AN INDUCTION LINAC TEST STAND*

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Abstract

A single-cell test stand has been constructed at LLNL for studies aimed at improving the performance of the FXR radiographic facility. It has guided the development of diagnostics, pulsed power improvements, machine maintenance, and interface issues relevant to the entire accelerator. Based on this work, numerous machine improvements have been made which have resulted in demonstrable improvements in radiographic resolution and overall machine performance.

INTRODUCTION

Although direct application of Faraday's Induction Law as a means to accelerate particles in a circular orbit in a changing magnetic field [1] was utilized early in the history of accelerators, the technique was not successfully applied to linear acceleration at high energy [2] until the mid 1960's. Advances in pulsed power technology [3] have enabled this field to steadily develop. Modern induction linacs find application [4] in fields such as heavy ion fusion, advanced radiography, and advanced rf sources for next-generation linear colliders.

The FXR Upgrade Project

The Flash X-Ray (FXR) induction linac (see Fig. 1) at Lawrence Livermore National Laboratory (LLNL) is one of the few early [5] linear induction accelerators (LIAs) to still be in daily use at a working radiography user facility. Compared to modern radiography LIAs such as DARHT and DARHT-II [6], FXR was beginning to "feel its age". With a 2.5-mm X-ray spot size, image resolution was no longer "world class". A sizable investment in a new Contained Firing Facility [7] had been made and, along with an aggressive radiographic test schedule, accelerator reliability would become increasingly important.

The Single-Cell Test Stand

Along with an aggressive spot size goal of 1.5 mm, to be achieved while maintaining dose on target, there were budget constraints in the upgrade program as well. It was believed [8] that significant program leverage could be obtained through construction of a single-cell test stand, as shown in Fig. 2.

As constructed, the Test Stand (see Fig. 3) provides diagnostic access to any part of the normal accelerator cell, serves as a test bed for diagnostic development and their calibration, including data acquisition and control, and is particularly valuable for pulsed power development and optimization. It can be operated independently of the accelerator and is ideal for aging components or performing longevity or reliability experiments. In the following sections, we will discuss several Test Stand experimental campaigns that ultimately yielded improvements in FXR performance.

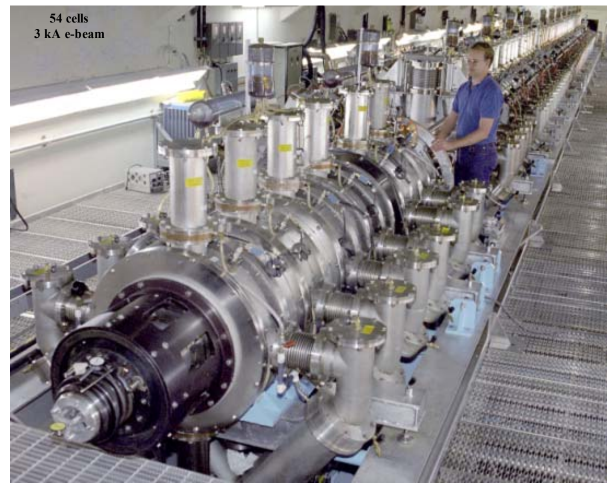

Figure 1: The FXR induction linac at LLNL.

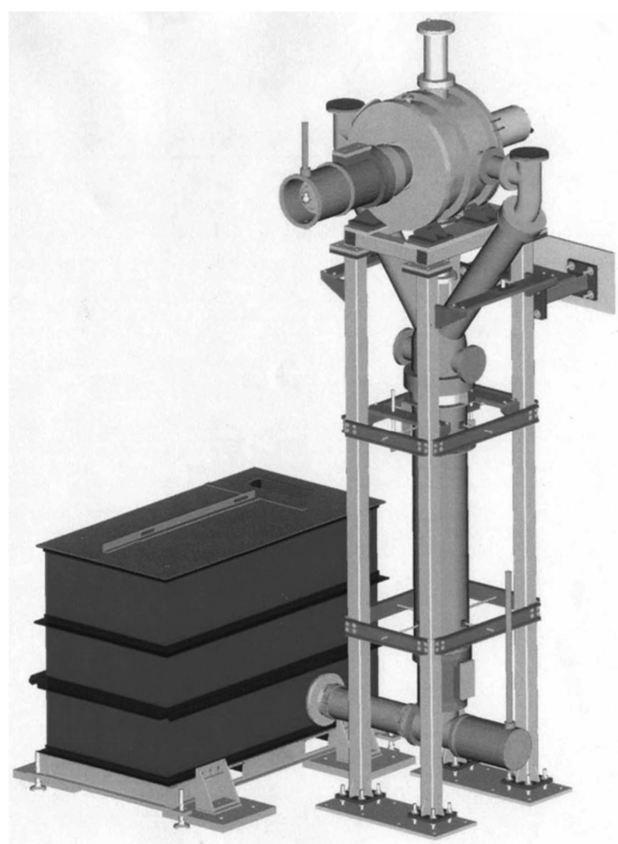

Figure 2: Solid model of the Single-Cell Test Stand.

