PERFORMANCE OF AN ADVANCED REPETITIVELY PULSED ELECTRON BEAM PUMPED KrF LASER DRIVER*

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Abstract

Electra [1] is a repetitively pulsed, electron beam pumped krypton fluoride (KrF) gas laser that is a step in developing the technologies that meet the Inertial Fusion Energy (IFE) requirements for durability, efficiency, repetition rate, and cost. The technologies to be developed in the Electra system are to be directly scalable to a full size fusion power plant beam line.

We have fielded an advanced pulsed power driver for the KrF preamplifier in the Electra system which serves two roles: it completes the laser system and serves as a demonstrator for the advanced pulse power topology that can meet the IFE requirements. The initial system employs a gas switched Marx with improved reliability and maintenance schedule. The Marx will later be retrofitted (circa 2006) with advanced solid state switches, presently under development in the Electra program [2].

The output of the pulsed power driver, delivered to counter-streaming electron beam diodes, is 20/40/30 ns (t_{rise}/flattop/t_{fall}), 150-175 kV, and 60-80 kA per side with a 1.1 ohm nominal impedance. The pulser operates in single-shot, burst, and continuous modes at up to 5 Hz, with 1 ns (1 sigma) or less absolute timing jitter. A single pulsed power driver is coupled to the opposing electron guns via four liquid-filled TTI's (transit time isolators). These TTI's are necessarily compound (oil/water/oil) in order to balance their electrical lengths against unequal mechanical lengths. The Marx is gas-insulated and charges a 1.1-ohm water PFL in less than 100 ns. An output magnetic switch with a saturated inductance of less than 14 nH using Metglas® cores discharges the pulseforming line (PFL) into the four parallel compound TTI's. A set of four (2 each side) inverted Z-stack bushings provide the interface between the TTI's and the vacuum chambers and diodes. The pulse power driver design for this preamplifier has been described previously [3].

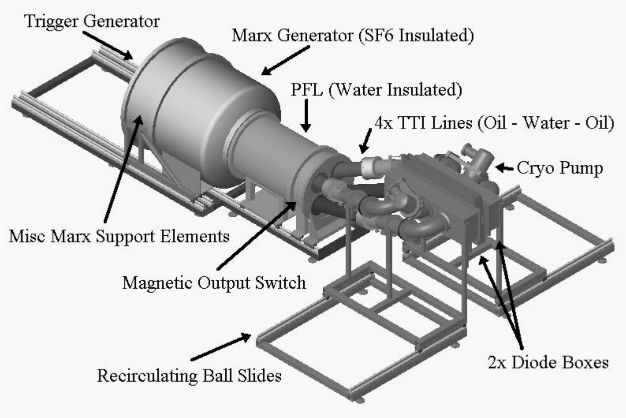

Figure 1. KrF LASER Conceptual Diagram

This paper will compare the design goals for performance and reliability with actual system performance. Discussion of electrical models used in the design and comparison of those models with actual data will be presented.

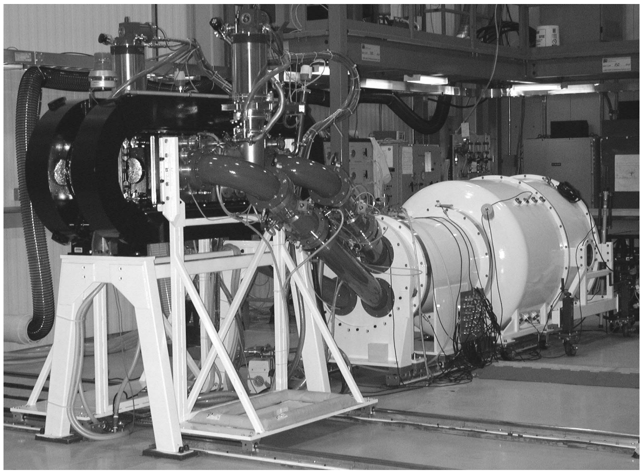

Figure 2. KrF LASER driver installed at NRL (Front View).

