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DEVELOPMENT PLAN FOR PHYSICS APPLICATION SOFTWARE FOR FRIB DRIVER LINAC *

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Abstract

Facility for Rare Isotope Beams (FRIB) is a high-power heavy ion accelerator facility currently under construction at Michigan State University. We recently decided to adopt EPICS V4 for the architecture for commissioning application software development for FRIB linac. In this paper, we present our plan for the commissioning application development with its present status.

INTRODUCTION

Facility for Rare Isotope Beams (FRIB) is a high-power heavy ion accelerator facility currently under construction at Michigan State University under a cooperative agreement with the US DOE [1]. Its driver linac operates in CW mode and accelerates all stable ions to energies above 200 MeV/u with the beam power on target up to 400 kW. The linac has a folded layout as shown in Fig. 1, which consists of a front-end, three Linac Segments (LSs) connected with two Folding Segments (FSs), and Beam Delivery System (BDS) to deliver the accelerated beam to target. The linac is located in a tunnel underground with the exception of two ECR ion sources located on the ground level (not shown in Fig. 1). The beam is delivered to the linac tunnel through a vertical beam drop. LSs consist of two types of superconducting QWRs (Quarter Wave Resonators) with geometrical β of 0.041 and 0.085, and two types of superconducting HWRs (Half Wave Resonators) with geometrical β of 0.29 and 0.53. LS1, LS2, and LS3, respectively, have 14, 24, and 6 cryomodules. The total number of superconducting cavities is 332 including rebuncher cavities in FSs. The linac has four tuning beam dumps, BD FS-1a, BD FS-1b, BD FS-2, and BD BDS, as shown in Fig. 1.

FRIB driver linac is substantially larger both in scale and beam power than existing facilities of a similar kind, which poses significant challenges in realizing beam commissioning or initial tuning of operating parameters. Efficient commissioning is essential to minimize the risk of component damage by beam loss during the commissioning. Then, high level application software assisted by online model is essential to realize efficient commissioning. In addition, we expect frequent change of accelerated ion species to meet the request from users once user operation is started. Judging from the present operation cycle of coupled cyclotron facility in Michigan State University, we may change ion species once in a week or two. Then, swift retuning after switching ion species is essential to realize high beam availability. It will require physics application to support model based retuning. We present our plan to develop physics applications to serve these purposes in this paper while our present emphasis is put on those to support commissioning. We here define physics applications as high level application software for commissioning utilizing model. We also discuss our plan to develop software infrastructure to support those applications and their development in this paper. Our discussion here does not include simple OPIs (Operator Interfaces) to show and set values for PVs (Process Variables) which is supposed to support accelerator operation.

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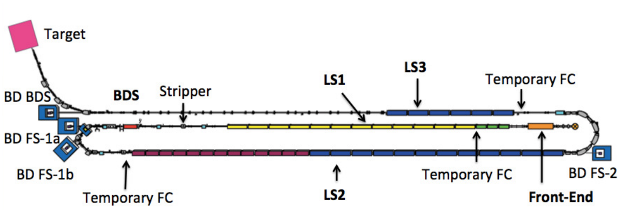

Figure 1: Schematic layout for FRIB driver linac.

ARCHITECTURE FOR PHYSICS APPLICATION SOFTWARE

While we have assumed OpenXAL [2] for the architecture for physics application software development, we recently decided to adopt EPICS V4 [3] for the architecture instead of OpenXAL. EPICS V4 has been rapidly developed to support recent commissioning of NSLS-II, and we can take advantage of the most up-to-date developments by adopting it. Its nobel design features include three-tier structure with middle layer services which enables efficient development of high level applications (See Fig. 2).

One of the advantages of OpenXAL is the integrated online model. However, OpenXAL model does not support features specific but essential to FRIB linac including multi-charge state acceleration, non-axial symmetric field of an RF cavity, etc. It necessitates significant extension of func-

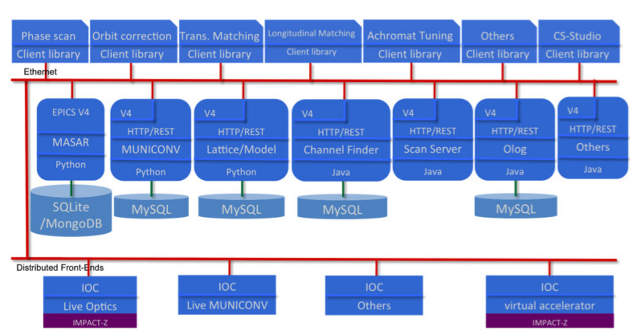

Figure 2: Planned architecture for FRIB physics application.

