XAL ADOPTION EXPERIENCE AT LCLS*

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Abstract

XAL [1-3] is a high level accelerator application framework originally developed by the Spallation Neutron Source (SNS), Oak Ridge National Laboratory. The XAL framework provides generic hierarchical view for an accelerator as well as many utility tools. In XAL, a built-in physics model calculates either single particle or beam envelope tracking for physics parameters. Modifications to the original XAL model are necessary for the Linac Coherent Light Source (LCLS). Work was done to manipulate MAD deck output within a database in support of the XAL configuration and model. The XAL graphical user interface has been replaced by a SLAC specific design. New applications based on the framework are also discussed in this paper.

INTRODUCTION

XAL is a Java based framework originally developed at SNS for physics and general purpose applications. Highlights of XAL features include: a hierarchical view of an accelerator, physics modelling tool, a common look-and-feel graphical user interface (GUI), EPICS [4] Channel Access (CA) wrapper, database access wrapper and many other utility packages.

Most of XAL configuration and model data are stored in relational database. The database schema holding the XAL data should be as close to XAL accelerator hierarchical class structure as possible. A relational database to Java class mapping is necessary so that XAL configuration can be generated from database quickly.

The XAL online model has been improved and modified for LCLS which is an electron accelerator. Because of highly relativistic electron beam, the longitudinal coordinate system for the online model has been changed.

The SLAC implementation of the XAL model was also required to be compatible with the existing applications which have been using the Stanford Linear Collider (SLC) online model system. The XAL online model data is stored in Oracle database which can be accessed via the AIDA system.

DATABASE SETUP

There are two major database schemas which contain data for XAL. The first schema, modified from existing database tables, is for XAL input configuration. The second schema is for storing XAL model run output and machine state for the corresponding model.

XAL Configuration

The LCLS *Infrastructure* schema provides the static information such as device names, types, locations and EPICS names. Typically a database query along with a mapping between the relational database and XAL data structure is performed to generate an XAL formatted XML file. The XAL configuration data are mainly extracted from two database views, the *elements* and the *symbols*. The element view contains information for each hardware device. Data for MAD optics design lattices are saved in the symbols view. These views were modified to accommodate XAL needs such as beam line sequence and distance-from-the-start-of-the-sequence.

The database to XAL data structure mapping within our present schema is still not fully completed. There will be more LCLS specific data attributes added to the XAL data structure and, therefore, the database schema.

XAL Model Data

After a model run, the XAL online model data can be uploaded to an Oracle database for other applications to pick up. An easy interface, Accelerator Integrated Data Access (AIDA) [5] provides a universal way to access the model data stored in the database. Currently, there are four model beam-line modes, 'Cathode to Main Dump', 'Cathode to Gun Spectrometer', 'Cathode to 135-MeV Spectrometer', and 'Cathode to 52SL2'. Each beam line may be modelled using either design or extant values for magnets and RF cavities. For each beam line, there is a Gold extant model and a Gold design model. These Gold models serve as the default model for AIDA query. The Gold tag is stored in the database and can be switched among the stored models.

ONLINE MODEL

The XAL online model [6] was first written for a spallation neutron source with H$^-$ or proton beam. The transfer map computation was based on TRACE 3-D [7] algorithm. On the other hand, LCLS is a light source with electron beam and unique devices such as undulators. The LCLS electron beam velocity is highly relativistic which means that the longitudinal coordinate has to be in the reference particle frame instead of fixed frame.

Transfer Map

The LCLS design and the SLC model system are based on MAD optics calculation, so a new model system should follow the same calculations. Transfer matrices for the following modelling elements in XAL were modified based on the MAD tracking algorithm [8]:

- Bend dipole

- RF accelerating gap
- Solenoid magnet
- Drift space

These new maps were also added:

