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AUTHOR(S) Mansfield, Charles R.
Oona, Hain
Shurter, Roger

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BEAM ROTATION AND SHEAR IN A LARGE ELECTRON BEAM DIODE

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C. R. Mansfield, H. Oona, R. P. Shurter

CLS-7, Pulsed Power Systems
Los Alamos National Laboratory
MS E525, P. O. Box 1663
Los Alamos, NM 87545

Abstract

The time averaged electron beam current distribution of one of the electron guns of the Large Aperture Module (LAM) of the Aurora laser was measured as part of a larger set of experiments designed to study the electron beam transport to and energy deposition in the LAM laser chamber. The LAM laser chamber has a 1-m x 1-m aperture and is pumped from two sides along a 2-m length. A 16 ga. stainless steel sheet was placed inside the laser chamber and served multiple purposes. First, it was used to convert high energy electrons into X-rays in order to make radiograms of the electron beam. Second, the sheet was used as a Faraday cup to measure the total beam current. Third, individual Faraday cups were mounted on the plate to sample the time history of the electron beam at various positions.

Each of the LAM electron gun diodes produces a beam of 750 kV electrons with a total current of about 500 kA which is relatively uniform over the cathode area of 1 m x 2 m. An applied magnetic field of about 1300 Gauss is used to prevent pinch of the beam during beam transport.

The radiograms made on the center line of the LAM laser chamber while the laser chamber was at vacuum (10-50 microns pressure) demonstrated several of the expected results. The beam was relatively uniform over the aperture with the exception of shadows cast by the diode anode wires, the hibachi ribs, and the hibachi support structure. At a depth of 50 cm into the laser chamber, the self-magnetic field of the beam produced a shear in the top and bottom edges of 15 cm. At the same depth the applied magnetic field caused a rotation of the entire beam profile of about 3 degrees. The radiograms were taken with Kodak SO-343 film with Kodak X-Omatic Regular intensifier screens placed on each side of the film. The film was mounted with the emulsion side of the film toward the electron beam.

Introduction

Detailed performance data for the Aurora Large Aperture Module (LAM) laser diode and laser chamber were needed in order to design upgrades for the existing facility, plan for future large-scale laser amplifiers, and to validate the various computer models of large laser diodes which are presently under development at Los Alamos National Laboratory as part of the KrF Inertial Fusion program. There was a large amount of uncertainty in the existing data on the amount of energy transported to the laser chamber and on the spatial distribution of the energy deposition within the laser chamber. This required that a series of experiments be conducted to characterize and quantify the existing facility.

The beam uniformity and structure within the laser chamber were of particular interest and are the subject of this paper. A schematic representation of one of the LAM electron beam diodes and the laser chamber is shown in Fig. 1. Both the standard diagnostic instruments used on the LAM during normal operation and the extra diagnostics added for these experiments are shown in this figure. The diagnostic instrumentation *** in this report is the laser box diagnostic plate. This plate cannot be used in normal operation since its intent is to intercept the beam and serve as an electron to X-ray converter, as a Faraday collector, and as a mount for several individual small area Faraday cups.

Diagnostic Plate Design

The diagnostic plate, Fig. 2, was fabricated from .157 cm (16 ga.) 304 stainless steel sheet. The edges of the plate were formed and spot-welded to produce a 3-cm wide flange around the circumference. Stainless steel stiffeners were formed from a 304 stainless sheet to produce seven diagnostic bays into which X-radiographic film and intensifier screens could be attached with spring clips to the rear surface of the plate. Faraday cups could be attached at any of 14 individual openings in the surface of the plate. When these openings were not in use they were covered with stainless steel covers.

Figure 1.

