PROGRESS AND PLAN OF OPEN XAL APPLICATIONS FOR FRIB*

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Abstract

FRIB driver linac will deliver all heavy ion beams up to uranium with beam energy above 200 MeV/u, maximum beam power on fragment target 400 kW for rare isotope productions. In the FRIB project, constructions of state-of-the-art low beta cryomodules and developments of advanced physics application software are important. In this paper, our major progress and the development plan of physics application software for the FRIB driver linac within the Open XAL framework are discussed, which include the FRIB linac online model, back-end database for physics applications, virtual accelerator for software testing, and several pilot physics applications. Deploying and initial testing of Open XAL and the pilot applications are currently planned for a new cryomodule at Michigan State University.

INTRODUCTION

The FRIB, Facility for Rare Isotope Beams, is currently under construction on the campus of MSU, Michigan State University. This nuclear project is funded by the Department of Energy Office of Science, MSU, and the State of Michigan. The total budget of the project is about 730 million dollars, and it will be completed in 2022 [1].

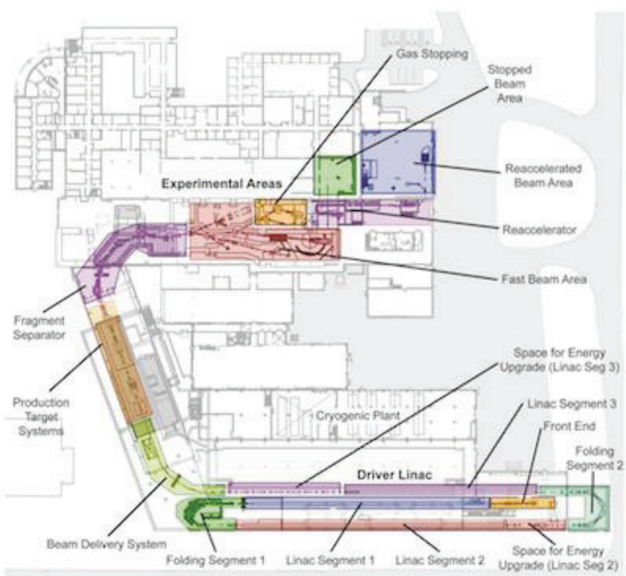

Figure 1: Layout of the FRIB

Figure 1 shows the layout of FRIB. Major components of the facility include a driver linac, a fragment target and separator, re-accelerator, nuclear experiment instruments, and several beam transport lines. The linac consists of a front end, three straight superconducting linac sections, two 180º isochronous, achromatic folding sections, and a beam delivery system. The driver linac accelerates and transports primary beams to the fragment target for rare isotope productions, and in the design, it will deliver all heavy ion beams up to uranium, beam energy above 200 MeV/u, and beam power on target 400 kW [2]. Because various ion species and different energy are necessary to a wide verity of nuclear research program, and a 90% beam availability is required – build, tuning, and operation of the world's first SRF linac for high-power heavy ion beams will be a challenge.

OPEN XAL COLLABORATION

Extended accelerator language, or XAL – a Java based accelerator physics software toolkit, has been successfully established at the Spallation Neutron Source (SNS) [3, 4]. It was later applied for Japan Proton Accelerator Research Complex linac [5], Linac Coherent Light Source [6], and some other accelerators. Because of the distinctiveness and complexity of each unique accelerator, it is difficult to build one-size-fits-all suit, however, as the similarity of accelerator structure and component, it is favourable to have a common toolkit. The Open XAL collaboration is formed to develop a common platform for accelerator modelling, control and analysis [7], participant institutes include SNS, European Spallation Source (ESS), FRIB, China Spallation Neutron Source (CSNS), TRIUMF, and Cosy Lab. Monthly meeting has been established, and there were several Open XAL workshops at SNS, FRIB, and ESS. Current status and more info about the Open XAL project can be checked online [8].

Even though XAL has been successfully applied for the SNS operation with a 1.4 MW beam power and a beam availability more than 90%, the SNS team still managed to make major contributions to the Open XAL project which benefits all other institutes: modified the software structure, reduced dependencies on third-party libraries, optimized the core, and migrated many validated physics applications into Open XAL. Most importantly, in earlier this year, it has been deployed at the SNS control room successfully; operators and physicists can use Open XAL to control and analyse the SNS accelerators [9].

