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AUTHOR(S): J. N. Downing, W. M. Parsons, L. M. Earley, J. G. Melton,
D. C. Moir, R. L. Carlson, G. A. Barnes, L. A. Builta,
S. A. Eversole, G. I. Keel, D. C. Rader, J. A. Romero,
R. P. Shurter

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Los Alamos
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

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PULSED POWER SYSTEMS FOR THE DARHT ACCELERATORS

J.N.Downing, W.M. Parsons, L.M. Earley, J.G.Melton, D.C.Moir,
R.L. Carlson, G.A. Barnes, L.A.Builta, S.A.Eversole, G.Keel,
D.C. Rader, J.A. Romero, and R.P. Shurter
Los Alamos National Laboratory, P.O. Box 1663,
Los Alamos, New Mexico, NM 87545

Abstract

The Dual-Axis Radiographic HydroTest (DARHT) Facility is being designed to produce high-resolution flash radiographs of hydrodynamics experiments. Two 16- to 20-MeV linear induction accelerators (LIA), with an included angle of 90° are used to produce intense bremsstrahlung x-ray pulses of short duration (60-ns flat-top). Each accelerator has a 4-MeV electron source that injects an electron beam into a series of 250-kV induction cells. The three major pulsed-power systems are the injectors, the induction-cell pulsed-power (ICPP) units, and the ICPP trigger systems, and are discussed in this paper.

Introduction

The DARHT facility at Los Alamos will generate intense bremsstrahlung x-ray pulses for radiography using two LIAs. Each LIA will produce a 3-kA, 16- to 20-MeV, 60-ns flat-top, high-brightness electron beam, using a 4-MeV injector and a series of 250-kV accelerating cells. Each cell consists of an oil-insulated ferrite core, an accelerating gap, and a solenoid magnet to transport the electron beam.[1] Three major pulsed-power systems are required to produce and accelerate the electron beam; the injectors, the induction-cell pulsed-power (ICPP) units, and the ICPP trigger systems. These systems are discussed in this paper.

Injector

The injector pulsed-power system has been designed by Pulse Sciences, Inc.,[2] and consists of a 1.5-MV, glycol-insulated Blumlein that is pulse-charged by a step-up transformer and switched by four, laser-triggered spark gaps. A series of transmission lines is used as a transformer to increase the output voltage of the Blumlein to 4 MV at the diode. The diode design used in the injector is identical to the diode developed on the relativistic electron-beam experiment (REX) machine [3] at Los Alamos. Injector specifications are listed in Table I.

A block diagram of the DARHT injector system [2] is shown in Fig. 1 and a cross-sectional view is shown in Fig. 2. The prime power supply consists of a 2.8-μF capacitor bank charged to 114 kV dc, which is switched through the primary of a 1:15 Stangenes iron-core pulse transformer by a single gas-blown spark gap. A glycol Blumlein, consisting of a 7.65- Ω line and a 7.3-Ω line, connected to the secondary of the transformer is pulse-charged to 1.5 MV in 4.6μs. The Blumlein output pulse traverses an adjustable L-C filter, which converts the initially sharp rising output pulse to a [1-cos(ωt)] shape with a 10-90% risetime of 20 ns. Three output lines are used to transform the output pulse from 1.8 MV to 4.0 MV on the diode. Circuit simulations [2] using a REX load [3,4] predict a pulse on the diode with a 16-ns (10-90%) risetime and 63-ns (± 1%) flat-top. Experiments are now underway on the Integrated Test Stand (ITS) at Los Alamos to demonstrate this capability.

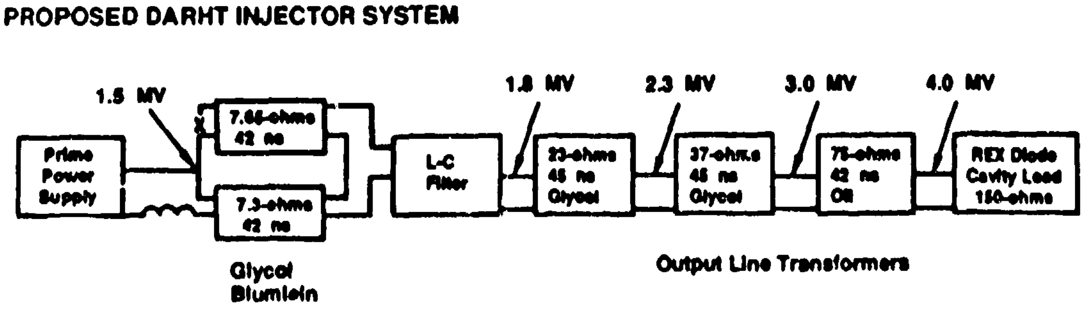

Fig.1. DARHT injector system block diagram.

