IMPACT MODEL FOR REA AND ITS BENCHMARK WITH DYNAC*

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Abstract

A new online model for the ReAccelerator 3 (ReA3) [1] has been developed for machine tuning using the IMPACT tracking code [2, 3]. A DYNAC [4-6] model was originally applied for REA3 optics analysis. However this model is limited to symmetric cavities, not asymmetric ones such as superconducting Quarter-Wave Resonators (QWRs), which are installed in ReA3. This limitation renders it difficult to effectively tune the ReA3 beamline with DYNAC. To address this situation, a new and more precise model of IMPACT is under development which more closely reflects the actual lattice.

This paper reports benchmarking results of IMPACT and DYNAC model for ReA3 acceleration line from just after RFQ exit to a transport line with a symmetric cavity as a first step before more precise simulations including non-axisymmetric cavities and the RFQ.

INTRODUCTION

Reaccelerator3

ReA3 is a post-target accelerator at the National Superconducting Cyclotron Laboratory (NSCL) and Facility for Rare Isotope Beams (FRIB). It reaccelerates beams of heavy ion isotopes with kinetic energy ranging 3 MeV/u to 6 MeV/u for nuclear experiments. First, an ion bunch is produced up-steam of the transport line and stored in an Electron Beam Ion Trap (EBIT) charge breeder [7], where an electron beam strips electrons. Bunches with higher charge state are extracted from the EBIT and selected by a 90 degree bending magnet in a mass-to-charge separator. A subsequent Multi-Harmonic Buncher (MHB) [8] with a fundamental frequency of 80.5 MHz compresses the beam longitudinally before entering a Radio-Frequency Quadrupole (RFQ) [9, 10]. The RFQ has a frequency of 80.5 MHz and is capable of accelerating 600 keV/u incident ions with *Q/A* ranging from 0.2 to 0.5.

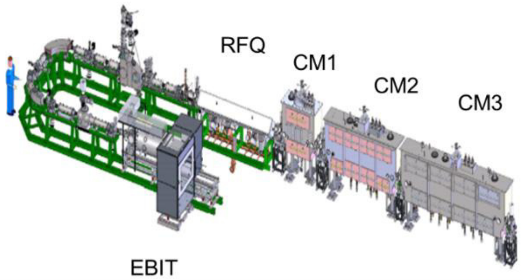

Figure 1: ReA3 beamline at NSCL/FRIB.

Ion beams extracted from the RFQ are accelerated by three super-conductive CryoModules (CM). CM specification are summarized in Table 1. These cavities are QWRs. Non- axisymmetric electromagnetic field components can kick the beam in vertical direction. In order to correct beam orbit errors caused by this effect and initial beam misalignments, several horizontal and vertical dipole correctors are installed within focusing solenoids. The design relativistic beta β of the CMs vary corresponding to the increasing beam velocity.

Table 1: Components of ReA3 Cryomodule

CM No.	Cavity No	Solenoid/Collector No
CM1	1 (β=0.041)	2/2
CM2	6 (β=0.041)	3/3
CM3	8 (β=0.085)	3/3

Beam tuning

For usual lattice tuning, intercepting monitors such as scintillation detectors and Faraday cups are located outside of CMs because typical beam current is a few hundred pA. Each CM has several cavities and induces accumulated orbit errors. A more precise beam simulation model is required to estimate the beam orbit error along the CMs. In addition, different species with various energies are required to be provided to experimental lines in a short period. This requires effective procedures to change ion species with different charge to mass ratios.

SIMULATION

Single-particle tracking simulations after RFQ section in both case of IMPACT and DYNAC are carried out with eight thousand macro particles. The ion beam species is He^{1+} with 600 keV/u kinetic energy. The Root Mean Square (RMS) measure beam size and angle are 1.25 mm and 1 mrad (both horizontal and vertical) with

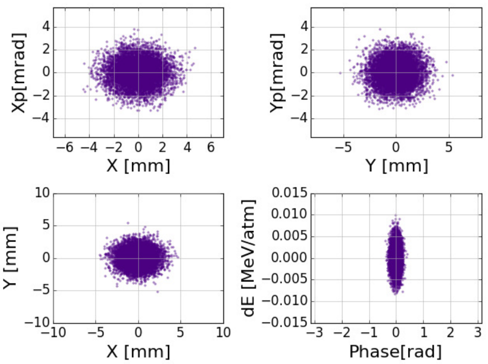

Figure 2: Projections of the initial distribution for the IMPACT and DYNAC simulations.