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14. ABSTRACT

Electra [1] is a repetitively pulsed, electron beam pumped krypton fluoride (KrF) gas laser that is a step in developing the technologies that meet the Inertial Fusion Energy (IFE) requirements for durability, efficiency, repetition rate, and cost. The technologies to be developed in the Electra system are to be directly scalable to a full size fusion power plant beam line. We have fielded an advanced pulsed power driver for the KrF preamplifier in the Electra system which serves two roles: it completes the laser system and serves as a demonstrator for the advanced pulse power topology that can meet the IFE requirements. The initial system employs a gas switched Marx with improved reliability and maintenance schedule. The Marx will later be retrofitted (circa 2006) with advanced solid state switches, presently un

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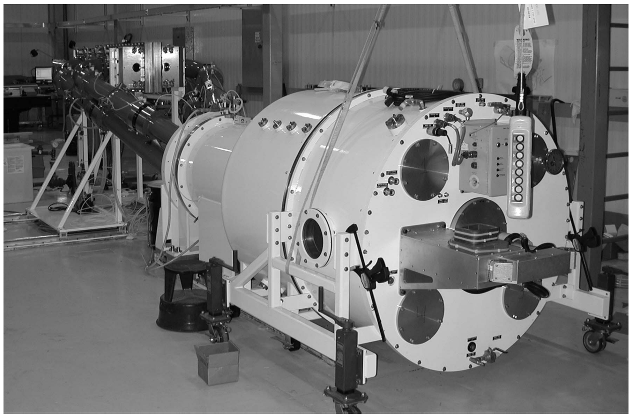

Figure 3. KrF LASER driver installed at NRL.
(Rear View)

I. DRIVER DESIGN SPECIFICATIONS

(1) Waveform:
  - (a) Load Voltage (high voltage mode): 175 kV
  - (b) Load Voltage (low voltage mode): 150 kV
  - (c) Current (high voltage mode): 160 kA*
  - (d) Current (low voltage mode): > 140 kA*
  - (e) Voltage Risetime: < 20 ns (10-90)
  - (f) Voltage Fall Time: < 30 ns (90-10)
  - (g) Flat top (power): 40 ns
  - (h) Flat Top Variation (power): ± 10%

(2) Jitter
  - (a) Spread: 1 ns, 1 sigma, measured: from t=0 trigger to voltage leading edge.

(3) Repetition Rate
  - (a) Single shot, 1 Hz, or 5 Hz

(4) Misfires, pre-fires, and duds
  - (a) < 1 shot in 500 (Electra has about 1/1000)

(5) System Lifetime
  - (a) Spark gap lifetime (service interval): >10,000 shots (goal is 100,000 shots)
  - (b) Lifetime of other components >100,000 shots (design point)

* Both sides in parallel

II. WAVEFORMS

The inductance of the Marx generator was measured by filling the PFL with a resistive solution before the output switch was installed and firing the generator. The resulting ringing waveform is shown in Figure 4 together with the results of the corresponding circuit simulation. The two waveforms are plotted in opposite polarities along with the sum of the waveforms which has been multiplied by a factor of five prior to plotting. The matching of the simulation to the measurement yields an inductance that is 7% less than calculated for the complex configuration of the generator. The inductance of the Marx generator was estimated using the FastHenry public domain inductance code [4].

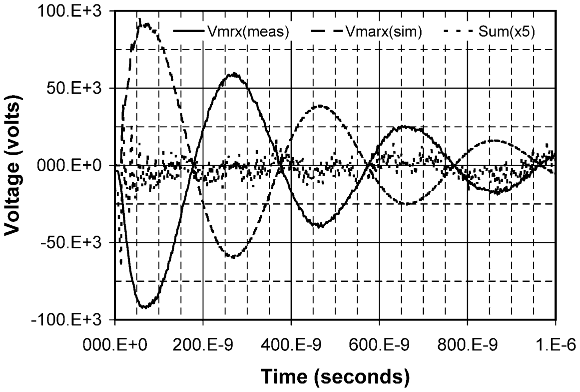

Figure 4. Marx generator measured and simulated ringing waveforms.

The waveform shape requirements were tested using a resistive load designed to approximate the anticipated electron beam diode resistance, inductance and capacitance. The load resistance was somewhat higher than the target 1.1 ohms resulting in slight impedance mismatch. An overlay of the load voltage is shown in Figure 5. The dashed trace is the simulation. The load voltage risetime (10-90) is ~20 ns. The fall-time is not directly measurable due to the load mismatch, but is estimated at 25-30 ns.

