VIRTUAL ACCELERATOR SYSTEM FOR ONLINE AND OFFLINE SIMULATIONS *

S. Q. Ma†, K. Xuan, W. Xu, C. Li, J. G. Wang, G. F. Liu‡
National Synchrotron Radiation Laboratory,
University of Science and Technology of China, Hefei, Anhui 230029, China

Abstract

Accelerator facilities have been becoming import scientific tools in various research areas, including physics, biomedical, materials, etc. In order to build a state-of-the-art accelerator complex, up-to-date technologies are adopt to build the subsystems. The integration of these subsystems need to be fully tested before the accelerator being operated, or even before being started to build. However, there lacks a good software to perform this work. The virtual accelerator (VAS) is developed at the National Synchrotron Radiation Laboratory (NSRL) to fulfill this purpose. This system was used to effectively test the functions of the Hefei light source (HLS) control system during the major renovation. It was also used to test the integration of the subsystems before commissioning the light source. Some high level application tools used for machine commissioning, studying and operation were tested and debugged using this system. This paper introduces the overall structure of the VAS system, and discuses each component in details. Some applications are also mentioned in a later part of this paper.

INTRODUCTION

Accelerators, including synchrotron radiation light sources, have been becoming important scientific tools in various research areas including physics, biomedical, materials, and so on. To build a state-of-the- art synchrotron radiation light source, one need to carefully study the linear and nonlinear dynamics of the charged beam in each component of the light source, such as the linac, transfer line, booster synchrotron and storage ring. There are many mature software tools, including the Methodical Accelerator Design (MAD) [1], Elegant [2] and Accelerator toolbox (AT) [3], can be used to accomplish these studies. On the other hand, the light source complex is usually comprised of many subsystems, including the magnet system, power supply system, vacuum system, RF system, etc. In order to acquire a high performance light source, up-to-date technologies are adopt to build these subsystems. For smooth commissioning, the functionality and integration of these subsystems need to be fully tested before the light source is commissioned, or even before started to build. However, there lacks a good software to perform this work. The virtual accelerator system (VAS) is developed at the National Synchrotron Radiation Laboratory (NSRL) to fulfill this purpose.

The VAS was used to effectively test the functions of the Hefei light source (HLS) control system during the major renovation. It was also used to test the integration of the subsystems before commissioning the light source. Some high level application tools used for machine commissioning, studying and operation were tested and debugged using this system.

This paper introduces the overall structure of the VAS system, and discuses each component in details. Some applications are also mentioned in a later part of this paper.

THE VIRTUAL MACHINE

The VAS is comprises of three parts, the virtual devices (VDs), virtual control system(VCS) and physical daemon (PD). A functional sketch of the VAS is illustrated in Fig. 1. The VAS uses a rich set of VDs to simulate real devices of an accelerator. The VCS is used to adjust and monitor the parameters of these VDs. Using the parameters of VDs, the PD calculates the optical parameters at the location of VDs and the parameters of the electron beam.

The Virtual Device

The VDs are used to construct a virtual accelerator. Each VD has a real device counter part in a real accelerator. Similar to that of a real machine, a VD can be any element of an accelerator system. The virtual dipoles, quadrupoles and sectupoles are used to build the linear and nonlinear optics of the machine. The virtual orbit correctors are used for orbit adjustment and feedback for the virtual electron beam (VEB). All of these virtual magnets are powered by virtual power supplies (PSs). The virtual RF system is used to compensate the energy lose and define the longitudinal motion of the VEB. The virtual beam position monitors (BPMs) are used to “measure” the transverse positions of the VEB in the accelerator.

Each VD has a set of engineering and physical properties, which are managed and controlled by the VCS. The VCS has a rich set of records for holding and controlling these properties. Each property can only be accessed via channel access (CA) of the experimental physics and industrial control system (EPICS) [4]. Figure 2 shows the physical properties and control flow chart of a virtual magnet. Like all other VDs, a virtual magnet has a set of optical properties of its start point, including the longitudinal position and phase advance relative to a reference point, the twiss parameters, η functions, and orbit position. It also has its own physical properties, e.g. the magnetic multipoles, alignment and field errors. Like that in a real machine, virtual magnetic multi-

* Work supported by the National Natural Science Foundation of China (No. 11375186).
† shqma@126.com
‡ gfliu@ustc.edu.cn, +86-551-63602080.

