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APPLICATION OF SCAN LASER HEATING
FOR
THERMAL IMAGERY NONDESTRUCTIVE TESTING



OCTOBER 1973

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by GREGORY ARUTUNIAN & OTTO RENIUS

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U.S. ARMY TANK AUTOMOTIVE COMMAND Warren, Michigan

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APPLICATION OF SCAN LASER HEATING
FOR
THERMAL IMAGERY NONDESTRUCTIVE TESTING

BY

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ABSTRACT

Evaluations were made using an infrared non-destructive testing technique employing scan laser heating of the specimen. Thermal images were obtained with a newly developed two-dimensional reflective scanner, coupled to a 50 watt CO₂ laser to irradiate the specimen and a thermal imaging camera to view the specimen's irradiated surfaces. The technique showed a capability of providing a real time non-destructive test for subsurface defects in a variety of materials and structures. It allows the laser heat source and infrared camera to be remotely positioned from the specimen under test, making it possible to examine large specimens.

TABLE OF CONTENTS

	<u>PAGE NO.</u>
Abstract	i
List of Figures	iii
Introduction	1
Recommendations	3
Summary & Conclusions	4
Equipment Description	5
Test Specimens	8
Experimental Procedure	10
Results	10
References	24
Distribution List	25
DD Form 1473	33

LIST OF FIGURES

FIGURE NO.

- | | |
|----|--|
| 1 | 50 Watt CO ₂ Laser Head |
| 2 | Schematic of Laser Tube |
| 3 | Optical Unit of Beam Positioner |
| 4 | Beam Positioner Control Unit |
| 5 | Rectangular Scanning Pattern |
| 6 | Elliptical Scanning Pattern |
| 7 | Thermal Imaging System |
| 8 | Laser Safety Equipment |
| 9 | Arrangement of Simulated Defective Specimen |
| 10 | Thermal Image of Fiberglass/
Aluminum Honeycomb |
| 11 | Thermal Image of Titanium/
Aluminum Honeycomb |
| 12 | Thermal Image of Rubber/Aluminum
Bond |

INTRODUCTION

The basic technique for use of a CO₂ laser to heat a specimen for infrared nondestructive testing was described in TACOM Report No. 11169 dated January 1971, and in the May 1973 issue of Materials Evaluation.

Basically, the technique uses the energy of the scanning high intensity long wavelength laser beam to heat the surface of the specimen under test. A thermal imaging device then views the heated specimen. If the specimen is homogeneous, heat is conducted away from the irradiated surface uniformly after the scanning laser beam has passed. If, however, areas of non-homogeneity exist, the thermal conductance is altered, resulting in surface temperature variations in the specimen. These temperature variations can then be detected by radiometry or thermal imagery and used to locate the defective area of the specimen.

As a result of the initial feasibility investigation reported in 1971, requirements for a reflective laser beam positioner of increased versatility were established. The additional features which were incorporated into the two dimensional scanner used in the evaluations described in this report are:

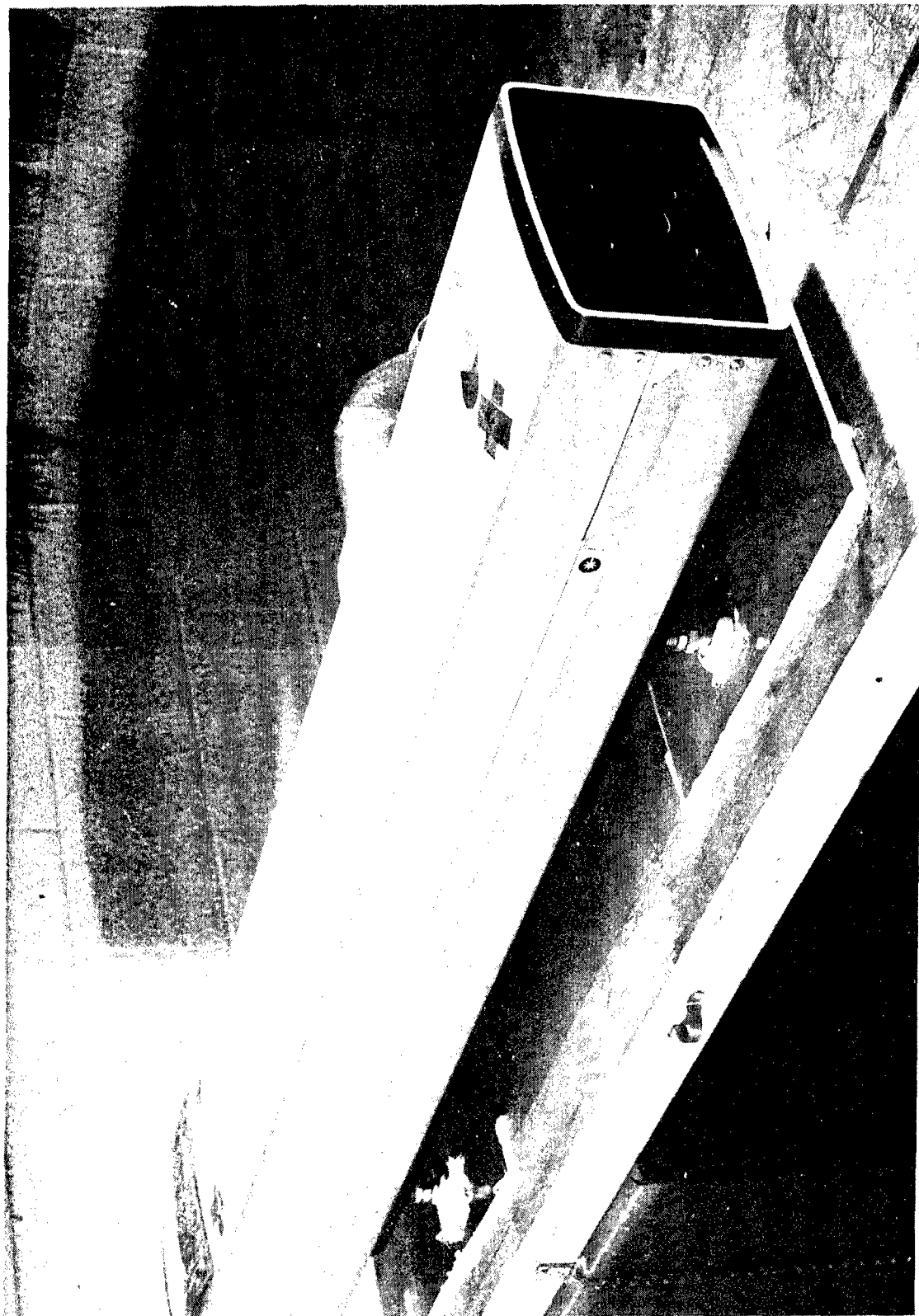
- a. Capability for use of a laser of increased power output
- b. Ability to vary the horizontal scan angle
- c. Ability to vary the vertical scan angle
- d. Incorporation of a beam spot locator
- e. Ability to adjust scanning rate
- f. Capability of varying scan line spacing

These modifications to the original concept of scan-laser specimen heating allowed a 50 watt continuous wave CO₂ laser to be used for heating the specimen's surface. This provided sufficient thermal energy to the specimen under test for thermographic evaluations of sub-surface defects to be made as the laser heating was taking place. It provided in effect a real time nondestructive testing technique for several types of materials and structures.

the skin specimen made it difficult to observe. The bright spot indication of a void faded quickly after the laser beam had passed.