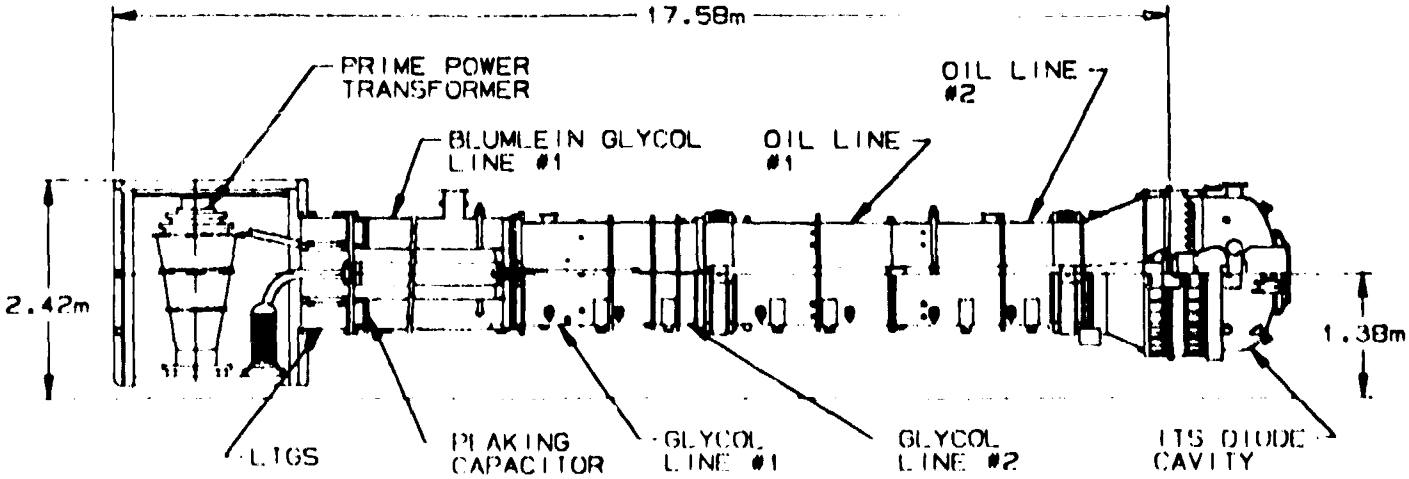

Fig 2 DARHT Injector cross sectional view

Table I. DARHT Injector Specification

DIODE INTERFACE VOLTAGE	
Risetime (10-90%)	17 ns
Duration of Flat-top (± 1%)	65 ns ± 5 ns
Flat-top Voltage (± 1%)	- 4.00 MV ± 40 kV
Pulse-to-Pulse Variation	± 40 kV (3σ)
Jitter	< 5 ns (3σ)
High-Frequency Ripple	< ± 1% for f <= 50 MHz -6dB/octave for f >50 MHz
Falltime (90 - 10%)	20 ns + 10 ns/- 5 ns
Maximum Prepulse Voltage	+ 500 kV - 100 kV
Maximum Postpulse Energy	< 50% of Main Pulse
Maximum Postpulse Voltage	± 1.5 MV
Maximum Rep Rate	0.2 Hz
Resistance Radial Resistor	175- to 185-Ω
SYSTEM LIFE, RELIABILITY AND MAINTAINABILITY	
Operations Between Maintenance	> 250,000
Operations Before Maintenance of High-Voltage Switches	> 25,000
Operations to End of Life of Major Components	> 10^6
Prefire Failure Rate	< 1/1000
Nofire Failure Rate	< 1/1000

