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A Double-sided Electron-Beam Generator for
KrF Laser Excitation

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Abstract

Several laser systems excited by electron beam have been identified as candidates for pump sources for laser fusion applications. The electron beam generators required must be compact, reliable and capable of synchronization with other system components. A KrF laser producing a minimum output of 25 J was needed for the RAPIER (Raman Amplifier Pumped by Intensified Excimer Radiation) system. A double-sided electron beam system was designed and constructed specifically for this purpose and has produced >35 J of KrF output. Each of the two electron beam machines in the system operates with an rms jitter of 0.4 ns and together occupy $\sim 3.5 \text{ m}^2$ of floor space. The successful operation of this laser has engendered requests for a description of the engineering details of this system. This document contains a brief description of the design issues and a full set of engineering drawings for this KrF laser amplifier.

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Introduction

Several laser systems excited by electron beam have been identified as candidates for pump sources for laser fusion applications. The electron beam generators required must be compact, reliable and capable of synchronization with other system components. A KrF laser producing a minimum output of 25 J was needed for the RAPIER (Raman Amplifier Pumped by Intensified Excimer Radiation) system. A double-sided electron beam system was designed and constructed specifically for this purpose and has produced >35 J of KrF output. Each of the two electron beam machines in the system operates with an rms jitter of 0.4 ns and together occupy $\sim 3.5 \text{ m}^2$ of floor space. The successful operation of this laser has engendered requests for a description of the engineering details of this system. This document contains a brief description of the design issues and a full set of engineering drawings for this KrF laser amplifier.

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The reader is cautioned against the use of the attached drawings for replication of the system without the aid of informed electrical and mechanical engineering support. There are several regions within the machine where the design tolerances are critical and other regions where they are not. No attempt has been made within this document to distinguish between critical and non-critical designs and dimensions. In addition, this machine is a research device, designed and operated at parameters near design limits. Performance and reliability may depend on intangibles not specifically associated with the mechanical design. The reader should anticipate that substantial debugging and redesign activity may be required to obtain acceptable performance from this system.

A list of the engineering drawings and the drawings themselves are attached as Appendix I.

System Design

The choice of electron energy is bounded from above by the combination of laser medium composition, maximum operating pressure, and desired output aperture, and from below by anode foil losses and the desire to keep the system impedance as large as possible. An output voltage of 300 kV was selected as a reasonable operating point. A Monte Carlo calculation of energy deposition was performed for a 10 x 10 cm aperture by 50 cm long cell filled with 2 atm of a mixture of 96% argon and 4% krypton gases. The cell was bounded on two sides by 13 μ thick Havar foils and thick aluminum walls on the remaining sides. The calculation indicated that 30% of the energy incident on the foil is deposited in the laser medium. The spatial distribution of energy deposited as viewed in the plane transverse to the laser axis is shown in Fig. 1 for two

electron beams incident from opposite sides of the volume. Contours of equal energy deposited per unit volume are plotted for 80% and 90% of the peak value demonstrating that pumping is uniform to within $\pm 10\%$ of the mean over nearly the entire volume. Allowing for a 20% loss to the anode foil support structure not included in the Monte Carlo calculation, the overall efficiency from the electron beam diode to energy deposited in the gas is 25%. Assuming that 5% of the deposited energy is converted to laser output, 500 J must be deposited requiring 1000 J from each electron beam which for a 60 ns pulse length implies a machine impedance of about 5Ω . The diode current of 60 kA results in a current density of 120 A/cm^2 in the diode. The required impedance and pulse length made a pulse charged water dielectric transmission line the obvious choice for forming the output pulse.

Since the A amplifier is to be used in a variety of pulse compression and stacking schemes involving synchronization with several other system components, timing jitter had to be kept to an absolute minimum. Thus a triggered output switch was chosen for the pulse forming line. The positive charged Blumlein configuration was selected for the pulse forming line because of the accessibility of the output switch for triggering and because the lower charge voltage permitted the design of a more compact four stage 400 kV Marx generator. The Blumlein itself is a cylindrically symmetric triax with an outer diameter of 36 cm. Extensive numerical calculations of electric field distributions in the output switch, pulse forming line and diode were used to minimize peak electric stress. The output switch consists of two annular main electrodes with a disc shaped midplane trigger electrode. The interelectrode gap is 1 cm and operates at 300 kV when pressurized with 100 psig of SF_6 gas. The trigger electrode is resistively biased at one-half the charge

voltage and the trigger pulse is coupled to it through an oil-insulated ring capacitor. The charge current to the intermediate conductor flows along a rod which passes through this entire assembly as shown in Fig. 2.