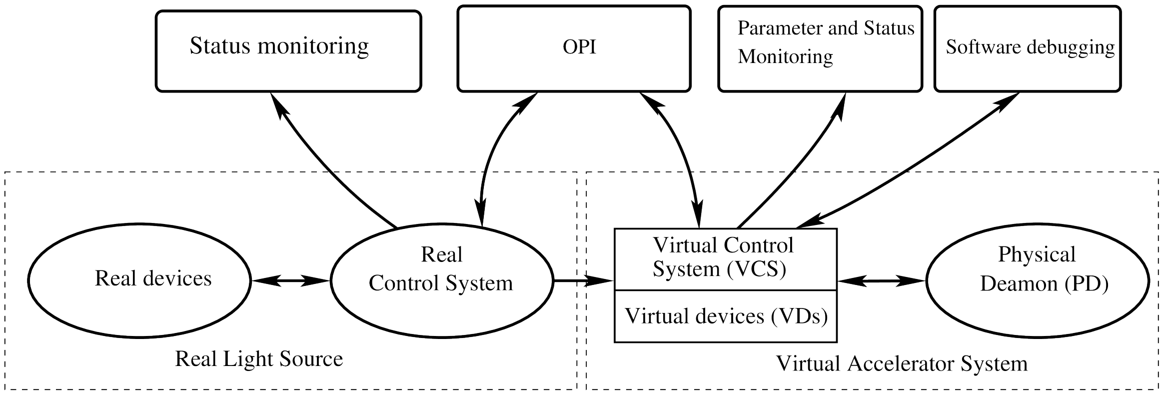

Figure 1: Functional sketch of the virtual accelerator system.

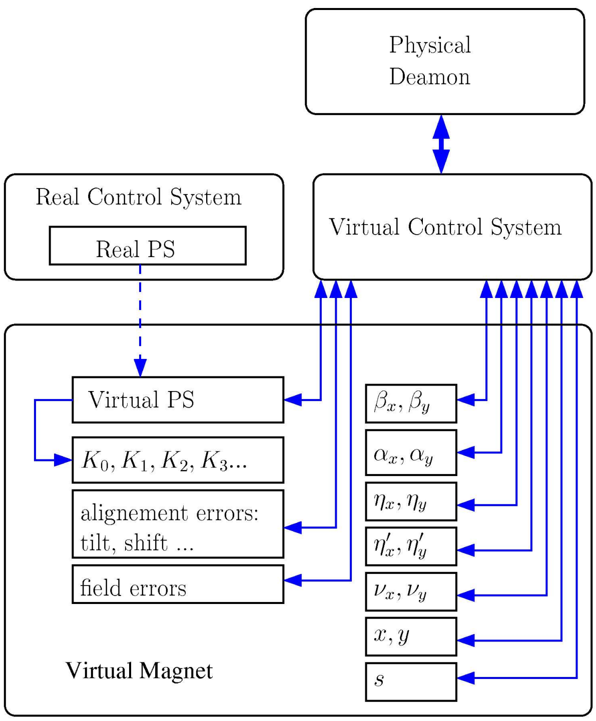

Figure 2: Control flow chart and physical properties of a virtual magnet.

poles is determine by the output current of the virtual PS. The virtual PS works in two modes, debugging mode and online mode, respectively. In debugging mode, the value of the virtual PS is controlled by the VCS, while in online mode the virtual PS uses the output value of its counter part in the real machine. The online mode is mainly used for monitoring optical parameters of the real machine.

The Virtual Control System

The VCS is developed under EPICS, and is similar to the control system for the real machine. Other than controlling real devices, the VCS controls VDs which make up a virtual accelerator complex.

The VCS can be divided into two parts. The first part is cloned from the real control system, and uses most part of

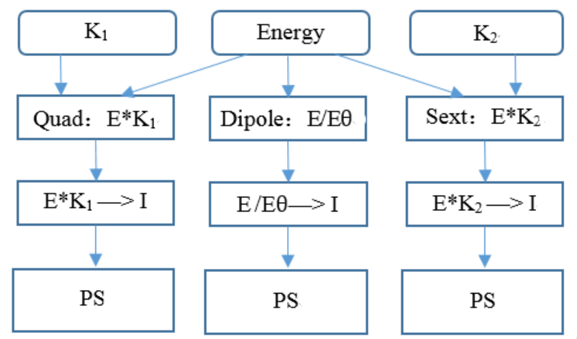

Figure 3: Physical quantity based control system.

the database and control functions of the real control system. Most records of the virtual system have corresponding records in the real control system. They have the same function except the virtual one controls a VD, while the real one controls a real device (RD). The records in the VCS use *VM* as their prefix in the name to distinguish from the record in the real control system. This part of control system is built based upon physical quantities of the accelerator element using the same strategy of the Duke FEL control system [5, 6].

As an example, the control of magnets is shown in Fig. 3. As shown in the figure, the outputs of all the magnet PS will change with the beam energy. They are synchronized using EPICS EVENT. The output of a PS can also be controlled individually at a given energy.

The second part of the VCS is used to manage the properties of VDs as discussed in section . For a virtual magnet, a mechanism is used to convert the PS output (in amperes) to magnetic multipole values, which is the inverse conversion as that used in the first part of the VCS.

The OPI control panels are developed using the Extensible Display Manager (EDM). They are the same as the real machine except using a different micro “*VM*” to distinguish from the real ones.