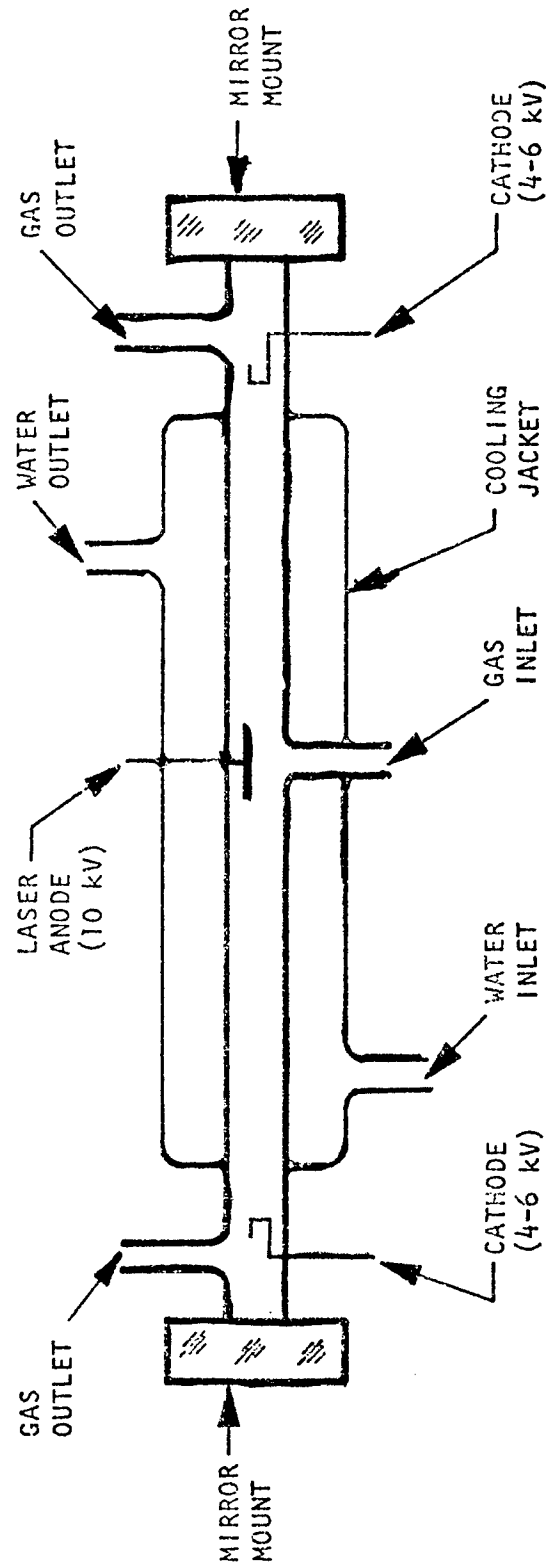
Defective areas of specimens which had a metallic skin bonded to a phenolic or paper honeycomb could not be detected. Similarly, the scan laser method of specimen heating was not effective for outlining voids in solid metal specimens.

Figure 12 is an example of the detection of disbond voids in a specimen of rubber bonded to aluminum. The voids appear hotter than the areas of solid bonding, and are readily detected under a wide variety of scanning conditions.



