

STATUS OF THE DARHT 2nd AXIS ACCELERATOR AT THE LOS ALAMOS NATIONAL LABORATORY *

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Abstract

The Dual Axis Radiographic Hydrodynamic Test Facility (DARHT) was constructed at Los Alamos National Laboratory as a radiographic facility to provide dual-axis multi-time radiography to support the US Stockpile Stewardship Program. The DARHT 1st Axis has been operational since 1999 and has been providing excellent radiographs. The DARHT 2nd Axis construction project was completed in early 2003. However, during the subsequent commissioning efforts to bring it to the full specifications of 17 MeV, 2 kA and 2 micro-second pulse length, high voltage breakdown was observed in several of the 78 induction accelerator cells [1].

In January 2004, the DARHT 2nd Axis Refurbishment and Commissioning Project was launched. It is a Los Alamos National Laboratory effort in collaboration with the Lawrence Livermore and Lawrence Berkeley National Laboratories. Its purpose is to first address the HV breakdown problems with the 2nd axis accelerator cells [2], address the remaining physics of the multi-pulse electromagnetic kicker and X-ray converter target and then commission the full energy 2nd axis accelerator. The redesign of the cell as well as long pulse beam stability tests were completed in 2005. Testing of the multi-pulse electromagnetic kicker and X-ray converter target was completed in February of this year using an 8 MeV scaled accelerator that used twenty-six refurbished accelerator cells. Commissioning of the 2nd axis 2.5 MV, 2.0 kA electron injector and the full-energy accelerator beamline is currently underway. Commissioning of the downstream transport section and multi-pulse kicker will begin in early October of this year after accelerator commissioning is completed. Target commissioning is scheduled to begin in November 2007.

The DARHT 2nd axis is scheduled for completion in early 2008, at which point the DARHT facility will be ready to support two-axis, multi-pulse radiography in

support of the Stockpile Stewardship Program. In this paper, we present the overall project status, commissioning strategy and schedule.

INTRODUCTION

The DARHT Second Axis (Cell) Refurbishment and Commissioning Project began in Jan 2004 to remedy the accelerator cell design and assembly defects found during the commissioning of the DARHT 2nd axis accelerator. The cell redesign has been completed and all seventy-four cells (six injector cells and sixty-eight accelerator cells) have been refurbished, installed and are currently being commissioned. This project is a collaboration among three University of California Laboratories, the Los Alamos, the Lawrence Berkeley and the Lawrence Livermore National Laboratories, with LANL having the overall project responsibilities.

The Dual Axis Radiographic Hydrodynamic Test (DARHT) facility, shown in Figure 1, was conceived in the early 1980's as a critical tool for nuclear weapons development and stockpile stewardship. At present, in the absence of underground nuclear testing, maintenance of an aging nuclear weapons stockpile relies on complex computer simulations. The purpose of DARHT is to benchmark and verify these computer codes by providing multiple X-ray images along two axes. These images are used to evaluate the primaries of nuclear weapons through non-nuclear hydrodynamic testing, or "hydrotests". DARHT consists of two induction linear accelerators oriented orthogonal to each other. Each accelerator generates a high current, 17 to 20 MeV electron beam. Each of these electron beams converges onto bremsstrahlung targets, which convert a fraction of the electron beam kinetic energy into X-rays. Multiple X-ray pulses are then used to image the mock imploding device onto detectors to produce "quasi- 3 dimensional" radiographic images.

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Figure 1. Aerial view of the Dual Axis Hydrodynamic Test (DARHT) facility at the Los Alamos National Laboratory.

Flash radiography measurements require three essential capabilities: high resolution, multiple views for “quasi-3D” reconstruction, and multi-time frames for dynamic code benchmarking. This is illustrated schematically in Figure 2. When completed, the DARHT facility will be the first to provide this capability.