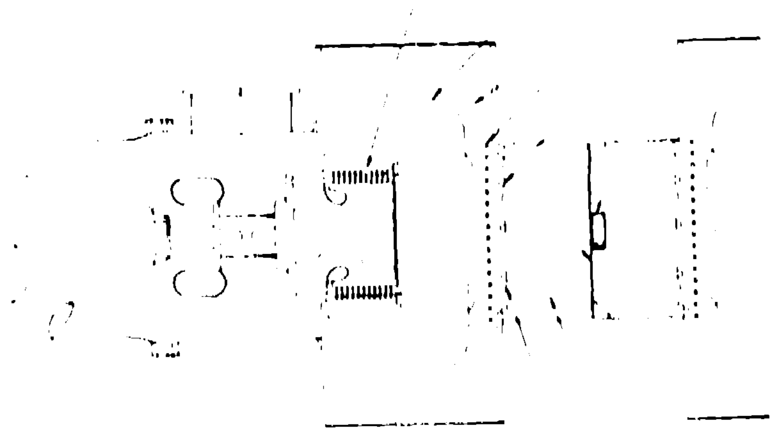
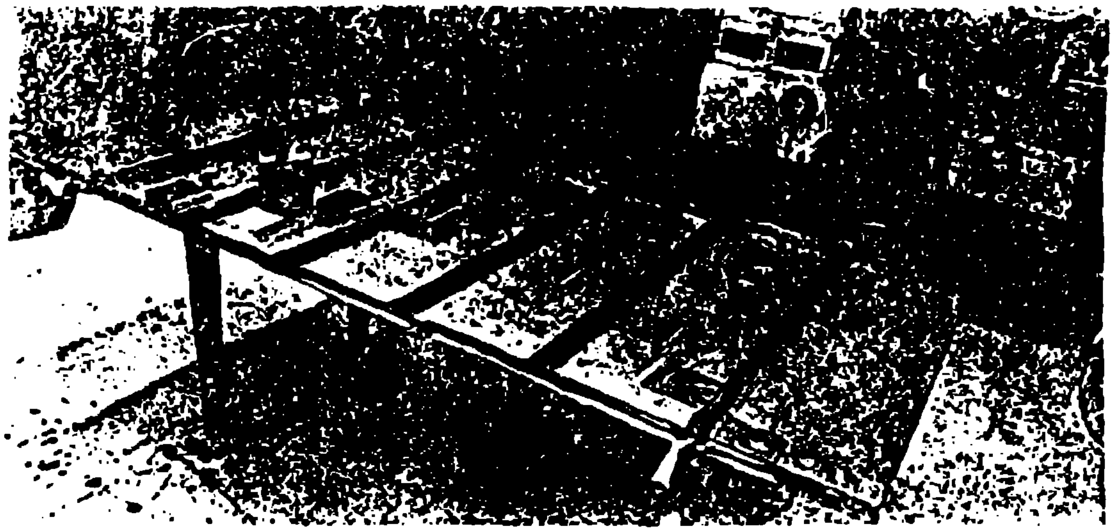


Figure 2.



The diagnostic plate was mounted inside the laser box by means of four jamb bolts located at the first inboard stiffener at each end of the plate. Copper grounding straps were used at each jamb bolt to reduce the inductive isolation of the plate from the box. Current transducers were placed around each of the bolt-grounding strap combinations so that the entire diagnostic plate could be used as a Faraday cup.

Observed Effects Modifying Diagnostic Technique

Since pressure surges of 20-30 torr out of a total gas pressure of 750 torr in the laser box were expected when firing the electron beam into laser gas, the electron gun was fired into the laser box under gas pressures of 20 microns or less. The initial concern in using this procedure was that because there was a "vacuum" in the laser box a virtual cathode would form and the beam would be repelled before reaching the diagnostic plate. It was found that at 20 micron pressure there was enough plasma formed to neutralize the beam and allow the beam to strike the plate.

The impingement of the beem on the diagnostic plate created another problem in regard to current density diagnostics. Since a current of 150 kA with a 50-ns rise time was striking the plate and flowing out the grounding straps near each corner of the plate, a voltage gradient was generated across the surface of the plate which may have reached a peak potential of several hundred volts. The plasma generated at the surface of the plate by the beam was accelerated from the plate toward the electron gun windows under this potential and created severe difficulties in interpreting the current density data. This problem was solved by coating the surface of the diagnostic plate with a 2-mil, adhesive-backed Mylar film.

However, even with the film in place, there was arcing between the edges of the plate and the laser box. The final solution was to abandon the current density measurements with the plate and ground the plate at the edges with finger stock.

Applied Magnetic Field

The magnetic field used to guide the electron beam in the diode is generated by a pseudo-Helmholtz pair of electromagnets. The individual magnet coils are shaped in a racetrack rather than circular configuration because of space and cost considerations. This results in a less than constant field strength across the diode and laser chamber, however, the deviation from uniformity is less than 10%. The drop in field strength at the edges is well within the requirements for guiding the electron beams.