The diode insulator is a flat lucite disc with the inner and outer line conductors shaped so that the electric field lines meet the insulator surface at 45° . The cathode mounting hardware is constructed of 15 cm diameter aluminum pipe housed in a chamber made from 22 cm diameter tubing in order to minimize diode inductance estimated to be <30 nh. The cathode mounting hardware was polished to permit operation without spurious emission at the resulting 115 kV/cm electric fields.

Blumlein Tests

The Marx generator, pulse forming line, and output switch were tested and characterized prior to the completion of the diode and laser cell designs. A radial copper sulfate load resistor was constructed for the output of the line. The pulse shape obtained with the triggered output switch is shown in Fig. 3. The risetime indicates a switch inductance of 12 nh which implies that a minimum of two current carrying channels are formed when the output switch is triggered.

Obtaining low jitter operation of the output switch was crucial to the success of the A amplifier system. A trigger generator was constructed from barium titanate capacitors pulse charged from the Blumlein Marx. These capacitors were discharged by an over-volted spark gap into a 4 m long $50\ \Omega$ cable. The pulse amplitude delivered to a $50\ \Omega$ load resistor was ~ 150 kV with a 10 ns risetime and an exponential decay giving 50 ns FWHM. After characterization the $50\ \Omega$ load resistor was removed and the cable connected to the

coupling capacitor of the output switch trigger electrode. A series of 20 shots were fired (one prefired) with the results shown in Fig. 4. The resulting standard deviation of the time between the arrival of the trigger pulse at the switch and the arrival of the output pulse at the load was 0.4 ns. This demonstrated the capabilities of the output switch though at present a different scheme is being used to trigger the system as described below.

Electron Beam Tests

Obtaining uniform emission from a cold cathode in electric fields < 200 kV/cm requires some gross field enhancement. A hexagonal stainless steel honeycomb material was selected for the cathode. The individual cells of the material are 3 mm across and are made of 75 μ thick foil. Electron pinhole images of the cathode indicate that an average of 3-4 emission sites are created at each cell resulting in acceptably uniform illumination of the anode plane.

The two nested coaxial transmission lines which make up the A amplifier Blumlein are charged in series with the innermost line charged through an inductor located near the diode insulator. During charging the voltage drop across this inductor also appears across the diode. To limit this prepulse voltage, the charging time for the line was set at 1 μ sec, the value of this inductor reduced to ~ 1.5 μ h and a 100 Ω resistor placed in parallel with the inductor. This combination of parameters results in a voltage swing on the cathode from +35 kV to -20 kV during the charging of the line. These voltages are sufficiently large to cause unwanted emission from excessively field enhanced regions of the diode. To control this emission which can lead to a shorted diode by the time the output pulse arrives, the foil support structure is covered with an aluminized Kapton foil to shield it from the +35 kV portion of the prepulse electric field and the honeycomb cathode is surrounded by a

stainless steel band to reduce the large field enhancement at the cathode corner. This combination shown in Fig. 5 eliminates emission in the diode during the charging of the line.

The output pulse delivered to the diode is shown in Fig. 6. The voltage pulse which differs markedly from that obtained with a resistive load droops principally due to the low value of charging inductance required to minimize prepulse. The inductor and resistor are in parallel with the diode during the output pulse and subtract ~ 150 J (12%) from the available energy. Plasma closure in the diode also contributes to the voltage droop. The shorter current pulse and slower current risetime suggest a delay in formation of the cathode plasma.

The characteristics of the electron beam after passing through the combination of anode foils and support structure were examined. The spatial profiles of the beam as measured with a film dosimeter are shown in Fig. 7. The beam energy measured with a carbon calorimeter was 650 ± 50 J for each beam which is consistent with the amount of energy needed to produce 500 J deposited in the laser medium.