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tionality of OpenXAL model to support those features. Another advantage of OpenXAL is the available set of commissioning application software mainly developed for SNS commissioning. However, the applicability of those applications to FRIB linac should be carefully verified because of the difference of assumed lattice. We note that solenoid lattice instead of quadrupole lattice are used, and that non-axisymmetric components of the RF cavity field are non-negligible. We have been developing a model in-hose as a prototype for the online model to meet FRIB specific needs which has not been integrated into the OpenXAL architecture [4, 5]. In short, we may have little benefit from those advantages of OpenXAL.

Meanwhile, most of EPICS V4 services are applicable to FRIB without significant modifications except for those related to online model. As the online model in NSLS-II has been developed for an electron ring, we need to develop adequate online model for FRIB use.

After evaluating the recent development for EPICS V4, we concluded that combination of EPICS V4 and the in-house developed online model will be the most reasonable choice for architecture to support development of physics application software for FRIB driver linac as it enables us to focus our resources to FRIB specific developments while taking advantage of the benefits from recent developments in NSLS-II.

STRATEGY FOR ONLINE MODEL DEVELOPMENT

As we discussed above, we have been developing an online model in-house to meet FRIB specific needs [4,5]. The emphasis of the development is put on fast execution speed and coverage of FRIB specific needs. To realize the fast execution speed, each accelerator component is modeled with a thin kick neglecting the space charge effect. The code is designed to accommodate multi-charge-state acceleration and non-axisymmetric field of an RF cavity. We call this model as TLM (Thin Lens Model), and we are developing an online model and virtual accelerator utilizing this model.

The specific features required for FRIB include the following;

- Solenoid focusing lattice
- Non-axial symmetric field component from RF cavity
- Multi charge state acceleration
- Achromat arc sections between linac segments
- Second order achromat with sextupole magnets

The physics model of TLM was verified with Matlab model, and it has been converted into a JAVA code to improve the execution speed. Its benchmark against IMPACT [6] code has mostly been completed and we are now implementing interface to utilize it as an online model and virtual accelerator.

In addition to TLM-based online model and virtual accelerator, we plan to develop those based on IMPACT also. We adopt IMPACT as the reference simulation code in designing FRIB linac. IMPACT is a three-dimensional PIC (Particle-In-Cell) code originally for modeling of space-charge dominated beams. We have been utilized it to track particles in FRIB linac taking advantage of its robust framework while the space-charge effect is negligible in most part of our linac. Although a 3D PIC simulation is generally time-consuming, IMPACT has a function to turn off all PIC calculations for zero-current simulation. We are developing a particle-tracking-based online model and virtual accelerator utilizing this function. We plan to utilize IMPACT-based virtual accelerator to verify the commissioning algorithms, and IMPACT-based online model to supplement TLM-based online model. IMPACT-based online model will be slower than the TLM-based counterpart, but it has an advantage in coverage of special elements, such as sextupole magnets, and its accuracy.

FIVE MAJOR APPLICATIONS

We have identified the following five major applications to support commissioning of FRIB linac for which we focus resources for development.

- Phase and amplitude scan for RF cavities
- Orbit correction
- Transverse and longitudinal matching
- Achromat tuning
- Energy manager

The first four applications respectively correspond to four major tuning activities assumed in the commissioning, for which we don't elaborate the detailed tuning procedures in this paper. The energy manager application calculates the operating parameters for different operation conditions based on a set of operation parameters established with a beam-based tuning. Use cases for this application include to find phase settings to recover the operation with a different amplitude set-point for a cavity and to find a set of operation parameters for different ion species. The former will be required to restore the operation after a cavity failure.

SCRIPTING ENVIRONMENT

Before investing significant effort in application development, we plan to prototype the application to verify the tuning algorithm carefully. This process is especially important for FRIB linac with no other facility of a similar kind in scale and beam power. We assume to use scripting environment for prototyping and verify the tuning algorithm with IMPACT-based virtual accelerator. We plan to adopt Python and Matlab for scripting environment.

