THE RIAPMTQ/IMPACT BEAM-DYNAMICS SIMULATION PACKAGE*

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Abstract

The Fortran 90 RIAPMTQ/IMPACT code package is a pair of linked beam-dynamics simulation codes that have been developed for end-to-end computer simulations of multiple-charge state heavy-ion linacs for future exotic-beam facilities. The simulations can extend from the low-energy beam-transport line after the ECR ion source to the end of the linac. The work has been performed by a collaboration including LANL, LBNL, ANL, and MSU. The code RIAPMTQ simulates the linac front end including the LEBT, RFQ, and MEBT, and the code IMPACT simulates the main superconducting linac. The codes have been benchmarked for rms beam properties against previously existing codes at ANL and MSU. The codes allow high-statistics runs on parallel supercomputing platforms, such as NERSC at LBNL for studies of beam losses. The codes also run on desktop PC computers for low-statistics design work. We show results from 10-million-particle simulations at NERSC of designs by ANL and MSU for the Rare-Isotope Accelerator.

INTRODUCTION

RIAPMTQ/IMPACT is a pair of multiparticle beam-dynamics codes for end-to-end computer simulations of future heavy-ion driver linacs for the production of rare isotopes. The parallel capability allows us to run simulations with large numbers of macroparticles for the computation of beam halo and beam-losses. An example of a heavy-ion driver accelerator for rare-isotope production is the Rare Isotope Accelerator (RIA) [1], which includes a 1.4-GV CW superconducting driver linac. This 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. At present the design parameters for future facilities under consideration are scaled back in energy and beam power by as much as a factor of two from that of the earlier RIA concept. For all such driver linacs, 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].

Driver linacs that are presently under study are 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 near 10 MeV/u, where the beam passes through the first stripper and higher 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 near 85 MeV/u. This medium-β section can accelerate 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 about 200 MeV/u. The final energy for RIA was 400 MeV/u. In either case 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 include all effects that can lead to emittance growth, halo formation, and possible beam losses.

Accelerator design work has been performed mainly at two institutions, Argonne National Laboratory [4] and Michigan State University [7], and both institutions have produced 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 approach for code development was to modify the well-established multi-particle beam-dynamics codes PARMTEQM [11] and IMPACT [12]. In previous publications we have reported preliminary simulation and benchmarking results [13, 14, 15]. Additionally, IMPACT code capability has been implemented at ANL [16] and MSU [17].

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RIAPMTQ

The Fortran 90 version of PARMTEQM was the basis for RIAPMTQ. The code was "parallelized" by incorporating 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 called "particle decomposition" was used. The most significant code modifications were required in the parallelization of the space-charge calculations. The following modifications were made to RIAPMTQ: transport and acceleration of multiple-charge-state beams (two at present before the first stripper), RFQ input transition cell which is desirable when the RFQ begins with vane modulations, 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 have both a PC version of the code and a parallel-processor version.

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. The IMPACT code modifications for a heavy-ion driver linac included 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.

MULTIPROCESSOR END-TO-END SIMULATIONS

RIAPMTQ/IMPACT end-to-end simulations using parallel processing were performed at the NERSC facility at LBNL for both the ANL and MSU RIA driver-linac designs using 10 million particles, each beginning at the multiharmonic buncher in the LEBT with transverse 4-D waterbag distributions that are uniformly distributed in phase. The MSU and the ANL simulations were done using 16 and 32 processors, respectively. The IMPACT simulations from the end of the MEBT to the end of the linac included charge stripping and beam selection sections. Figures 1 and 2 show 10 million simulation-particle final transverse phase-space results for the MSU (uranium charge states q=87, 88, and 80) and ANL (uranium charge states q=86, 87, 88, 89, and 90) RIA driver linac designs, respectively.

Rather than plot all 10M particles we employ a technique in which we impose a threshold cut in the 2D projections: in regions of the 2D phase space where the projected density is below the threshold, we plot every simulation particle; in regions where the projected density is above threshold, we use a rejection method to statistically sample the particles to approximately hold the plotted density at the threshold value. This allows us to completely observe the halo without plotting a needlessly large number of particles in the beam core. For the phase space plots below, the threshold was taken to be 0.1% of the maximum density in each projection. For illustrative purposes the plots also contain the particles comprising every 100th particle of the distribution.

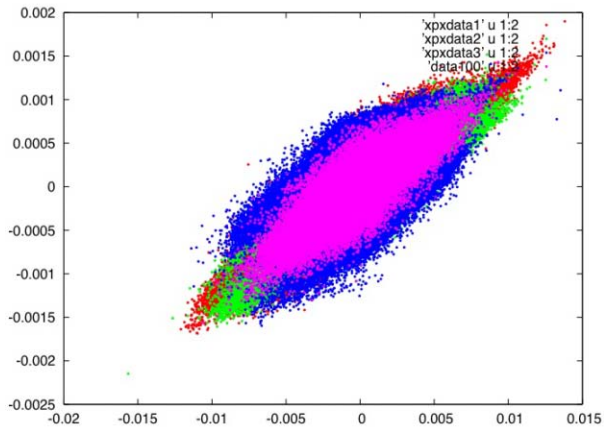

Figure 1: Transverse phase-space plot (x vs px) of 10M particle simulation for three-charge-state uranium beam at the exit of linac for the MSU RIA design. As described in the text, the plotting algorithm displays all the halo particles. The dense central region is obtained by plotting every 100th particle.

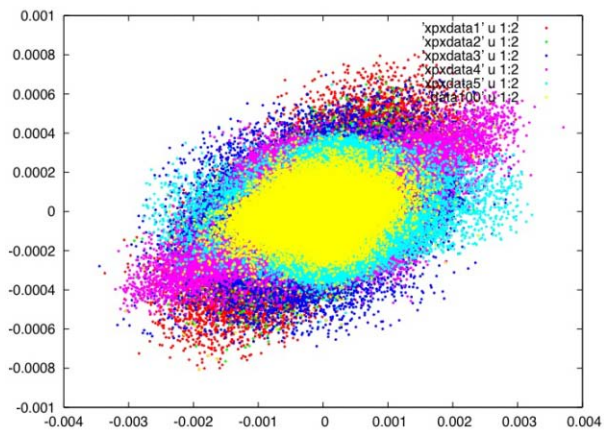

Figure 2: Transverse phase-space plot (x vs px) of 10M particle simulation for five-charge-state uranium beam at the exit of linac for the ANL RIA design. As described in the text, the plotting algorithm displays all the halo particles. The dense central region is obtained by plotting every 100th particle.

SUMMARY AND CONCLUSIONS

The first end-to-end simulations at NERSC using RIAPMTQ and IMPACT have been carried out for both the MSU and the ANL RIA designs. Both were 10 million particle simulations, and used 16 and 32 processors respectively. 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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