

LARGE SCALE PARTICLE TRACKING AND THE APPLICATION IN THE SIMULATION OF THE RFQ ACCELERATOR*

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Abstract

Large scale particle tracking is important for the design and optimization of the Radio-frequency Quadrupole (RFQ) accelerator. In this paper, we present RFQ simulation results of new parallel software named LOCUS3D, which is developed at Institute of Software, Chinese Academy of Sciences. It is based on Particle-In-Cell method and calculates three-dimensional space charge field by an efficient parallel Fast Fourier Transform method. The RFQ accelerator at Tsinghua University is simulated by tracking 100 million macro particles. This RFQ is designed to accelerate protons from 50 keV to 3 MeV, with peak beam current of 50 mA. As large number of particles been simulated, more accurate and detailed information have been obtained.

INTRODUCTION

With the rapid development of supercomputer technologies, large scale particle tracking is playing a more and more important role in the design and optimization of accelerators [1].

LOCUS3D software is being developed to take full advantage of supercomputer technologies in the design and optimization of various medium-energy and high-intensity linear accelerators. It solves the Poisson's equation for counting the space charge effect, and adopts symplectic time integration algorithm [2,3].

In this paper, a Radio Frequency Quadrupole (RFQ) accelerator built for the Compact Pulsed Hadron Source (CPHS) at Tsinghua University [4] is simulated by LOCUS3D. The main parameters of the CPHS RFQ are presented in Table 1.

Table 1: Basic Parameters of the CPHS RFQ

Parameters	Value	Unit
Particle	Proton	
Type	Four-vane	
Duty factor	2.5	%
Frequency	325	MHz
Input beam energy	50	keV
Output beam energy	3.0	MeV
Peak beam current	50	mA
Emittance (norm. rms)	0.2	π mm·mrad
Total length	296.87	cm

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We will first present some progress made in LOCUS3D, including electric field calculation of RFQ, parallel I/O, post-processing. Then the large scale particle tracking results of the CPHS RFQ at Tsinghua University is presented.

NUMERICAL METHOD

The numerical methods for LOCUS3D can be divided into two parts: particle tracking and electromagnetic (EM) field computation, including external fields and space charge (SC) fields. Time stepping scheme similar to reference [3] has been used, but it has many differences from BEAMPATH, such as units of quantities, Poisson solver, parallel model, etc. A more complete system and user-friendly interface have been added. Besides these, new functions of handling large scale computing will be introduced in the following section. For RFQ simulation, two-term formula in [5] has been adopted.

SOFTWARE PROGRESS

LOCUS3D is a newly developed parallel software for beam dynamics simulations. It uses object-oriented C++ language and is based on Message Pass Interface (MPI) library. It targets on efficiently use of modern supercomputers. Recent progress of LOCUS3D includes parallel I/O and particle phase-space display.

Parallel I/O

Large-scale simulations produce large amount of data, which needs to be processed and kept in hard disk. There are two methods to complete data dump in LOCUS3D. For the first method, data are dumped by multiple processes which open different files between each other. Data are firstly transferred to these processes, and then stored as binary data files or textual data files. For the second method, MPI functions are called, such as MPI_File_write. Data are stored with only binary format, but with faster speed.

Particle Phase Display

Since large numbers of particles are simulated, it is prohibitively expensive to display every particle's phases on picture or screen. During the simulations, LOCUS3D solves the problem by interpolating particles' phases onto a 2D phase grid. The produced data are particle densities in phase spaces. This makes it easy to handle billions of particles.

SIMULATION RESULTS

The physical design of the CPHS RFQ was carried out by the code of PARMTEQM [6], which includes the effects of image charges, higher order multipole field components and two-dimensional space-charge calculation. The matched input Twiss parameters are: $\alpha_{ix,y} = 1.35$ and $\beta_{ix,y} = 7.73$ cm/rad. The particle distributions in the transverse plane at the entrance and exit of the RFQ are presented in Fig. 1. The transmission rate given by PARMTEQM is 97.2%.

Large scale particle tracking with 100 million macro particles have been carried out by LOCUS3D. With the same input parameters, LOCUS3D gives the transmission of 94.1% (total) and 92.5% (accelerated). The particle distributions in phase spaces at the entrance and exit of the RFQ are presented in Fig. 2~6. It can be seen that these results are basically consistent with PARMTEQM, and Fig. 6 shows that in $(d\phi, dW)$ plane the phase contours are distorted. Growth of the average energy along the RFQ is presented in Fig. 7. A small difference of average energy at exit is due to lacking consideration of lost particles. Except that, average energy matching is excellent. Emittance variation along the RFQ is presented in Fig. 8, which shows that they are nearly constant at latter part of RFQ. The envelope variation of the horizontal and vertical plane along the RFQ are presented in Fig. 9, which show slight increases. Total lost particles on the horizontal vanes and vertical vanes along the RFQ are presented in Fig. 10, which means that they are basically the same.

