ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-MOPWI046

eDT AND MODEL-BASED CONFIGURATION OF 12 GeV CEBAF *

D. Turner, Jefferson Lab, Newport News, VA 23606, USA

Abstract

This paper discusses model-driven setup of the Continuous Electron Beam Accelerator Facility (CEBAF) for the 12GeV era, focusing on the `elegant` Download Tool (`eDT`). `eDT` is a new operator tool that generates magnet design setpoints for various machine energies and pass configurations. `eDT` was developed as a tool to facilitate reducing machine configuration time and reproducibility by way of an accurate accelerator model.

MOTIVATION

An accurate accelerator model is critical for accelerator operations, as it enables comparisons of expected and observed beam behavior and helps identify root causes of discrepancy [1]. A well-modeled machine ensures predictability and reproducibility.

CEBAF supports a highly dynamic nuclear physics program. Energy and pass changes occur rather frequently. In an extreme case, we performed eleven pass changes and three energy changes in a one month period. Reducing tune time is crucial for such a program. An infrastructure of tools and procedures that systematically identify differences between the machine and the model will permit convergence which will lead to reductions in tune time, faster recovery from failures, and a better understanding of CEBAF 12GeV accelerator controls and dynamics.

`eDT` is a major component of the new infrastructure and operational paradigm supporting model-driven setup and operation of 12GeV CEBAF. `eDT` computes magnet design setpoints directly from the CEBAF model and applies them to the machine.

OVERVIEW OF CEBAF

CEBAF is a 5.5-pass, 12GeV continuous wave (CW) electron accelerator. It utilizes a photoinjector source capable of delivering greater than 85% spin polarization. CEBAF is comprised of two anti-parallel superconducting RF linacs connected by two sets of recirculation arcs. Jefferson Lab recently completed the upgrade of CEBAF from a 5-pass, 6GeV machine to 5.5-pass, 12GeV. See Fig. 1.

MACHINE SETUP DURING THE 6GeV ERA

Operators would initially configure the machine for a given energy and passes by using a software tool which scaled machine settings from previous configurations which were believed to be well-tuned. This usually didn't work without excessive tuning time as the machine was not modeled well and the magnet mapping was incomplete. The mode of operations would then be a cycle of tweaking, measuring, and tweaking again. Using these methods, pass and energy changes would take from several hours to several shifts.

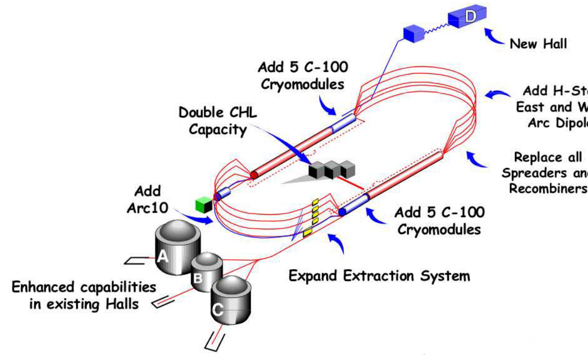

Figure 1: Scope of the 12GeV CEBAF upgrade.

During 6GeV, there was no central source for configuration control. Occasionally, hardware changes did not propagate to operator tools and screens. There was also no feedback into the model. The model was not updated to reflect operational experience.

MACHINE SETUP FOR 12GeV

To address the problems with configuring and modeling CEBAF, the CEBAF Modeling Team was formed to establish tools and procedures for model-driven configuration for 12GeV [1]. The Modeling team meets weekly while CEBAF is running, and semiweekly during scheduled maintenance periods.

The Modeling Team switched to `elegant` [2] to model CEBAF. `elegant` is a 6-D accelerator simulation code that does particle tracking, optimization, synchrotron radiation, scattering, and others. It is open-source code developed at the Advanced Photon Source (APS) at Argonne National Laboratory and it is actively maintained and continuously improved by both APS and the worldwide accelerator community. It has a large user base and it is more "industry standard" than the `OptiM` or `Art++` modeling tools previously used at CEBAF [6]. `elegant` is a command line tool that works well behind the scenes as an engine to drive operator tools. `elegant` is parallel capable for large scale simulations. `elegant` integrates well with the fully developed Self Describing Data Sets (`SDDS`) [3] toolset and infrastructure, making large scale data processing simpler [4], [5]. `elegant` also has better (and better tested) functionality to incorporate magnet errors which is an important part of reconciling online modeling with machine measurements [6].

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To address configuration control, the CEBAF Element Database was created [7]. CED is a relational database that stores beamline elements and their attributes. It is the authoritative source of hardware, control system, and model information for the accelerator. It is accessed real-time by control system software and operator tools. Operator screens are generated from CED "on the fly" so they are always correct and up to date. CED can be accessed by the web interface, command line interface, or by an available API for C++, Perl, PHP, and Tcl.