By using a pulse transformer instead of a Marx generator to pulse charge the Blumlein, a single spark gap can be used instead of the multiple series spark gaps of a Marx generator. This feature improves reliability by reducing the number of components and simplifing maintenance. The Blumlein is switched to ground with four parallel laser-triggered gas switches (LTGS), and produces a pulse with a 10 - 90% risetime of 20 ns. The LTGS were chosen for this application because low-jitter operation has been demonstrated at Sandia National Laboratories.[5,6] These switches also exhibit long lifetime because they do not suffer from accelerated wear on a trigger electrode, which is required for low-jitter operation of an electrically triggered gas spark gap.

Recent injector diode experiments (~ 250 shots) with an A-K gap of 15 cm, an anode voltage of 2.3 MV, show pulse-to pulse reproducibility of ±1%. The anode voltage has a 61-ns flat-top and a 20-ns risetime. Beam current measurements indicate a peak current of 1.5 kA with a ±3% variation across the 60-ns flat-top. The risetime of the current was 10 ns. Excellent timing results have been obtained with the LTGS producing an overall machine jitter of < 1 ns. Measurements on each individual LTGS show jitters < 1 ns with ~ 10 mJ per LTGS at 266 nm. The experiments have indicated that the specification for maximum postpulse, + 1.5 MeV, is a concern, because the diode insulator flashes on a postpulse of < 0.950 MeV. Experiments are underway to evaluate the seriousness of the insulator flashing. A diverter switch is presently under investigation.

Induction-Cell Pulsed-Power System (ICPPS)

The electrical requirements of the pulsed-power system for a LIA to be used for radiography applications are dictated mainly by the beam handling and focusing requirement of the accelerator. A minimum spot size is necessary for high-resolution radiography, and one of the critical requirements for producing a small spot size is the generation of a mono-energetic beam of electrons. To meet this requirement the ICPPS must produce a flat-top accelerating voltage with minimal voltage variations. These voltage variations are either low-frequency variations that produce a "slope" or high-frequency ripple.

While the flat-top portion of the voltage pulse produces the radiographic output of the accelerator, the rising portion of the pulse represents wasted energy. The electrons produced during pulse rise do not transport through the accelerator because of the energy acceptance of the solenoids. A longer risetime requires a larger cross-section of ferrite core material and a longer Blumlein to produce the same length of flat-top on the voltage pulse. A very short risetime is also not desirable because it can excite electromagnetic modes in the accelerator cavity. Therefore, the integrated LIA design is a compromise between cavity design and pulsed-power design.[1,7-10]

The ICPPS for each accelerator consists of 24 water-insulated Blumleins, each energizing two induction cells. The modular design unit is based on eight induction cells corresponding to four ICPP units. A block diagram illustrating the ICPP module is given in Fig. 3. Maxwell Laboratories has designed the DARHT ICPPS. Each ICPP consists of a Blumlein that is pulse-charged through a step-up transformer and switched by an electrically triggered coaxial spark gap. The ICPPS specifications are given in Table II. The DARHT ICPPS design philosophy emphasizes minimum risk with maximum reliability and component life.

The Blumlein charging unit (BCU) uses two 1.2-μF Maxwell primary capacitors charged to 28 kV. Two EEV CX 1722 thyratrons are used in parallel to switch the primary capacitor into a 1:11 step-up Stangenes

