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PLANS FOR THE EUROPEAN SPALLATION SOURCE BEAM PHYSICS CONTROL SOFTWARE

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Abstract

The commissioning and operations planning for the European Spallation Source is currently being defined. It is foreseen that the ESS will begin to deliver beam on target by mid 2019, something which is urging a well structured and thought through plan both for commissioning and operations. In this paper we will discuss the plans for beam physics operational software, priorities and software services needed during the different stages of beam commissioning.

INTRODUCTION

The European Spallation Source will become the world's brightest neutron source when it begins the user program in 2023. The neutrons are produced through a spallation process using a 5 MW proton beam as the driver. The accelerator providing such a proton beam needs to be carefully designed and commissioned in order to meet requirements for performance and radiation levels, and allow for safe and reliable operation.

At ESS it has been decided [1] that the Open XAL framework will be used [2–4]. Open XAL is based on the earlier XAL framework, which was developed and thoroughly tested at the Spallation Neutron Source (SNS) at ORNL in Oak Ridge, USA for many years. Since the SNS and ESS accelerators share similar structures of components and similar interfaces such as for example the EPICS layer [5], it has been recognised in several earlier evaluations that this is a suitable choice for ESS [1, 6]. The Open XAL is an open-source development, and brings a multitude of existing applications, some of which can be directly deployed at ESS as is, and some which have great potential for reuse. This allows a rapid development of full suite of needed applications for the commissioning and provides many opportunities for benchmarking since the framework is already used in production at partner labs [7, 8].

It has been recognised that an online model of the machine is desirable in order to allow for more advanced and accurate control of the beam. The online model needs to provide reasonably good predictions of the beam transport through the machine while at the same time be fast enough to provide live feedback to the operations. The Open XAL framework is built around an online model and allows flexibility for us to develop and provide alternative modelling solutions within the framework.

UNDERLYING FRAMEWORK

In particular during commissioning, but also during machine studies, it is often hard to predict well in advance precisely what activities will be carried out and in which order. An anticipated method for a certain calibration might not work as well as expected, beam instrumentation that was planned to be used as input might not be operational, or other equipment may to some degree not function properly.

For this reason it is important to have access to general, multipurpose applications. An example is scanning of one or several parameters (e.g. magnet strengths) while logging the data from a set of instrumentation devices. Off-line analysis might be required in order to be able to compare to simulations and fully understand the results, but advanced generic applications that allow for analysis such as multiparameter fitting of data and immediate comparison to an online model will be valuable during beam commissioning.

Scripting

The Open XAL framework already support the option to write the applications in JRuby or Jython. These applications will still be Java applications, but the source code language is more Ruby- or Python-like. At ESS we have been investigating the option to write native Python scripts which access the Open XAL framework through a Python-Java layer. We have successfully tested the integration of JPype[9] at SNS, and there is ongoing work at ESS to set up an environment with Jupyter[10] servers that can be accessed through a web interface [11]. We believe this will allow physicists to do quicker prototypes of application routines. It will also serve as a useful tool in stages of commissioning where rapid development is needed, and the vast library of available Python analysis modules may come in handy.

Virtual Accelerator

An advanced virtual accelerator can aid during the development of the applications and development of commissioning strategies. With a reasonable feedback to the correction routines one might get a first idea of how well the correction will perform and iron out early bugs and problems in the software. Communication with a virtual EPICS layer, logging of data etc should be tested well in advance of the start of commissioning with beam.

ESS Linac Simulator

The ESS Linac Simulator (ELS) [12] has been under development at ESS for several years now. It is a new online model which is optimised for the ESS linac. The well defined

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structure of Open XAL allows us to quickly switch between different underlying physics models in used by the online model. This benefits both us and the community of labs that make use of this framework. It is straight forward for us to benchmark the model at other labs [7, 8].

The ELS for the moment implements only envelope tracking, as macro-particle tracking codes have been deemed too slow for online analysis. It has however been recognised that availability of some form of particle tracking code is necessary for e.g. the commissioning of the RFQ, and that one might be able to write a sufficiently fast particle tracking code for an online model using for example GPU programming [13, 14]. For the moment there are no definite plans to develop macro-particle tracking in the online model. A method based on beam density tracking is currently being analysed at ESS [15].

LIST OF APPLICATIONS

Defining a complete and finalised list of applications is an ongoing task that will likely see further iterations after the start of commissioning or even operations. A certain set of standard applications can already be defined, such as general applications needed for commissioning and machine development studies, to e.g. collect and sort data, run parameter scans, acquire instrumentation measurements etc. Further, there are fundamental beam based tuning activities that needs to be implemented for any linac such as trajectory correction and RF phase and amplitude corrections. The implementation of in particular the latter can often vary depending on the technical specifics of each machine. One might often have a rudimentary and largely manual approach during the early stages and develop a more sophisticated routine as the machine is better understood over time.

There has been ongoing work to define and sort the list of needed applications at ESS in the past year [16]. A review of the (re-)usability of the existing applications within the Open XAL framework has also been carried out [17]. In Table 1 a short summary of some of the planned applications are listed. In this list we have included the first section of the machine where the application will be needed during commissioning. Most of these applications are marked as “partly” available, which indicates that while existing applications might not be possible to use as is, there are similar applications where parts of the logic may be reused or modified to our purpose.

Transversal and longitudinal corrections of the beam centroid positions are one of the most essential tasks during the beam commissioning. In the following we discuss applications for those adjustments as examples.

Trajectory Corrections

It is necessary to correct the beam trajectory from the exit of the RFQ until the raster magnets in the Accelerator to Target (A2T) area. An example of uncorrected beam trajectory through the linac is shown in Fig. 1.