- SLAC RF cavity
- Undulator segment with vertical focusing and no energy loss.
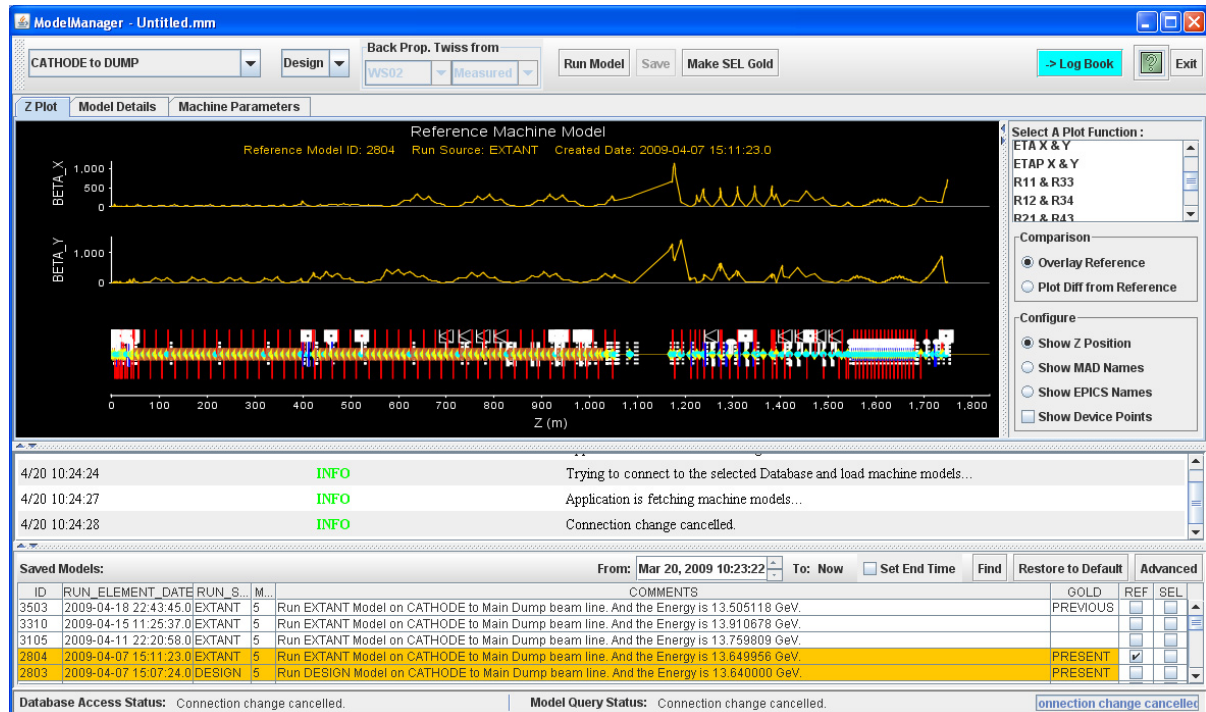

Figure 1: Model Manager application for running, viewing and saving the XAL model. The top tool bar is for running the model, the main panel in the middle is for data display, the section below the main panel is for message display, and the bottom panel is for selecting from available models in the database. The data panel shows an example of extant machine β-function over the entire LCLS.

Particular attention was paid to handle the edge effects for bend dipoles and RF cavity/accelerating gaps when these elements are split within the program. After our modifications the transfer matrices computed by XAL and MAD are nearly identical as shown in Fig. 2.

Twiss Parameters

Together with the correct transfer matrix computation, the Twiss parameters are now computed with proper relativistic correction.

Benchmark Comparison

After the transfer map modification described above, the XAL model was carefully compared with the MAD model in terms of energy calculation, R-matrix and other physics parameters. Initially the Twiss parameters did not agree well enough, so we took the R matrices from XAL, computed Twiss parameters in a Matlab script outside XAL and loaded them back to XAL model. We have now modified the XAL Twiss parameter calculation so that the entire process is handled by the new LCLS XAL model. Figure 2 shows a comparison between this version of XAL model and MAD throughout the entire LCLS main beam-line, from gun to undulator. There is slight difference near the largest β-function (larger than 500 m).

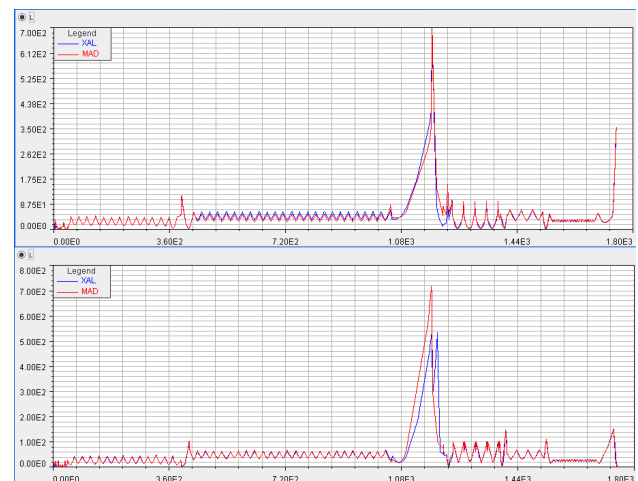After careful study, we have confidence that the XAL model does the right calculation.