The ESS team built an automation testing framework for Open XAL physics applications, benchmarked the online model against other linac models such as, the Java ESS linac model and TraceWin, and they also improved the documentation in order to ease the learning curves to the developers and to general users. They are planning to work on benchmarking and improving the space charge model, and adding new RF cavity model [10].

Because many accelerator physicists favour scripting languages, such as MATLAB and Python, for the control room testing and for fast developments, it is required to

* Work supported by the U.S. Department of Energy Office of Science under Cooperative Agreement DE-SC0000661
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support scripting languages within Open XAL. Currently, FRIB plans to support MATLAB, ESS plans to support Python, and SNS will continue to support Jython and Jruby. The selection of a specific scripting language is mainly determined by the available resources and the majority of physicists at each individual institute.

PLAN OF PHYSICS APPLICATIONS

Open XAL physics applications are planned for design, construction, commissioning, and operation of the FRIB accelerator systems, and the back-end database for FRIB physics applications in the plan is to use MySQL, because it is also an open source project, and the FRIB accelerator configuration database uses MySQL too.

A total of nearly 400 independently phased low beta SRF cavities will be built and installed in more than 50 cryomodules at the FRIB, and because of the high beam power and large scale of SRF acceleration structures, a robust machine protection system (MPS) is critical to the commissioning and operation. In physics applications, we plan to develop MPS software tools to handle different machine modes and beam modes to cover both tuning and normal operation, and fault postmortem analysis.

Beam tuning is the main focus of physics applications, and we plan to develop an online model for multi-charge state beams, and develop physics applications for linac lattice design, online beam tuning, and operation [11]. Because second order beam optics will be needed to tune the folding areas and non-linear issues can be important to the FRIB linac, which is difficult to be covered by the linear model, we plan to use well established accelerator models for offline analysis and for fine tuning of the FRIB linac. In the current plan, linac uses IMPACT [12], and folding uses MAD-X [13]. A model server is under development to handle both offline and online models seamlessly [14].

In addition to accelerator modelling and beam physics applications, it is preferable to cover other important areas such as RF conditioning and cryomodule commissioning software for FRIB, which are very useful to complete the accelerator commissioning campaign, smooth transition from maintenance to routine operation, and to increase the beam availability. Developments of Web based services and physics applications are also preferable to us, because it will reduce the costs and efforts for deployments and maintenances of physics applications. Totally about 30 physics services and applications are planned for the commissioning including cavity phase and amplitude tuning, transverse matching, and longitudinal matching etc, and we plan to deploy and test several Open XAL applications recently on a newly installed cryomodule.

PROGRESS OF PHYSICS APPLICATIONS

Virtual Accelerator (VA) application is mainly used for the purpose of software testing, and it can be very helpful even before the real machine been built; it can also be applied for accelerator design and construction: test the accelerator design models and beam tuning algorithms for planned diagnostics with errors and noise. It is developed at SNS originally, and FRIB added more new features to it later. Figure 2 shows a snapshot of Virtual Accelerator application for the FRIB linac segment 1 (LS1).