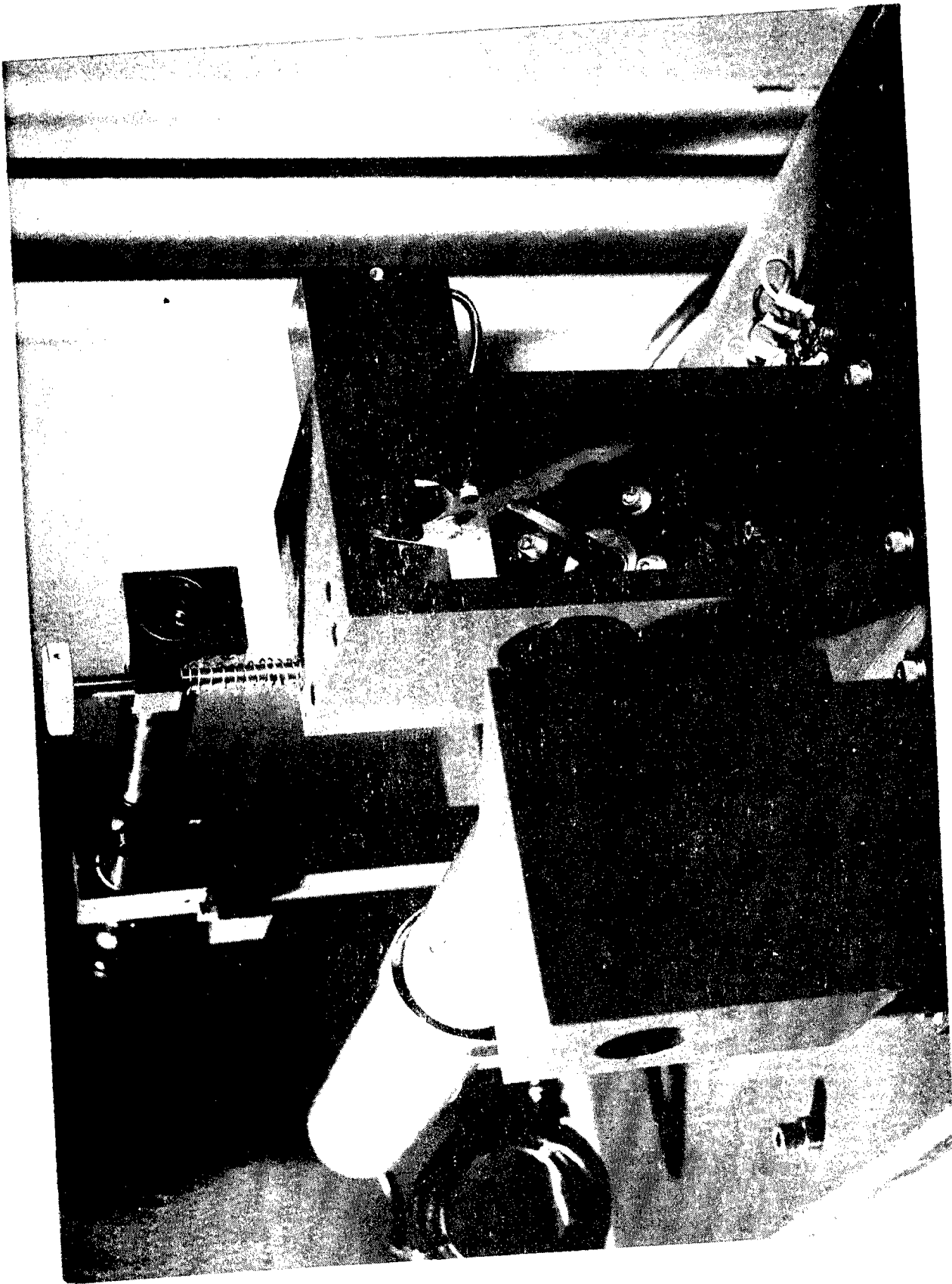
50 Watt CO₂ Laser Head

FIGURE 1



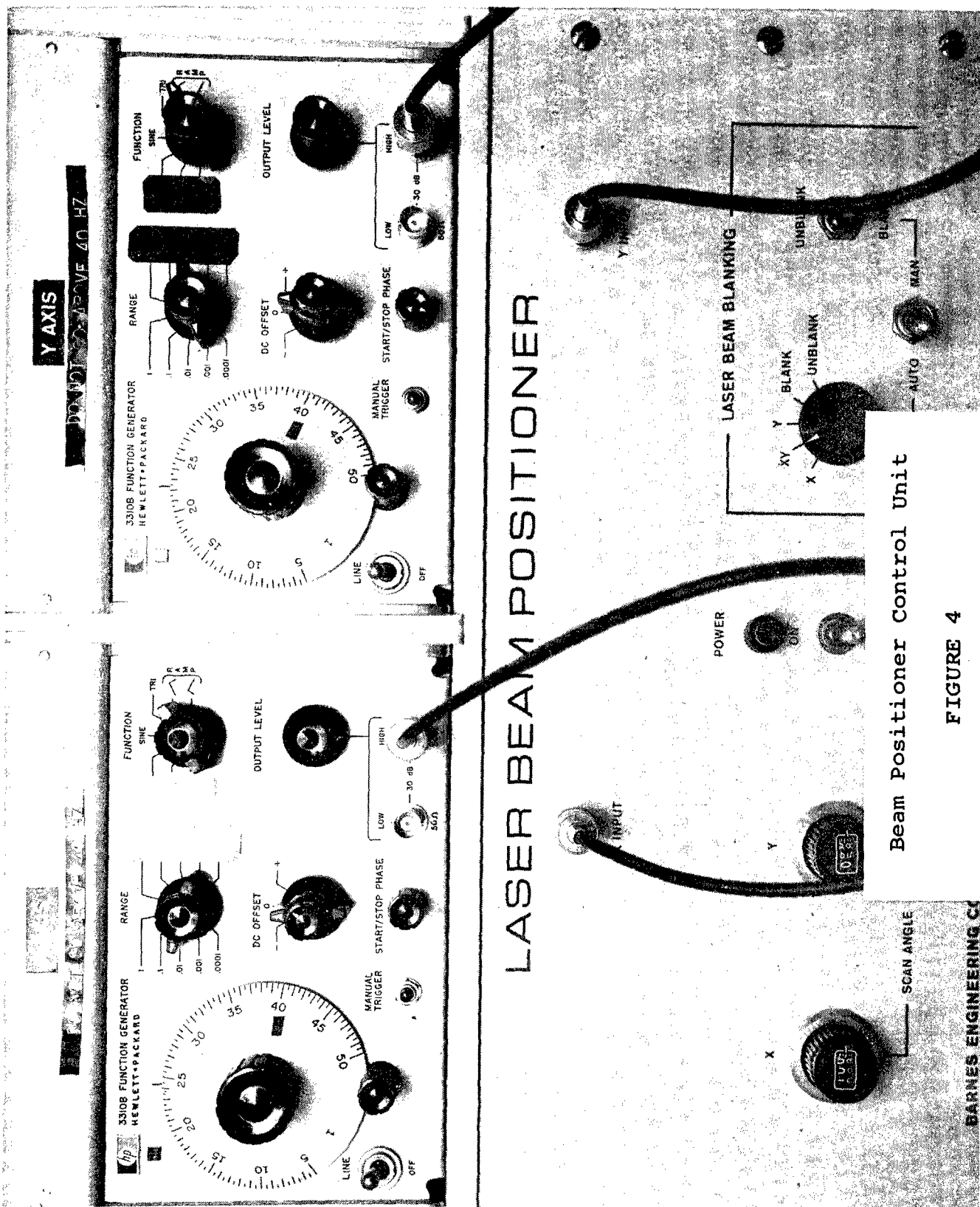