Triggering Systems

The initial laser experiments require only that the two electron beam machines fire within a few nanoseconds of each other. Rather than construct a separate trigger generator, the scheme shown in Fig. 8(a) was used. A pair of 50Ω cables were pulse charged from each Marx. Both cables were connected to a single spark gap located midway between the two machines. This common switch operated in an over-volted mode shorting both cables and simultaneously producing trigger pulses for both machines. The rms jitter for this system has been verified as < 0.4 ns.¹ More recently this common gap has been

replaced with a trigatron gap which is triggered by a pulse formed with a laser triggered spark gap.¹ (Fig. 8(b)) The overall standard deviation from the arrival of the laser pulse to the arrival of the voltage pulse at the diode is 0.4 ns.

Summary

An electron beam system has been designed and constructed to pump a KrF laser which has produced >35 J of optical energy. The two machines which make up the system have been synchronized with each other and with another laser system with a measured rms jitter of 0.4 ns. This approach should permit the construction of larger, more complex electron beam pumped laser systems employing pulse stacking and pulse compression techniques.

References

1. R. Rapoport, private communication.

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Appendix A

<u>Drawing No.</u>	<u>Sub. Assy.</u>	<u>Detail</u>
AAA78-108946-0A	Marx-Capacitor	Side-R.H. (Small)
AAA78-108477-00	Blumlein	Block Resistor (LG)
AAA78-108947-0A	Marx-Capacitor	Side-L.H. (Small)
AAA78-108948-00	Marx-Capacitor	Rod, Short
AAA78-108929-00	Marx Capacitor	Spacer-Large
AAA78-108931-00	Marx Capacitor	Block-Capacitor
AAA78-108930-00	Marx-Capacitor	Spacer-Small
AAA78-108932-00	Marx-Capacitor	Cap-Capacitor
AAA78-108922-00	Blumlein Carriage	Adjustment Screw
AAA78-108933-00	Marx-Capacitor	Channel-Base
AAA80-103995-00	A Amplifier	Screw, Cathode Mount
AAA79-106525-0A	450 KeV Output Switch	Ring, Locating
AAA79-106523-00	450 KeV Output Switch	Block, Resistor
AAA79-106527-00	450 KeV Output Switch	Capacitor Fitting
AAA80-104457-00	450 KeV Output Switch	Bolt
AAA79-114114-00	Laser Triggered Output Switch	Pin Spacer
AAA79-114119-00	Laser Triggered Output Switch	Rotation Pin
AAA78-104764-00	Blumlein	Rod-Support, Capacitor
AAA78-104781-0A	Blumlein	Ladder, Resistor
AAA78-104783-00	Blumlein	Support-Half, Capacitor
AAA78-104785-00	Blumlein	Support, Outer
AAA78-104774-0A	Blumlein	Base-Probe, Flex
AAA78-104508-0A	Blumlein	Cap, Blank-Off
AAA78-104504-0A	Blumlein	Cap
AAA78-104787-0B	Blumlein	Rod, Charging
AAA78-105132-0B	Blumlein	Plug-Cap. Cavity (LG)
AAA78-105128-0A	Blumlein, Marx	Bkt, Cap, Switch
AAA78-115029-00	Blumlein	Ring, Coil Retainer
AAA78-105129-00	Blumlein-Marx	Center, Post
AAA78-115028-00	Blumlein	Plug, Inner Tube
AAA78-114009-00	Marx-Capacitor	Ball, Feedthru
AAA78-111728-00	Blumlein	Rod, Anti-Rotation

