RHIC INJECTOR COMPLEX ONLINE MODEL STATUS AND PLANS*

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Abstract

An online modeling system is being developed for the RHIC injector complex, which consists of the Booster, the AGS and the transfer lines connecting the Booster to the AGS and the AGS to RHIC. Historically the injectors have been operated using static values from design specifications or offline model runs, but tighter beam optics constraints required by polarized proton operations (e.g. accelerating with near-integer tunes) have necessitated a more dynamic system. An online model server for the AGS has been implemented using MAD-X [1] as the model engine, with plans to extend the system to the Booster and the injector transfer lines and to add the option of calculating optics using the Polymorphic Tracking Code (PTC [2]) as the model engine.

OVERVIEW

Beam in the RHIC injector complex consists of two sources (for polarized protons and heavy ions respectively) and three acceleration stages. Protons are accelerated through a 200 MeV Linac, while heavy ions are accelerated in a Tandem van der Graaf. The beams are then delivered, via separate transfer lines, to the Booster. Once accelerated in the Booster, beam is delivered to the Alternating Gradient Synchrotron via the Booster-to-AGS transfer line (BtA) and subsequently to RHIC via the AGS-to-RHIC line (AtR) for acceleration and collision at top energy.

Prior to the 2009 proton run, only the AtR line and RHIC had online model capability. That is, only beginning at injection into RHIC were optics parameters (e.g. beta functions and phase advances) calculated in real time using the as-run magnet currents to control to the beam [4]. Optics parameters of the beam in the Booster and AGS were calculated and the beam controlled using design values, results of offline model runs and manual tuning.

The RHIC physics program has created increasingly demanding requirements for the injectors, including more stringent requirements on emittance preservation and the need to accelerate beam in the AGS with near-integer vertical betatron tune in order to preserve polarization of protons for RHIC spin physics. In addition, two partial Siberian snakes have been installed in the AGS to aid in the preservation of polarization through the acceleration cycle. These elements significantly distort the superperiodicity of the original design AGS lattice at injection energy and provide a significant challenge to achieving an optical match between the BtA transfer line and the AGS.

In response to these challenges an online model server has been developed for the AGS. Using the CDEV API developed at Thomas Jefferson National Laboratory [3] as an interface to the AGS controls system, the server reads the operational settings and readbacks for all accelerator components in the injector complex and provides those currents as inputs to a model for calculating optics parameters and delivering those values to client applications. Currently only a MAD-X description of the lattice is used for model calculation. Plans for extending the servers capabilities to other model engines, including PTC, will be discussed here.

AGS LATTICE

The AGS main bend field is provided by 240 normal-conducting combined function magnets with twelve-fold supersymmetry in 60 FODO cells. The lattice also has two strings of quadrupoles used for horizontal and vertical tune control, respectively. Each string is powered in series. Similarly there are two strings of sextupoles used for chromaticity control, each also powered in series.

Orbit distortions for closed orbit matching at injection and extraction are provided by windings around main magnet back-legs. The contributions these winding make to the dipole, quadrupole and sextupole fields produced in the combined function mains are all included in the model. In particular they are included in the MAD-X description as error statements on the main magnets.

The above mentioned lattice elements are generally sufficient for heavy ion operation. During polarized proton running two partial Siberian snakes are powered, one normal-conducting and one superconducting, called the ’warm’ and ’cold’ snakes, respectively. The perturbation of these snakes to the lattice is sufficiently large so as to require additional external lattice elements to prevent the distorted beta functions from becoming prohibitively large. Each snake has four quadrupoles associated with it, two on either side, powered so as to minimize the effect of the snakes on the lattice. In addition, the cold snake was designed to operate with a beam that enters the magnet with a horizontal closed orbit displacement of about two centimeters. This displacement is achieved using a three-bump consisting of back-leg windings around the main magnets in the vicinity of the cold snake. All of these compensation components are included in the online model.

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MODEL SERVER

The server itself is a simple implentation using the CDEV API. At a user's request, the server receives a data structure containing the setpoints and readbacks of all injector components necessary for calculating optics parameters at about thirty different times during the AGS acceleration cycle. The server then calculates optics parameters at each of these times and asynchronouosly delivers them to client applications.

The AGS and Booster are synchrotrons capable of changing between configurations on a pulse-to-pulse time scale. Typical cycle times are about 400 ms for the Booster and two to four seconds in the AGS. The model server is thus capable of receiving live current readbacks from active, operating configurations and current references for inactive ones and using either to calculate model parameters. This can be particularly useful for developing a configuration for a particular use of the injector chain during operation in a different configuration. For instance, a model for a polarized proton user can be developed and tested using the online model infrastructure during heavy ion operation using magnet current references as they will be in the machine.