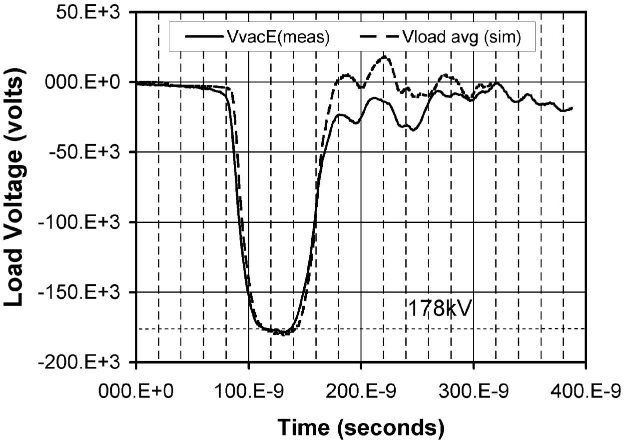

Figure 5. Actual and simulated load voltage waveforms with a resistive load.

Figure 6 is an overlay of the measured load power and simulated load power. Figure 7 is an expansion of the flat top portion of the measured power waveform. The width of the flat top (±10%) portion of the load power has been measured to be 43 ns.

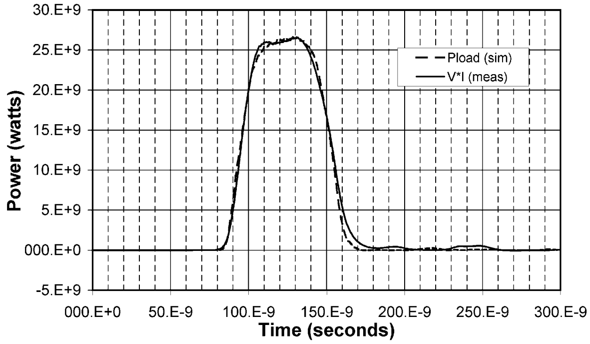

Figure 6. Power into 1.2-ohm resistive load. Simulation normalized to measured peak.

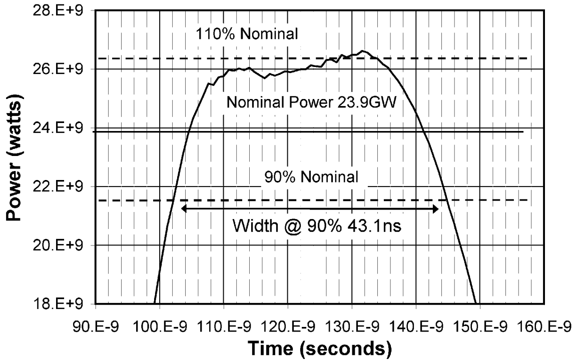

Figure 7. Load power flattop measurement.

Some measurements have been made with an electron beam load. A temporary cathode has been constructed by simply wrapping the cathode holder with velvet as shown in Figure 8 pending delivery of a more permanent cathode.

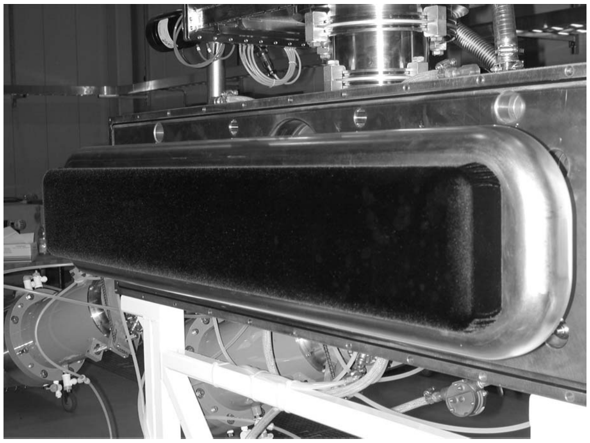

Figure 8. Temporary velvet cathode.

Further details of the e-beam diode design and test results are presented in another paper at this conference [6].

Circuit simulations have been performed for this load configuration with the results shown in Figure 9.

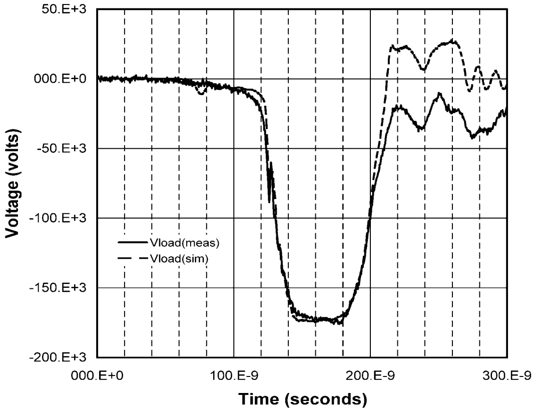

Figure 9. Actual and simulated load voltage with an electron beam load.

