USE OF A SIMPLE STORAGE RING SIMULATION FOR DEVELOPMENT OF ENHANCED ORBIT CORRECTION SOFTWARE*

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Abstract

At the Advanced Photon Source (APS) most of the testing of minor operational software is done during accelerator studies time. For major software changes, such as the porting of the complex workstation-based orbit control software to an EPICS IOC, much of the testing was done "offline" on a test IOC. A configurable storage ring simulator was created in a workstation with corresponding control system records for correctors and orbit readbacks. The simulator's features will be described as well as the method used to develop and debug the most recent improvement of the APS orbit control software, among others. The simulator is also useful in general-purpose software testing.

BACKGROUND

With the increasing percentage of time dedicated to user operations at APS and accelerator physics studies, less and less time is available for testing new or updated controls software. With the advent of extended top-up operation [1], the amount of software testing that can be accommodated for the injector subsystems has continued to decrease. Faced with limited software testing time and striving to maintain high reliability, we have created new methods for testing software. These include using simulations of accelerator systems that interact with normal channel-access applications. These simulations have continued to evolve and have helped us develop more sophisticated high-level applications, the latest example being an enhanced version of our orbit correction software.

SIMULATED LINAC

VxWorks IOC

The first simulation created was of a simple linac. It runs on a VxWorks EPICS input/output controller (IOC) that is used exclusively for testing. This simulation includes an rf gun cathode, beam correctors, and beam position monitors (BPMs). While this simulation is quite simple, it has been very useful in debugging various EPICS applications while in an office environment. The simulation includes various types of process variables, including analog inputs, analog outputs, and binary outputs. A simple response matrix connects the BPMs and correctors, allowing testing of feedback software, such as **sddscontrollaw**.

This simulator has been used in the testing of one of the components of our enhanced orbit correction software, namely, the VxWorks port of **sddscontrollaw**. However, there are limitations to this type of simulation. In particular, as it was modified to simulate the storage ring, we found that the memory in the IOC was quickly consumed before an adequate simulation could be created. We also found that large-scale simulations required more processing power than was available in the IOC that was being used. Avoiding these two limitations led to the creation of a workstation-based version of a storage ring simulator.

SIMULATED STORAGE RING

Workstation with EPICS 3.13

The second simulation created was of a storage ring that runs on a Solaris workstation. This simulation was created by extension modifications of the portable EPICS CA server [2], which is available with EPICS 3.13. This simulation, like the previous linac simulation, also interacts with standard channel-access applications but it is not running on an IOC. Instead it is a standalone application that mimics some of the behavior of an IOC. Two SDDS files, giving the horizontal and vertical response matrix for the storage ring, configure this simulation. The response matrices can be generated by the accelerator code **elegant** [3], meaning that one can simulate any accelerator for which an **elegant** input lattice is available. In addition, the response matrices can be generated by actual measurements on an accelerator.

One of the features of this simulator and the other simulators described here is that randomness that can be added to the corrector strengths and/or the BPM readbacks. This permits much more realistic simulation of feedback processes, which are strongly affected by noise. It also allows development of data analysis algorithms, for example, algorithms for finding the source of unexpected orbit motion.

While this simulation removed the memory limitations of the VxWorks EPICS IOC simulation and is flexible enough to simulate different accelerators, it does have limitations. The major limitation is that it was very time-consuming and error-prone to add new types of process variables (PVs). Since it was not an EPICS IOC there were no such things as database DB or DBD files, which are normally used to define PVs. This meant all the behavior of new PVs has to be programmed into the code. With the wide range of different types of PVs for the various accelerator systems, this limitation meant that developing more detailed simulations would require

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extensive programming work. With the release of the latest version of the EPICS source code it was possible to overcome this limitation by developing a new kind of simulator.

Workstation with EPICS 3.14

The release of EPICS 3.14 enabled us to run an IOC on a Solaris workstation [4]. This meant we could develop an improved simulation by taking advantage of the ease-of-development of the VxWorks IOC simulation combined with the increased available memory and processor speed from the workstation. Like the original workstation-based simulation, this new simulation also uses response matrices. Hence, the simulation is easily configured for different accelerators.

This simulator makes it easy to add waveform process variables. Such process variables are used in the enhanced orbit correction software for the APS storage ring. The values in the waveforms represent vectorized corrector and BPM values for the storage ring. The simulation was created by using a combination of EPICS database records to create bending magnets, correctors, quadrupole magnets, sextupole magnets, trim magnets, and waveforms of vectorized correctors, along with special PVs to dynamically change the level of randomness. Most simulated PVs have related calc and sequence PVs that are used to calculate the simulated values.

