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IMPROVEMENT PLANS FOR THE RHIC/AGS ON-LINE MODEL ENVIRONMENTS *

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Abstract

The on-line models for Relativistic Heavy Ion Collider (RHIC) and the RHIC pre-injectors (the AGS and the AGS Booster) can be thought of as containing our best collective knowledge of these accelerators. As we improve these on-line models we are building the framework to have a sophisticated model-based controls system. Currently the RHIC on-line model is an integral part of the controls system, providing the interface for tune control, chromaticity control, and non-linear chromaticity control. What we discuss in this paper is our vision of the future of the on-line model environment for RHIC and the RHIC pre-injectors. Although these on-line models are primarily used as Courant-Snyder parameter calculators using live machine settings, we envision expanding these environments to encompass many other problem domains.

INTRODUCTION

The Collider Accelerator Department (C-AD) at Brookhaven National Laboratory (BNL) operates a series of accelerators that serve the purpose of providing beams to the RHIC experiments. These accelerators include the AGS, which first operated with beams in 1960 and the two RHIC rings, that began beam operations in 2000.

RHIC consists of two super-conducting accelerators, 2.4 miles in circumference, with counter-rotating beams. It has six interaction regions where the two beams can be put into collisions with zero crossing angle. We currently operate with collisions in two of these regions. RHIC can be operated in many different modes and with many different types of beams [1]. For example, RHIC is able to run with two different ion beams in the two rings simultaneously (e.g., gold and deuteron beams in collision) [2]. RHIC can accelerate gold ions up to 100 GeV/nucleon and polarized proton beams up to 250 GeV/c (for more on RHIC performance see [3, 4]).

To deliver polarized protons to RHIC, the beam accelerates as H^- ions through the 200 MeV LINAC is stripped to H^+ and brought up to 2.16 GeV/c in the Booster synchrotron. The beam is then transferred into the AGS and accelerates to 23.8 GeV/c. Finally the beam is transferred to the two RHIC rings, ending with polarized protons up to 250 GeV. For ion operations the process starts at the Tandem Van de Graff. A gold beam, for example, is stripped of some of the outer shell electrons at the Tandem and is brought through a long transport line to the Booster. From the Booster the gold ions are transferred to the AGS and stripped to Au^{77+} in the transfer line. The final two electrons are stripped off in the AGS to RHIC transfer line.

ACCELERATOR CONTROLS SYSTEM

We have two ways to view accelerator controls interfaces. One can take an engineering view in which we think in terms of power supply configurations and in physical units of current and voltage. This paradigm had worked well for decades, before large scale computing was able to take over the more computationally involved process of working in terms of beam parameters, such as betatron tune, chromaticity, and other Courant-Snyder parameters [5].

What is important is that we develop controls that allow the best mapping between how we think of the accelerator and how we control it. This also allows more of the information that describes the various subsystems to be captured into the controls systems. For example, if you have a transport model of a beam line in the controls, the system will contain not only the transfer functions for control units (e.g., some 0 to 10 volt reference to a power supply, derived from a 16 bit digital to analog conversion module) but also transfer functions from current to field, gradient, and even normalized strengths. This then captures not only the power supply information, but also the magnet information. The controls system now begins to hold the best collective knowledge of the accelerators. It could even contain the best collective knowledge of the beam dynamics.

The controls systems at C-AD span multiple generations of technologies. The controls for RHIC represent the largest systems, in terms of total number of control points (over 220,000 settings and over 160,000 measurements) [6]. From the point of view of the online models, there are then multiple interfaces that need to be defined to collect live parameters of the accelerators.

Generally speaking, all of the controls systems are hierarchical with multiple physical and software layers. At the lowest level we speak of a front end computer (FEC) that directly interfaces to some piece of hardware (a power supply or an instrumentation module). The front end systems interface to the console layers of the system through high speed Ethernet employing fiber-optic network connections. In this respect one can think of the controls system as a widely distributed computer system where computational work is performed in parallel. This is somewhat

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naïve, since each FEC performs a very specific task (they cannot share the work of some other FEC). Our reason for making this analogy is to highlight two things. First is the concept of distributing the accelerator state for the controls to the lowest levels of the hierarchy. The other is to allow us to make the point that this form of a controls system implements an engineering paradigm of controls. The work is distributed according to the power supply configurations(which often don't parallel magnet configurations), not according to the magnet configurations. So the work that the online model performs cannot be distributed down to the lowest level of the controls hierarchy, but must remain at a higher abstraction in the software layers.

HOW MODELS FIT IN

The software layers of the controls can be divided up into three parts. There is the software on the FEC's, then there is the middleware manager (server) layer, and finally there is the console layer. The online models reside in the middleware manager layer, that being the lowest level of the software hierarchy that can perform that work. Each manager acts as a domain-specific arbiter between the console applications and the FEC's. Multiple hardware systems can be employed to distribute managers, but a single manager, unless it threads itself off into multiple instances, remains fixed on a single computer server as a single process.