Schematic of Laser Tube

FIGURE 2



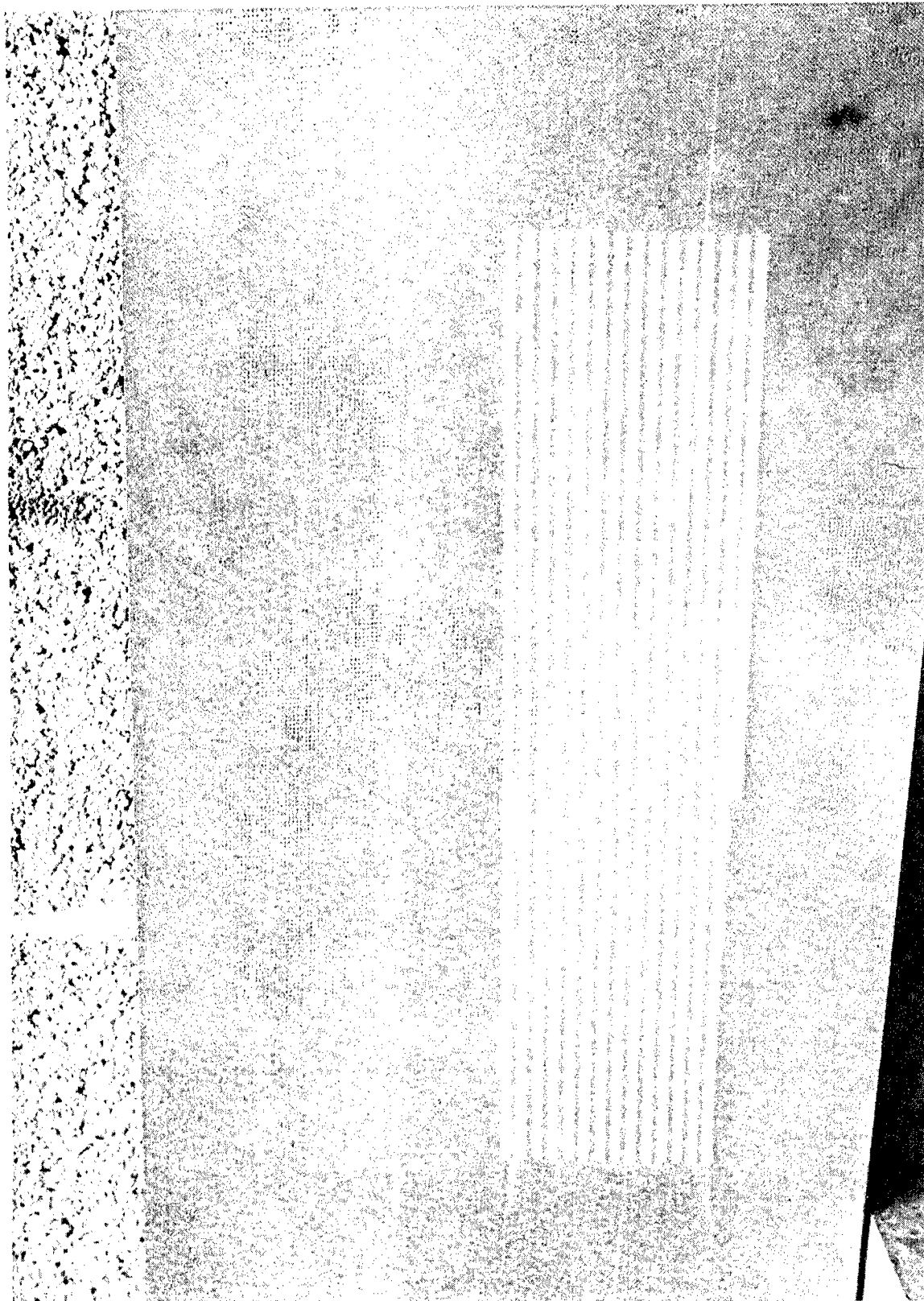
Optical Unit of Beam Positioner