ISBN 978-3-95450-147-2

The Physical Daemon

The PD is developed based upon AT and Matlab. It runs in the background to simulate the physical processes of the accelerator and motion of the electron beam. The PD periodically reads the physical properties of the VDs via EPICS CA, and calculates the physical parameters of the accelerator and beam, including the twiss parameters and closed orbit at the location the each VD, betatron tunes, etc. The calculated parameters are then set to corresponding records in the VCS for other purposes. Due to the large the number of the physical properties, the Matlab CA (MCA) access tools are used to fetch the VD values and update optical parameters.

The PD has four main modules: the accelerator module, the VD initialization module, the lattice fetching module, and twiss updating module. These modules work as following:

- The accelerator module uses a cell array named vmRING to hold all the information of the VDs. It has the same structure as the AT cell array THERING. The PD uses vmRING to calculate the twiss parameters (including $\beta_{x,y}$, $\alpha_{x,y}$, $\eta_{x,y}$, $\eta'_{x,y}$, and betatron and synchrotron tunes) and six dimensional positions of the VEB;
- The VD initialization module initializes or resets the VD physical properties using the values saved in vmRING. This module initializes the VD values as soon as it get a RESET command from the VCS;
- The lattice fetching module is used to read the VD values from the VCS using MCA and update the values saved in vmRING.
- The twiss parameter updating module calculates the twiss parameters and six-dimensional positions of the VEB as soon as the lattice fetching module updates the vmRING values. The newly calculated twiss parameters and six-dimensional positions are then written to corresponding records in the VCS using MCA.

The PD works as shown in Fig. 4. The VD initialization module is processed only when receiving a RESET command, while the lattice fetching module and twiss updating module are processed periodically. The time interval between two cycle of calculations is determined by the scale of the accelerator and the calculating power of the computer system. At NSRL, the PD fetches the lattice settings and updates the twiss parameter every second.

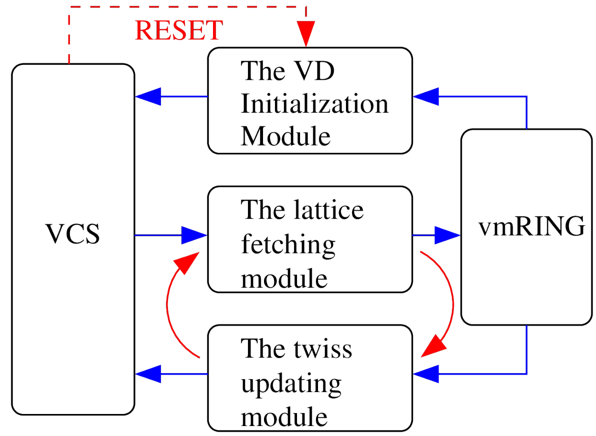

Figure 4: The work flow chart of the PD.

APPLICATIONS OF THE VAS

The VAS has two types of applications at NSRL, the software debugging and online monitoring. When used for software debugging, the VD values can be changed as needed by high level applications or by the PD. The integration of the control system of the HLS was tested using this scheme before it been brought into operation. Some control functions, such as the lattice restoring and ramping, were also tested under this system. All the control panels developed using various EPICS extensions were also fully tested. Further more, a number of high level applications, such as the orbit feedback and beam based alignment programs, were also tested and debugged using this scheme. Since both the virtual control system and real control system use the same set of records, except the virtual ones use *VM* as its prefix in the record name, the applications tested using the virtual system are very easy to be ported into the real system using a different macro.

When used online monitoring, VDs read values from the real control system. Neither the VCS or the PD can not change the physical properties of the VDs. The PD can only update the twiss parameters and six-dimensional positions of the VEB. In this mode, the calculated optical parameters can be used for monitoring the operation status of the real machine, and for trouble shooting of device failures.

SUMMARY

The VAS developed at NSRL has been used for testing the integration of the HLS control system, and for tuning and debugging high level applications used for machine commissioning and operation. This system was also used for online monitoring of the optical parameters of the HLS accelerators. The VAS has been playing a important role in the machine commissioning and trouble shooting device failures of the light source operation. The authors would like to thank all the scientists at NSRL who give us valuable discussions and precious assistance.

REFERENCES

[1] See the MAD website, http://mad.web.cern.ch/mad/.

[2] M. Borland, “elegant: A Flexible SDDS-Compliant Code for Accelerator Simulation”, ANL, Chicago, IL, USA, Rep. Advanced Photon Source LS-287, September 2000.

[3] A. Terebilo, “Accelerator modeling with matlab accelerator toolbox”, in *Proc. of PAC'01*, Chicago, IL, USA, paper RPAH314, p. 3203.

[4] EPICS, `http://www.aps.anl.gov/epics`

[5] Y.K. Wu, S. Hartman, S.F. Mikhailov, “A physics based control system for the Duke storage ring”, in *Proc. of PAC’03*, Portland, OR, USA, paper WPPB033, p. 2482.

[6] K. Xuan, “HLS-II physical quantity based control system and related applications”, Ph.D. thesis, University of Science and Technology of China, 2015.

ISBN 978-3-95450-147-2