We can utilize the scripting environment for efficient prototyping in preparing commissioning applications. After

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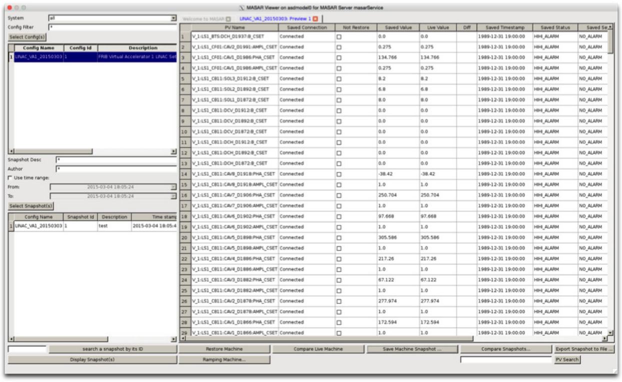

Figure 3: MASAR service, or save and restore service, under testing with FRIB configuration.

we start commissioning, we may also use it for quick development of small software to flexibly respond to unexpected demand we may encounter in the course of commissioning.

PRESENT DEVELOPMENT STATUS AND PATH FORWARD

We have been started to port EPICS V4 services to test with FRIB configurations, most of which will be ready for use soon (See Fig. 3 for example). We are now focusing to develop infrastructure necessary for application prototyping, which includes IMPACT-based online model/virtual accelerator and scripting environment (See Fig. 4). It will be followed by prototyping of five major applications we discussed and implementation of the application software.

We adopt staged approach for the commissioning of FRIB linac [7], where we start beam commissioning from ion source and expand the area with beam downstream in a staged way. We are now in coordination with civil construction to accelerate the installation of ion source, and the ion source beam commissioning can be started as early as at the end of 2016. However, the need for physics application for ion source commissioning is limited. The beam commissioning of the next section, or front-end including RFQ, will be started in early 2018. We plan to complete the development of major application software and related software infrastructure with sufficient float to the start of the beam commissioning of this section.

SUMMARY

While we have assumed OpenXAL for the architecture for commissioning application software development for FRIB linac, we recently decided to adopt EPICS V4 for the architecture instead of OpenXAL. It enables us to focus on developments to meet FRIB specific requirements while taking advantage of recent development in EPICS V4. Online model is a major area we need significant development and we can utilize TLM which has been developed in-house. We

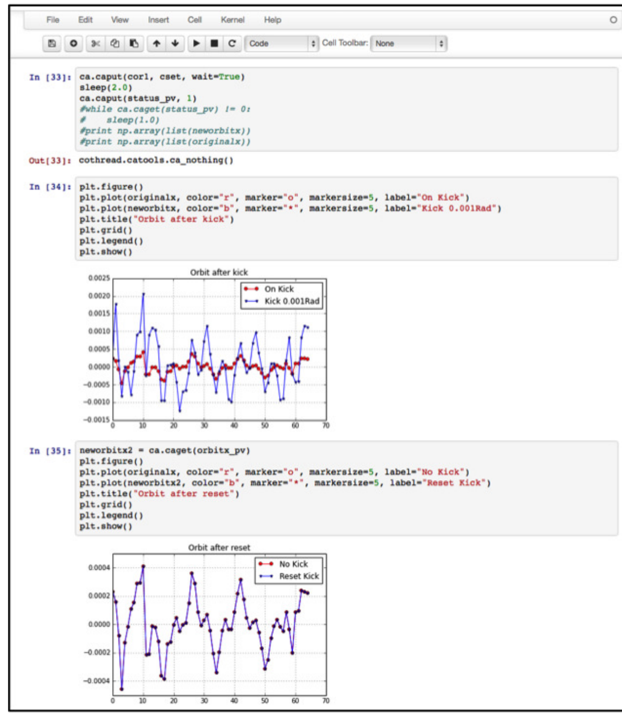

Figure 4: IMPACT based virtual accelerator under testing with Python environment.

also plan to develop IMPACT based online model to complement TLM model.

Our goal is to deliver five major applications and related software infrastructure with sufficient float to the start of the beam commissioning of the front-end including RFQ, which is planned in early 2018. We already started to port EPICS V4 services to successfully test with FRIB configurations. We expect to deploy IMPACT-based online mode and scripting environment soon to support prototyping of major applications.

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