Relativistic Difference Scheme Particle-in-Cell (REDPIC) Documentation

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Abstract

This PIC code has been developed since 2022 at the Budker Institute of Nuclear Physics as an alternative to ASTRA, SAM, and other codes. For particle dynamics simulation using finite difference scheme relativistic.

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1 Introduction

2 Physical model

First, we write the main quantities in the difference scheme, then we consider the algorithm.

2.1 Basic values

At the initial time t set Cartesian coordinates of the $i-$particles $\overrightarrow{r_i} = (x_i, y_i, z_i)$ and the initial pulses $\overrightarrow{p_i} = (p_{x_i}, p_{y_i}, p_{z_i})$. Minimum time step is set δt.

For convenience, made dimensionless physical quantities (with tilde) (1 - 3):

$$\widetilde{\overrightarrow{r_i}} = \frac{\overrightarrow{r_i}}{c\delta t}, \tag{1}$$

$$\widetilde{\overrightarrow{E_i}} = \frac{\overrightarrow{E_i} e}{mc}\delta t, \tag{2}$$

$$\overrightarrow{\widetilde{H_i}} = \frac{\overrightarrow{H_i} e}{mc} \delta t, \tag{3}$$

where m is the speed of light, e is the particle charge and m is the particle mass.

2.2 Algorithm

Consider the relativistic difference scheme algorithm step by step [LMS11]:

1. Calculation of electric fields $\overrightarrow{E_i}$ at the points where the particles are.
2. Pulse increment:
$$\overrightarrow{p_i} = \overrightarrow{p_i} + 2 \cdot \overrightarrow{E_i}, \tag{4}$$
where the coefficient means that the increment of the pulse is made for the entire time interval $2\delta t$.
3. New speeds are calculated by new impulses:
$$\overrightarrow{v_i} = \frac{\overrightarrow{p_i}}{\gamma_i}, \tag{5}$$
where $\gamma_i = \sqrt{1 + \overrightarrow{p_i}^2}$.
4. At new speeds, new coordinates are calculated:
$$\overrightarrow{r_i} = \overrightarrow{r_i} + 1 \cdot \overrightarrow{v_i}, \tag{6}$$
where the coefficient means that the increment of the coordinate is made for the time interval δt.
5. Calculation of magnetic fields $\overrightarrow{H_i}$ at the new points where the particles are.
6. Calculated velocity values (after rotation in a magnetic field):
$$b_1 = 1 - \frac{H_i^2}{\gamma_i}, b_2 = 1 + \frac{H_i^2}{\gamma_i}, b_3 = 2 \cdot \frac{\overrightarrow{v_i} \cdot \overrightarrow{H_i}}{\gamma_i},$$
$$\overrightarrow{f_i} = 2 \cdot \frac{\overrightarrow{v_i} \times \overrightarrow{H_i}}{\gamma_i},$$
$$\overrightarrow{v_i} = \frac{\overrightarrow{v_i} b_1 + \overrightarrow{f_i} + \frac{\overrightarrow{H_i}}{\gamma_i} b_3}{b_2}. \tag{7}$$
7. At new speeds, new coordinates are calculated:
$$\overrightarrow{r_i} = \overrightarrow{r_i} + 1 \cdot \overrightarrow{v_i}, \tag{8}$$
where the coefficient means that the increment of the coordinate is made for the time interval δt.
8. New impulses are calculated according to the new rates:
$$\overrightarrow{p_i} = \overrightarrow{v_i} \gamma_i. \tag{9}$$

One cycle is performed in a time interval $2\delta t$.

References

[LMS11] Pavel Logatchev, Dmitriy Malyutin, and A. Starostenko. "Application of a low-energy electron beam as a tool of nondestructive diagnostics of intense charged-particle beams". In: *Instruments and Experimental Techniques* 51 (Jan. 2011), pp. 1–27. DOI: 10.1134/S0020441208010016.