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ELECTRO-AERODYNAMIC LASER-BEAM-PARAMETER MEASUREMENTS

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This report has been reviewed by the Information Office (ASD/OIP) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

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A diagnostic system to measure the beam power and quality of the Air Force Aero Propulsion Laboratory 15-kW CO_2 electro-aerodynamic laser has been designed, fabricated, and tested. An anti-reflection-coated ZnSe beam splitter was employed to split off a small fraction (0.5%) of the main laser beam for diagnostic purposes. The low-power beam was split again to provide two beams for power and energy-distribution measurements, concurrent with sample irradiation by the main beam. An electrically calibrated disc

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20. ABSTRACT (Continued)

calorimeter was used to measure beam power. The temporal and spatial energy distributions were measured by means of a mechanically scanned, one-dimensional pyrolytic array. This provided a 16 × 16-element two-dimensional map of the beam profile at a rate of up to 10 Hz. High-speed data acquisition was accomplished by transmitting the digital data to a PDP-8A minicomputer system (located in a central control room) configured for tape-cassette masss storage and hard-copy plotting. Initial experimental spatial/temporal beam-energy distributions obtained with this system have demonstrated the efficacy of this beam-profiling technique.

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SUMMARY

A diagnostic system to measure the beam power and quality of the Air Force Aero Propulsion Laboratory 15-kW CO_2 electro-aerodynamic laser has been designed, fabricated, and tested. An anti-reflection-coated ZnSe beam splitter was employed to split off a small fraction (0.5%) of the main laser beam for diagnostic purposes. The low-power beam was split again to provide two beams for power and energy-distribution measurements, concurrent with sample irradiation by the main beam. An electrically calibrated disc calorimeter was used to measure beam power. The temporal and spatial energy distributions were measured by means of a mechanically scanned, one-dimensional pyroelectric array. This provided a 16 x 16-element two-dimensional map of the beam profile at a rate of up to 10 Hz. High-speed data acquisition was accomplished by transmitting the digital data to a PDP-8A minicomputer system (located in a central control room) configured for tape-cassette mass storage and hard-copy plotting. Initial experimental spatial/temporal beam-energy distributions obtained with this system have demonstrated the efficacy of this beam-profiling technique.

INTRODUCTION

In order to accurately interpret the effects produced by laser-beam irradiation of materials, the average power and transverse-intensity profile of the beam at the plane of the sample must be known during the irradiation time interval. Measurement of these laser-beam parameters concurrent with sample irradiation is desirable due to the possibility of laser-power fluctuations and beam-wander effects. This report describes a diagnostic system used to measure the beam power and quality of the Air Force Aero Propulsion Laboratory 15-kW CO_2 electro aerodynamic laser and thereby provide beam-parameter data for correlation with irradiation-effects data.

Monitoring of laser-beam parameters concurrent with sample irradiation can be accomplished by beam sampling via coarse transmission gratings or beam splitters. The main problem with these beam-sampling techniques is the possibility of distortion or damage of the grating or splitter at high beam intensities. Of course, the grating or splitter should introduce only negligible perturbation of the beams used for diagnostics or irradiation.

The use of coarse transmission gratings for beam sampling has been investigated by O'Neil, et al.,[1] for high-energy pulsed CO_2 laser beams. The same technique has also been used in mapping the beam of a 1-kW cw CO_2 laser.[2] The susceptibility of the transmission grating to damage or distortion in a high-intensity cw laser beam has not been fully investigated. Wire-dimension changes of uncooled gratings due to evaporation or oxidation are possible problems. A definite drawback of beam sampling with a transmission grating is the percentage of the beam lost for irradiation purposes: ~ 27% in Ref. 2.

Until recently, the use of beam splitters to provide a fractional sample of the main beam from a high-power CO_2 laser was impractical due to beam-splitter distortion or damage incurred under high-power loading. Beam-splitter materials are now available, however, which can accommodate power densities on the order of 1 kW/cm^2. This has been demonstrated by Franzen[3] who showed that wedges of GaAs, CdTe, ZnSe, and KCl made good beam splitters having stable splitter ratios, with nominal precision of 1% for power densities up to 1 kW/cm^2. ZnSe is the most desirable material for the following reasons: large-diameter samples with good surface polish are available commercially, it is transparent in the visible, it is non-hygroscopic and has good thermal conductivity, and it has the best transmittance of the semiconductor materials.

A significant advantage of using ZnSe beam splitters rather than a transmission grating is that > 99% of the beam is available for sample irradiation. Just as in the grating case, the diagnostic instrumentation can be located at the target-interaction plane by maintaining equal path lengths from the beam splitters to diagnostics and to the target. This procedure assumes that the path lengths from beam splitter to target and from beam splitter to diagnostic are optically equivalent.

An appropriate detector for the measurement of beam power is a conduction disc calorimeter based upon the design of Jennings and West.[4] This device is particularly applicable for medium-power and large-beam laser measurement. In operation, a steady-state temperature gradient which is proportional to laser power is established between the absorbing disc and the disc enclosure. A measurement of the temperature gradient determines cw power, whereas energies in pulses of timed intervals are measured by integrating the temperature gradient until it returns to zero.

