XAL'S ONLINE MODEL AT REA3 TO UNDERSTAND BEAM PERFORMANCE*

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Abstract

The ReA3 facility at the NSCL at MSU has been designed to reaccelerate rare isotope beams to 3 MeV/u. ReA3 consists of a charge to mass selection section, a normal conducting RFQ, a superconducting linac, and transport beam lines that deliver the beam to the experiments. The beam optics designs were developed using COSY [1] and IMPACT [2]. A code with an online model capable of interacting with the control system, such as XAL [3], developed at SNS, would be ideal for studying this system. New elements have been added to XAL's already extensive list of supported devices in order to model elements unique to the NSCL. The benchmarking process has been completed for establishing the use of XAL's Online Model at the NSCL, and preliminary results from its use at the ReA3 control room have been obtained. The development of applications to fit the needs of the program is ongoing. A summary of the benchmarking process is presented including both transverse and longitudinal studies.

INTRODUCTION

One challenge in accelerator physics is beam tuning: controlling the particle beams in order to deliver the highest quality beam possible to the experiment. This requires achieving specific beam parameters along the beam lines. With the complexity of accelerators today it is important to take advantage of many different tools to facilitate this process.

Fast on-line physics modelling is one such powerful tool that can be used to improve the beam tuning procedure. It is important that the modelling software be robust and reliable in order to be utilized in the control room during real-time beam tuning.

The accelerator code XAL has this capability, however before being used at the National Superconducting Cyclotron Laboratory (NSCL) it was first benchmarked against the design codes used for earlier modelling of NSCL's ReAccelerator (ReA), namely COSY and IMPACT. XAL will soon be ready for use at ReA and may also be useful for other ion accelerators in the future, such as the Facility for Rare Isotope Beams (FRIB).

ReA3 Facility at NSCL

The goal of ReA [4] at the NSCL is to provide low energy rare isotope beams which are typically difficult to produce at Isotope Separation On-Line (ISOL) facilities. The rare isotopes are produced by fast fragmentation at high energies, and then cooled in a gas-stopper to preserve the beam's emittance quality. The isotopes are then passed to an Electron Beam Ion Trap (EBIT) for charge breeding, selected for mass to charge ratio in the Q/A section, and finally reaccelerated to the desired energy in the linac. The accelerating components of ReA3 include a normal conducting room temperature Radio-Frequency Quadrupole (RFQ), and three cryomodules with two types of superconducting quarter-wave RF cavities operating at 80.5MHz. The maximum final energy achievable from ReA3 is 3 MeV/u for heavy nuclei such as uranium, and 6 MeV/u for ions with A<50.

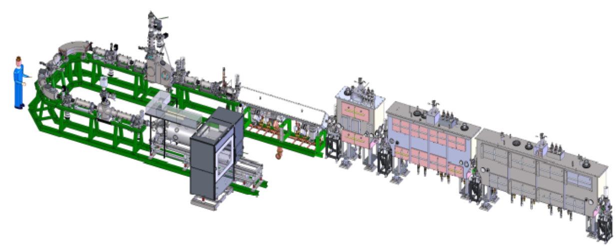

Figure 1: ReA3 Layout, including EBIT charge breeder, Q/A section, RFQ and Linac.

BENCHMARKING PROCESS

The elements benchmarked include drift, magnetic and electrostatic quadrupole, solenoid, dipole, sextupole, RF cavity, spherical and cylindrical bends. The quantities studied include element transfer matrices, beam phase space, energy gain, and transverse and longitudinal Courant-Snyder parameters.

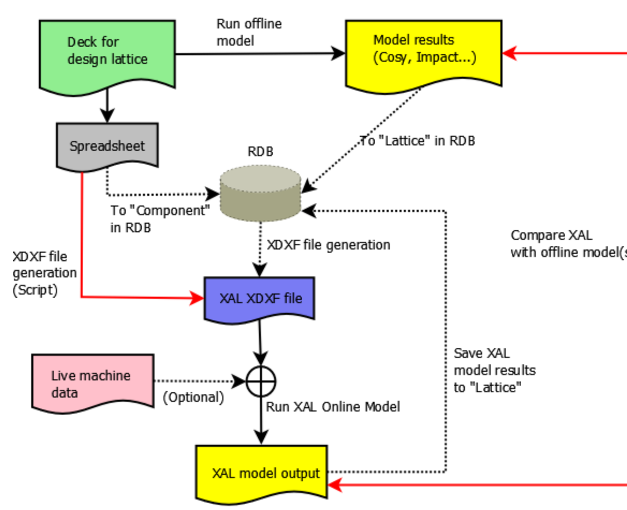

Figure 2: XAL benchmarking schematic.

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Beam line elements are benchmarked by running XAL and COSY simulations of the individual elements with the same initial beam conditions and comparing the final beam parameters along with the 6x6 transfer matrices.

Once the individual elements have been benchmarked, full beam line lattices can be run. Comparing XAL with COSY, both matrix-based simulation codes, ensures that XAL is working for the individual elements; however, we also desire to match XAL's results with IMPACT, a multi-particle tracking code. Their agreement is not necessarily guaranteed, since the two codes use different methods for simulation. Therefore the ReA3 linac and beam transport line simulations are also compared to ensure good agreement between XAL and IMPACT.