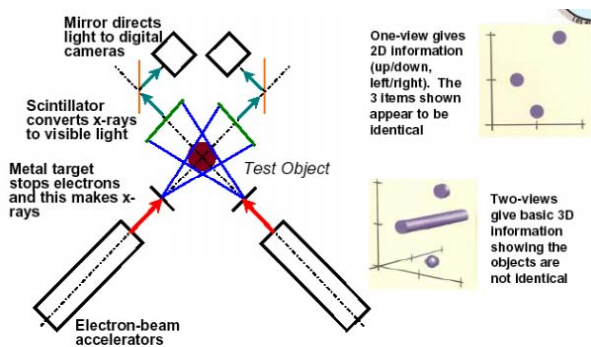


Figure 2. DARHT's dual axes design is based on generating “quasi-3D” X-ray images.

DARHT 1st Axis

The DARHT 1st axis [3] has been operational since 1999 and provides a single, high-resolution radiograph. The DARHT 1st axis accelerator consists of a 3 MV, 1.9 kilo-Ampere electron injector having a 60 nano-second pulse duration and 64 accelerator cells that operate at 250 kV/cell, producing a final beam energy of 20 MeV. The 1st axis accelerator cells, installed in one wing of the DARHT facility is shown in Figure 3. The 1.9 kA, 60 ns electron beam is focused to less than 2.0 mm in diameter (MTF) onto a Tantalum converter target, generating an X-ray fluence of 625 Rad at one meter. During the later part of the original DARHT 2nd Axis Construction Project and throughout the current DARHT 2nd Axis (Cell)

Refurbishment and Commissioning Project, the DARHT facility, utilizing the 1st axis, has been and will continue to be a fully functioning radiographic capability in support of the US National Hydrotest Program for Stockpile Stewardship.



Figure 3. The DARHT 1st axis accelerator consists of a 3 MV injector and 64 induction cells, each cell operating at 250 kV to produce a 19 MeV, 1.9 kA, 60 ns electron beam. The electron beam is focused onto a Tantalum target, generating a 625 Rad X-ray pulse having a spot size diameter of less than 2.0 mm (MTF).

DARHT 2nd Axis

The DARHT 2nd axis accelerator is a 17 MeV, 2.0 kilo-Ampere, 1.6 micro-second linear induction accelerator and is shown in Figure 4. The operational parameters of the 2nd axis are given Table 1. The DARHT 2nd axis accelerator consists of a 2.5 MV injector and 6 injector cells each operating at 175 kV and 68 accelerator cells each operating at 200 kV. The injector cells have a larger diameter bore compared to the accelerator cells to allow for a larger acceptance of the beam from the injector at the lower energies. Following the cell redesign, all seventy-four cells (six injector cells and sixty-eight accelerator cells) have been refurbished (Figure 5).

An electromagnetic kicker, in the downstream transport section located at the exit of the accelerator alternately diverts the electron beam to the target and beam dump respectively at pre-selected time intervals to produce four electron beam pulses. The four pulses are then focused onto an X-ray converter target to generate the four X-ray output pulses while the remaining beam current is transported to a graphite-tungsten beam dump. This alternate diversion of the beam is schematically shown in Figure 6.

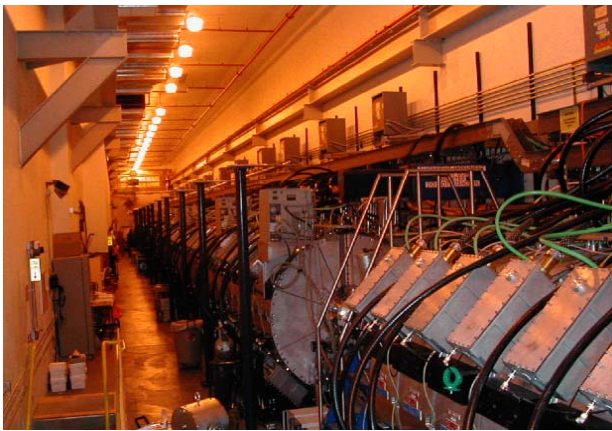


Figure 4. The DARHT 2nd axis accelerator consists of a 2.5 MV injector and 6 injector cells each operating at 175 kV and 68 accelerator cells each operating at 200 kV to produce a 17 MeV, 2.0 kA, 1.6 microsecond electron beam.