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Gaussian distribution, while it also has a Gaussian distribution of 2.5 keV and 0.1 rad at 80.5 MHz longitudinally as shown in Fig. 2.

Cavity fields

The cavity model applied is axisymmetric for purposes of benchmarking comparisons between DYNAC and IMPACT. A typical QWR waveform obtained from a CST-Studio [11] simulation is shown in Fig. 3. The QWR has two accelerating gaps with the total axial length of 24 cm. For present purposes, these two gaps are modeled as one cavity.

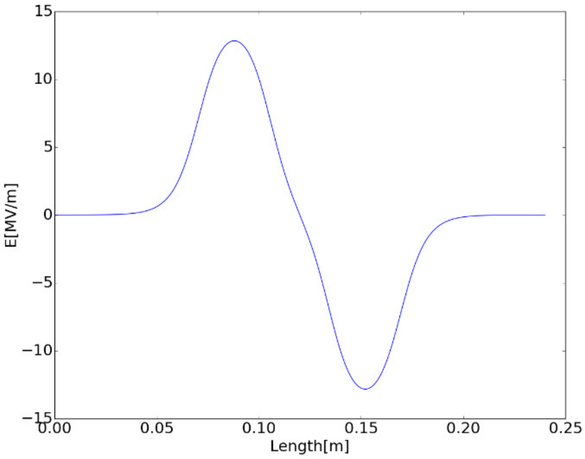

Figure 3: QWR on-axis electric field.

DYNAC and IMPACT employ different models for transverse focusing effects in RF cavities. DYNAC employs a Picht transformation developed for electron gun applications [12]. In this model, particle relativistic factors are coupled to the longitudinal electric field according to

$$\frac{d^2R}{dz^2} - R\frac{q}{2m_oc^3}\frac{1}{\beta^3\gamma^3}\frac{\partial E_z}{\partial t} + R\left(\frac{q}{2m_oc^2}\right)^2\frac{\gamma^2+2}{\beta^4\gamma^4}E_z{}^2 = 0 \quad . \qquad (1)$$

Here, reduced radius of beam is

$$R = \sqrt{\beta\gamma}\ . \qquad (2)$$

In contrast, IMPACT directly employs the 3D electromagnetic fields derived from the cavity model to advance the particles.

Benchmarking result

DYNAC and IMPACT simulation results for total kinetic energy, horizontal and vertical rms beam sizes are shown in Fig. 4 for the ReA3 lattice. The beam is accelerated through CM sections from 2.4 MeV/atm to 11.7 MeV/atm. Particle energies agree to within 0.12 % error. The both simulations find no beam losses due to wide apertures of the elements and a relatively compact initial distribution.

