle velocity has two components: The beam (ordered) and the random (chaotic, Gaussian) one. Various initial perturbations of the beam shape can be performed. Zero and first order weighting of particles and fields had been implemented in the model.

Our PIC program code was written in Compaq Visual FORTRAN 6.6 C embedded in the Microsoft Development studio GUI.

2. PIC package add-ins

A special graphical package based on the OpenGL and Qt libraries was developed for visualization of the particles and fields [10]. The field visualization method is based on LIC (Line Integral Convolution) algorithm [2]. The LIC method has two inputs: the vector field and noise texture represented by noise function. The noise texture is locally blurred along the field lines and the resulting output picture matches the structure of the field. The convolution procedure creates highly correlated pixels along the field line, while the pixels in perpendicular direction are not correlated.

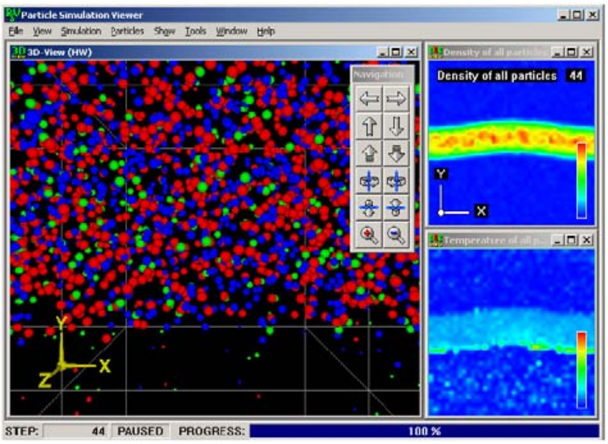

Figure 1. Developed GUI for visualization procedures

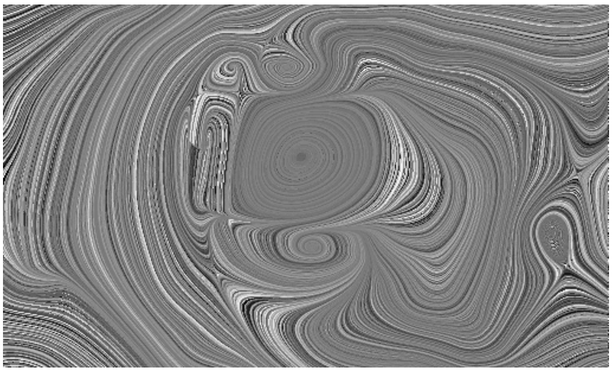

Figure 2: PIC simulation of the surface magnetic turbulent structures depicted via LIC method. Magnetic field lines are visualized in the cross section plane perpendicular to the filament. Number of particles: 600 000. Radial electric field perturbation: 5%, initial temperature 3 eV for both fiber and surroundings. The filament diameter: 30 % of the computational parallelepiped width.

The particles are represented in the scene as 3D polyhedrons which evoke the spherical shape. Depiction of a great number of such objects is very time-consuming and therefore it is possible to change the complexity of the polyhedron. User can enter two parameters determining the number of meridians and parallels on the sphere. A polyhedron best fitting the sphere is calculated from these data. The diameter of the sphere can be chosen for every kind of the particle. There are various filters implemented in the package which enable user to depict only some of the particles. The scene can be zoomed, rotated and translated.

In the PIC package there are also implemented various diagnostic routines, e.g. calculating total current density, polarization, magnetization, electric and magnetic fields an their variances.

Collisions of the neutrals with electrons and ions were included in the model via known cross sections by Monte Carlo method [1]. The elastic collisions, excitation, recombination, ionization and charge exchange processes are included in the model.

Another package was developed for calculation of the filament radiation processes [5]. Radiation is a very important kind of energy losses. The intensity of bremsstrahlung radiation and synchrotron can be calculated directly from the positions, velocities and accelerations of the individual particles. The intensity of the radiation can be optionally projected on a sphere in the graphical output.

3. Plasma structures in our PIC code

In the numerical simulations it had been proved, that surface turbulent phenomena can be linked together with radial electric field perturbations. The perturbed field along with axial magnetic field causes azimuthal drift and the succeeding diocotron instability forms vortices which are evolving into structures with non-zero helicity [6, 8, 9]. The directional dependence of the radiation during the fiber evolution is calculated in all cases.

4. Conclusion

The PIC model developed during the past five years enables a deep understanding of the processes in the plasma fiber. It is also very efficient package for simulation of MHD shocks, instabilities, electric double layers, polar cusps and other interesting phenomena. In present time the model was used for plasma fiber simulations, but the authors of the package are sure it can be useful for a variety of plasma simulations in the future.

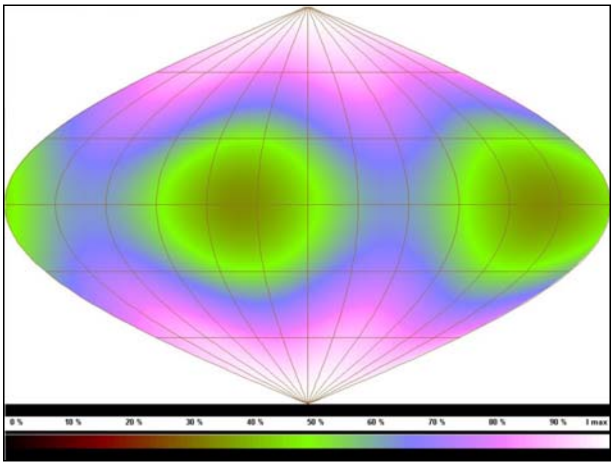

Figure 3. Plasma fiber radiation in the PIC simulation of the plasma fiber. Fiber is oriented horizontally. Number of electrons: 500, simulation step: 1000. This picture is one sample frame from the acquired animation avi file. The grid for field calculation was 33×33×33.

Acknowledgments

This research has been supported by the research program No. 6840770016 “Investigation of physical principles technical instruments in relation to the environment” of the Czech Technical University in Prague, by the research program No. 1P2004LA235 “Research in Frame of the International Center for Dense Magnetized Plasmas” and “Research Center of Laser Plasma” LC528 of the Ministry of Education, Youth and Sport of the Czech Republic.

References

1. C. K. Birdsall, *IEEE Trans. on Plasma Sci*. **19**, 65 (1991).
2. D. Stalling and H. C. Hedge, Fast and Resolution Independent LIC, Proc. SIGGRAPH 95, pp. 249-256, ACM SIGGRAPH, 1996.
3. C. A. John, *Package MUDPACK 5.0.* National Center for Atmospheric Research; http://www.scd.ucar.edu/css/software/mudpack; 1999.
4. P. Kulhanek, *Czechoslovak J. Phys*., **50/S3**, 231 (2000).
5. D. Bren, *Czechoslovak J. Phys*. **52**, D226 (2002).
6. P. Kulhanek, *Czechoslovak J. Phys*. **52**, D221 (2002).
7. D. Skandera, *Czechoslovak J. Phys*. **52**, D240 (2002).
8. M. Zacek, *Czechoslovak J. Phys*. **52**, D251 (2002).
9. P. Kulhanek P., D. Bren, et al., in Proc. *3rd International Conference on the Physics of Dusty Plasmas*, Durban, 2002.
10. P. Kulhanek, M. Smetana, *Czechoslovak J. Phys*. **54**, C123 (2004).