Figure 5: All accelerator cells have been refurbished and tested at LANL.

Table 1. DARHT 2nd Axis Performance Requirements

Injector Voltage	2.5 MV
Injector Current	2.0 kilo-Amperes
Injector Pulse Length	1.6 micro-seconds
Number of Injector Cells	6 @ 175 kV/cell
Number of Accel. Cells	68 @ 200 kV/cell
Total Beam Energy	17.1 MeV (goal 18.1 MeV)
Number of Pulses	4
X-ray Output	100, 100, 100, 300 Rads @ 1 meter
X-ray Spot Size -FWHM	<1.6 mm diameter (all pulses)

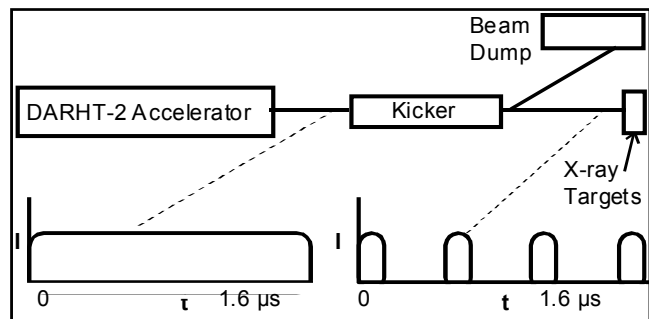


Figure 6. An electromagnetic kicker, at the exit of the accelerator alternately diverts the electron beam to the target and beam dump respectively to produce the four electron beam pulses. The four pulses are then focused onto an X-ray converter target to generate the four X-ray output pulses.

SCALED ACCELERATOR TESTS

Scaled Accelerator Configuration

The Scaled Accelerator tests addressed the physics issues associated with the beam transport, beam quality, beam centroid motion, as well as the four-pulse kicker and target performance, albeit at a lower energy of 8.0 MeV. The Scaled Accelerator test configuration shown in Figure 7 began in March 2006 and was completed in February 2007 [4]. It consisted of 6 un-refurbished injector cells, and 26 of the refurbished accelerator cells operated at a voltage of 200 kV per cell.

Electron Beam Energy

The accelerator cells were aligned to final specifications and the cell drivers, PFNs, and tuned to the required voltage “flat-top” of $\pm 1.0\%$. The scaled accelerator achieved an energy of 8.0 MeV with a beam energy regulation of $\pm 0.65\%$ (Figure 8) as measured with a magnetic spectrometer placed at the exit of the accelerator.

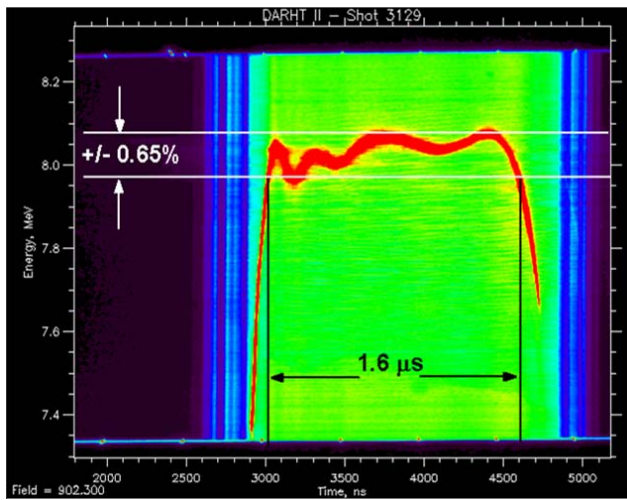


Figure 8. The kinetic energy measured with a magnetic spectrometer at the accelerator exit is within $\pm 0.65\%$ during the flattop.

