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時間発展に拡張したGavobich’s modelによる低エネルギービーム輸送系の空間電荷緩和とビーム輸送のシミュレーション

Simulation of space charge neutralization and beam transportation in low energy beam transport line with time evolutionary extended Gabovich's model

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For beam dynamics in low energy beam transport (LEBT) lines in intense ion beam linear accelerators like LIPAc, the space charge compensation (SCC) effect by electrons generated from residual gas ionization by beam-gas collisions plays an important role. Particle simulations by such as Particle-in-cell codes are known to be a strong tool to understand time evolution of such space charge compensated beams, but they generally need large computational resources and time so that they are not suitable for comprehensive survey of various cases. We are developing a new simulation code by simple means based on the envelope approach to simulate time evolution of the beams with the SCC effects. In this code, the SCC rate is predicted with Gabovich’s model[1,2] for saturated situation and with a newly extended model for time evolution before saturation. The principal idea of Gabovich’s model to predict the saturated SCC rate is based on the energy balance of electrons, that is, the required energy to sweep out the electrons generated per unit time should be equal to the energy gain of the electrons from Coulomb collisions with the beam particles. We extended this idea to non-equilibrium situations by taking the ratio of these two energies as the loss rate of electrons generated in the time step.

Figure 1 shows a simulation example of 50 keV H^+ beam transportation in the LIPAc LEBT, with a beam current of 20 mA, H_2 gas pressure of 1.2×10^{-3} Pa, and currents for two solenoid lenses of 135 A and 160 A with an integrated axial field on axis of the each solenoid under nominal current of 560 A is 0.2 T.m. Initial conditions of the beam are, (ε_n, σ, $d\sigma/ds$)=(0.120 π.mm.mrad, 1.76 mm, 36.6 mrad) where ε_n and σ denotes a normalized emittance and an rms beam radius. These values were chosen so that they will be matched to (0.120 π.mm.mrad, 10 mm, 42 mrad) at s=200 mm in saturated situation, which are calculated values in ref [3] based on D^+ beams. Particles except the beam and gas ionized electrons, such as ions from gas ionization and secondary electrons from beam pipe surface, are not considered yet.

In figure 1(a), solid lines show time evolution of beam envelope resulting from roughly proportional increase of SCC rate shown with dashed lines as the electrons are accumulated over time. The SCC rate is seen saturated in most part of s-axis at 60 μs, which is found reasonable compared with a reference time of the SCC build-up evaluated from the ratio of the numbers of beam particles in beam pipe and electrons generated per unit time being around 51 μs. In the saturated situation where the basic Gabovich’s model[1,2] was applied, the SCC rate in figure 1(b) shows so high value more than 95% for the entire beam. This almost agrees with simulation results using PIC code[4], except that the SCC rate is a little high in the region before the first solenoid, which might be caused by factors not included in this simulation such as effect of solenoid field to electrons.

In conclusion, our simulation shows reasonable results so that it is a strong way for rapid simulation about time evolution of the beam with SCC effect.

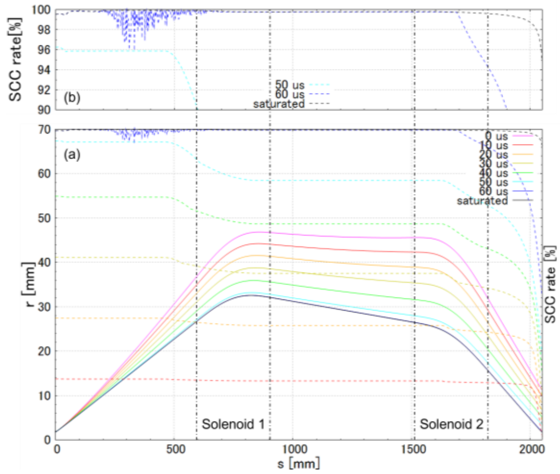

Figure 1 (a) Time evolution of Beam track and SCC solid: 1σ envelope of beam, dashed: SCC rate (b) Focused view of SCC on more than 90%

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