To run beam lines in XAL, certain files need to be generated. MATLAB scripts are used to convert lattice data from Excel spreadsheets into an XML file in the XAL XDXF format. The script can also take in the lattice information from an IMPACT model sim.dat file instead, although with this method no Experimental Physics Industrial Control System (EPICS) channels are included. It is important to have the channel names in XAL, as it allows XAL to connect with devices and simulate real time operation, so in the future these XDXF file will need to be generated from a relational database (RDB) which has both IMPACT lattice information and EPICS channel names. In addition to the lattice file (rea.xdxf) XAL also needs another file, model.params, which has the initial beam properties, such as species, energy, and Courant-Snyder parameters in the X, Y and Z planes.

New Elements in XAL

Several element types had to be implemented for the first time in XAL, including the electrostatic quadrupole (Equad), and cylindrical and spherical bends. The transfer matrix for the electrostatic quadrupole was taken from Ion Optics with Electrostatic Lenses [5] while the cylindrical and spherical bend matrices were taken from Electrostatic Bender Optics [6]. The results are found to be consistent with the transfer matrices from COSY.

Transverse Benchmarking

For all elements discussed so far, the transverse benchmarking has been completed. First, individual elements were benchmarked separately, followed by a low energy beam line before the RFQ, the ReA3 linac and the first segment of the present FRIB linac design.

This beam line before the RFQ includes an Equad triplet, LB004, followed by a spherical bend, LB006DE, a cylindrical bend, L051DE. and two Equad doublets, L057 and L057, ending at diagnostic BOX2 (see Figure 3). There is very good agreement between the COSY and XAL models.

In order to benchmark transverse motion in XAL with IMPACT, we look at the ReA3 linac through the second cryomodule, and the first segment of the present FRIB linac design. The ReA3 linac consists of three cryomodules containing 15 independently phased superconducting quarter-wave cavities, and 8 superconducting 9T solenoids. The subsection of the current FRIB design lattice compared with XAL contains 112 cavities, 42 solenoids, 12 quadrupoles and 4 dipoles.

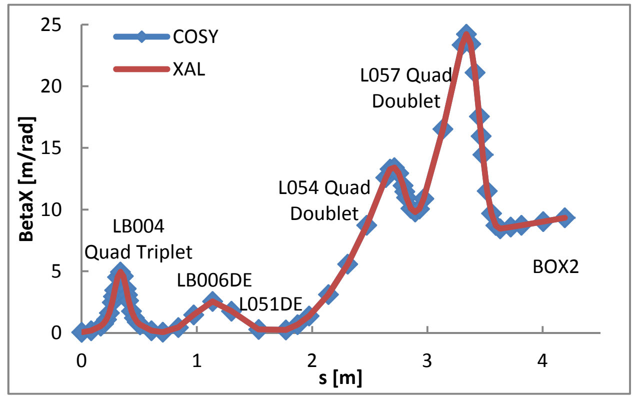

Figure 3: LB to BOX2 BetaX in XAL and COSY. In all data plots, s refers to the ideal particle path length.

Before looking at the Courant-Snyder parameters from these simulations, we need to verify that the energy matches. Right now, the energy gain through each two-gap cavity is approximated with a single gap at the center of the cavity. The model can be expanded in the future to include multiple gap cavities. The energy gain is given by the following formula:

$$\Delta E = \frac{Q}{A} \times Amp \times V_0 \times TTF \times \cos\phi \, . \qquad (1)$$

The Transit Time Factor (TTF) is calculated by XAL by inputing the coefficients to a polynomial function that fits the TTF vs relativistic beta curve for the accelerating cavity. The coefficients of the derivative of this function are also input. For the ReA3 simulation, the b041 cavity type (optimized for beta=0.041) energy agreement is good between the XAL and IMPACT models (see Figure 4). The FRIB simulations considered here used TTF=1, and the IMPACT and XAL models had identical energy gains.

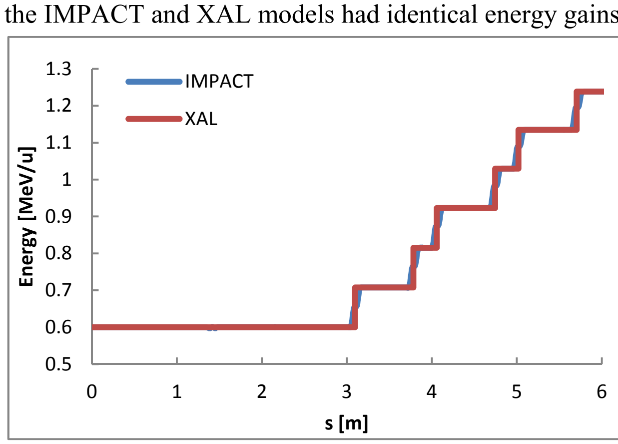

Figure 4: ReA3 Linac through second cryomodule Energy [MeV/u] in XAL and IMPACT.

