BENCHMARKING TRACK AGAINST PARMELA AND ASTRA IN THE DESIGN OF THE TRIUMF E-LINAC

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Abstract

The TRIUMF ARIEL project plans to build a 50 MeV electron linac at 10 mA to produce radioactive ion beams through photo-fission. Beam dynamics studies of the accelerator are on-going. The TRACK code originally written to simulate proton and heavy ion linacs has been used in e-linac modelling studies. This paper will summarize the TRACK simulation studies and the simulation results will be compared with other codes like PARMELA and ASTRA.

INTRODUCTION

The TRIUMF ARIEL project plans to build a 50 MeV electron linac at 10 mA to produce radioactive ion beams through photo-fission. It has two main parts including an injector section and a driver linac. The injector section accelerates electrons from 100 keV source potential to 10 MeV and the driver linac accelerates electrons from 10 MeV to 50 MeV. The benchmarking layout of TRIUMF ARIEL linac is shown in Fig 1. The user friendly features of the TRACK [1] program, make it an interesting choice to use in the conceptual design study of the TRIUMF ARIEL linac. This paper will present the benchmarking result of beam simulations using TRACK compared against standard electron beam codes such as PARMELA and ASTRA.

There are several codes broadly used for beam dynamics simulations of electron accelerators, such as PARMELA, ASTRA and ELEGANT. The ray-tracing code TRACK originally developed to fulfill the special requirements of the RIA accelerator systems is a general beam dynamics code [2]. The code has been used in many projects in the last several years for the design and simulation of proton and heavy-ion linacs [3]. Recently TRACK was updated with some new features and broadened its scope to be able to simulate electron acceleration.

TRACK is a multi-particle beam dynamics code. It supports 3D fields, including fringe fields, considering boundary condition and appropriate space charge calculations, which is more realistic than matrix-based and single particle codes [4] and more close to the realistic model. TRACK is also user friendly: the self-explained commands, phase definition, compatible field conversion software (can support field conversion from Microwave studio, Superfish, Poisson etc) and field model plotting software provide more convenience to the user.

INJECTOR

The key part of the TRIUMF ARIEL e-Linac is the injector section. The injector can be separated into four parts: the gun, a warm buncher and a cold section consisting of a capture section and a multi-cell cavity. The capture section and the multi-cell fit inside a single cryomodule. The injector is followed by a driver linac which consists of two cold cryomodules. Each of the crymodules hosts two 9-cell cavities. There are several variants being discussed for the injector section. The focus of this paper is to benchmark the beam simulation of TRACK with PARMELA and ASTRA for one of the variants and some sample elements.

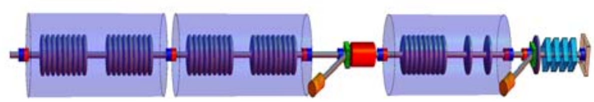


Figure 1: Benchmarking layout of TRIUMF ARIEL linac.

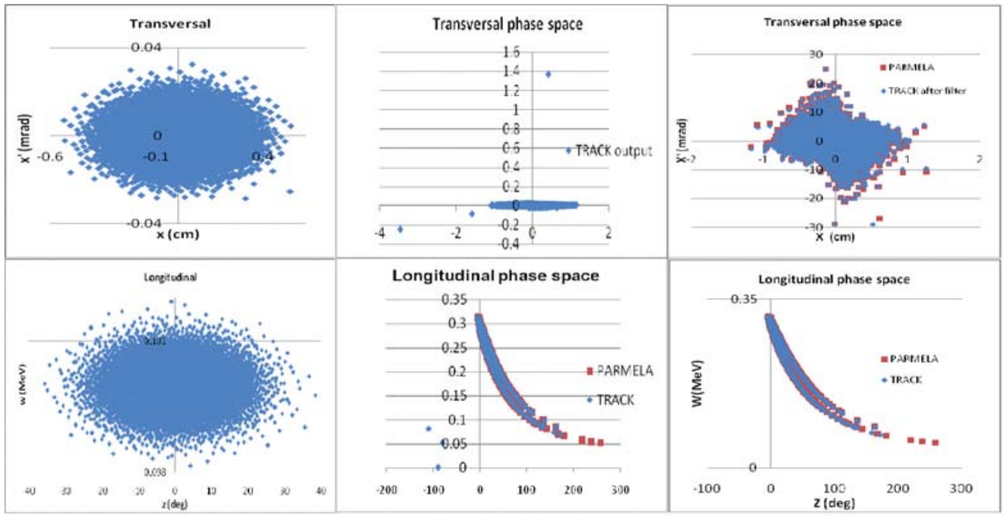
The first section of the linac consists of a 100 kV thermal gun with 650 MHz repetition rate to produce 100 keV pulsed beam with 15.4 pC/bunch corresponding to a 10 mA beam intensity. The beam emittance for the simulations after the gun are as follows: the transverse total emittance is assumed to be 30 $\pi\mu m$ (unnormalized) with a longitudinal phase spread of ±20 degrees (171 ps) at 650 MHz and an energy spread of ±1 keV. The 650 MHz buncher is followed by two single cell capture cavities and a 1.3 GHz 9-cell (β=1) cavity. The buncher is a room temperature device modelled after the Elbe resonator while the capture cavities and 9-cell cavities are superconducting elliptical structures modelled after the Tesla design. The injector section is specified to accelerate electron beams from 100 keV to 10 MeV.