Downstream Transport Kicker and Target Tests

After beam transport commissioning through the 26 cells was completed, the Down Stream Transport (DST) kicker, dump and target were tested [5]. This represented the first test of the multi-pulse kicker and target over a full pulse duration of $> 1.6 \mu\text{sec}$ to produce four pulses. The Scaled Accelerator Tests also served as the initial test of the accelerator and Downstream Transport section as a system. Experimental results show that the X-ray dose rate for all the four pulses remains approximately constant (Figure 9), showing that the X-ray dose goals identified in Table 1 can likely be attained. The images of the four X-ray pulses are shown in Figure 10 for both a standard “DARHT 1st Axis” target as well as the specially designed target. All four pulses are measured to be approximately 1.0 mm FWHM and meet the spot size requirement of 1.6 mm FWHM.

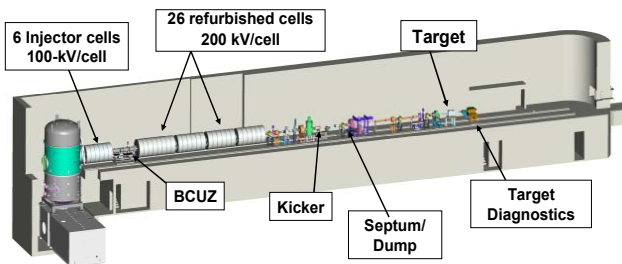


Figure 7. The Scaled Accelerator Tests provided the first look at the four-pulse kicker and target performance.

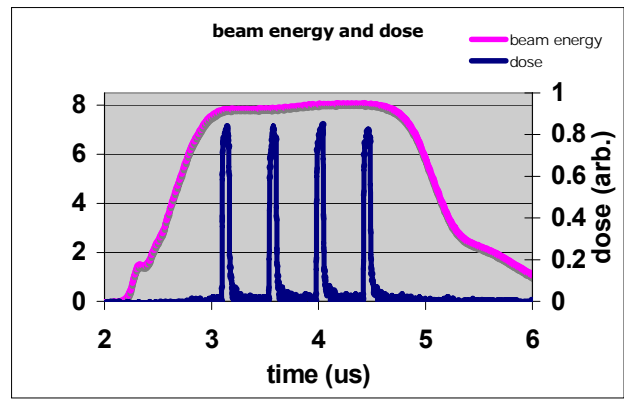


Figure 9. The X-ray dose rate for all four pulses remains approximately constant.

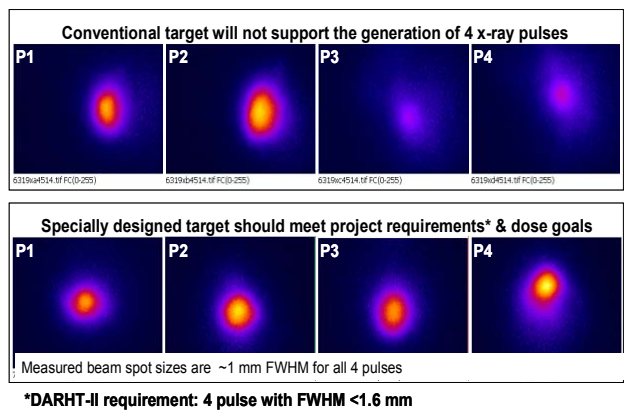


Figure 10. DARHT 2nd axis is on track to provide unprecedented hydro-test data.

FULL ENERGY COMMISSIONING

Full Energy Commissioning Tests

The DARHT 2nd axis accelerator, shown in figure 11, is the first long-pulse, high current accelerator and, therefore, represents a considerable advancement in linear induction accelerator technology. At the exit of the accelerator, the electron beam has an energy of about 75 kilo-joules, 20 to 30 times the beam energy of currently operating electron linacs. Commissioning of the accelerator began in June 2007 and will continue through most of July. The 2.5 MV electron injector uses a 16.5 cm diameter thermionic cathode that produces a 2 kA electron beam when operated at a true temperature of 1120 degC. Recently, a 2 kA, 1.6 μsec electron beam was successfully transported through the accelerator to an energy of 17 MeV (Figure 12). Effort is now underway to measure the beam energy at the exit of the accelerator using a magnetic spectrometer. At the completion of the accelerator commissioning in July 2007, the downstream transport section, which includes the multi-pulse electromagnetic kicker will be installed and commissioned.