After XAL's energy gain model has been verified by matching with IMPACT's results, we find that there is also good agreement for the transverse motion in both the

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X and Y planes for both the ReA3 and FRIB models.

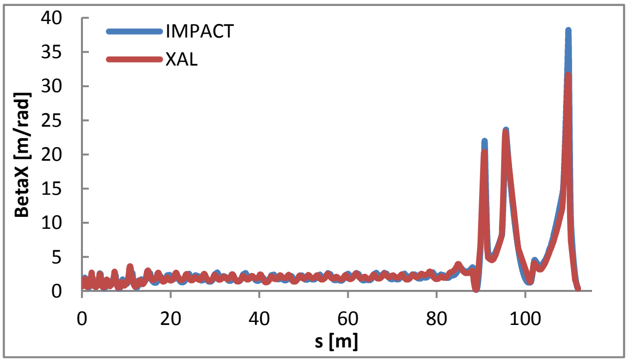

Figure 5: Current design FRIB Segment 1 through first bending section BetaX [m/rad] in XAL and IMPACT.

Figure 5 shows the IMPACT and XAL results for β_x for the current design of FRIB's first linac segment through s~85m. The first bending segment is from s~85-115m. The ReA3 simulations also agree very well (see Figure 6).

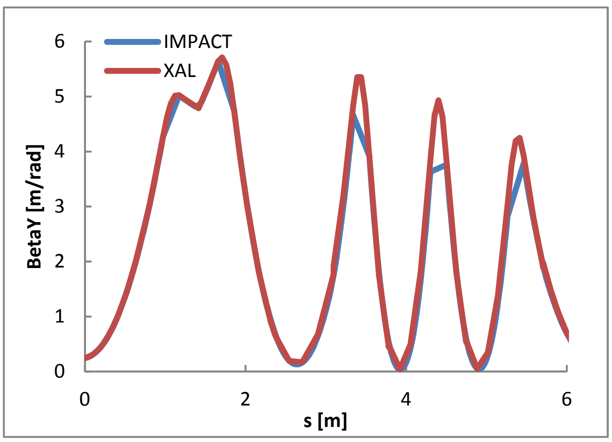

Figure 6: ReA3 Linac through second cryomodule BetaY [m/rad] in XAL and IMPACT.

Longitudinal Benchmarking

The longitudinal benchmarking process is slightly more complicated than the transverse benchmarking, in that each code uses different units for their longitudinal motion. XAL's coordinates are (z,z') while COSY uses (l,ΔW/W) and IMPACT uses (Δϕ,ΔW/W). This requires a simple coordinate transformation, given by:

$$\begin{pmatrix} z \\ z' \end{pmatrix} = \begin{pmatrix} \frac{\gamma+1}{\gamma} & 0 \\ 0 & \frac{1}{\gamma(\gamma+1)} \end{pmatrix} \begin{pmatrix} l \\ \frac{\Delta W}{W} \end{pmatrix}, \quad (2)$$

$$\begin{pmatrix} z \\ z' \end{pmatrix} = \begin{pmatrix} \frac{-\beta c}{360 f_{RF}} & 0 \\ 0 & \frac{1}{\gamma(\gamma+1)} \end{pmatrix} \begin{pmatrix} \Delta\phi \\ \frac{\Delta W}{W} \end{pmatrix}. \quad (3)$$

The 6x6 transfer matrix for vertical/horizontal dipoles including entrance/exit angles has been confirmed with COSY. XAL has been compared to IMPACT simulations to benchmark the RF cavities (see Figure 7). The vertical dashed lines indicate the location of the cavities.

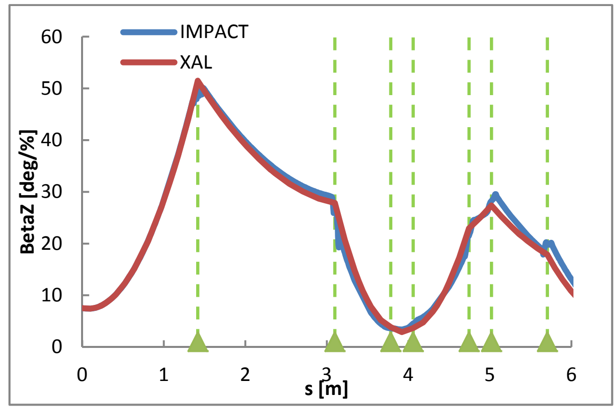

Figure 7: ReA3 Linac through second cryomodule BetaZ [deg/%] in XAL and IMPACT.

CONCLUSIONS AND OUTLOOK

The benchmarking of XAL has been completed for many elements. Its cavity model can be improved in the future to include 2-gap cavities, but for now the model matches IMPACT very well through ReA3's second cryomodule which is currently being commissioned. XAL's on-line model is ready for use at ReA3, and will soon hopefully become a key tool in its tuning procedure.

As we gain experience using the XAL on-line model at ReA3, we will begin working on a cavity phase tuner/optimizer, with model simulation of cavity settings. In addition to facilitating the commissioning process at ReA3, such techniques may be useful in the future for other ion accelerators such as FRIB.

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