FIELD MODEL BENCHMARKING

Single Particle Studies

First benchmarking performance is tested by tracking single electron off the axis through both the buncher and the capture cavities separately for both low velocity and high velocity input energies. Electrons with high input energy (β close to 1) are tested for one of the capture cavities both in ASTRA (DESY) [5] and TRACK. The discrepancy is less than 0.33%.

We also tracked 100 keV off-axis electrons with an accelerating gradient of 6 MV/m and phase of φ=0° and φ=10° respectively for the capture cavity. This has also



(a) (b) (c)

Figure 2: Benchmarking space charge simulations between PARMELA and TRACK with one single cell cavity and a 100 keV injection energy: (a) shows the initial distribution with 10000 particles, (b) shows TRACK and PARMELA output in the transverse and longitudinal planes (upper plot just shows the output of TRACK), and (c) shows the comparison after filtering the three rogue particles coming from TRACK simulation.

been done for the buncher with an accelerating gradient of 2 MV/m and phase of φ=90° and φ=80° respectively. The phase angle of φ=0° is defined as the maximum energy gain for the reference particle and -90° for the bunching phase [6]. The benchmark results with PARMELA are shown in Table 1. The left part is off-axis particles, in one dimension only with all other dimensions set to zero. The right part is the disagreement between PARMELA and TRACK after tracking these particles through. Note that for the buncher cavity, the results agree well with a maximum difference of 0.75%. But for the capture cavity, there is a larger discrepancy for the divergence and phase, of around 2%. Those zero values labelled by stars come from absolute values smaller than 10^{-3}. The source of the differences is still being investigated.

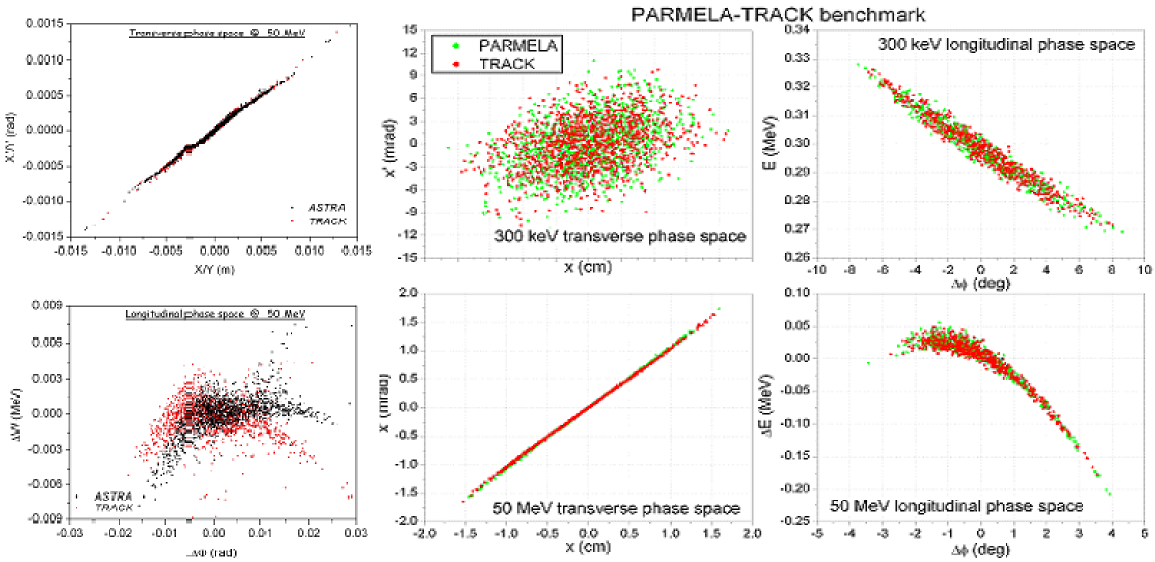
Multi-Particle Simulations for Benchmarking with Space Charge

For low energy electron beam dynamics, the space charge effect should be considered. In TRACK, the hard edge option can be used for no space charge cases using a simple linear matrix for the calculation. For space charge simulations, the real field model should be employed. We compared with one solenoid and one cavity with space charge and nonzero phase the TRACK and ASTRA are matching quite well.

