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USING A PARTICLE-IN-CELL MODEL FOR ACCELERATOR CONTROL ROOM APPLICATIONS*

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Abstract

Many accelerator control rooms rely on envelope models to simulate beam dynamics because they are fast and accurate at tracking the beam core. Particle-in-Cell (PIC) models, however, can track particles inside and outside the core and, with the improvements of computers, are now fast enough to be used in control rooms. The Spallation Neutron Source (SNS) at Oak Ridge National Laboratory is currently developing a tool to use a PIC model for control room applications. This report covers the progress so far and the future goals of using PyORBIT, a PIC simulation model, in the SNS control room.

INTRODUCTION

As accelerators are incredibly complex tools that require many hands to operate successfully, it is important to develop applications that streamline using and maintaining the accelerator. These include applications that turn the accelerator on, tune cavities, correct orbit, etc. These tools rely on having a physics model to describe the accelerator, and many of them use an envelope model [1, 2]. These models are fast and accurate at predicting beam core, but they do have some drawbacks. Envelope models have no means of predicting particle behavior outside of the core, they cannot model nonlinear forces like space charge, and they cannot handle complicated beam shapes. With improvements in computers, models that are slower but more accurate can now be used for the same purposes.

PIC models, while traditionally too slow for live applications, are now fast enough for use as live models [3–5]. These codes are able to simulate nonlinear forces, such as space charge, and can handle apertures and slits that cause particle loss. These models work by using macro-particles, collections of real particles, to simulate particle motion in an accelerator. Figure 1 shows an example comparing a PIC bunch to the beam envelope, as well how PIC codes handle beam loss. The PIC code PyORBIT is the model the Spallation Neutron Source (SNS) is planning to use in their control room [6]. PyORBIT has recently been updated to python 3 and can model both linacs and rings. We are building a virtual accelerator of the SNS using PyORBIT as the model, which we plan to use as a development and training aid as well as an online model.

VIRAC: THE VIRTUAL ACCELERATOR

The virtual accelerator, called Virac, is a PyORBIT simulation of SNS that sends and receives information through

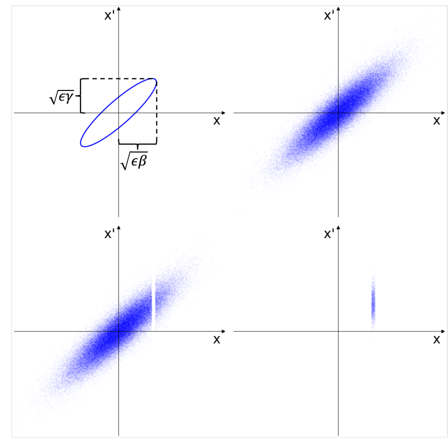

Figure 1: Plots showing the difference between envelope and PIC models. Top left: the ellipse of an envelope model. Top right: the bunch of macro-particles from a PIC model. Bottom left: a PIC bunch with particles removed after interacting with a wire. Bottom right: A bunch after going through a slit.

the Experimental Physics and Industrial Control System (EPICS). It simulates controlling a real accelerator as if the user is in the control room. This means it uses EPICS with the same Process Variable (PV) names as the SNS control room and a refresh rate that determines when diagnostics are updated. Only the linac is currently implemented, but we plan to eventually include both the ring and the Beam Test Facility (BTF).

The architecture for Virac, shown in Fig. 2, is divided into two main parts, the model and the server, with dictionaries passing information between them. The dictionaries are model-based so that the model does not need to be adjusted to fit the server. This means that, even though PyORBIT is the main model, other models can easily be used. A controller handles running the PyORBIT simulation using a given lattice and starting macro-particle bunch. The default bunch is small, 1000 macro-particles, in order to decrease the tracking time, but this can be increased if higher accuracy is desired. The controller also only re-tracks when the lattice is changed, and, to save time, only tracks from the most upstream change. The controller takes an incoming parameter dictionary, adjusts the lattice accordingly, tells PyORBIT when to track, and sends diagnostics out of PyORBIT in a new dictionary. This is illustrated in the bottom half of Fig. 3. Any model that has these three functions can be used. The PyORBIT model in Virac currently has BPMs, wire scanners, and screens as available diagnostics not included in the base PyORBIT.