Appendix A

<u>Drawing No.</u>	<u>Sub. Assy.</u>	<u>Detail</u>
AAA79-114115-00	Laser Triggered Output Switch	Lucite Window
AAA79-114116-00	Laser Triggered Output Switch	Rear Plate (Cap. Cavity)
AAA79-114120-00	Laser Triggered Output Switch	Flange Feedthru
AAA79-114118-00	Laser Triggered Output Switch	Cap. Driver
AAA79-114113-00	Laser Triggered Output Switch	Inner Tube
AAA79-114117-00	Laser Triggered Output Switch	Spacer Ring
AAA79-114109-0A	Laser Triggered Output Switch	Ring, Inner
AAA79-114129-00	Blumlein	Corona Ring
AAA78-107856-0A	A Amplifier	Brewster Mount
AAA78-106089-0C	A Amplifier	Frame-Foil Window
AAA78-107860-0A	A Amplifier	Frame-Window (SM)
AAA78-107858-0A	A Amplifier	Window Adapter
AAA78-107859-00	A Amplifier	Plate, Filler Cell
AAA78-116888-00	Marx Capacitor	Strap, Ground
AAA78-111727-00	Electron Beam Accelerator	Marx Tank Assy
AAA78-114010-00	Marx-Capacitor	Insulator, Marx
AAA78-111730-00	Blumlein	Flange, Rod
AAA78-108456-00	A Amplifier	Mount Incline 5°
AAA78-108927-00	Blumlein Carriage	Rear Adjustment Saddle
AAA78-114007-00	Marx-Capacitor	Outlet Flange Blumlein
AAA78-108724-0A	Blumlein Carriage	Carriage Track w/Angle
AAA78-108925-00	Blumlein Carriage	Carriage Track
AAA78-108926-00	Blumlein Carriage	Front Adjustment Block
AAA78-108923-00	Blumlein Carriage	Bottom Adjustment Block
AAA78-108950-0A	Marx Capacitor	Tank Assy (Small)
AAA78-108934-00	Marx Capacitor	Base, Plate
AAA78-108458-00	A Amplifier	Stalk-Cathode
AAA78-108469-00	A Amplifier	Cathode

Appendix A

<u>Drawing No.</u>	<u>Sub. Assy.</u>	<u>Detail</u>
AAA78-108457-0A	A Amplifier	Mount Cathode
AAA78-108459-00	A Amplifier	Spacer Cathode
AAA79-106533-0A	450 KeV Output Switch	Ring Inner R.H.
AAA79-106531-0B	450 KeV Output Switch	Trigger Blade Assy
AAA79-106532-0A	450 KeV Output Switch	Ring, Inner (L.H.)
AAA79-106513-00	450 KeV Output Switch	Insulator Disc
AAA79-106520-0A	450 KeV Output Switch	Ring, Outer
AAA79-106515-0A	450 KeV Output Switch	Rod, Capacitor
AAA79-106524-0A	450 KeV Output Switch	Electrode Ring
AAA79-114111-00	Laser Triggered Output Switch	Electrode Ring
AAA79-104137-00	Electron Beam Accelerator	Marx Assy
AAA79-114110-0A	Laser Triggered Output Switch	Trigger Plate
AAA78-108472-0B	A Amplifier	Mount Cathode Assy
AAA79-106517-0B	450 KeV Output Switch	Middle Conductor
AAA79-106516-0B	450 KeV Output Switch	Trigger Plate
AAA78-108949-0B	Marx-Capacitor	Cover, Tank (Small)
AAA78-108455-00	A Amplifier	A Amplifier Assy (Sheet 1)
AAA78-108454-00	A Amplifier	A Amplifier Assy (Sheet 2)
AAA78-108471-0B	A Amplifier	Housing Diode Assy
AAA78-108470-0A	A Amplifier	Inner Conductor Assy
AAA78-104517-0A	Blumlein	Cover-Top
AAA78-106090-0A	A Amplifier	Insulator
AAA78-106091-00	A Amplifier	Field Shaper Plate
AAA78-106097-0A	A Amplifier	Laser Cell
AAA79-109339-0B	A Amplifier	Brewster Window
AAA79-114122-00	Laser Triggered Output Switch	Trigger Assembly
AAA78-106083-0B	A Amplifier	Hibatchi Plate
AAA78-104516-0A	Blumlein	Capacitor-R.H.
AAA78-104515-0A	Blumlein	Capacitor-L.H.
AAA78-114011-00	Marx-Capacitor	Inductor Form.
AAA78-110145-0B	A Amplifier	Near Normal Incidence Window

Appendix A

<u>Drawing No.</u>	<u>Sub. Assy.</u>	<u>Detail</u>
AAA78-102833-0C	Blumlein	Outer Conductor
AAA78-114007-00	Marx-Blumlein	Outlet Flange Assy
AAA78-114007-00	Marx-Capacitor	Outlet-Flange
AAA78-104519-0C	Blumlein	Capacitor, Cavity
AAA80-103837-00	A-Star Laser	Assembly
AAA78-104519-00	Blumlein	Capacitor Cavity
AAA78-108928-0A	Blumlein Carriage	Carriage Welded Assy
AAA78-104519-0C	Blumlein	Capacitor Cavity