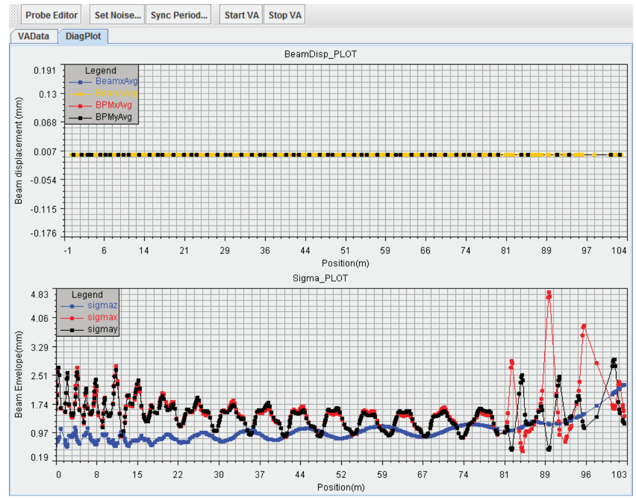
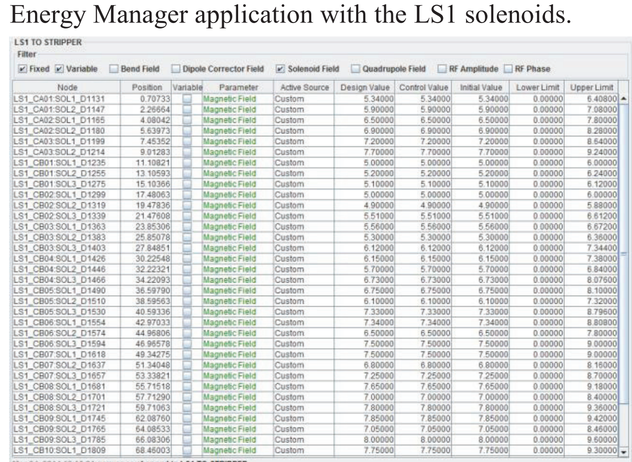


Figure 2. FRIB linac segment 1 in Virtual Accelerator. Upper, beam centroid along the linac; lower, transverse and longitudinal beam size along the linac.

Energy Manager application is developed to design and optimize accelerator lattice for different beam energy, it has been applied in the SNS accelerators for both beam commissioning and routine operation. It is an important tool to an SRF linac for proton or heavy-ion beams, but unfortunately, solenoid was not coded in the application. We added solenoid into the application as the FRIB linac sections use solenoid focusing, and now it can be applied to optimize solenoid lattice too. Figure 3 shows a screen of Energy Manager application with the LS1 solenoids.


LS1 TO STRIPPER

Filter

Fixed, Variable, Bend Field, Dipole Corrector Field, Solenoid Field, Quadrupole Field, RF Amplitude, RF Phase