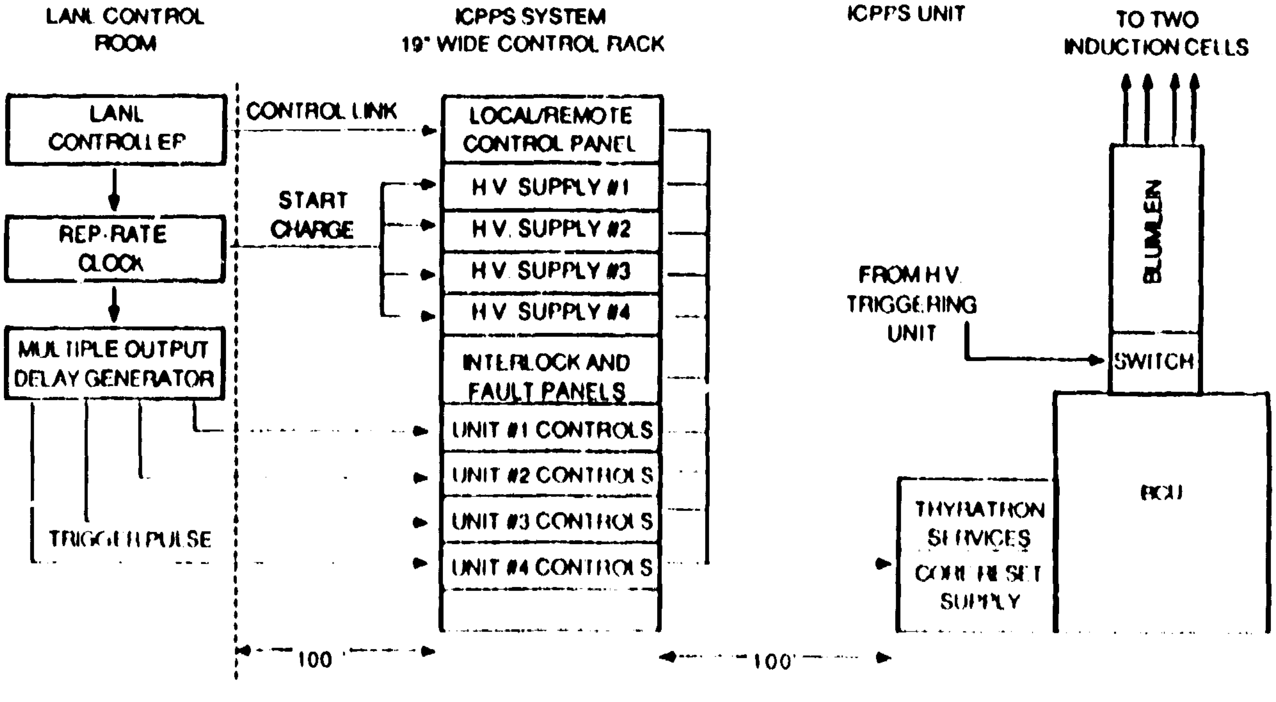

Table II. DARHT ICPPS Specifications

OUTPUT PULSE	
Nominal Blumlein Output Voltage	+250 kV
Range Blumlein Charge Voltage	+100- to +275-kV
Reproducibility	±1% (3σ)
Pulse Length Flat-top ±1%	67- to 75 ns
High-Frequency Ripple	< ± 1% for f <= 50 MHz -6dB/octave for f > 50 MHz
Blumlein Charge Time	< 10 μs
BCU Timing Jitter	< 50 ns (3σ)
Maximum Operating Frequency	0.2 Hz
SYSTEM LIFE, RELIABILITY, AND MAINTAINABILITY	
Operations Between Maintenance	> 250,000
Operations to End of Life of Major Components	> 10^7
Prefire Failure Rate	< 1/5000 Operations
No-fire Failure Rate	< 1/5000 Operations
Out-of-Spec Voltage From BCU Jitter	< 1/1000 Operations
Out-of-Spec Voltage	< 1/1000 Operations

on core transformer that charges the Blumlein to 250 kV in 5 μs. Using o thyratrons in parallel assures thyratron operation at very moderate rrent and current reversal values. All the components on the BCU ere selected to provide good reliability and very low probability of ilure. The CX 1722 should have a life > 10^8 operations at the erating conditions. Similarly, the Stangenes transformer is derived om SLAC transformers, which have a demonstrated lifetime of > 10^4 s at 180 Hz. The capacitors chosen for the BCU should have a system of more than 10^7 operations with a 99% confidence level.

The Blumlein pulse forming line has been designed with a low erating-to-breakdown field ratio of 0.35 (for a 5-μs pulse charging ne). Water is the insulating medium in the Blumlein. The outer diameter of the Blumlein is 16 in, and the impedance of each of the two lines is 6 Ω. Each of the lines has a nominal electrical length of 60 ns. The Blumlein is connected to a cable distribution box, that can use either oil or water for insulation. Four high-voltage 49 Ω cables are distributed in parallel to two induction cells.