In order to benchmark space charge calculation in TRACK and PARMELA, 10000 particles in a Gaussian distribution are injected into one cavity with an accelerating field of 6MV/m at Φ=0°. The initial particle distribution of x-x' and z-w planes are shown in Fig. 2(a). The output of TRACK is shown in Fig. 2(b) with the upper picture showing the output of the transverse phase plane, and the lower picture showing the output of the longitudinal phase plane both for TRACK and PARMELA. From the TRACK output, we can see that there are three rogue particles separated from the others. The source of these is being investigated. After the three rogue particles are filtered the results are plotted in Fig. 2(c) where a reasonable match occurs.

Table 1: Benchmarking Results Between PARMELA and TRACK for 100 keV Off-Axis Particles

		Comparing with PARMELA			
		X	X'	z	E
φ=0° 1.3 GHz Capture cavity	ΔX=5 mm	0.4%	1%	1.8%	0.04%
	ΔX'=0.5 mrad	0.7%	2.6%	0*	0.0025 %
	ΔZ=4 deg	0	0	2.5%	0.02%
	ΔE=5 keV	0	0	0.2%	0.026%
φ=10° 1.3 GHz Capture cavity	ΔX=5 mm	0.4%	0.7%	2%	0.1%
	ΔX'=0.5 mrad	0.7%	3.9%	0*	0.07%
	ΔZ=20 deg	0	0	0.9%	0.2%
	ΔE=5 keV	0	0	0.2%	0.038%
φ=90° Buncher 2MV/m	ΔX=5 mm	0.4%	0.5%	0.75%	0.1%
	ΔX'=0.5 mrad	0.05%	0.7%	0.4%	0.1%
	ΔZ=-10 deg	0	0	0.19%	0.01%
	ΔE=5 keV	0	0	0.19%	0.1%
φ=80° Buncher 2MV/m	ΔX=5 mm	0.18%	0.1%	0.1%	0.05%
	ΔX'=0.5 mrad	0.1%	0.3%	0	0.054%
	ΔZ=-10 deg	0	0	0.1%	0.01%
	ΔE=5 keV	0	0	0.07%	0.04%



(a) (b)

Figure 3: Benchmark of the full TRIUMF ARIEL linac between ASTRA, PARMELA and TRACK: (a) shows the comparison between ASTRA and TRACK after 50 MeV with space charge, and (b) shows the comparison between PARMELA and TRACK without space charge: the upper plot is after the first capture cavity, the lower plot is after 50 MeV.

INJECTOR SIMULATION RESULT BENCHMARKING

ASTRA and TRACK benchmarking with space charge for the injector section has been done. The layout of this benchmarking simulation is similar to Fig. 1, except that the transverse focusing after the gun is done using two solenoids instead of quadruples. The initial Gaussian distribution is as follows:

$\varepsilon_{xRMS} = 2.5\ \mu m$, $\alpha_x = 0.$, $\beta_x = 13.3$ cm/rad,

$\varepsilon_{yRMS} = 2.5\ \mu m$, $\alpha_y = 0.$, $\beta_y = 13.3$ cm/rad,

$\varepsilon_{zRMS} = 3.56$ deg-%, $\alpha_z = 0.$, $\beta_z = 14.23$ deg/%

Fig. 3(a) shows the output particles distribution at 50 MeV transversally (upper plot) and longitudinally (lower plot). For the injector section (up to 10 MeV) the resulting distribution is well matched. At 50 MeV there is some small longitudinal difference between the results of the two codes as shown in Fig. 3(a). This could be coming from the different way of phasing the cavities. Now it is being investigated.

Benchmarking between PARMELA and TRACK for the full linac has also been done with and without space charge. Fig. 3(b) shows both the output particles without space charge transversally and longitudinally. The upper plot shows the particle distribution after the first capture cavity. The lower plot shows the particle distribution at E=50MeV; transversally (left plot) they are matching, longitudinally there is a 50 keV (1%) difference. For the space charge case, the phase space shape agrees well except the longitudinal tail is longer from PARMELA simulation.

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