The simplest method for obtaining an indication of the intensity distribution over the cross section of an IR laser beam involves burn patterns in a thermally sensitive material. Typical materials -- listed in order of increasing sensitivity -- are[1] Lucite, thermal chart-recording paper, developed photographic paper, exposed Polaroid film, frosted Mylar, and Thermofax paper; discoloration levels range from ~ 5 J/cm^2 to 0.1 J/cm^2. Energy-distribution data from burn patterns, however, are of limited value since the results are time-averaged and absolute values are obtained with low accuracy.

More sophisticated methods for measuring the energy distribution include: 1) scanning by means of a spinning disc having a spiral arrangement of apertures,[5] 2) one- or two-dimensional arrays of pyroelectric detectors,[6] and 3) the pyroelectric vidicon.[7] The pyroelectric vidicon is a very promising technique for producing a real-time thermal image of an IR laser beam. However, at its present stage of development, it is not suitable for our purposes. Improvements in resolution (thermal spreading is a problem) and sensitivity expected within the next few years could make this an effective technique for real-time laser-beam profiling.

The use of a mechanically scanned one-dimensional array of pyroelectrics appears to be the most promising technique for laser-beam profiling. The beam is deflected by a scanning mirror, chopped, and then read by a linear array of pyroelectric elements. Each element is scanned sequentially after each chop cycle which results in a one-dimensional intensity profile along the vertical axis of the beam, with the horizontal position being determined by the scanning mirror. A full two-dimensional map of the beam profile can be obtained many times a second, depending upon scanning and chopping rates.

EXPERIMENTAL APPARATUS AND RESULTS

A schematic diagram of the experimental configuration used for laser-beam-parameter measurements is shown in Fig. 1. A 4-in.-diam. anti-reflection-coated ZnSe beam splitter was used to split off 0.5% of the main beam. This gave a beam of ~ 50 W which was split by a 50% ZnSe beam splitter to provide two beams for simultaneous energy-distribution and power measurements. The beam splitters had wedge angles of ~ 1 deg. for spatial separation of higher-order reflections.

According to the manufacturer,[8] the ZnSe has < 0.002/cm bulk absorption and ~ 0.06% absorption in each surface coating. At a power level of 15 kW, this results in about 18 W power absorbed in the bulk and 9 W absorbed at each surface of the primary beam splitter. Since the thermal-coefficient of refractive-index change of ZnSe is positive ($+48 \times 10^{-6}/°C$),[9] heating of the beam splitter by the laser beam will tend to focus the beam. The potentially serious problem of surface-coating damage at high power loading has not materialized.

It was necessary, due to space limitations, to position the primary beam splitter at a 30-deg. angle of incidence with respect to the main laser beam. The beam splitter was specified for 0.5% reflectance at 30-deg. angle of incidence and random polarization. Small changes in direction of incidence, polarization, and divergence of the incident beam will result in small changes in beam-splitter reflectance and, therefore, in the responsivity of the beam-monitor system.[10] The extent of responsivity changes should be determined analytically and/or experimentally to ensure precise quantitative beam-parameter measurements.

The transmitted beam of the secondary beam splitter impinged on a Scientech disc calorimeter having a 4-in. aperture and a measurement range of 3-100 J or 0.3-50 W at an accuracy of $\pm 5\%$. The output of this calorimeter, which is displayed on a strip-chart recorder (see Fig. 2) can be related to the main beam power by calibration against calorimetric measurements of the main beam.