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Figure 3: The Single-Cell Test Stand as constructed.

TEST STAND EXPERIMENTS

C-T Timing, Precision and Jitter

Pulsed power for FXR takes place in three stages of energy compression. First, a Marx bank is charged in a few seconds via two ±40 kV commercial charge supplies. Next, as the Marx erects, it resonantly charges (see Fig. 4) a nested coaxial Blumlein in a CT ("charge-to-trigger") time of ~2 µs. Finally, the triggered Blumlein switches out a 90-ns square pulse (see Fig. 5) to the accelerator cell ferrite via a 2-point cell feed geometry.

In practice, CT becomes a convenient "knob" for the slope of the pulse's flattop. For each accelerator cell, this contributes to some degree of temporal voltage variation in final beam voltage. Since the behavior of the final focus solenoid is highly energy-dependent, this strongly impacts final spot size on the X-ray conversion target.

On the Test Stand, families of curves for different charge voltages and CT times were generated permitting precise relationships to be established for timing precision and jitter. Additionally, as full accelerator optimizing was underway, cell voltage data from each cell could be used to predict final energy spread and adjust CT time in advance. Along with attention to basic switch timing, this had an important effect on FXR improvement.

In comparing different cell waveforms or the dependence of a given cell to various parameters, it is valuable to fit straight lines to the flat top portion of the pulse. A goodness-of-fit parameter as simple as the root-mean-square error could be used to determine its optimal starting point. Key to this is realizing that the wider the line width, the worse the fit as that particular width adjusts itself to a different portion of the flat top. Hence, pulse flatness is dependent on the pulsewidth of interest. This becomes a tradeoff between minimizing image

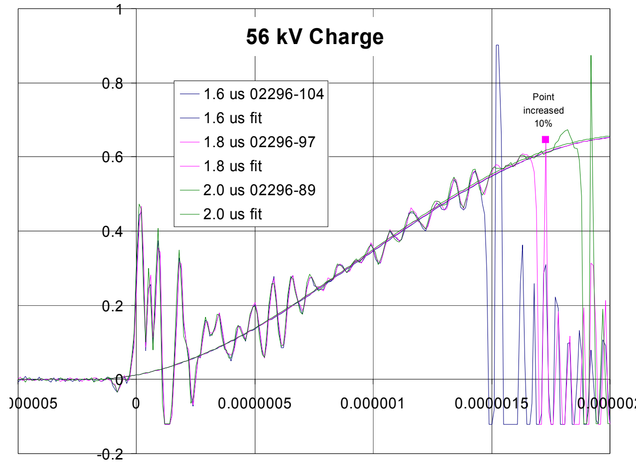

Figure 4: Measured marx outputs with 1–cosine best fits for different CT times.

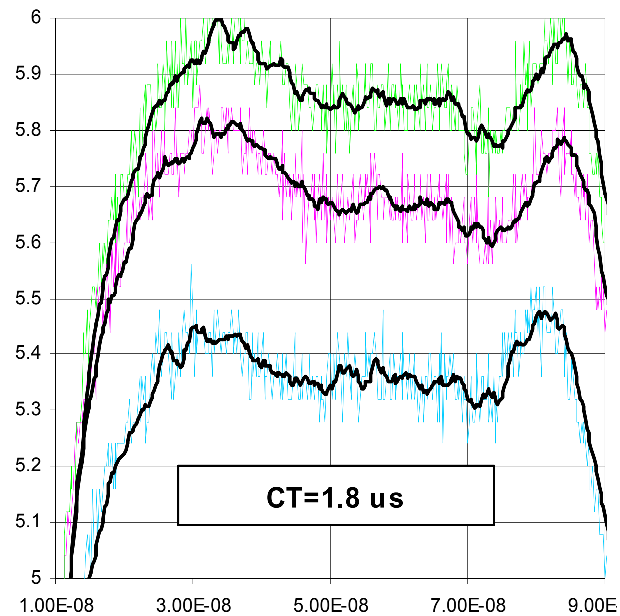

Figure 5: Measured cell voltage for 3 different blumlein charge voltages.

motion blur and maximizing dose and must include some allotment for inevitable systematic errors and component jitter.