The basic design of the RHIC online model server allows for multiple instances using different computational model engines [7]. The main computational engine used is an in-house system we call Opticalc. The communication interface for the online model uses CDEV [8]. The main client interfaces that connect the online model to the controls system are the *RampManager* server and *RampEditor* console application [9]. Through this system we achieve control of the accelerator in units of betatron tune and chromaticity. The division of work, between the online model server, the *RampManager*, and the FEC's permits each to focus on a specific function. The model server works purely in normalized strengths, with the *RampManager* handling the management of transfer functions, along with the *WaveformGenerator* manager that builds the actual references that are sent to the FEC and eventually into the various power supplies. In this system the *RampManager* acts as the central authority, managing the interfaces between the hardware, the model, and the operator.

The AGS/Booster online model system is not yet an integral component of the controls system. It acts more as an advisor, providing basically what is a fast offline interface to the operator. The basic design follows very closely the design of the RHIC online model system [10, 11], except *madx* [21] is used as the computational engine. The communication interface uses CDEV, and the design allows for multiple instances using different computational model engines. The main client is the *AGSModelViewer*, which obtains controls data (e.g., the tune control functions, the main magnet ramp, and the RF functions) as well as data logged from instrumentation (i.e., to compare tune and chromaticity measurements with the model). The *AGSModelViewer* also works with a longitudinal model of the accelerators, encapsulated in a library interface, and so presents to the operator both longitudinal and transverse beam parameters.

The kind of online model system we are working towards is a manager, advisor cooperative, in which the *RampManager* is the central authority and the model server acts as an advisor to all other applications. This is shown in figure 1. The RHIC system is very close to this kind of system, lacking only a model viewer that is as extensive as the AGS/Booster system. The model viewer, when built to encapsulate not just the simple linear model, but to allow comparison to other models and measurements, grows in functionality to a controls viewer. That is, the conceptual view of the accelerator and the mapping to the controls begin to converge where the *RampEditor* is the controls interface and the model viewer is the visualization interface. Figure 2 shows a snapshot of the *AGSModelViewer* application interface.

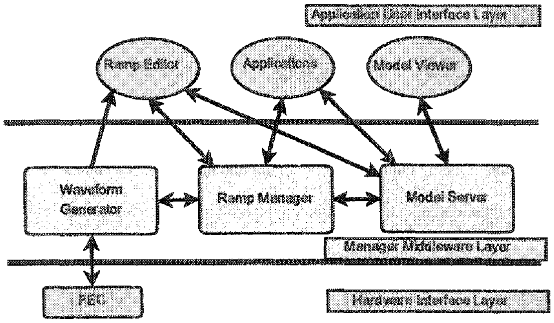

Figure 1: The manager, advisor online model cooperative in the controls system.

OFFLINE SIMULATION ACTIVITIES

Offline simulation activities tend to be focused on understanding phenomena that limit beam performance. This can include relatively simple simulations, such as matching at injection, to highly specialized simulations, such as predicting the performance of transverse stochastic cooling in RHIC. It is interesting to review the current set of activities and consider what offline work could prove useful as either online simulations that become part of the controls or as activities that can be improved by linking to the online system.

In the Booster and the AGS a significant amount of the offline simulation activities are associated with improving the performance of polarized protons operations. To preserve polarization in the AGS the vertical betatron tune needs to be kept very near the integer [12]. A significant amount of work goes into comparing beam based measurements to predictions, including momentum offset and other effects. This work will eventually lead to precise

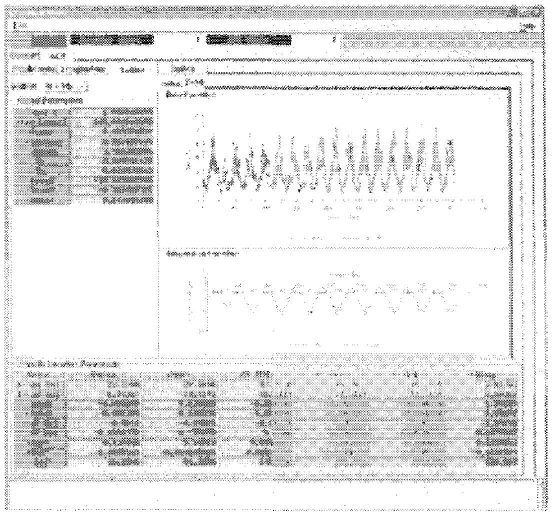

Figure 2: *AGSModelViewer* showing polarized proton lattice at injection. β-functions are distorted by the presence of partial snakes in the lattice.

tune control in the AGS, through the online model interface. Another activity is learning how to match the Booster to AGS transfer line optics to the AGS lattice distorted by the partial snakes [13]. The main area of activity here is in trying to understand how to model the snakes and bring that model into the online model [14]. Keeping transverse emittance as small as possible is important for polarization preservation, simulations of emittance growth on the injection foil during Booster injection are another area of activity [15]. Having these simulations online could benefit machine performance, especially since the dynamics are complicated enough to not be entirely intuitive.