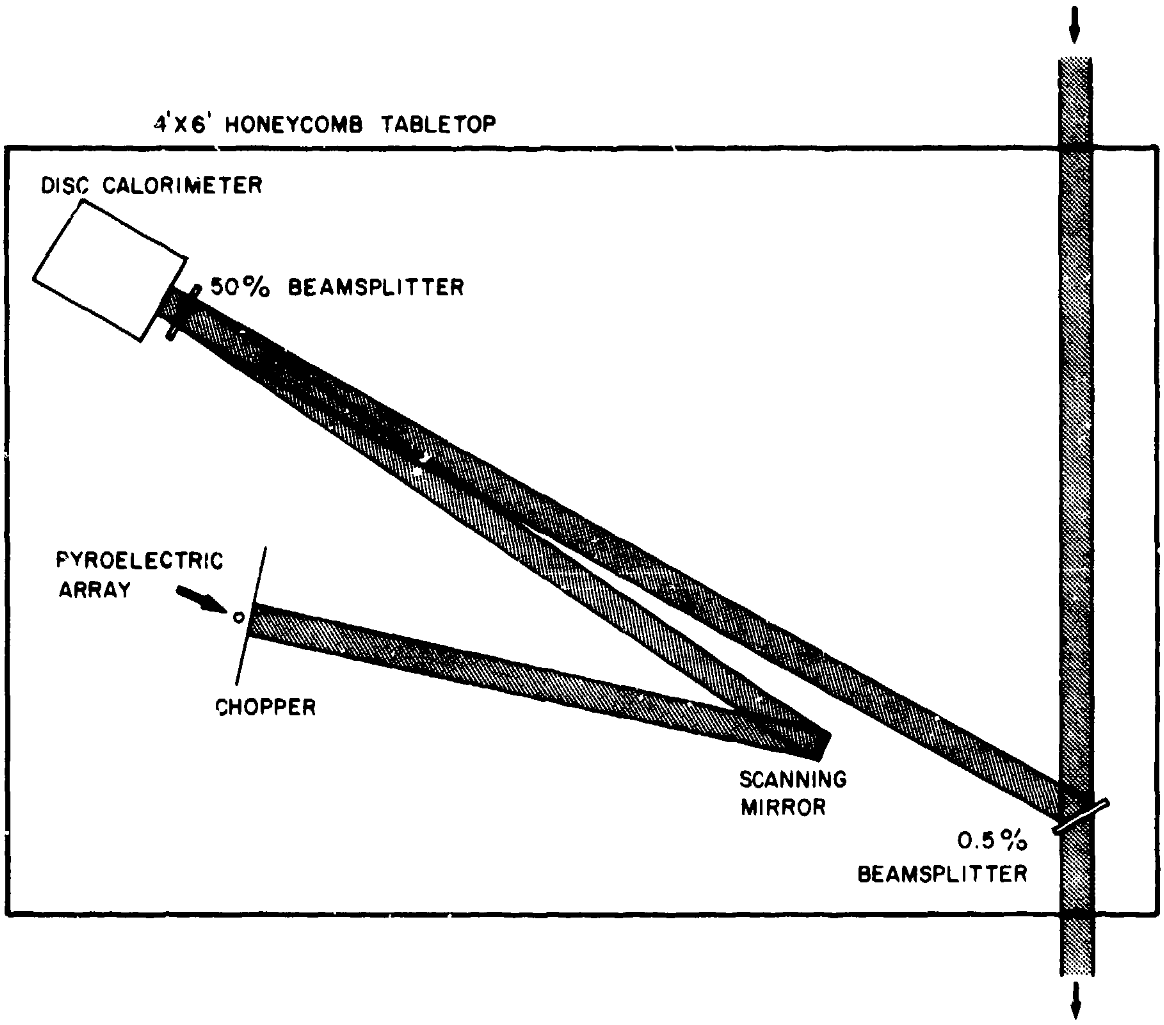

Figure 1. Schematic Diagram of Experimental Configuration for Laser-Beam-Parameter Measurements

