RIAPMTQ/IMPACT: BEAM-DYNAMICS SIMULATION TOOL FOR RIA*

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Abstract

We have developed a pair of multiparticle beam-dynamics codes for end-to-end computer simulations of the proposed RIA heavy-ion driver linac. The two codes are: 1) an adaptation of PARMTEQ called RIAPMTQ for the normal-conducting-linac front end, and 2) IMPACT for the superconducting linac. The codes run on a PC as well as on parallel supercomputing platforms such as NERSC at LBNL. The parallel capability allows us to run simulations with large numbers of macroparticles for the computation of beam halo and beam-losses. The codes are being benchmarked for rms beam properties against previously existing codes at ANL and MSU. The work is being performed by a collaboration including LANL, LBNL, ANL, and Michigan State University (MSU). In this paper we present an overview, the status of the work, comparison of simulation results from RIAPMTQ and the ANL code TRACK for the ANL front-end design, and the first RIAPMTQ/IMPACT end-to-end multiprocessor simulation for the MSU design.

INTRODUCTION

The concept for the Rare Isotope Accelerator (RIA) project [1] includes a 1.4-GV CW superconducting driver linac. The driver linac is designed for multicharge-state acceleration [2] of all stable species, including protons to >900 MeV and uranium to 400 MeV/u, and for high-power beams of several hundred kilowatts.

The high-power beam associated with multiple charge-state acceleration introduces a new design requirement to control beam losses that can cause radioactivation of the linac [3]. It is important for the RIA project to be capable of computing the beam losses.

The driver linac is made up of three sections. The first is the pre-stripper accelerator section consisting of an ECR ion source, and a low-energy beam transport (LEBT) line, which includes a mass and charge-state-selection system, and an external multi-harmonic buncher system. The pre-stripper section continues with the initial linac stage consisting of a room-temperature RFQ linac, a medium-energy beam transport (MEBT) line, and the low-velocity (low-β) superconducting accelerating structures. The pre-stripper section, accelerates the beam, consisting of two charge states for uranium, to an energy of about 10 MeV/u, where the beam passes through the first stripper and new charge states are produced.

The second section of the linac uses medium-β superconducting structures to accelerate the multicharge-state beam from the first to the second stripper ending at an energy of about 85 MeV/u. This medium-β section accelerates about five charge states for uranium. This is followed by the third and final section of the linac, which uses high-β superconducting structures to accelerate typically three or four charge-states for uranium to a final energy of 400 MeV/u. Beam losses must be limited to less than about 1 watt per meter [4, 5, 6] particularly in the high-energy part of the accelerator. The beam-dynamics computation requires the use of simulation codes that includes all effects that can lead to emittance growth, halo formation, and possible beam losses.

A significant amount of accelerator design work has already been done at two institutions, Argonne National Laboratory [4] and Michigan State University [7]. At present both institutions have a RIA driver-linac design. The LANA code [7, 8, 9] is presently used at MSU for superconducting linac simulations. The code TRACK [10] is used at ANL.

CODE DEVELOPMENT AND STATUS

Our starting point for the development of these codes for RIA has been to modify the well-established and benchmarked, multi-particle beam-dynamics codes PARMTEQM [11] and IMPACT [12]. The IMPACT code, originally developed to run on parallel-processor machines, models the high-energy superconducting accelerator of the driver linac. A new parallel-processor version of PARMTEQM, now called RIAPMTQ, has been developed to model the LEBT, RFQ, and MEBT of the RIA driver linac. To facilitate the use of the codes for the design process, where low statistics runs are adequate, both codes also have PC versions.

RIAPMTQ

The Fortran 90 version of PARMTEQM was the basis for RIAPMTQ. The code was "parallelized" by incorporating the necessary Message Passing Interface (MPI) commands to allow the code to run in the parallel-multi-processor environment. Optimization of the code using "domain decomposition" was not thought to be necessary for this initial phase; the simpler approach

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called "particle decomposition" was used. The most significant code modifications were required in the parallelization of the space-charge calculations which can consume the majority of the computing time in multi-particle simulations. The following RIA-specific modifications were made to RIAPMTQ: transport and acceleration of multiple-charge-state beams (two at present before the first stripper), RFQ input transition cell to facilitate initial vane modulation, beam-line elements including high-voltage platforms within the linac, interdigital accelerating structures, charge-stripper foils, capabilities for simulations of the effects of machine errors including misalignments, and other off-normal operating conditions, and automated beam steering where the program applies the steering that is needed. We presently have both a PC version of the code and a parallel-processor version, running in single processor mode. The multiprocessor version is still being debugged.

IMPACT

The IMPACT code is a parallel particle-in-cell (PIC) beam dynamics code. It has a large collection of beam line elements, calculates the acceleration numerically using RF cavity fields obtained from electromagnetic field-solver codes, and calculates 3D space charge with several boundary conditions. Because of already being "parallelized," the IMPACT code has required only modifications for RIA, including multiple-charge-state capability, improved modelling of bending magnets, stripping models, a beam scraper, and a multipole magnet model including a sextupole, octupole, and decapole.