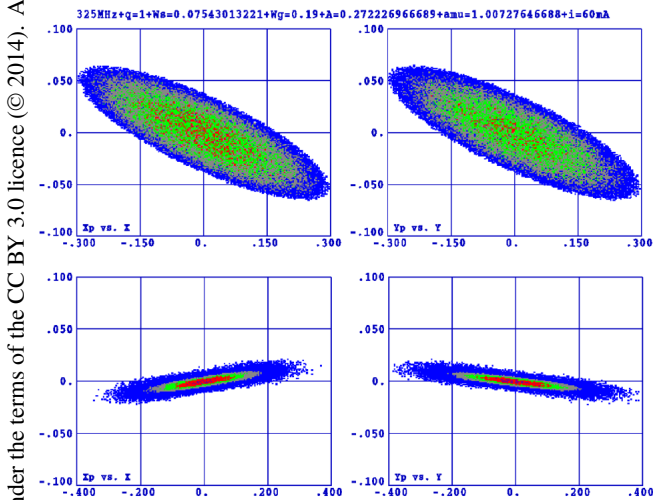


Figure 1: Particle distribution in the transverse plane provided by PARMTEQM at the entrance and exit of the RFQ.

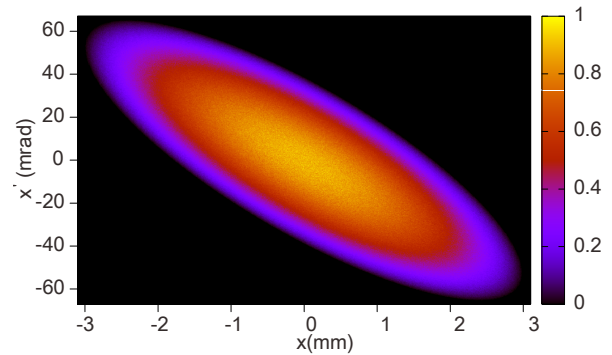


Figure 2: Particle distribution in $x-x'$ phase space at the entrance of the RFQ by LOCUS3D.

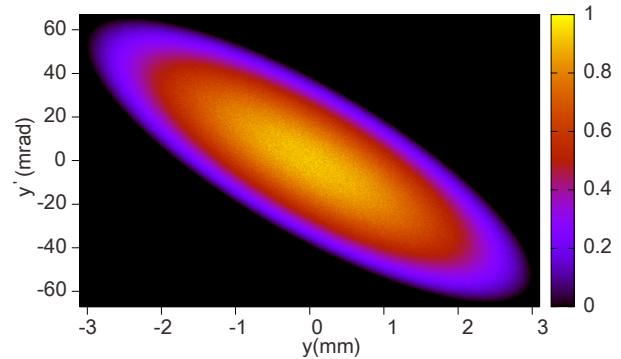


Figure 3: Particle distribution in $y-y'$ phase space at the entrance of the RFQ by LOCUS3D.

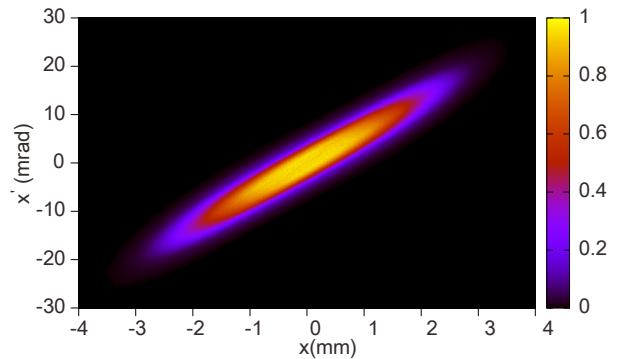


Figure 4: Particle distribution in $x-x'$ phase space at the exit of the RFQ by LOCUS3D.

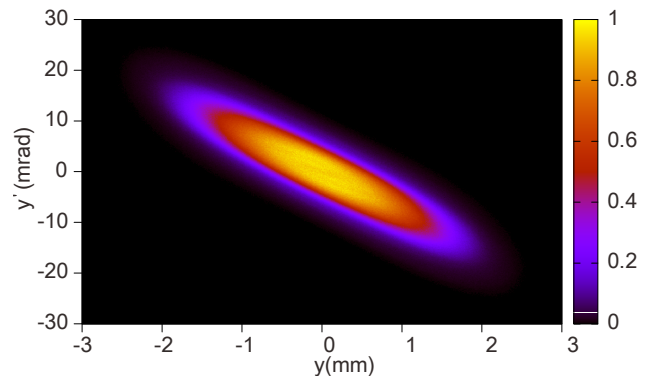


Figure 5: Particle distribution in $y-y'$ phase space at the exit of the RFQ by LOCUS3D.