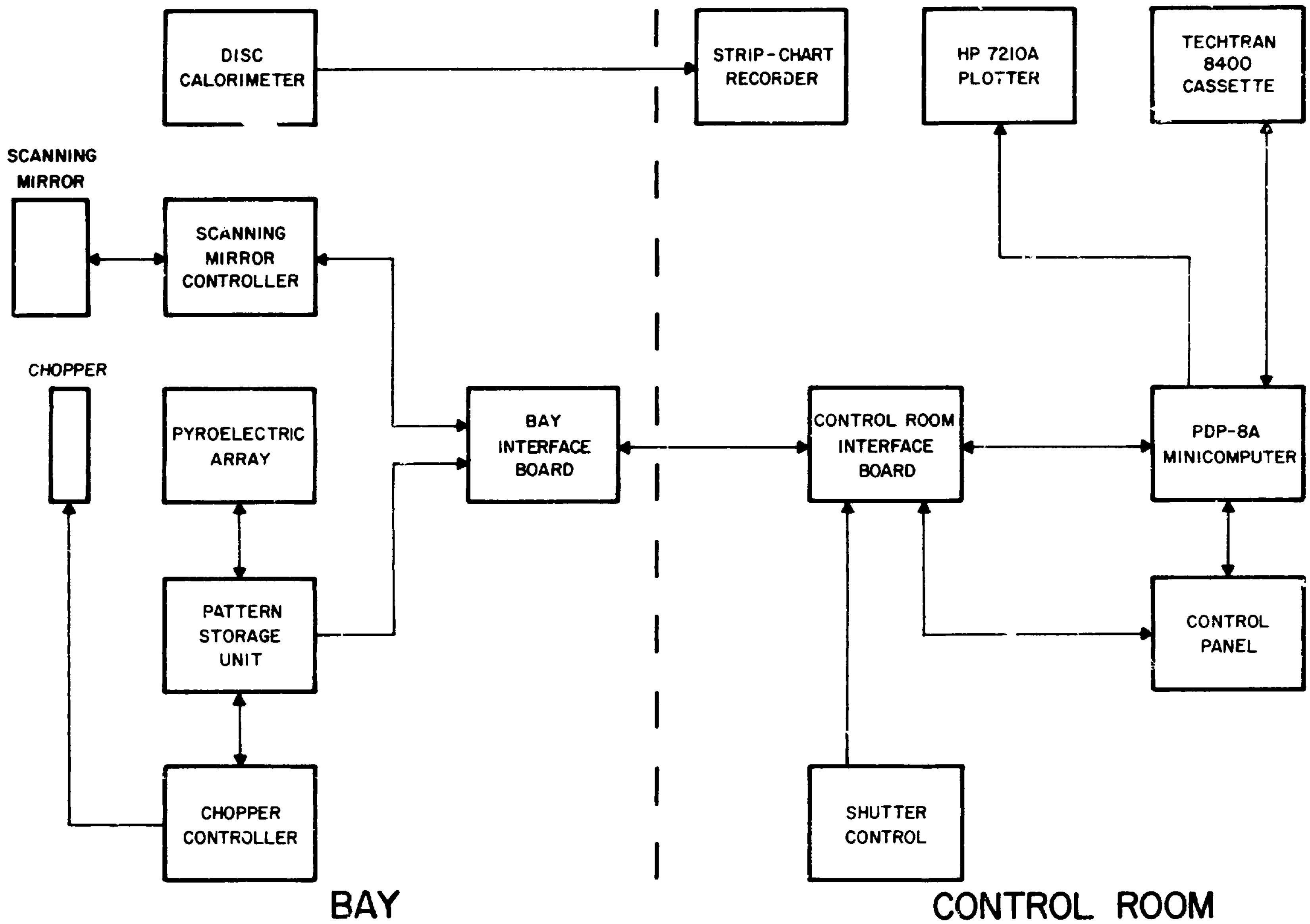

Figure 2. Block Diagram of Electrical Layout for Laser-Beam-Parameter-Measurement System

The reflected beam of the secondary beam splitter was directed onto a 2.5-in. diam. total reflector mounted on a General Scanning Inc. Model G-300 PDT Scanner which caused the reflected beam to scan across the 16-element pyroelectric-array/chopper combination. By synchronizing the mirror position (total scan, angular displacement of < 5 deg.) with the array timing, the horizontal position of the beam at the detectors at each chopper cycle is predictable.

The pyroelectric-array system (Laser Precision Corp.) consists of a Model AK 2940 array with 16 pyroelectric elements measuring 1 x 1 mm mounted in a linear array on 3.1-mm centers, a Model CTX-296 chopper asssmbly with 2-in. clear aperture, speed selectable from 60 to 180 Hz, and a Model AS pattern-storage assembly which provides digital conversion of each element (sequentially multiplexed) and stores an entire line between chopper cycles. The pattern storage contains the baseline subtract option, permitting the detector value with the chopper closed to be subtracted from the "chopper-open" value in order to eliminate baseline drift and minimize changes in responsivity due to thermal effects.

As shown schematically in Fig. 2, the output of the pattern-storage unit (12-bit words plus timing signals) is connected to a PDP-8A microcomputer through two interface cards which are connected by a ~ 100-ft length of shielded-pairs cable. The main function of the interface cards is to provide line driving and optically isolated receiving capability, minimizing the effects of EMI/RFI generated by the laser discharge. Synchronizing signals of the scanning mirror also pass through these cards. During operation (RUN mode), the chopper-synchronizing and laser shutter signals are monitored continually. Upon detection of an open shutter, the mirror is allowed to scan. Array output (pattern storage) for the next 16 chopper cycles is stored in the computer. The system then awaits a signal from the scanning-mirror controller which indicates the return of the mirror to the starting position, at which time reading commences for the next 16 chopper cycles. This process is continued until the laser shutter is closed. After the "closed shutter" is detected, the system remains on until the present frame (set of 16 chopper cycles) is complete, at which time the mirror scan is terminated and the system returns to the "standby" mode. The recorded data can be stored on cassette and/or plotted on an X-Y plotter. Figure 3 shows the optical table setup. The laser beam enters at the bottom left with the primary beam splitter located at top left. The incident angle of the beam splitter is ~ 30 deg. to the normal. The secondary beam splitter is located at the bottom right, with the disc calorimeter (out of the picture) immediately behind. The scanning mirror is located near the center of the table and the chopper/array system is at the right center. The control boxes are located on the table in order to minimize cable lengths, the bay interface board being mounted just outside. The entire optical system is enclosed in a black plexiglass box (shown with hinged cover raised).

Figure 4 shows the minicomputer and system control panel along with the X-Y plotter and cassette storage unit. Once the system is activated, all operations are initiated from the control panel. Plot routines available are a skewed X-Y-intensity plot for beam profile, and skewed T-X-intensity and T-Y-intensity plots for time variance records where X corresponds to the laser-beam horizontal coordinate; Y is the vertical coordinate, and T is the time, relative to the chopper frequency.

Figure 5 displays the entire set of X-Y profile plots for a typical laser shot (total time of ~ 1 sec). Each frame represents a 16 x 16 element array with the elements in the horizontal direction being connected by straight lines for ease of interpretation only. It must be emphasized that these lines do not represent a continuous measurement. The spikes present in the last frame correspond to the closing of the laser shutter and are probably due to noise generated by the shutter solenoids, rather than laser-beam intensity.

The value of time-resolved beam profiling is dramatically illustrated in Fig. 6. The deterioration of beam quality and energy content during the irradiation time is obvious, although previous diagnostic techniques did not indicate that the discharge arced until after the laser shutter had closed. The time plots of Fig. 7 clearly indicate a decrease in power for three of the four lines shown on each axis.