MODEL VIEWER

The authors that the accelerator model should represent the most complete, accurate available understanding of the machine and that that information be readily available to users wishing to improve understanding of machine optics and ultimately machine performance. To that end, additional effort has been expended to supply to accelerator users ready access to model calculations. An application called AgsModelViewer has been developed as a graphical user interface to the model server to make live optics parameters for the AGS available to users in real time (Fig. 1). We have also integrated existing code for calculating longitudinal phase space parameters (e.g. bucket size, momentum spread) as a move toward an interface to as comprehensive a model as we have for the injector complex (Fig. 2).

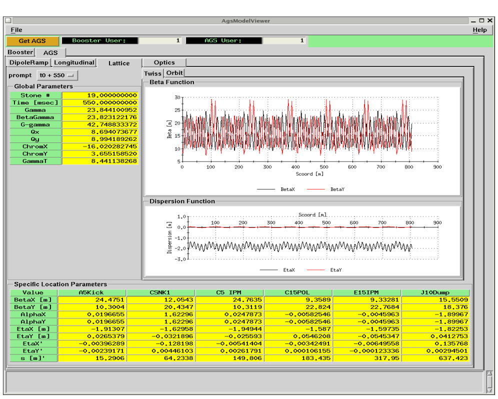

Figure 1: AgsModelViewer showing lattice functions calculated by online model.

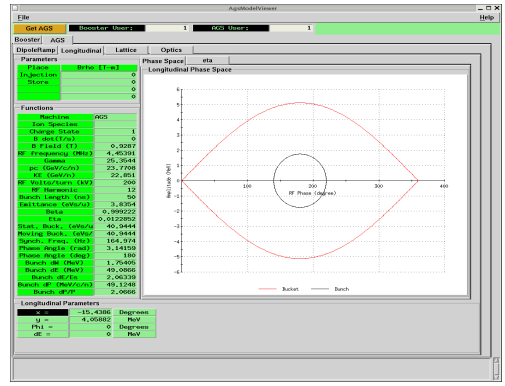

Figure 2: AgsModelViewer showing longitudinal phase space calculated by online model.

STATUS OF MODEL PREDICTIONS

Reducing emittances, both horizontal and vertical, is important both for improvement of the collider luminosity and for minimizing the depolarizing effects of intrinsic spin resonances. In addition, the partial Siberian snakes cause the optics values to deviate significantly from their design values, including strong breaking of the twelve-fold superperiodicity of the AGS lattice.

Figure 3 shows the comparison of the measured betatron tunes in the AGS as a function of the relativistic gamma of the beam compared with the model predictions. It should be noted that the snakes are DC elements, and it is thus expected that their effects on the machine optics will decrease with increasing energy. One can see in the figure that the model agreement improves at high energy, but deviates by several units of 10^{-2} at lower energy. The disagreement is reduced to the level of a few 10^{-3} when a lattice without snakes is considered (e.g. a heavy ion lattice). Transition in the AGS occurs at a relativistic gamma of approximately 8.5. The radial shifts and gamma jump used during transition are not currently accounted for in the model, resulting in the significant disagreement seen there.

Studies of the effects of the snakes on the AGS optics are ongoing and beyond the scope of this article. It is hoped that the ready availability of model data helps to expedite the process of comparing model predictions to measured optics and subsequently to improving the model.

PLANS

The 2009 RHIC polarized proton run was used as a commissioning period for the AGS online model server and viewer. We plan to extend the infrastructure we have built to use additional model engines and to extend the modeling capability from the AGS to the entire injector chain.

In particular, we plan to add functionality that will allow the use of PTC as the model engine. The use of PTC will allow the online calculation of proton spin motion and the rigorous modeling of the effect of the partial Siberian snakes on the AGS lattice. The inclusion of PTC is also a

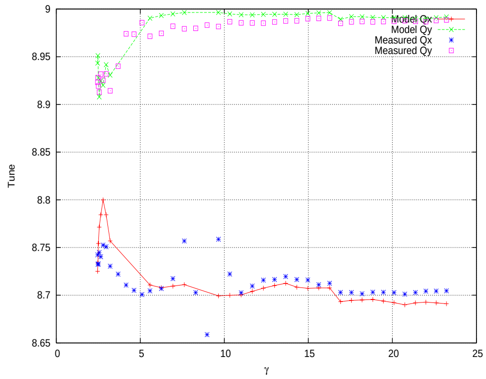

Figure 3: Betatron tune model predictions and measurement for polarized proton operation in the AGS.

move towards unifying the model environment of the entire RHIC complex as RHIC also moves to include PTC as an option for producing model data.

Prior to the the 2009 RHIC run, an extensive study of the Booster extraction and BtA model was conducted [5]. During this time preliminary work was also conducted to begin extending the online model capability to the Booster cycle and eventually to the Booster injection transfer lines. The goal is to extend the model server's capabilities to integrate the Booster and the BtA and AtR transfer lines by the 2010 RHIC run.

SUMMARY

Control of the RHIC injector complex beam parameters has previously been accomplished using design model values or the results of infrequently updated offline model runs. Significant progress has been made in providing model data for accelerator control to accelerator users in real time in order to meet more stringent demands on injector performance.

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