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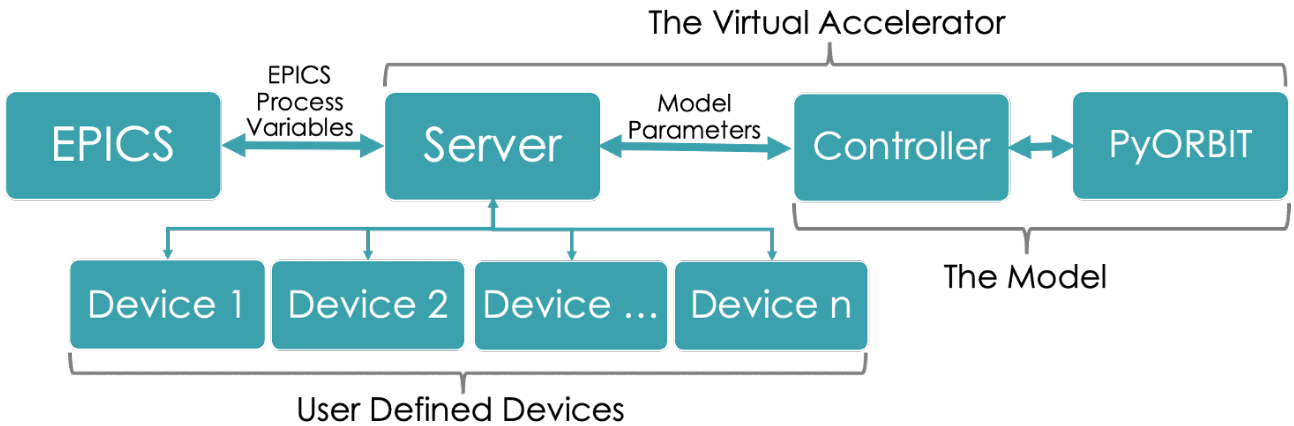

Figure 2: The architecture of Virac.

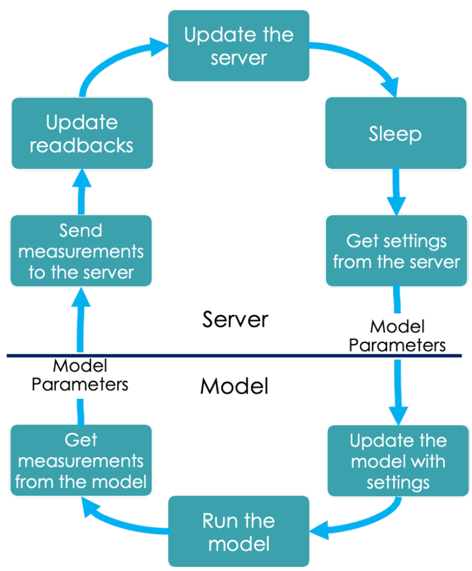

Figure 3: Flow chart showing the loop of how Virac receives new settings from EPICS, updates the model, and sends new measurements to EPICS.

The server handles transferring values between the model and EPICS using individual devices. These devices specify how the PVs from EPICS correlate to the parameters in the model. Devices are highly customizable, allowing for users to create their own as needed. One example is having a device for a quadrupole that gets information from a separate magnet power supply device. Many devices are already implemented, including cavities, quadrupoles, correctors, power supplies, and the diagnostics listed above. Devices add noise before sending values to EPICS, letting the model ignore noise. The main loop of Virac is shown in Fig. 3 with the top half illustrating what the server does.

CURRENT APPLICATIONS OF VIRAC

While development continues, Virac is already in use at SNS for application development, operator training, and AI training.

Accelerator Application Development

SNS is planning to overhaul the suite of applications used for running the accelerator, such as orbit correction and cavity tuning. Developing and testing these applications on the real accelerator requires using valuable beam time. Virac, as a digital twin, allows for development to proceed without needing to test on the physical machine. It can run on any local machine and uses EPICS the same way as in the control room. Because the PV names are identical between the real and virtual machines, code will require no changes when deploying in the real accelerator.

One such application currently getting updated is the Injection Dump Wizard. Used for beam that doesn't strip correctly when entering the ring, the wizard helps control the waste beam to the injection dump. As the injection dump beam line has received updates during this most recent down time, including a new camera, the wizard is being rewritten using Virac to test and debug without requiring the real accelerator [7]. Figure 4 shows a screen shot of the new wizard reading results from Virac.

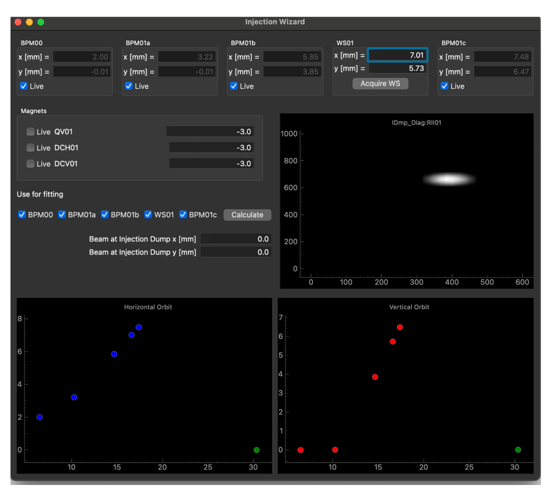

Figure 4: Screenshot of the new Injection Dump Wizard currently in development. The measurements are from Virac.