Figure 2: Design β-function comparison between MAD and XAL model. The plots show horizontal (top) and vertical (bottom) β-function along the entire LCLS. Red curves from MAD are overlaid on blue ones from XAL.

Chicane magnets

Typically, the XAL online model assumes that the reference trajectory always follows the design bend angle while passing through a chicane magnet. For LCLS, the energy variation can be quite large and, therefore, this assumption is no longer valid for live machine. The reference angles are therefore dynamically adjusted according to the ratio of the live magnetic field to the design one.

Acceleration Structure

At present, the LCLS control system does not provide EPICS CA signals for most of its RF cavities. A separate routine is written to query the old SLC control system for the klystron settings via AIDA. This routine also calculates the phases and amplitudes for all the accelerating cavities based on klystron information as well as five well-defined reference energy points. The result is then inserted back into the XAL model.

Reference point Twiss Back Propagation

The beam-line tracking that starts at the cathode of the 6 MeV gun in the LCLS suffers from inaccurate modelling of the space charge effects and would result in unrealistic Twiss parameters being propagated downstream. A more accurate method that we adopted for the online modelling is to take either the measured or the design Twiss parameters at a well-defined Twiss parameter point where is far enough downstream and then back propagate along the machine to give an accurate representation of the Twiss parameters in the extant lattice for the majority of the machine. The back propagation of this beam through the solenoid at the low-energy gun requires that solenoids are treated as drift spaces, since the conventional Twiss parameters we use do not include coupling terms that a solenoid would introduce. This has not been a problem for us since the optics of interest during machine operation are all downstream of the gun solenoid.

APPLICATIONS

The LCLS XAL model is now the primary online model for LCLS operation. Four XAL-based Java applications are the mainstays of control room operation, the Orbit Display, the Model Manager shown in Fig. 1, the Save-Compare and Restore (SCORE) and the linac energy management (LEM) GUI shown in Fig. 3. The XAL model Application Program Interface (API) means that online model and its data are now used by host of other programs in the control room including LEM and a number of other Matlab scripts used for emittance measurement, beta matching and feedbacks. The accessibility of online XAL model data to Matlab applications has allowed LCLS to rapidly prototype many new applications. Model data can also be exported to spreadsheet files for offline analysis.

Additionally, every application developed for LCLS is trying to follow Model-View-Controller design pattern. If

any functionality of an application can be shared by multiple applications, the function is written in terms of callable API and packaged as a library module. Examples of such callable modules include LEM, Orbit Display and SCORE. A Matlab script written for quick machine energy change is using some of these callable Java modules.
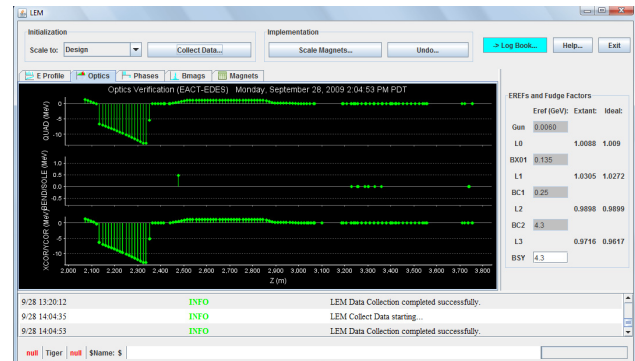

Figure 3: LEM GUI application for scaling LCLS linac magnet fields according to either extant or design lattice and present energy profile. In the right panel, it shows all five reference point energies and the fudge factors used in energy profile tracking; in the left panel, the tab shown is for each magnet the energy difference between present machine and a reference taken earlier. If the energy difference is larger than a certain threshold, magnets can be rescaled to the present energy.

A SLAC specific GUI framework has been designed and prototyped. As shown in Figs. 1 and 3, at the top tool bar, common application features such as save-to-electron-logbook, Help and Exit buttons can be part of the GUI framework. This SLAC GUI framework is to help facilitate SLAC operation.

Some applications such as LEM and Orbit Display also have a trim-down version to run continuously for control room information display purpose. These display-only applications also use the callable API provided by their original applications.

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