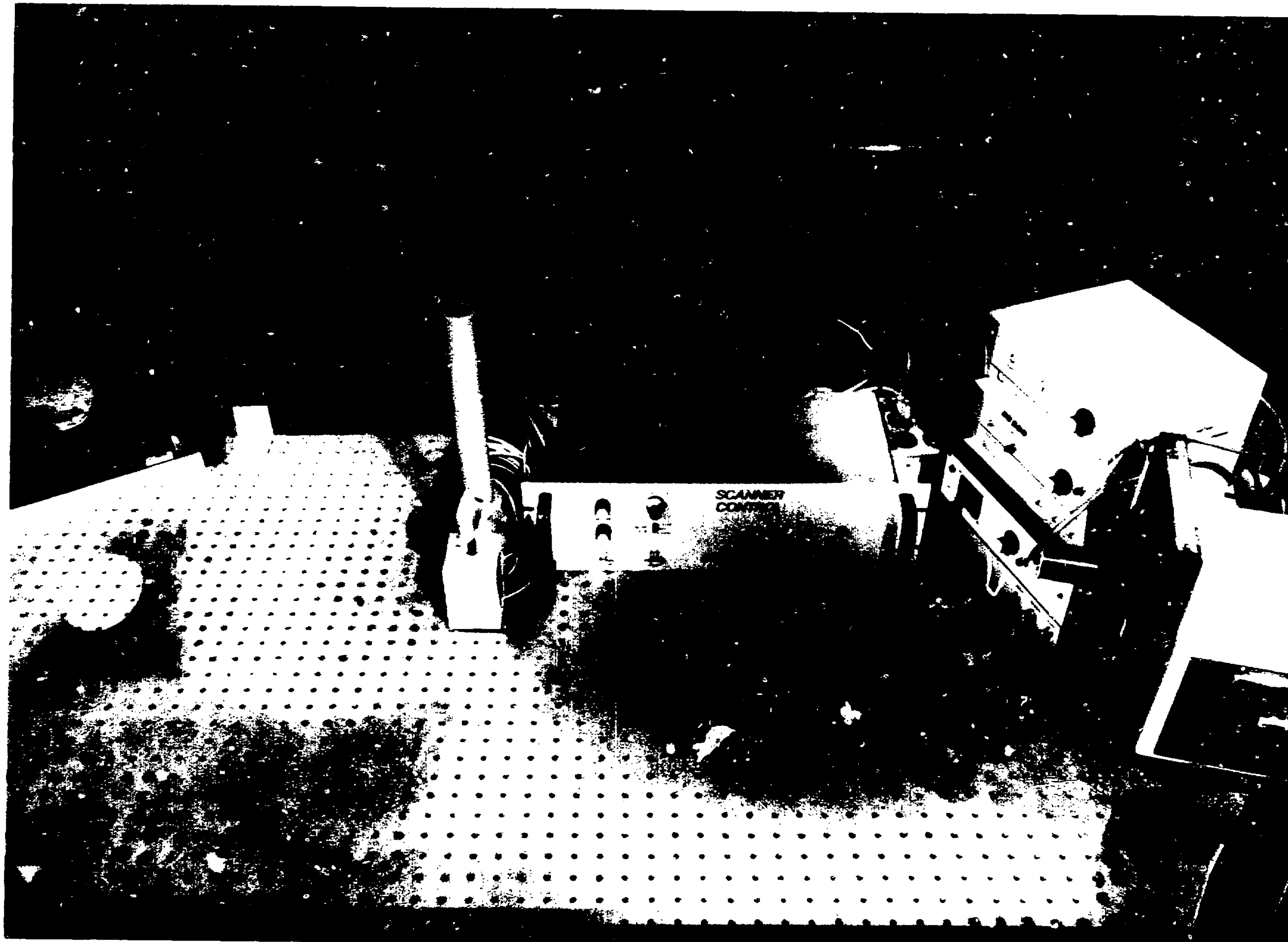

Figure 3. Photograph of Laser-Beam-Parameter-Measurement System

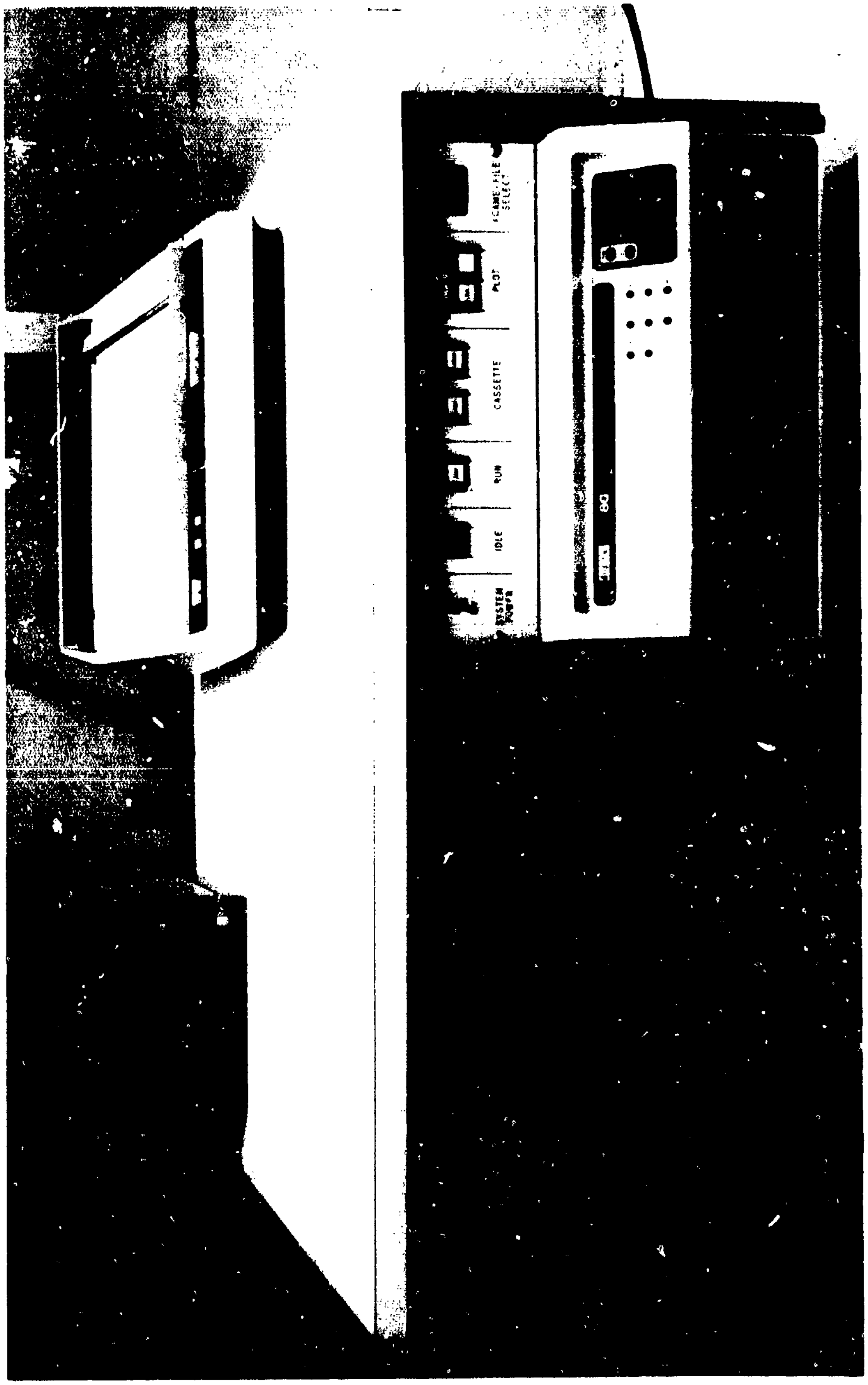

Figure 4. Photograph of Data-Acquisition/Processing Instrumentation

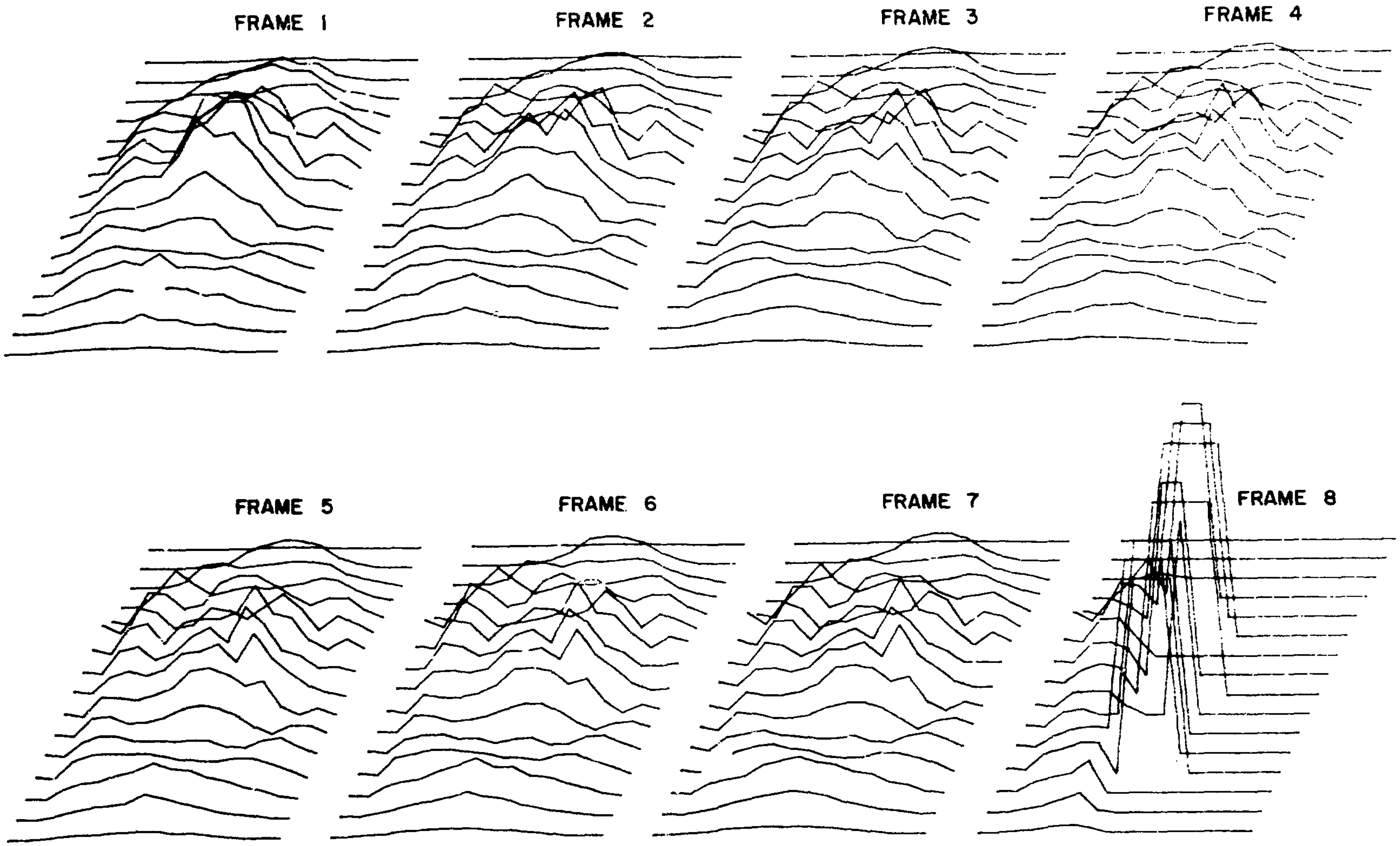