Node	Position	Variable	Parameter	Active Source	Design Value	Control Value	Initial Value	Lower Limit	Upper Limit
LS1_CA01:SOL1_D1131	0.70733		Magnetic Field	Custom	5.34000	5.34000	5.34000	0.00000	6.40800
LS1_CA01:SOL2_D1147	2.26664		Magnetic Field	Custom	5.90000	5.90000	5.90000	0.00000	7.08000
LS1_CA02:SOL1_D1165	4.08042		Magnetic Field	Custom	6.50000	6.50000	6.50000	0.00000	7.80000
LS1_CA02:SOL2_D1180	5.63973		Magnetic Field	Custom	6.90000	6.90000	6.90000	0.00000	8.28000
LS1_CA03:SOL1_D1199	7.45352		Magnetic Field	Custom	7.20000	7.20000	7.20000	0.00000	8.64000
LS1_CA03:SOL2_D1214	9.01283		Magnetic Field	Custom	7.70000	7.70000	7.70000	0.00000	9.24000
LS1_CB01:SOL1_D1235	11.10821		Magnetic Field	Custom	5.00000	5.00000	5.00000	0.00000	6.00000
LS1_CB01:SOL2_D1255	13.10593		Magnetic Field	Custom	5.20000	5.20000	5.20000	0.00000	6.24000
LS1_CB01:SOL3_D1275	15.10366		Magnetic Field	Custom	5.10000	5.10000	5.10000	0.00000	6.12000
LS1_CB02:SOL1_D1299	17.48063		Magnetic Field	Custom	5.00000	5.00000	5.00000	0.00000	6.00000
LS1_CB02:SOL2_D1319	19.47836		Magnetic Field	Custom	4.90000	4.90000	4.90000	0.00000	5.88000
LS1_CB02:SOL3_D1339	21.47608		Magnetic Field	Custom	5.51000	5.51000	5.51000	0.00000	6.61200
LS1_CB03:SOL1_D1363	23.85306		Magnetic Field	Custom	5.56000	5.56000	5.56000	0.00000	6.67200
LS1_CB03:SOL2_D1383	25.85078		Magnetic Field	Custom	5.30000	5.30000	5.30000	0.00000	6.36000
LS1_CB03:SOL3_D1403	27.84851		Magnetic Field	Custom	6.12000	6.12000	6.12000	0.00000	7.34400
LS1_CB04:SOL1_D1426	30.22548		Magnetic Field	Custom	6.15000	6.15000	6.15000	0.00000	7.38000
LS1_CB04:SOL2_D1446	32.22321		Magnetic Field	Custom	5.70000	5.70000	5.70000	0.00000	6.84000
LS1_CB04:SOL3_D1466	34.22093		Magnetic Field	Custom	6.73000	6.73000	6.73000	0.00000	8.07600
LS1_CB05:SOL1_D1490	36.59790		Magnetic Field	Custom	6.75000	6.75000	6.75000	0.00000	8.10000
LS1_CB05:SOL2_D1510	38.59563		Magnetic Field	Custom	6.10000	6.10000	6.10000	0.00000	7.32000
LS1_CB05:SOL3_D1530	40.59336		Magnetic Field	Custom	7.33000	7.33000	7.33000	0.00000	8.79600
LS1_CB06:SOL1_D1554	42.97033		Magnetic Field	Custom	7.34000	7.34000	7.34000	0.00000	8.80800
LS1_CB06:SOL2_D1574	44.96806		Magnetic Field	Custom	6.50000	6.50000	6.50000	0.00000	7.80000
LS1_CB06:SOL3_D1594	46.96578		Magnetic Field	Custom	7.50000	7.50000	7.50000	0.00000	9.00000
LS1_CB07:SOL1_D1618	49.34275		Magnetic Field	Custom	7.50000	7.50000	7.50000	0.00000	9.00000
LS1_CB07:SOL2_D1637	51.34048		Magnetic Field	Custom	6.80000	6.80000	6.80000	0.00000	8.16000
LS1_CB07:SOL3_D1657	53.33821		Magnetic Field	Custom	7.25000	7.25000	7.25000	0.00000	8.70000
LS1_CB08:SOL1_D1681	55.71518		Magnetic Field	Custom	7.65000	7.65000	7.65000	0.00000	9.18000
LS1_CB08:SOL2_D1701	57.71290		Magnetic Field	Custom	7.00000	7.00000	7.00000	0.00000	8.40000
LS1_CB08:SOL3_D1721	59.71063		Magnetic Field	Custom	7.80000	7.80000	7.80000	0.00000	9.36000
LS1_CB09:SOL1_D1745	62.08760		Magnetic Field	Custom	7.85000	7.85000	7.85000	0.00000	9.42000
LS1_CB09:SOL2_D1765	64.08533		Magnetic Field	Custom	7.05000	7.05000	7.05000	0.00000	8.46000
LS1_CB09:SOL3_D1785	66.08306		Magnetic Field	Custom	8.00000	8.00000	8.00000	0.00000	9.60000
LS1_CB10:SOL1_D1809	68.46003		Magnetic Field	Custom	7.75000	7.75000	7.75000	0.00000	9.30000

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Figure 3. Energy Manager application with solenoid lattice of the FRIB linac segment 1.

Back-end database becomes more and more important to modern accelerator controls and physics applications. MySQL is adopted at FRIB, which is different from the SNS as where ORACLE is used. Plug-ins for connection of Open XAL physics applications with MySQL database are developed. To reduce data duplication, we merged the database schemas of PVLogger application with SCORE (save/compare/restore) application, the two applications

ISBN 978-3-95450-142-7

share the same database tables then. We also modified the application interfaces (APIs) accordingly, so that the two applications have full features – both can take machine snapshots on demand, and/or periodically.

In the beam commissioning, verification of the polarity of magnet power supplies – including focusing magnets and correctors, and polarity of beam position monitors (BPMs) is a tedious but necessary task. At SNS, a physics application Orbit Difference has been developed for this purpose, and because there is no beam coupling in the quadrupole lattice, it was relatively easy to find the errors. However at FRIB, we use solenoid lattice for acceleration and transport of multi-charge state beams, which causes strong horizontal-vertical beam coupling, and in this case, it is not straight forward to distinguish between a wrong corrector and a wrong solenoid from orbit difference. We developed a new application, Orbit Response, which not only shows model predicted orbit against measurements, but also include rotation angles of the beam centroid. It will help finding errors of solenoids, correctors, as well as BPMs. Figure 4 shows snapshots of the application, and at here, Virtual Accelerator application provides all the signals for both BPM measurement and the linac model.