RIAPMTQ AND TRACK COMPARISON FOR ANL DESIGN

In previous publications we have reported preliminary simulation and benchmarking results [13,14]. Additionally, IMPACT code capability has been implemented at ANL [15] and MSU [16]. Recently, we have compared the RIAPMTQ code results with the ANL TRACK code results for the ANL design. The simulation was run for two charge states (28 and 29) of uranium 238. The initial input beam distributions (4-D Waterbag unbunched beams) with 50,000 macroparticles for each charge state were generated at the entrance of the LEBT. The two charge-state beams were then simultaneously tracked through the LEBT, RFQ, and MEBT for each code to simulate and compare the beam-dynamics performance. Table 1 summarizes the results at the end of the MEBT in terms of the Courant-Snyder parameters and the rms-normalized emittances for each degree of freedom, and for the total beam including both charge states. The total transmission values are in good agreement. The transverse emittances agree to about 3%, and the longitudinal emittance agrees to within about 12%. The Courant-Snyder parameters show fairly good agreement. We attribute some of the discrepancies to small differences in the RFQ design, but overall we consider the agreement between the two codes to be quite acceptable.

After completing the debugging of the parallel version of RIAPMTQ, we will complete the high statistics end-to-end simulations using RIAPMTQ and IMPACT for the ANL designs. The most important result at higher statistics will be the comparison of beam losses.

Table 1: Courant-Snyder Parameter and Emittance Comparisons for the ANL TRACK code versus RIAPMTQ Simulations at the end of the MEBT.

	TRACK results	RIAPMTQ results
Transmission	83.8%	83.2%
α_x	1.39	1.11
β_x	0.566 mm/mrad	0.950 mm/mrad
$\varepsilon_{n,rms,x}$	0.087 mm-mrad	0.090 mm-mrad
α_y	0.799	0.856
β_y	0.525 mm/mrad	0.656 mm/mrad
$\varepsilon_{n,rms,y}$	0.086 mm-mrad	0.089 mm-mrad
α_z	0.834	0.663
β_z	2140 deg/MeV/amu	2270 deg/MeV/amu
ε_z	0.0045 deg-MeV/amu	0.0040 deg-MeV/amu

MULTIPROCESSOR END-TO-END SIMULATION FOR MSU DESIGN

The first RIAPMTQ/IMPACT end-to-end simulation using multiple processing has been carried out for the MSU design at the MSU High Performance Computer Center. The RIAPMTQ simulation from the LEBT, through RFQ, to the end of the MEBT was done using 400K particles and only a single processor, since the multiprocessor RIAPMTQ version is still being debugged. The IMPACT simulation from the end of the MEBT to the end of the linac, including charge stripping and beam selection sections, was done using eight processors. Typically, a million particles were used in the simulation of linac errors evaluation [16].

Figure 1 shows the three rms emittances of the multiple-charge uranium beam (atomic number =92) from the entrance of LEBT to the exit of linac. The charge states are q=28 and 29 before the first stripper, q=71, 72, 73, 74, and 75 between the first and second stripper, and q=87, 88, and 89 after the second stripper to the end. The large excursions in the x emittance are caused by the dispersion at the dipoles near each stripper. The oscillations in the longitudinal emittance are caused by the multiple charge-state beam, because the charge states are not overlapping longitudinally.

Figure 2 shows phase-space plots of the three charge-state final beam, using sampled particles from the simulation. Comparisons (not shown) of IMPACT and LANA results, of the energy gain and the rms emittances for the MSU superconducting linac design including strippers and magnetic chicanes, are in very good agreement [16].

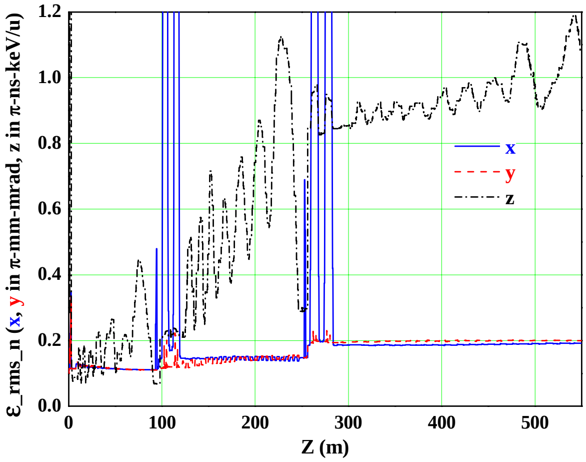

Figure 1: Normalized rms horizontal (x), vertical (y) and longitudinal (z) emittances along driver linac. (MSU design).

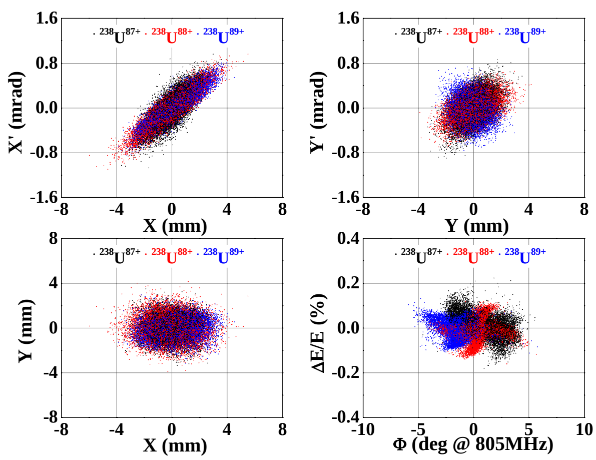

Figure 2: Phase-space plots of three-charge-state uranium beam at the exit of linac for the MSU design.

SUMMARY AND CONCLUSIONS

Comparisons of RIAPMTQ versus ANL's TRACK, and of IMPACT versus MSU's LANA, show good agreement. The first end-to-end simulation using RIAPMTQ (single processor) and IMPACT (multiple processors) has been carried out at MSU for the MSU design. At present IMPACT has parallel mode capability, but the multiprocessor version of RIAPMTQ is still being debugged. Both codes can run on a PC for design work. The codes will be used to do high-statistics simulations including operational and alignment errors for the prediction of beam losses.

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