One of the first uses of this simulator was to improve storage ring power supply startup, condition, and shutdown Procedure Execution Manager (PEM) procedures. By artificially decreasing the time needed for conditioning, it was possible to rapidly test modifications to the procedures.

ENHANCED ORBIT CORRECTION SOFTWARE

The main goal of the enhanced orbit correction software [5] is to more precisely control the position of the beam in the storage ring. To accomplish this, the correction software has to run at a faster rate than is possible with the workstation version. The workstation version is limited because it has to contact many different IOCs at each iteration to send and receive the BPM and corrector data. To overcome this limitation, the orbit correction software has been ported to VxWorks and is running on a dedicated IOC. This IOC has special hardware that it uses to send and receive vectorized corrector and BPM values to and from a memory back plane, which almost instantaneously moves the data to and from the other related IOCs. The orbit correction software then reads and writes these waveform PVs using optional direct database access routines. When all these systems are put together, the orbit can be corrected up to twenty times per second.

The process of porting this software to run on a VxWorks EPICS IOC was greatly aided by the use of the simulators described above. Beyond the benefits of using a VxWorks EPICS IOC simulator to port software that was never intended to run on VxWorks when it was originally written, these simulators were used to track down problematic race conditions that did not occur on the Solaris version. The VxWorks version of the orbit correction software was only able to run on the linac simulator as opposed to the two newer simulators because the target platform was VxWorks. However, by turning off the optional direct database access routines and using channel access instead, it was possible to use the latest workstation version of the simulator to run more detailed tests.

GENERAL SOFTWARE TESTING

Different combinations of these simulators have been used to test and debug other channel-access software here at the APS. The high-level accelerator applications at APS make use of the SDDS/EPICS toolkit. This consists of a collection of about 20 separate programs that can be configured to perform various data collection and process control tasks. Upgrades to the toolkit programs obviously must be thoroughly tested prior to releasing new versions into operation. To accomplish this, various testing scripts have been written that test most of the capabilities of the toolkit.

In addition, new programs such as **sddslogonchange**, **sddsglitchlogger**, **sddswget,** and **sddswput** have been developed with the help of these simulators [6]. The first program is used to log PV changes in efficient SDDS array data format. The second is used to log data when user-specified glitch events occur. The latter two programs are used to read and write waveforms to and from SDDS files.

SDDS/EPICS DEMONSTRATION SOFTWARE

The storage ring simulator based on the Portable Channel Access Server has also been used to develop a set of Tcl/Tk scripts that demonstrate the capabilities of the SDDS/EPICS toolkit. The demonstration software allows one to choose from among several accelerator configurations, from a small FODO transport line to a large ring. The simulator is fast enough that most of these configurations can be simulated with good results on a laptop. (Simulating the large ring requires a fast PC.) Whichever configuration is chosen, the simulation is configured from an **elegant** input lattice along with several extra parameters, such as the noise level for BPMs and correctors. In particular, **elegant** provides the horizontal and vertical response matrices, from which the PV names for the BPMs and correctors are determined. The SDDS toolkit (a general-purpose data analysis and display suite) is used to create input files for data logging.

The purpose of the demonstration scripts is to show how SDDS/EPICS tools can be used for data collection and how the SDDS tools can then be used for data analysis and display. To provide some interesting signals, one of the scripts imposes a small oscillation on two of the correctors. Another script collects data from the simulation and illustrates use of the SDDS toolkit to find the frequency, relative amplitude, and the location of the oscillating correctors. The final step is performed using singular value decomposition and comparison of the singular vectors to the response matrix.

The scripts generate an input file for the Array Display Tool (ADT) program to allow the user to view the orbit in real time. In addition, the scripts allow measurement of the response matrix and comparison to the ideal matrix. Following this, the user can perform orbit correction using the measured matrix. An MEDM screen allows the user to change the gain of the orbit correction while it runs, to start and stop the correction, and to change several corrector values. The programs **sddsstatmon** and **sddsplot** are used to create a stripchart of the rms orbit. The demonstration scripts are intended to be tutorial in nature. All SDDS commands are displayed as they are performed. The software is available for download from the Operations Analysis Group web site at APS (www.aps.anl.gov/asd/oag/oaghome.shtml). Adding a new accelerator to the demonstration is very simple, provided an **elegant** lattice is available.

FUTURE PLANS

In the future we hope to use these simulators to train the accelerator operators. Operator training takes a significant amount of time and has some of the same problems allocating time from user operations, similar to software testing. By using the simulated accelerator it would be possible to teach basic operations and problem solving skills.

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