The Blumlein switch is a coaxial midplane trigger high-voltage switch based on the ATA switch design [14]. Extreme care has been taken in the switch design to minimize any field stresses and to minimize the inductance (70 nH) of the switch. The switch is designed to operate in pure SF_6 and to have an extremely low prefire probability. A design safety margin (operating voltage/breakdown voltage) of 0.71, at 5-μs pulse charge time, assures a low prefire probability (1/2000). A high dV/dt (10kV/ns), high-voltage (200-kV) trigger pulse will be used to switch the gap reliably. Multi-channeling of the switch is a high probability, but it is not required to meet the ICPPS specifications. The mechanical design of the switch emphasizes the main gap's precision alignment that is needed to achieve the jitter, life, and switch-to-switch repeatability. Concentricity of all three electrodes will be maintained to within 0.025 mm. The switch is designed to have minimum distortions when exposed to high operating pressure. Elkonite has been chosen as the material for all three electrodes.

ICPP Trigger Systems

The DARHT triggering system modular unit has been designed by Maxwell Laboratories and consists of a single control console and four independently selected, identical trigger units, each of which is used to trigger a single ICPP. A block diagram of the modular unit is given in Fig 4. Each trigger unit is located in a separate oil-insulated steel enclosure, and each ICPP has its own trigger generator to facilitate timing adjustments. One high-voltage power supply with a fanout arrangement is used to charge the four trigger units. The output voltage is adjustable in the range of 150- to 200-kV and is routed to the ICPP units using DS #2077 cable. The triggering unit consists of a thyratron-switched, step-up transformer that drives a magnetic pulse-compressor which reduces the risetime of the 200-kV output pulse to less than 10 ns into the trigger

