Model-Driven CEBAF Setup After the 12GeV Upgrade

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Workshop on Accelerator Operations
Mainz, Germany
October 28, 2014

Abstract

For the 12GeV upgrade, improvements in agreement between the CEBAF model and machine performance, along with new software tools and processes, were implemented such that new machine configurations can be set from the model with less tune time. Over the course of 12GeV CEBAF commissioning, these new tools and processes were tested and improved upon. The result was a measurable reduction in necessary time for new machine configurations. This talk will discuss the new tools and processes and compare with those of the 6GeV CEBAF era.

1 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 reproducibility.

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

2 Overview of 6GeV CEBAF

CEBAF stands for **C**ontinuous **E**lectron **B**eam **A**ccelerator **F**acility. It was a 5-pass, 6GeV continuous wave (CW) electron accelerator. It utilizes a photoinjector source which gives greater than 85% spin polarization. It is comprised of two superconducting RF linacs connected by two sets of recirculation arcs. It can deliver up to 180μA beam current and it can deliver simultaneous beam to three experiment halls.

3 Scope of 12GeV Upgrade

Jefferson Lab recently completed an upgrade to CEBAF to double its available beam energy. Five new higher-gradient superconducting RF cryomodules were added to each linac. The refrigeration capacity of the Central Helium Liquefier was doubles to support the extra load. Magnets is the recirculation arcs and their power supplies were modified to be able to steer the higher energy beam. A new experiment hall, Hall D, was added along with a new beamline connecting it to the accelerator.

4 Machine Setup During the 6GeV Era

During the 6GeV era, the modeling codes of choice were `OptiM` and `Art++`. These tools are not widely used outside of CEBAF, and are no longer being maintained by their authors. `OptiM` is built only for Microsoft Windows, while the CEBAF controls run on Linux. `OptiM` is more of a graphical tool which is not well suited to running in batch mode behind the scenes and driving operator tools. Both `OptiM` and `Art++` have limited functionality to incorporate magnet errors, which is an important part of reconciling online modeling with machine measurements.

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. "Grope and Hope" was a favorite catch-phrase in Operations. Using these methods, pass changes could take four or more hours, and energy changes could take eight or more hours. Drastic changes in energy could take many shifts.

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.

5 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 tracking, optimization, synchrotron radiation, scattering, and others. It is open-source code developed at the Advanced Photon Source at Argonne National Laboratory and it is actively maintained and continuously improved by APS and the worldwide accelerator community. It has a large user base and it is more "industry standard" than `OptiM` or `Art++`. [3] `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 `SDDS` 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. [3]

To address configuration control, the CEBAF Element Database was created. `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 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.

6 New Software Tools for Model Driven 12GeV

6.1 `elegant` Utilities Library (`eUtilities`)

`eUtilities` is a set of Perl modules which provide an object-oriented interface to `elegant`. It provides methods for creating and manipulating `elegant` lattice and command files. Many of our new tools were built upon `eUtilities`.

6.2 `elegant` Download Tool (`eDT`)

`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, `elegant`, and `eUtilities`.

6.3 Quad Scan Utility (`qsUtility`)

`qsUtility` is a tool for performing and analyzing transverse emittance measurements. It uses `CED` and `elegant` to determine design optics parameters, transport matrices, etc. It produces phase-space plots to visualize the quality of the match.

The previous emittance measurement tool was not transparent to the operator. It provided little feedback concerning the quality of the measurement while the measurement was taking place. It relied on an expert to analyze the data offline, after the measurements were taken. Often measurements did not provide useful data, but the operator had no direct way of knowing.

`qsUtility` provides "real-time" feedback while the measurements are being taken and provides the operator with an immediate indication of measurement quality. The operator then has the ability to modify the measurement parameters to perform to collect useful data.

6.4 `matchingTool`

Even with a machine behaving as modeled, sometimes matching is required. For example, beam parameters from the early part of the injector can vary from run to run or even drift over time, requiring rematching the beam entering the North Linac. `matchingTool` provides a means for operators to perform matching. `matchingTool` takes Twiss parameters measured with `qsUtility` and uses `elegant`'s built-in optimizer to provide automated matching.

Matching used to be performed only by optics experts. Each expert had a different method, some better than others. When the match was found to be bad, experts needed to be called in to rematch. `matchingTool` provides a consistent method for matching that operators can use without the help of optics experts.

7 Path Forward

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.

References

[1] Todd Satogata. Jlab accelerator division model-driven cebaf operations scientific/technical project charter.

[2] M. Borland. *elegant: A Flexible SDDS-Compliant Code for Accelerator Simulation*. Advanced Photon Source LS-287, September 2000.

[3] Todd Satogata. Private communication.

[4] Mike Spata. Private communication.

[5] Yves Roblin. Private communication.