Expected Results

In the absence of an applied magnetic field, the electron beams would pinch under the influence of the self-field. In addition, since their self-field and electron trajectories are not orthogonal, there is a general rotation of the beam produced by the self-field.

The applied magnetic field is directed along the general direction of the electron trajectories. The electrons tend to spiral around the resultant field so that the tendency to pinch is greatly reduced. However, since the overall beam in most lasers has an aspect ratio (ratio of beam width to height) greater than 1, there is an additional shearing component of the beam introduced on the general rotation.

Experimental Conditions

These experiments with the LAM were run at the nominal operation conditions used for standard operation. These conditions are given in Table 1.

Table 1. Standard Operation Conditions for the Aurora LAM

Cathode Voltage	600 kV
Cathode Current	425 kA
Current Density in Laser	7.5 A/cm^2
Applied Magnetic Field	1.3 kGauss

Local filamentation of the electron beam has been seen at the EGTF at high magnetic fields. This has lead to damage of the electron beam foils. In order to check on the advisability of operating large area electron-gun diodes at high magnetic fields, an additional experiment was conducted at 2100 Gauss, the maximum applied magnetic field available from the magnet power supplies. The field under the condition was 2100 Gauss.

Recording Materials

Radiographic Film

The peak X-ray dose at the back surface of the diagnostic plate was determined to be about 50 RAD as measured by thermoluminescent dosimeters. This fluence is far in excess of the amount useable with standard radiographic film. It was necessary to find a combination of photographic film, X-ray fluorescent sheets, and photographic processing which would yield useable photographic densities under the operating conditions found in the LAM.

In a series of experiments conducted at Electron Gun Test Facility (EGTF) it was determined that Kodak SO-343 high-resolution film with Kodak X-Omatic Regular intensifier screens placed in either side of the film would produce useable photographic densities when the film was processed in a Versamat Processor with Hunts Type B chemistry at 81°F. It is important that the film-intensifier combination be mounted with the film emulsion side toward the source of x-rays. Under the conditions found in the LAM, the well-shielded portions of film produced a background photographic density of .05. In the typically exposed regions an average density of .2 was achieved with a peak density in the areas where beam filamentation occurred resulting in a density of 0.5. This variation of neutral density corresponds to a variation of current density from ~.75 A/cm^2 to 16.0 A/cm^2.

Radiachromic Film

Radiachromic film has achieved prominence as a quick method of determining the spatial distribution of electron beams. This film undergoes a color change on exposure to electrons. Radiachromic film was used to measure the spatial distribution of electron current density near the electron beam windows inside of the laser cavity. Standard 6-inch square sheets of the film were taped between sheets of 1-mil black plastic, and the sandwich was attached within 1 cm of the electron beam windows. The purpose of the black plastic was to prevent bleaching of the radiachromic film by ultraviolet light in the laser chamber and in the room.

Relation of E-Beam Current Density to Photographic Neutral Density

The relationship between the measured photographic density on the radiograms and the electron current density was determined in the Electron Gun Test Facility (EGTF). Small samples of the stainless steel converter plate and the radiographic film-intensifier plate combinations were exposed in the EGTF. The current density on the EGTF is well known as a function of operating parameters so that it served as a well calibrated source of exposure. The radiographic film was processed under the same conditions as the LAM radiograms.

Qualitative Results

The spatial distribution of the current density at the center of the LAM laser chamber and at one of the electron gun windows was recorded on discrete pieces of 6 inch x 6 inch radiachromic film and 8 inch x 10 inch radiographic film. The exposed and processed film was used to generate photographic copies which have been assembled into a montage for presentation.

Radiachromic Film

The radiachromic film exposures, Fig. 3, are in the form of a negative where increased electron exposure is indicated by increased darkening of the film. Since the film was not held flat but allowed to bow, the distance of the film to the electron beam window varied from 1 to 2 cm. At the center of the film (minimum distance), the shadows cast by the hibachi ribs are evident. The shadows cast by the wider sections between the columns of hibachi ribs and by the structure supporting the hibachi frames are quite evident if blurred. Note that the shadows of the ribs and frame show little distortion which indicates that the amount of rotation and shear of the beam in the flight distance of 1 to 2 cm is relatively small. There is evidence of distortion of the beam at the extreme lower left edge of the montage. The boundary of the electron beam, which is generated by the graphite felt surface of the cathode, has been rotated and appears as a white triangular area on the left of the frame.