Other areas of offline work include space charge calculations at AGS injection, spin tracking, and understanding horizontal resonances. A new project in the AGS is the horizontal tune jump system. Two fast quadrupoles were added to the AGS lattice [16]. They will be programmed to perform tune jumps across 82 horizontal spin resonances. Including this system into the online model has already proved desirable, where some pieces of the online system were used to provide predictions.

In RHIC, the focus of offline simulations is on polarized proton performance and ions operation performance.

Even though RHIC has full snakes (each ring has two 180 degree snakes), there are still spin resonances that can cause polarization loss. Areas of study related to spin include spin tracking and polarization preservation above 100 GeV, where there are strong resonances [17]. There can also be polarization losses during stores. Polarized protons are also susceptible to beam-beam interactions [18].

For ions operations, the dominant intensity limitation is instabilities that occur after the gamma transition jump. Various areas of exploration are being pursued, including electron cloud effects and nonlinear chromaticity. During store intrabeam scattering (IBS) limits luminosity. New lattices have been developed to suppress IBS [19]. The development of a new lattice is an offline activity. This is because great care must be taken to build functions that are realistic for the power supplies to follow.

Other areas of offline activity include orbit feedback, orbit response matrix measurements (ORM) [20], and injection steering and matching. This last activity is actually a mostly online activity, but developing optical matches between the AGS to RHIC transfer line and the RHIC lattice remains an offline activity. Significant work also goes into offline analysis of collimation.

Finally a significant amount of effort goes into simulation of individual elements or systems. These include improving our understanding of the RHIC injection kickers and for the development of a superconducting 56 MHz RF cavity.

INFRASTRUCTURE IMPROVEMENTS

All online software systems are version controlled and under a backup system.

The lattice descriptions are managed outside of the main controls infrastructure, although they are under some form of version control. All lattices are under a backup system. The lattices used in the online models are provided by the responsible physicist for the given system. For these lattices the plan is to encapsulate them into a true version controlled system. The responsible physicists will then employ this system to make changes.

There are a number of tools, either obtained from other accelerator laboratories, or built in-house, that are not managed within the main controls infrastructure. Some of these tools are used by the online system, such as *madx*, and others could be useful for the online systems, such as certain in-house built spin tracking modules. This software should, but may not, be under source control and backups. Since some of this software resides on individuals computers. Documentation of this software is usually minimal and mechanisms for bug tracking and reporting are not implemented.

A particular problem we are focusing on is the linking of the online models to offline analysis. One example of this is the ORM analysis. In this case clearly the online and offline descriptions of the accelerator need to be identical. But there is no mechanism, besides individual initiative, that ensures they are identical. So we are moving to systems where everyone uses the same lattice descriptions, there is a responsible contact for each lattice and lattice tool, and there is user guide documentation.

We have formed an online model working group to work through these infrastructure improvements, consisting of members of the physics group, controls group, and operations. A significant amount of the work is currently focused on model development and verification for the online models. But the infrastructure is being built to permit offline and online simulations to use the same descriptions of the accelerators and beam lines.

MOVING OFFLINE WORK ONLINE

We often discuss the process of moving offline work to online [22]. Some offline work needs only better access to real time machine parameters. Some is associated with beam experiments and is only useful during those periods. What is important, from our perspective, is that there is a need for mechanisms that allow faster offline work to be done using real time machine parameters.

Members of the physics group do most of the offline work. Since they have a diverse set of tools they employ for simulations, we focus on providing a framework with which they can easily access the information they need to perform offline studies. This can satisfy the difficulty of getting real time parameters to offline work, but it doesn't bring the offline work into the online infrastructure. For this we need to define what physics is needed in the online environment. This is a continual process, since as models become more sophisticated and realistic, we can seriously consider bringing them into the online system. We also need to consider that much of the offline work is computationally demanding. Bringing it online may mean purchasing better servers or bringing cluster computing into the controls system.

Finally, but most importantly, bringing offline work into the online environment necessarily brings it to a larger audience. This provides the ability to use these offline tools in the online system as teaching aides.

LONG TERM PLANS

Our goal is to support a model based accelerator controls system and to provide an accelerator physics based approach to accelerator operations. We intend to provide support to accelerator physicists and operators assisting physicists. To do these things we need to have well understood models of the accelerators and transfer lines that have been tested against beam based experiments. At C-AD there is a strong collaboration amoung physics, operations, and controls. We intend to build on this collaboration to achieve our goals.

We are actively investigating improved simulation engines for the online models, investigating ways to make *madx* faster and learning about other systems such as *ptc* [23]. We are also looking into ways of standardizing and improving the data formats with tools such as *SXF/ADXF* [24] and *HDF* [25].

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