Diagnostic Development

The Test Stand was used to calibrate voltage and current sensors and has ushered in a new era of Best Practices in precision rf measurements at FXR, such as time domain reflectometry (TDR) analysis [9] of cell transmission element matching. Attention has been paid to cable dispersion, beam loading effects, and cell-to-cell variation in ferrite properties as well as renewed attention paid to ambient temperature control and switch maintenance. FXR has seen a 128-channel suite of Acqiris fast digitizers implemented on the accelerator, the value of which was born out of the array of GPIB oscilloscopes that initially diagnosed the Test Stand.

These digitizers have been separately verified for linearity, amplitude fidelity, and intermodulation product content.

VALIDATION

The entire FXR accelerator is being fully characterized in this upgrade effort to improve its radiography capabilities. A magnetic dipole-based energy spectrometer has recently been constructed for FXR. The dipole images the electrons scattered from a fine wire, insertable in the main beam just before the final focus solenoid, to a detector array at the dipole's exit. The 40-detector array is arranged in a resistive divider arrangement and multiplexed to two different output channels that can be summed and differenced to give the resulting energy spread across the array. Initial results from this real-time fast beam diagnostic (see Fig. 6) are encouraging. Other fast detectors include pinhole camera arrays and a Mucaddix diamond detector array obtained from AIRIX. In combination with time-integrated, accepted spot size measurements on film from mildly rolled, high-Z edges and thermoluminescent calibrated detector readings, a complete story of FXR's capabilities (see Fig. 7) is being charted.

CONCLUSIONS

A convenient Figure of Merit for radiographic capability is the ratio of dose to aperture, or dose to spot-size-squared. This upgrade effort, aided by Test Stand experiments, has paid off (see Fig. 8) in an FXR record in terms of this important Figure of Merit.

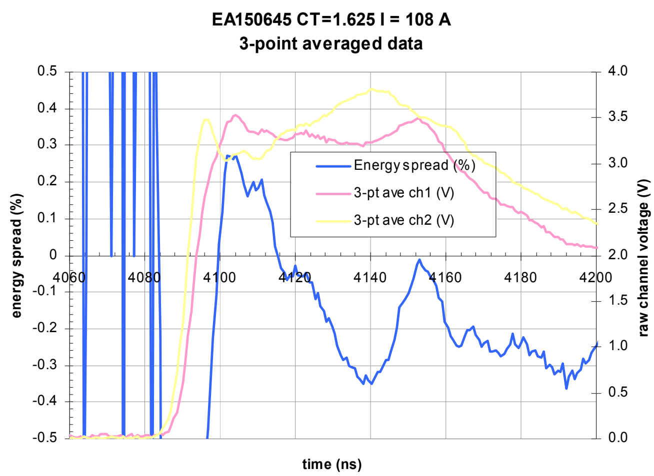

Figure 6: Initial results of the FXR Wire Scatter Energy Analyzer. The pulse is taken from 4100-4160 ns.

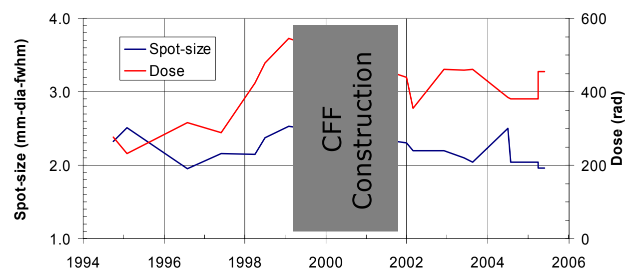

Figure 7: History of FXR dose and spot size measurements.

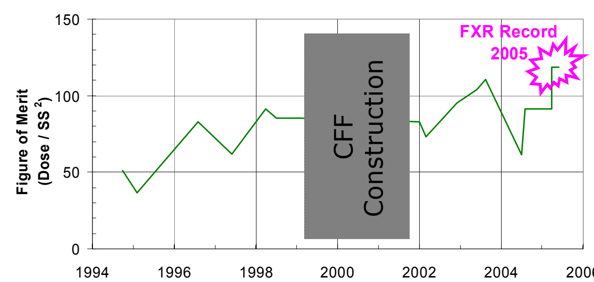

Figure 8: Steady improvement in radiographic figure of merit.

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