Figure 3.

Radiographic Exposures

The radiographic exposures are presented in the usual photographic representation with light areas representing areas of higher intensity. The radiogram made at 1.2 kG is shown in Fig. 4 and the radiogram made at 2.1 kG is shown in Fig. 5. Since it was possible to hold the radiographic film packets in intimate contact with the diagnostic plate, there is more detail in the radiographic exposures than in the radiachromic film exposures. Gaps in the montage result from the location of other sensors, such as Faraday cups on the diagnostic plate during the exposure.

Three general observations can be made about both of the radiographic montages. First, details of the hibachi structure are transported across the 45 cm gap between the hibachi and the diagnostic plate with relatively good fidelity. In some instances, the shadows of the wire grid which forms the anode appear to transfer even though the wires are only .025 cm in diameter. Second, the electron beam is highly distorted in transit between the electron gun window. This distortion should not be as extreme when laser gas is in the laser chamber due to the scattering and neutralization of the beam by the gas. The structure in the beam does appear when laser gas is in the chamber, as demonstrated by the drop in transverse small signal gain measured at the center of the laser chamber in the geometric shadow of the structure in the center of the electron gun windows. Third, the current density is not uniform across the entire beam. The radiographic film exhibits densities of around nd 0.15 at the edges of the beam and around nd 0.35 in the center of the beam. There is no evidence of a strong halo around the edges of the beam (generated by the edges of the cathode) which would account for the low values of beam transport which are observed.

In the 1.2 kG magnetic field case, Fig. 4, there is ample evidence of both rotation and shear of the beam by magnetic fields. The rotation is defined to be the relative angular change of the upper edge of the beam with respect to the edge of the radiachromic film. Whereas, the shear is defined to be the horizontal shift of the beam at the upper and lower edges less the measured rotation. The irregular shape of the shadows of the support structure was not expected. The mottled character of the current density distribution cannot be explained only as resulting from the shadows of mechanical components. It is felt that at least some of the mottling results from filamentation of the beam either at the surface of the cathode or during the transport of the beam. In the center of the beam there is a large area in which the shadow details are washed out. This detail is most probably due to temporal changes of the structure during the exposure. Such movement has been observed in framing camera photographs of the beam taken at the EGTF.

When the magnetic field intensity is increased to 2.1 kG case, Fig. 5, the rotation of the beam is decreased as evidenced by the shadow parallelism to the radiograms at the top and bottom of the montage. Since the rotation of the beam is primarily due to the self-field of the beam, the increase of guide field strength is effective in pinning the beam in space. The filamentation of the beam at higher field strengths

Figure 4.

Figure 5.

is shown in the center of the montage. Both times that the LAM was fired at high field the electron gun window was damaged in the general area which was transversed by the beam, the Mylar film on the beam side of the diagnostic plate was destroyed. In addition, when the LAM was fired at high magnetic field there was sufficient heating to damage the adhesive holding the Mylar in an area approximately 30 cm in diameter.

Quantitative Results

The effect of the magnetic field on the beam shear and rotation is shown in Table 2.

Table 2. Effect of Magnetic Field Strength on Electron Beam Shear and Rotation at the Center Plane of the Aurora LAM.

Magnetic Field	Rotation	Shear
1.2 kG	2.1°	7.3°
2.1 kG	0.1°	5.3°

From this data it is seen that the increase of magnetic field does reduce the rotation of the beam with a small decrease in the beam shear. The increased magnetic field has a major drawback which is the increased amount of beam filamentation. The peak current density in the filamented regions, as determined by measurements of the neutral density of the film, are nearly 18 A/cm^2. This is compared to the average current density over the 2 m^2 area of 7.5 A/cm2.

Conclusions

The use of a stainless steel sheet as an X-ray converter and photographic film and intensifier sheets as an X-ray recording medium provides a viable means of recording the time-averaged spatial distribution of the current density produced by a large-aperture electron gun. This method does require that the beam be interrupted so that the method cannot be used directly as an on-line diagnostic tool. The method is quantifiable and can yield accurate relative measurements of current density to an accuracy of around ± 5% and most probably yields current density results accurate to ±15%.