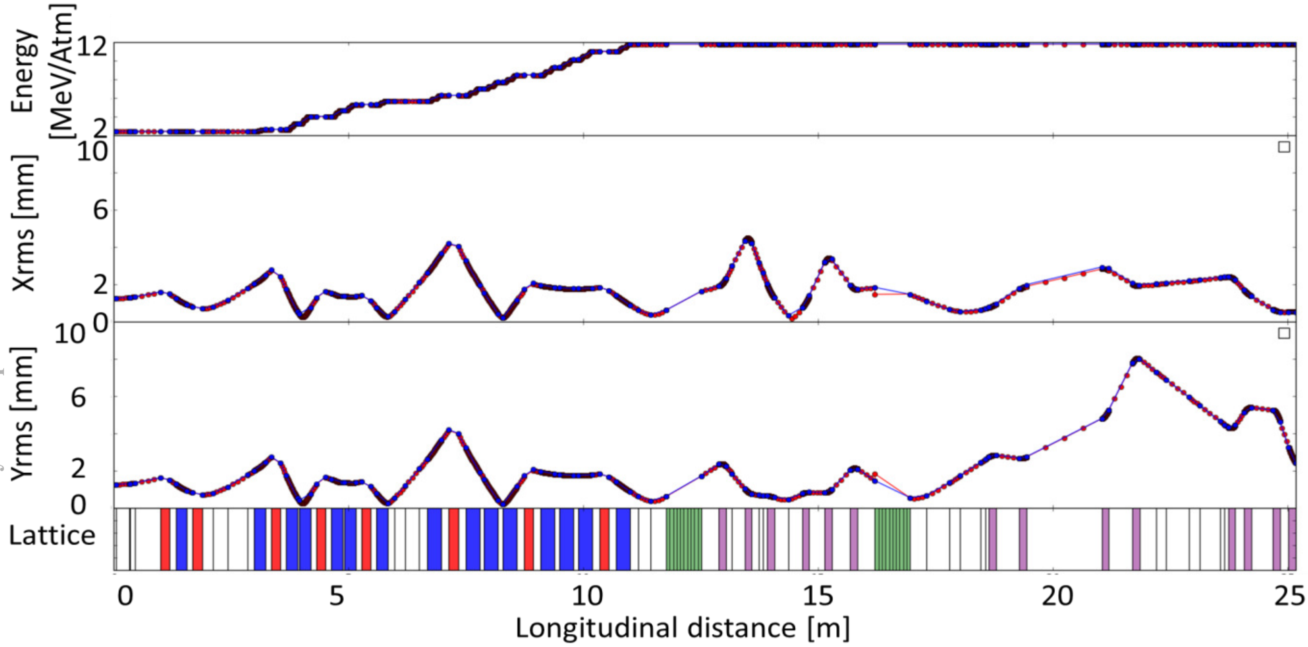

Figure 4: Comparison of DYNAC and IMPACT simulations for the ReA3 lattice just after RFQ section. DYNAC and IMPACT results are shown in red and blue respectively. (a) Total beam energy, (b) horizontal (x) rms beam size (c) vertical (y) rms beam size, and (d) lattice element locations. Lattice elements consist of RF cavities (blue), solenoids (red), vertical bending magnets (green) and quadrupoles (purple).

The transverse beam distribution has xy-symmetry from the initial location from the end of final CM before the first vertical bending magnet due to the use of an axisymmetric acceleration waveform.

After the final CM, the horizontal and vertical beam distribution has different structure. At the second bending section, beam sizes of both directions rapidly differ due to the way IMPACT treats vertical bending magnets as being composed of a horizontal magnet and two 90 degree rotations in the transverse plane. This results in the horizontal and vertical beam distributions being replaced with each other at the entrance and exit of vertical bending magnet. Therefore, this discrepancy is not real. RMS beam sizes have a good agreement through the whole section. Maximum horizontal and vertical errors are 4.5 % and 5.0 % where beam waists occur.

The final RMS emittances obtained in the DYNAC and IMPACT simulations are given in Table 2. Corresponding comparisons of transverse and longitudinal plane distribution projections are shown in Fig. 5. The two codes have good agreement.

Table 2: Transverse emittance comparison between IMPACT and DYNAC.

Parameter	**IMPACT**	**DYNAC**
εx mm mrad	0.0480	0.0482
εy mm mrad	0.0689	0.0709

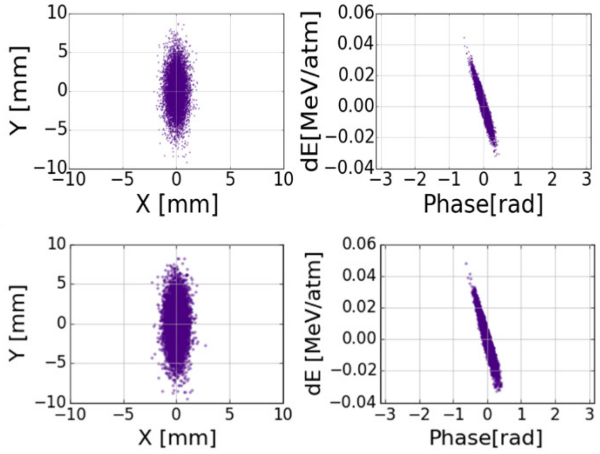

Figure 5: Final distribution projections for IMPACT (upper row) and DYNAC (lower row).

CONCLUSION

IMPACT and DYNAC simulation for ReA3 were benchmarked within a simplified axisymmetric cavity idealization of the ReA3 lattice. Although different cavity calculation models, they have a good agreement for beam energy, and rms beam sizes for typical ranges of beam parameters expected in ReA3.

ACKNOWLEDGEMENT

We thank ReA3 group members A. Villari, D. Crisp, and S. Nash for providing information on the ReA3 operation and lattice, and Q. Ziang, Z. He, K. Fukushima and T. Maruta for helpful discussions and guidance on the simulations.

This work is supported by the U.S. Department of Energy Office of Science under Cooperative Agreement DE-SC0000661 and the U.S. National Science Foundation under Grant No. PHY-11-02511.

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