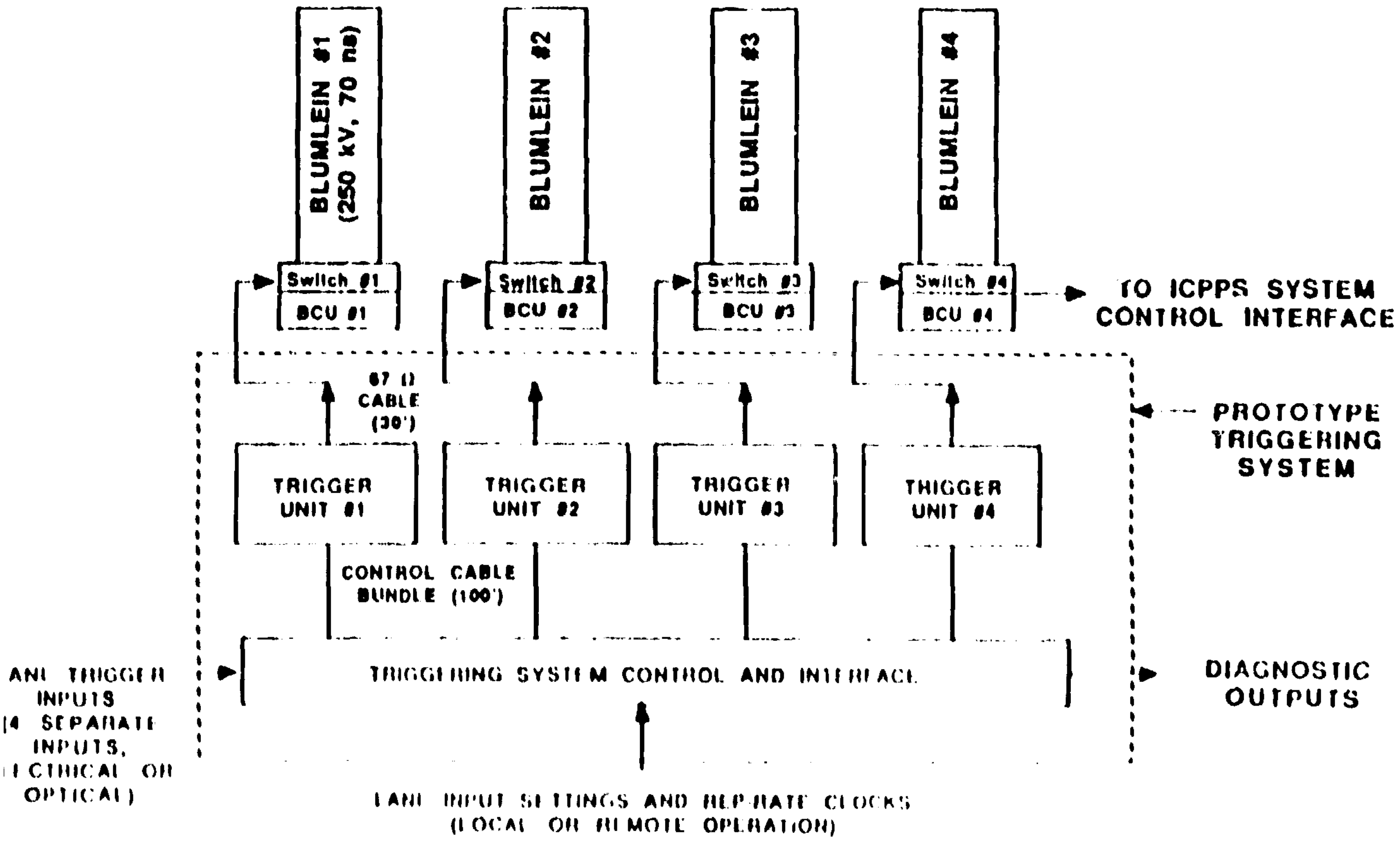

Fig 4. DARHT trigger system block diagram

able which results in a risetime of 20 ns at the Blumlein spark gap rigger electrode. The design specifications are given in Table III and a chematic drawing is given in Fig. 5.

An EEV CX 1725 thyratron has been selected as a well-haracterized device with demonstrated long lifetime and high eliability.[11] At the anticipated system operating voltages and urrents, a lifetime of > 10^9 operations is expected. The jitter ontribution from the thyratron should be < 1 ns. The two primary apacitors will be 15 nF each, and rated at 70 kV. This type of capacitor as a 99.95% survival rate at 10^7 shots for the anticipated primary oltages and currents. The 1:4 step-up transformer is a Stangenes #SI-638 auto-transformer. For a charging time of 200 ns, the secondary is ated at 300kV. The transformer output is fed through a low inductance

Table III. DARHT Triggering System Specifications

INPUT SIGNAL	
Electrical	$500V_{pk}$, 100 V/ns Slew Rate
Fiber Optic	Laser Diode
OUTPUT PULSE	
Trigger Unit Load	67 Ω Cable (DS 2077), 9.1 m
Peak Voltage Into DS 2077 Cable	150- to 200-kV
Reproducibility	± 2.5% (3σ)
Polarity	Negative
Jitter	< 3 ns (3σ)
Maximum Pulse Rep Rate	0.2 Hz
Risetime (10% to 90%) Into Spark Gap Load	< 20 ns
SYSTEM LIFE, RELIABILITY, AND MAINTAINABILITY	
Operations Between Maintenance	> 250,000
Operations to End of Life of Major Components	> 10^7
Prefire Failure Rate	< 1/5000 Operations
No-fire Failure Rate	< 1/5000 Operations
Out-of-Spec Voltage From BCU Jitter	< 1 in 1000 Operations
Out-of-Spec Voltage	< 1 in 1000 Operations

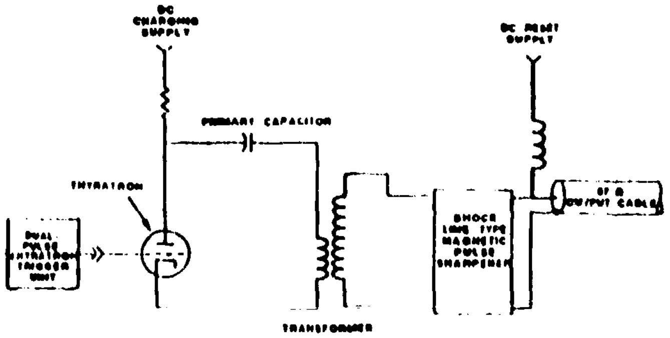

Fig. 5. DARHT trigger system schematic

rallel plate buswork to the magnetic pulse sharpener section. The agnetic pulse sharpener consists of a ferrite loaded transmission line wenty-nine ceramic ferrites (C2010) are used in each trigger unit. The axial line has an inner conductor with an o.d. of 3.8 cm and an outer nductor with an i.d. of 9.53 cm. A total length of 81.3 cm is required to ntain the ferrites. The line impedance is ~ 30 Ω when saturated and 300 Ω when unsaturated.