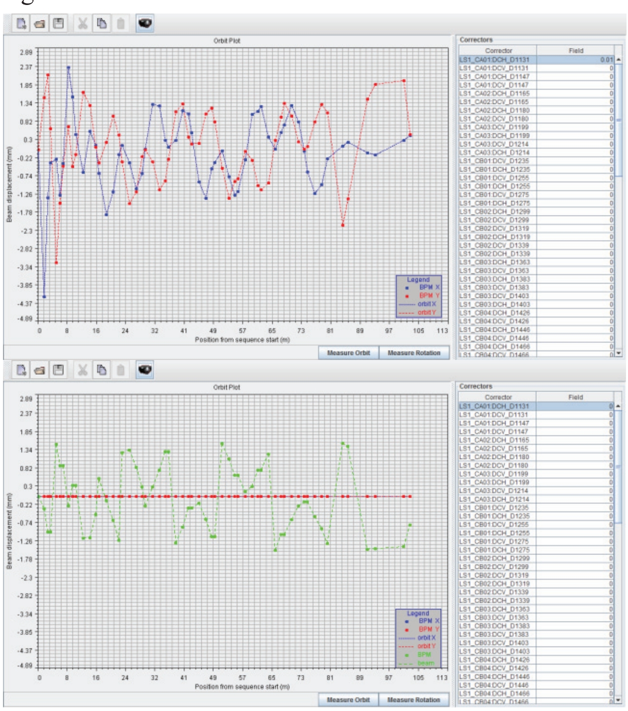

Figure 4. Orbit Response application. Upper, beam orbit response along LS1, and lower, rotation angle response.

In addition to beam modelling and analysis, Open XAL applications could cover other areas of accelerator control and tuning such as, building soft feedback, automation of RF conditioning and cryomodule testing, cycling normal conducting magnet, and degaussing SC magnet. Because superconducting dipole correctors and 9-Tesla solenoids are installed in most FRIB cryomodules, degaussing the magnets is necessary to reduce residual magnetic fields near the SRF cavities. We conducted degaussing process manually for a few times in the cryomodule testing which was very time consuming, and the Degauss application is developed to address this issue. It can degauss or cycle solenoids and correctors simultaneously, and GUI of the application is based on JavaFX and HTML5.

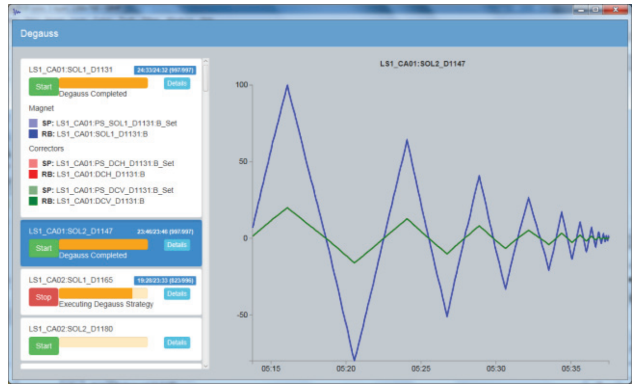

Figure 5. Degauss application for cryomodule magnets, currents versus time of SC solenoids and dipole correctors simulated with Virtual Accelerator.

Several Open XAL physics applications for FRIB have been successfully demonstrated using Virtual Accelerator, however, it cannot replace testing on a real machine. A new cryomodule has recently been installed at MSU [15], which is a good test bench for physics applications. We are working on testing physics applications: Scan1D/2D, SCORE, PVLogger, and Degauss, for control of the real machine, and with the back-end database.

CONCLUSIONS

Plan and progress of Open XAL physics applications for the FRIB linac are discussed. It is a very challenging project, and we are facing a lot of technical difficulties. However, solid and steady progress has been made in the developments.

ACKNOWLEGEMENTS

We would like to thank all the developers who made Open XAL an attractive project. All previous and current members of the physics application group are highly appreciated for discussions and contributions.

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