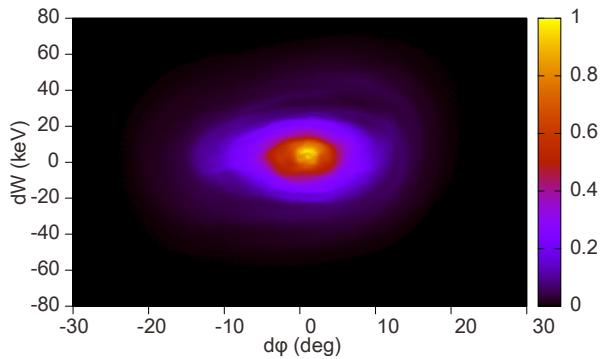


Figure 6: Particle distribution in ϕ - W phase space at the exit of the RFQ by LOCUS3D.

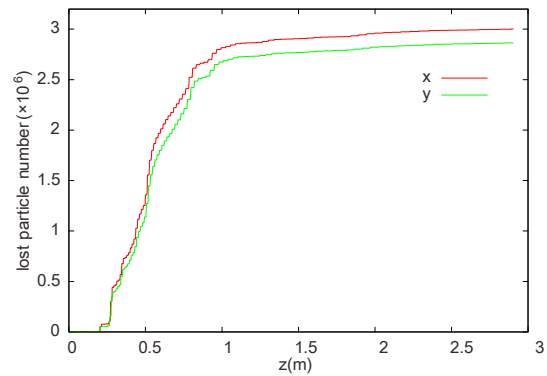


Figure 10: Total lost particles on the horizontal vanes and vertical vanes along the RFQ by LOCUS3D.

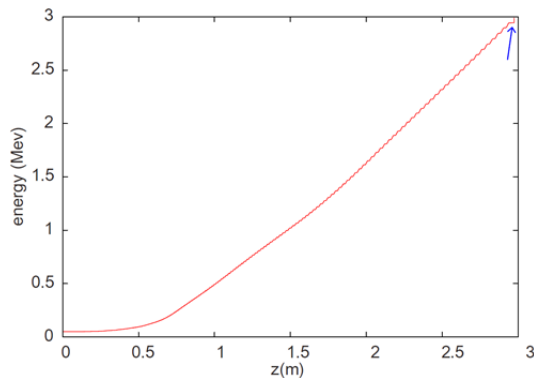


Figure 7: Growth of the average energy along the RFQ by LOCUS3D.

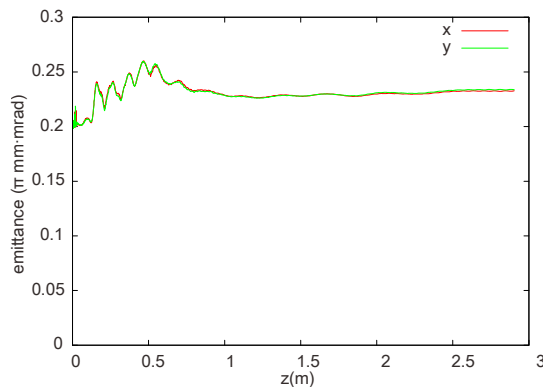


Figure 8: Emittance variation along the RFQ by LOCUS3D.

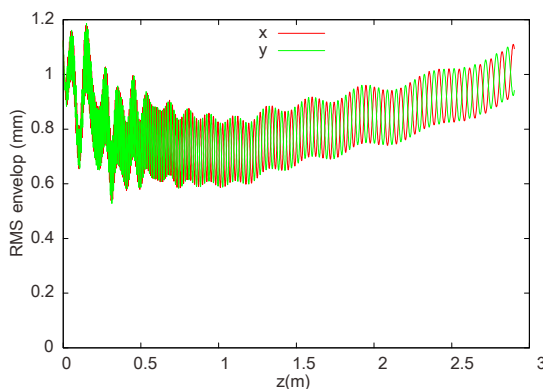


Figure 9: Envelope variation of the horizontal and vertical plane along the RFQ by LOCUS3D.

SUMMARY

This paper presents RFQ simulation results of parallel beam dynamics software, LOCUS3D, which is developed at Institute of Software. In this paper, one of the most complicated accelerator devices, RFQ, was successfully simulated. In order to handle large amount of particles, many new features have been added to the software, such as parallel I/O, on-going post-processing, user-friendly interface, etc. The RFQ accelerator from Tsinghua University has been studied, and more accurate and useful information have been obtained, which is very important to accelerator physicists. LOCUS3D will be improved further to make use of large supercomputers. Collaborations are welcome.

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