Conclusions

Three major pulsed power systems have been designed for the ARHT Facility. Each system has been designed for maximum liability, longevity, reproducibility, and for low jitter. These units are pable of producing the electron beam and drive voltages to accelerate e beam while maintaining the critical parameters required to produce a gh quality x ray source. All the essential elements of the DARHT facility

References

[1] M.Burns, P.Allison, L.Earley, D.Liska, C.Mockler, J.Ruhe, H.Tucker, L.Walling,"Cell Design for the DARHT Linear Induction Accelerators", IEEE 1991 Particle Accelerator Conference,San Francisco, CA,May1991.

[2] J.Fockler, B.Bowen, V.Carboni, P.Corcoran, J.Kishi, R.Keunning, "A 4MV ± 1% Flat-Top Electron Diode Driver", Eighth IEEE International Pulsed Power Conference,San Diego,CA,June 1991

[3] R.L.Carlson,P.W.Allison, T.J.Kauppila, D.C.Moir, and R.N.Ridlon,"Electron-Beam Generation, Transport, and Transverse Oscillation Experiments Using the Rex Injector",IEEE 1991 Particle Accelerator Conference, San Francisco, CA,May 1991.

[4] R.L.Carlson, T.J.Kauppila, D.C.Moir, R.N.Ridlon, "REX, a 5-MV Pulsed-Power Source for Driving High Brightness Electron Beam Diodes", Eighth IEEE International Pulsed Power Conference, San Diego, CA, June 1991.

[5] T.H.Martin, B.N.Turman, S.A.Goldstein, J.M.Wilson, D.L. Cook, D.H.McDaniel, E.L.Burgess, G.E.Rochau, E.L.Neau, and D.R.Humphreys, "PBFA II, The Pulse Power Characterization Phase", 6th IEEE Pulsed Power Conference, (IEEE Press,New York, 1987), 225.

[6] G.J.Denison, J.P.Corley, D.L.Johnson, G.J.Weber, R.A.Hamil, L.P.Schanwald,and J.J.Ramirez, "Hermes-III High Voltage, Multistage Laser-Triggered Gas Switch", 7th IEEE Pulsed Power Conference, June 11-14, 1989, Monterey,CA, paper P1-24.

[7] M.Burns, K.Chellis, C.Mockler, T.Tucker, G.Velasquez, "Magnet Design for the DARHT Linear Induction Accelerators", IEEE 1991 Particle Accelerator Conference,San Francisco, CA,May1991.

[8] L.Walling, P.Allison, M.Burns,D.J.Liska, D.E.McMurry, and A.H.Shapiro,"Transverse Impedance Measurements of Prototype Cavities for a Dual-Axis Radiographic Hydrotest Facility DARHT", IEEE 1991 Particle Accelerator Conference,San Francisco, CA,May1991.

[9] P.Allison, M.J.Burns, G.J.Caporaso, A.G.Cole, "Beam-Breakup Calculations for the DARHT Accelerator", IEEE 1991 Particle Accelerator Conference, San Francisco, CA, May 1991.

[10] L.L.Reginato, D.Branum, E.Cook, W.Denhoy, C.Fong, D.Kippenhan, E.Moor, M.Newton, W.Pollard, D.Rogers, S.Hibbs, J.Schmidt, M.Smith, W.Weiss, J.White, "ADVANCED TEST ACCELERATOR (ATA) PULSE POWER TECHNOLOGY DEVELOPMENT", IEEE Transactions on Nuclear Science, Vol. NS-28, No.3, June 1981.

[11] H.Menown, C.A.Pirrie, and N.S.Nicholls, "Advanced Thyratrons as Switches for the Nineties ", Proceedings of the 17th Modulator Symposium, June 1986, Seattle,WA.