The circuit simulation software used during the bulk of the electrical design process and for the above waveform matching results is a transmission line based code. An early version of this type of electrical simulation code was described at a pervious pulsed power conference [5].

III. TIMING JITTER

System timing jitter has been measured at 700-850 psec (1 sigma) during numerous 100 shot runs for the first ~20,000-30,000 shots after a Marx spark gap rebuild. The Marx is typically pressurized at 45-50 psig. Figure 10 shows system jitter as a function Marx switch pressure.

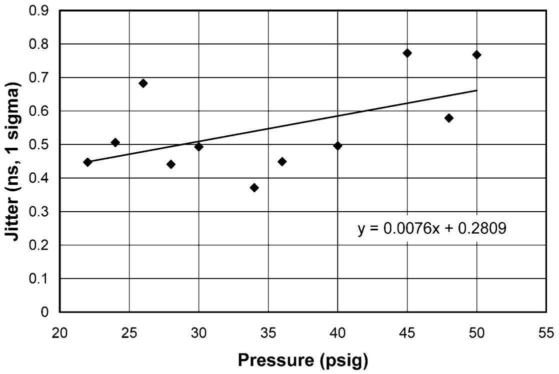

Figure 10. System Jitter vs. Marx Switch Pressure.

System jitter increases over time with increasing accumulation of Marx shots. Figure 11 shows system jitter as a function of accumulated Marx shots, measured during repetitive operation at 5 Hz and a Marx switch pressure of 50 psig.

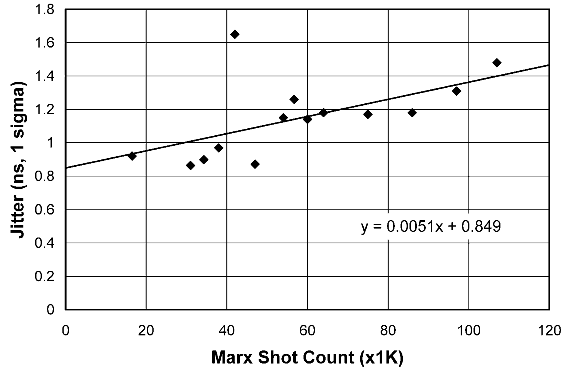

Figure 11. System Jitter vs. Accumulated Marx Shots

IV. RELIABILITY

The reliability specification of less than one unacceptable pulse in 500 pertains to any pulse that is missing, late by more than 5 ns, early by more than 5 ns, low in amplitude by >15% or significantly truncated. This measurement was done utilizing a waveform “mask” on a digital oscilloscope.

Reliability of about 1 unacceptable pulse in 700 was achieved at 5 Hz during numerous 10,000 shot runs. About one-half of the unacceptable pulses were low amplitude and the remaining one-half were pre-fires or no-fires.

The Marx spark gaps were pressurized to 50 psig while flowing the gas at approximately 0.25 SCFM per switch string (four strings in parallel). The gas used was AIRGAS® “Ultra-Zero” grade air.

V. SYSTEM LIFETIME

The components downstream from the Marx generator were designed for very long lifetimes (on the order of 10^8 pulses). The spark gaps and capacitors within the Marx and trigger generator are the components of primary concern.

The requirement for at least 10,000 shots between maintenance cycles has been easily met for the Marx spark gaps. A set of Marx spark gaps was operated for over 100,000 pulses. The jitter of the Marx did increase from ~0.8 ns to ~1.5 ns as the pulse count increased beyond 10,000 pulses as noted above.

The Marx capacitors have been designed to have a MTBF of about 5 x 10^8 pulses. After some initial problems with case construction and “infant mortality” the capacitors have proven to be very reliable. The dielectric system utilized in the capacitors is polypropylene with full floating foil and a low inductance design. The capacitors are impregnated with castor oil.

VI. SUMMARY

A compact, high-reliability, repetitively pulsed KrF driver has been installed and tested in support of the IFE program at NRL. The system utilizes a low inductance Marx generator pulse charging a PFL in ~100 ns. The PFL is switched out by a Metglas® output switch into a set of compound TTIs which carry the pulse to a pair of opposed electric beam guns. The Marx portion of the system will be retrofitted to solid state based design circa 2006. System performance agrees well with the design intention and circuit simulations.

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