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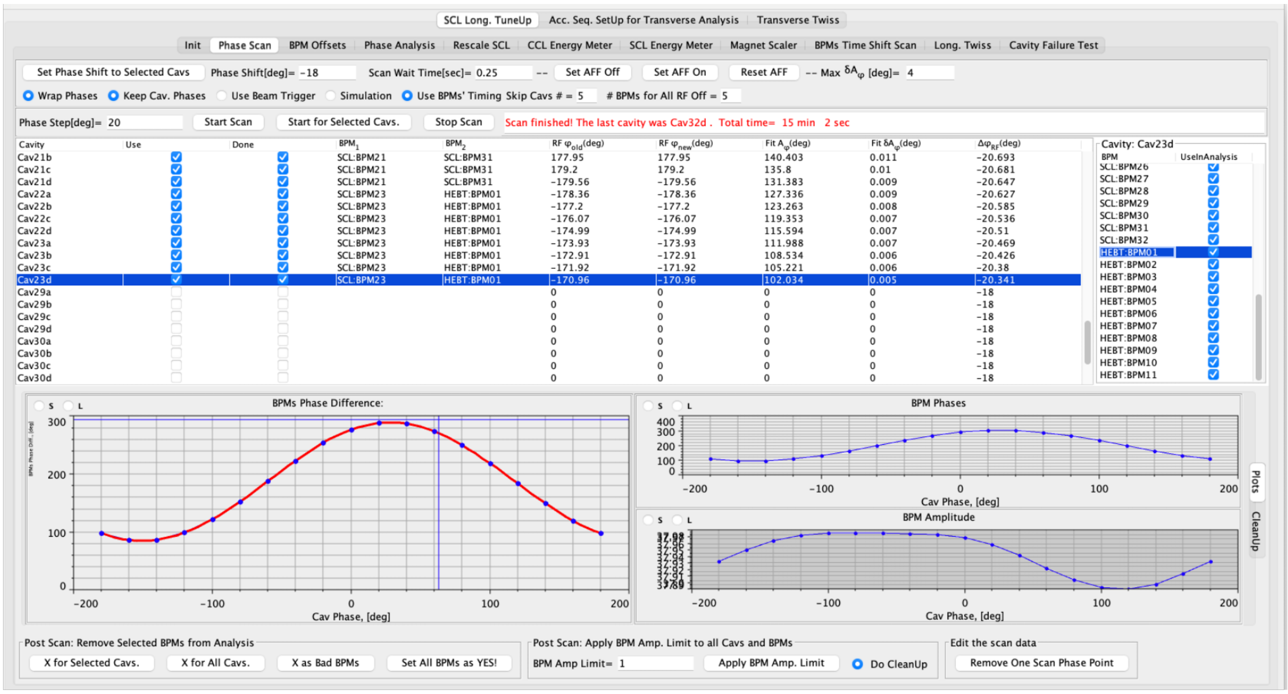

Figure 5: Screenshot of the SNS SCL Wizard performing cavity scans using Virac. The wizard uses XAL envelope code and shows agreement with the the virtual accelerator.

Operator Training

Operating an accelerator is a complicated task requiring multiple people. When new people are brought on, it can be difficult to give them a proper demonstration of the tools used by operations because the machine is already running and the tools are largely either for start-up or a malfunction. As such, operators may not be able to get hands-on training until they are expected to perform the actual task.

Virac gives operators a way to not only get a demonstration of the tools, but a way to practice using them. All applications will work with Virac just like the real machine, allowing operators to acclimate to their tools before they need to use them. As Virac is currently only simulating the linac, we have successfully performed cavity scans for both warm and super conducting cavities. Figure 5 shows a screen shot of the Super Conduction Linac (SCL) Wizard, our application for setting up and tuning the SCL cavities, performing a cavity scan on Virac just like it would on the real accelerator [8]. Operators have now begun using Virac for practice on both the Warm Linac Setup Application and SCL Wizard before the upcoming start-up.

AI Training for Machine Learning

The SNS has to balance beam size between aperture sizes and intra-beam stripping, meaning the beam cannot be too large or too small [9, 10]. Operators currently empirically tune the SCL cavities to minimize beam loss detected by beam loss monitors. These monitors are incredibly sensitive, but they do not identify the location of beam loss, just the presence. As such, we do not have a physics model to help with beam loss tuning. This is why machine learning will be used to develop models to assist operations with beam loss, as well as other applications at SNS [11].

Before deploying AI developed models on the real machine, Virac will be used to train the AI and test that the new models are safe to implement. As Virac uses the same PV names, the AI will be able to use the same training between both virtual and real without modifications. The AI has been successfully tested on orbit correction problems in the virtual accelerator, and a simple beam loss monitor model will be implemented into Virac in order to begin training to mitigate beam loss.

CONCLUSION

SNS is creating a virtual accelerator, Virac, to use the PIC PyORBIT model for control room applications. Currently, Virac only simulates the linac, but will include the ring and BTF in the future. It uses the same EPICS PV names as the real accelerator, allowing for no changes needed between it and the control room. Virac is already being used for application development, operator training, and AI training, and as applications in SNS are updated, it will also be used as an online model.

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