The correction algorithms we have applied in simulations so far are reasonably straight forward 1-1 corrections, where

Table 1: Some of the needed applications for beam physics operations at ESS (Second column indicates to which extent there is an already existing application available in Open XAL. The final column indicates the first section of the linac where this application is needed. The acronyms stands for Low Energy Beam Transport, Radio Frequency Quadrupole, Medium Energy Beam Transport, Drift Tube Linac and Accelerator to Target.)

Title	Existing	First Needed
Online Model	Partly	Early
Virtual Accelerator	Yes	Early
Parameter Scan	Partly	Source
Pulse Shape	No	LEBT
Matching Tool	Partly	RFQ
Synoptic Viewer	No	RFQ
Twiss Scan	Partly	MEBT
Trajectory Correction	Partly	MEBT
RF Cavity Scan	Partly	MEBT
Energy Meter	Partly	DTL
Rastering Control	No	A2T

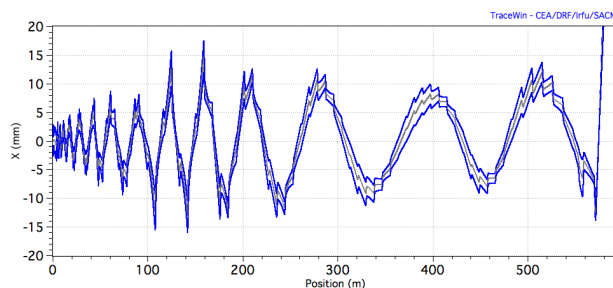


Figure 1: An example showing an uncorrected trajectory in the ESS linac, from the exit of the RFQ until the target.

each steering magnet has a manually defined BPM where the trajectory is minimised. In a dedicated trajectory application, one should anticipate that more advanced correction algorithms might be desired or even needed at some point in the future. Examples include a 1-1 steering using response matrix and a SVD solver [18], or more advanced correction algorithms such as dispersion free steering [19]. The trajectory correction is not expected to be the most challenging part of the beam based correction in the ESS linac.

RF Phase & Amplitude

It is important that the correct phase and amplitude is seen by the beam in order to get the correct amount of capture and acceleration through the different sections of the linac. In hadron linacs this becomes more complicated because the beam is not relativistic and the space charge effect adds a significant amount of non-linearity. Because the beam is not relativistic it does not accelerate on crest through all cavities.

There are several strategies for performing a beam based RF alignment that one may consider [20–22]. The response from amplitude or phase modulation in a cavity is seen as a

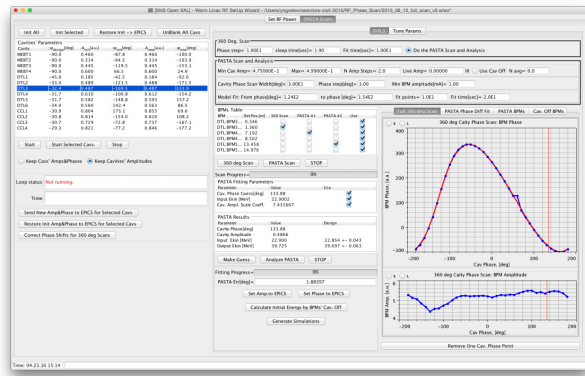


Figure 2: A screenshot from the warm linac RF setup application currently in use at SNS, developed by A. Shislo.

phase variation in downstream BPM's. Hence the specific design of BPM's, low level RF, and phase reference (timing) of the machine all impact how and how well these corrections may be done.

The different sections of the machine may need separate applications for their setup. For example at SNS there is a separate application for the warm and cold linac even though the approach is similar for both parts of the machine [21]. A screenshot from one application is shown in Fig. 2. For phase and amplitude scan application one might expect that several applications will eventually be written, each focusing on different methods of optimisation and/or sections of the machine.

BEAM COMMISSIONING STAGES

The beam commissioning stages are discussed in detail in [23], and an updated summary will be given in [24]. The beam commissioning stages essentially follow the sections of the machine from the ion source to the target, with reduced pulse length of the beam until safe operation with longer pulses can be guaranteed. At each new stage of beam commissioning, additional applications and routines are needed to perform the different optimisations. There is ongoing work to define a prioritised list of applications based on these stages, as has already been outlined in Table 1.

SUPPORTING SERVICES

For a successful and efficient commissioning of the machine, there are several services that needs to be available. The online model has already been mentioned. Additionally one may anticipate that access to a server for more heavy simulations will most likely be needed for offline analysis (macro-particle tracking).

An operational electronic logbook is essential to keep track of all the various non-standard operations that have been performed, keep track of where to find data for different off-line analysis, keep track of problems that arise with hardware and software etc. A good example of a well advanced and functional electronic logbook is that deployed at SNS

[25]. At GANIL a professional software called J5[26] is used. At ESS we are currently reviewing available logbook solutions.

The "Save & Restore Service" [27] will be responsible for storing the information that is gathered by the various instruments in the accelerator. This includes storing information about the settings of the various components in the machine, such as for example magnet and corrector strengths, RF phase and amplitude, chopping profile and operational modes. It is foreseen that one should be able to save the complete machine state in this service (snapshot). This will be useful for example before a study and then restore that state afterwards, making sure that the machine is back in a known state.

SUMMARY

Thanks to the availability of the open source framework Open XAL, which includes the ESS Linac Simulator now at an advanced stage of development and benchmarked in a real machine, we believe we are well on track to deliver a set of useful and efficient applications in time for the beam commission start in 2018-19.

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