Figure 5. Time History of Laser-Beam Spatial-Intensity Profile

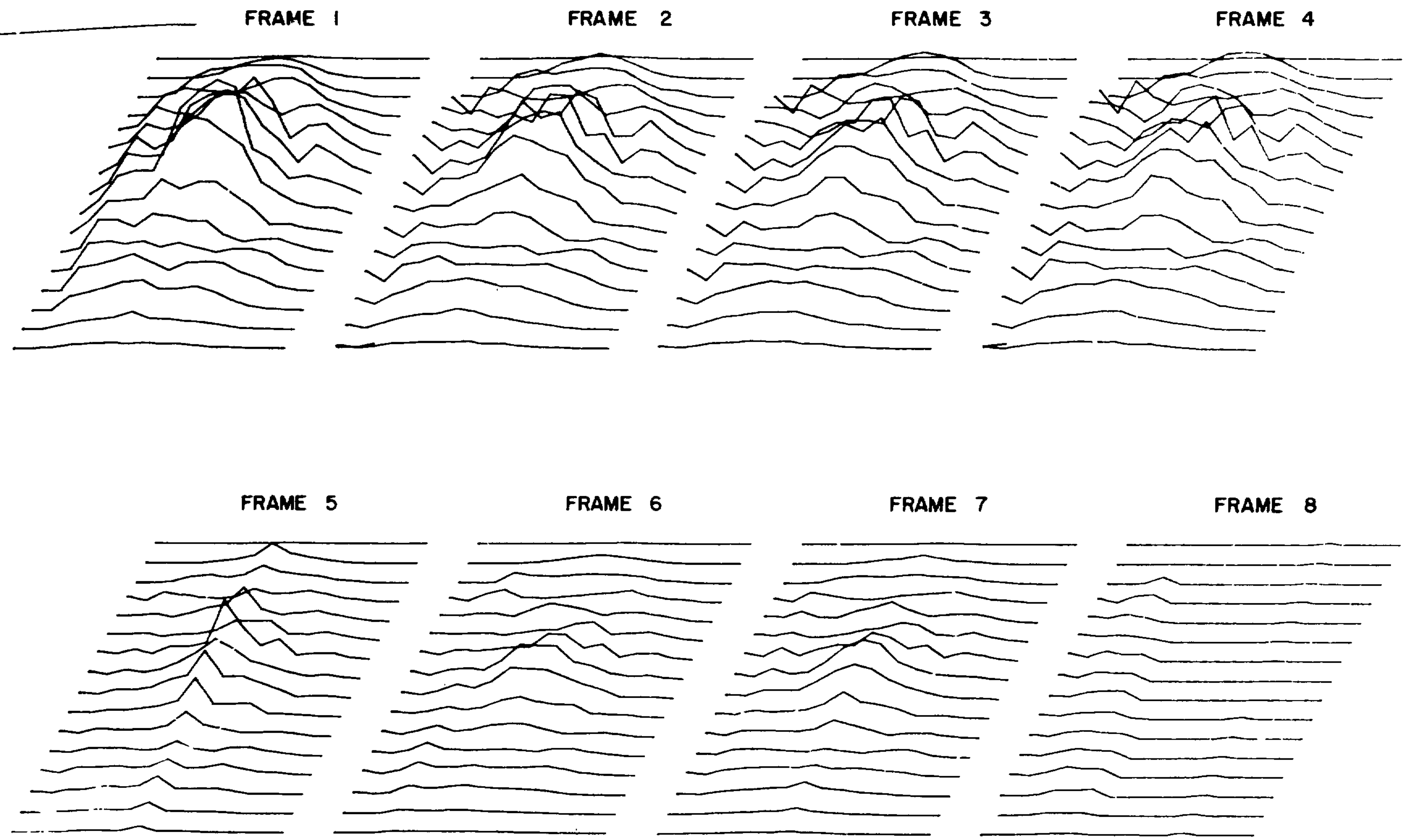

Figure 6. Effect of Discharge Arcing upon Laser-Beam Spatial-Intensity Profile

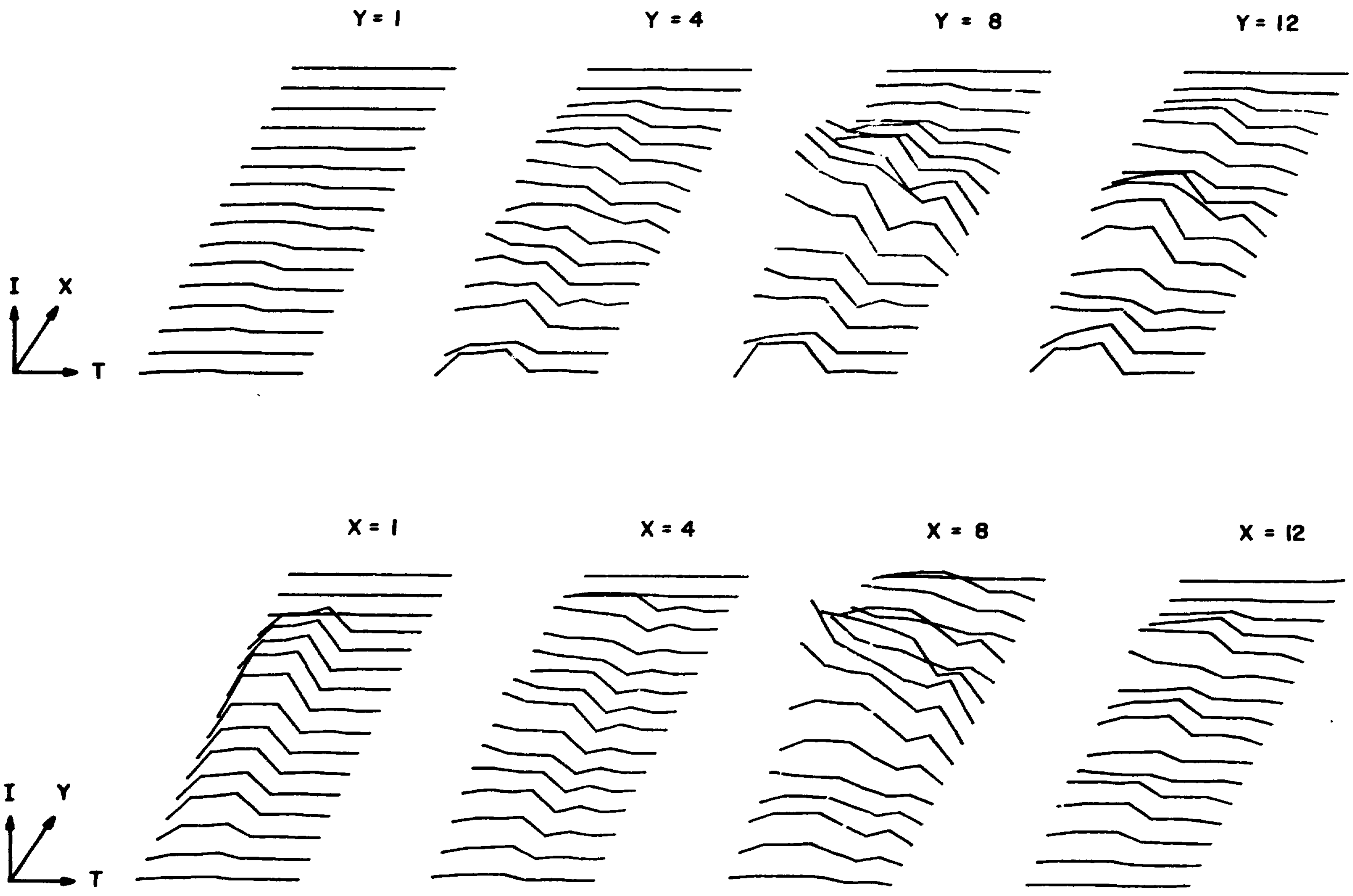

Figure 7. X-T and Y-T Plots of Beam Intensity During Discharge Arcing

CONCLUSIONS

It has been shown that the laser-beam-parameter monitor described in this report is capable of time-resolved qualitative (quantitative with calorimeter calibration) measurements of the spatial energy distribution in a high-power cw CO_2 laser beam. The use of ZnSe beam splitters permits beam-parameter measurements concurrent with sample irradiation by the main beam. The system can be easily upgraded to provide finer spatial resolution and more sophisticated numerical data analysis.

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