The Modeling Team also established a formal "feedback loop" process such that model discrepancies discovered during commissioning and operation are fed back to the model, thus providing a path for convergence. The process includes a formal audit to verify consistency and correctness.

elegant DOWNLOAD TOOL

eDT is an operator tool that generates magnet design setpoints for various machine energies and pass configurations. The design setpoints are computed from the elegant design values stored in CED rather than scaling from previous settings as we did before. eDT converts settings from elegant units to control system units and compares design values to current machine values. eDT computes allowed ranges for designated tuning knobs. eDT also provides a mechanism for overlaying non-design configurations over top of the design. eDT utilizes the CED API and elegant.

eDT was developed using the Perl [8] programming language. Perl was chosen to leverage existing CEBAF-specific libraries, and because it is the most commonly used scripting language for operator tools at CEBAF.

The design values for magnets are stored in CED in terms of bend angles, focusing strengths, and effective magnet lengths. eDT must know the momentum at each element in order to convert the design values into control system setpoints. The momentum at a given element is determined by the linac energy gains, number of passes through the machine before extraction (in the case of an element in an experiment hall), and cumulative synchrotron radiation losses. The linac energy gains and number of passes are retrieved directly from the control system in the form of EPICS process variables.

During the 6GeV era, energy losses in CEBAF due to synchrotron radiation were small enough to be considered negligible as far as machine setup was concerned. Doubling the beam energy from 6GeV to 12GeV increases the energy losses by a factor of 16 since radiated power increases as the fourth power of particle energy [9]:

$$P_\gamma = \frac{cC_\gamma E^4}{2\pi\rho^2}.$$

elegant computes synchrotron radiation losses and provides the resulting beam momentum at each element in a manner trivially accessible to the user. eDT invokes elegant for exactly this reason.

The overall workflow of eDT is as follows: Given a beam destination, eDT fetches the corresponding set of beamline elements from CED. From this set of elements, eDT creates an elegant lattice and command file. eDT then invokes elegant to compute the momentum at each beamline element, taking linac energy gains, number of passes, and synchrotron radiation losses into account. Finally, eDT computes the control system setpoints for all magnets up to the chosen beam destination and presents them as a list to the operator. The operator can sort and filter the list according to various criteria, compare present magnet setpoints to design, and download design setpoints to the machine.

The primary use case for eDT is initial setup after a shutdown or before a machine reconfiguration. Operators typically begin machine setup by invoking eDT with the appropriate linac energy gains and number of passes at extraction points. eDT then computes the design setpoints for the machine and makes them available to download into the machine by the operators. Occasionally, the design setpoints are generated ahead of time to be reviewed by accelerator physicists for correctness and consistency. Reasons for review include debugging eDT and verifying model data were properly imported into CED.

Ideally, once the design setpoints are downloaded, the machine would be optimized and ready for physics. In reality, due to an imperfect model, tuning is always required. One of the major goals of the Model-Driven CEBAF effort is to minimize tuning time with improvements to the model. The improved model will be applied to the machine by way of CED and eDT.

A particular example of reduced tune time by model improvement occurred during early 12GeV commissioning. Operations crews were configuring the machine at various energies, starting with design setpoints for each energy generated by eDT. At each new energy, accelerator scientists and crews noted vertical dispersion leakage out of the first spreader and into the first recirculation arc. The designated tuning quadrupole magnet had to be adjusted away from the design setpoint given by eDT by approximately 11% each time to zero the dispersion leakage. It was found that the body gradient for a particular vertical bending dipole in the first spreader had been entered incorrectly into the design decks and CED. Once the discrepancy in the model was corrected, the dispersion tuning was no longer necessary. In this case, eDT revealed a tuning trend which in turn revealed a model discrepancy.

The second use case for eDT is to compare a set running machine setpoints to design, and to correct or explain discrepancies. Occasionally, a magnet can be left at an incorrect setpoint due to operator errors, software errors, or procedural errors. Identifying the offending magnet was often not trivial. eDT simplifies the search for magnets that are not set to their design setpoints by presenting the operator with a list of magnets along with their design and present setpoints. The list can be filtered and sorted by various criteria such as percent off-design, absolute difference from design, or beamline order, to name a few.

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There have been numerous instances in the commissioning and operation of 12GeV CEBAF where beam was not of adequate quality or transportability after a procedure or downtime incident. Using eDT, an operator can quickly determine whether there are magnets that are not at their correct setpoints and correct them if so.

CONCLUSION

The machine and model will converge over the course of 12GeV operations, leading to a measurable reduction in necessary tune time for new machine configurations and improved CEBAF operational beam quality. As we gain more experience with the new machine and new model-driven operational paradigm, we will streamline our tools and procedures for more efficient machine operation. eDT and the new model-driven paradigm have seen success in the initial commissioning and subsequent operation of 12GeV CEBAF.

ACKNOWLEDGMENT

The author would like to thank (in alphabetical order) Arne Freyberger, Michele Joyce, Marie Keesee, Theo Larrieu, Yves Roblin, Todd Satogata, Chris Slominski, Mike Spata, and Mike Tiefenback for their support and criticism, as well as all others who made this project possible.

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