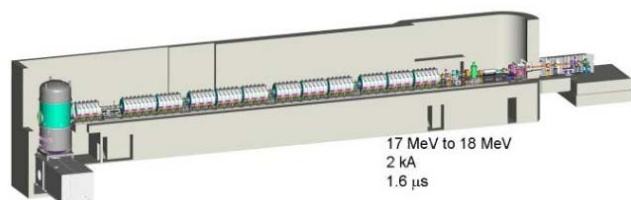


Figure 11. Commissioning of the full Energy accelerator began in June 2007.

The full energy commissioning tests will conclude with the installation of the four-pulse X-ray converter target and the measurement of the beam X-ray dose and spot size for each of the four output pulses. At the completion of the full energy commissioning tests, the DARHT 2nd axis will be ready for integration into the DARHT facility to support the hydro-testing program. The DARHT facility is scheduled for dual-axis, multi-pulse operation in support of the National Hydrotest Program in April 2008.

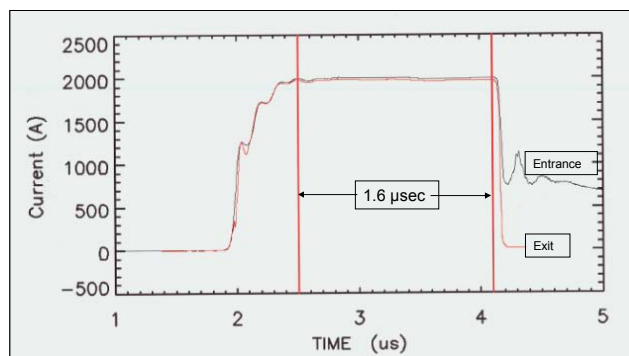


Figure 12. A 2 kA, 1.6 μ sec Flat-top beam has been transported through the accelerator to an energy of 17 MeV.

SUMMARY

The Dual Axis Radiographic Hydrodynamic Test Facility (DARHT) was constructed at Los Alamos National Laboratory as a radiographic facility to provide dual-axis multi-time radiography to support the US Stockpile Stewardship Program. The DARHT 2nd Axis Refurbishment and Commissioning Project began in January 2004. Its purpose is to first address the HV breakdown problems with the 2nd axis accelerator cells, address the remaining physics issues of the multi-pulse electromagnetic kicker and X-ray converter target and then commission the full-energy 2nd axis accelerator. The redesign of the cell as well as long pulse beam stability tests were completed in 2005. The Scaled Accelerator tests addressed the physics issues associated with the beam transport, beam quality, beam centroid motion, as

well as the four-pulse kicker and target performance at an energy of 8.0 MeV. Data from the scaled accelerator tests show that all four pulses are approximately 1.0 mm FWHM and meet the spot size requirement of 1.6 mm FWHM.

Commissioning of the 2nd axis 2.5 MV, 2.0 kA electron injector and the full-energy accelerator beamline is currently underway. Recently, a 2 kA, 1.6 μ sec electron beam was successfully transported through the accelerator to an energy of 17 MeV (Figure 12). Effort is now underway to measure the beam energy at the exit of the accelerator using a magnetic spectrometer.

The full energy commissioning will conclude with the installation of the four-pulse X-ray converter target and the measurement of the beam X-ray dose and spot size for each of the four output pulses. At the completion of the full energy commissioning, the DARHT 2nd axis will be ready for integration into the DARHT facility to support the hydro-testing program. The DARHT facility is scheduled for dual-axis, multi-pulse operation in support of the National Hydrotest Program for US Stockpile Stewardship in April 2008.

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