FIGURE 3



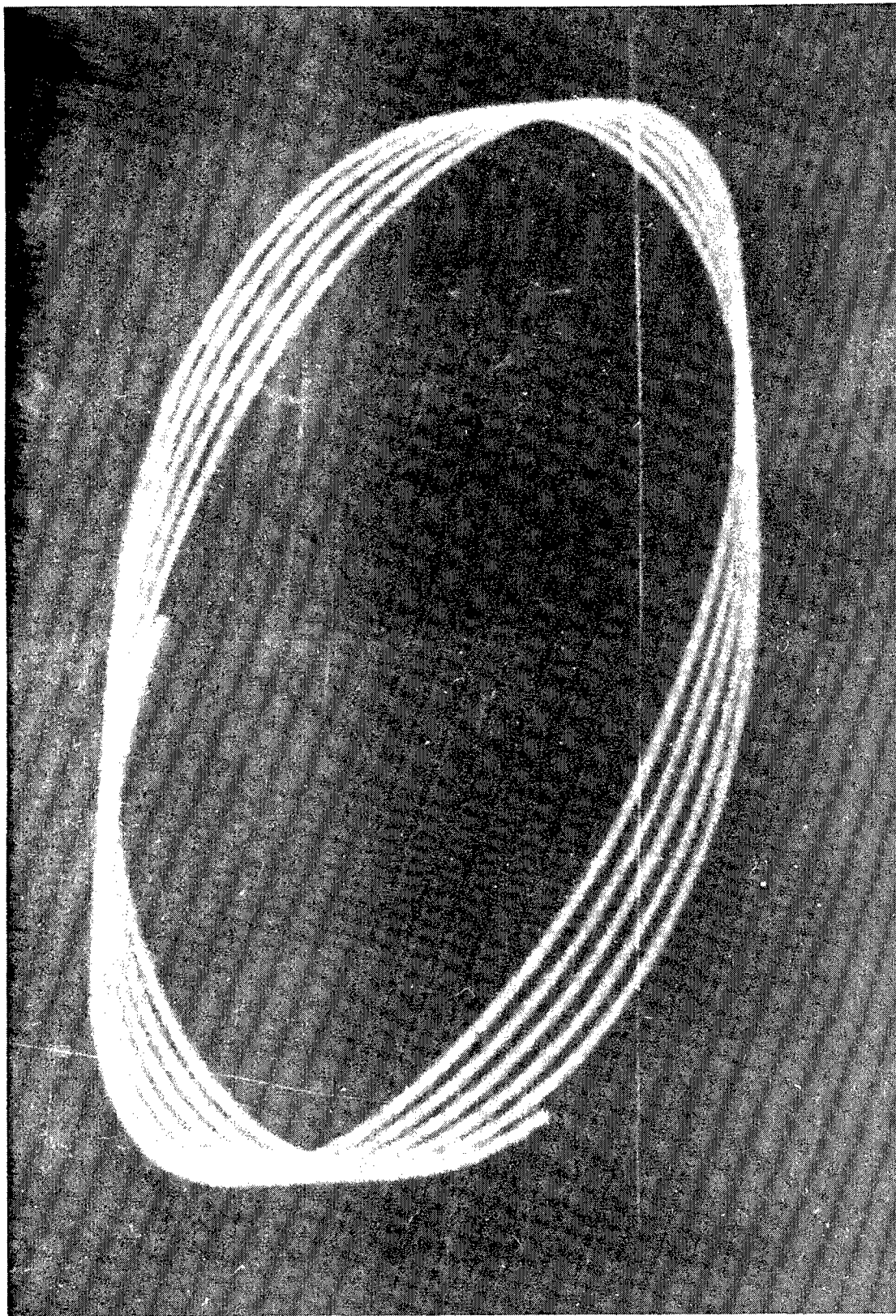
Beam Positioner Control Unit

FIGURE 4



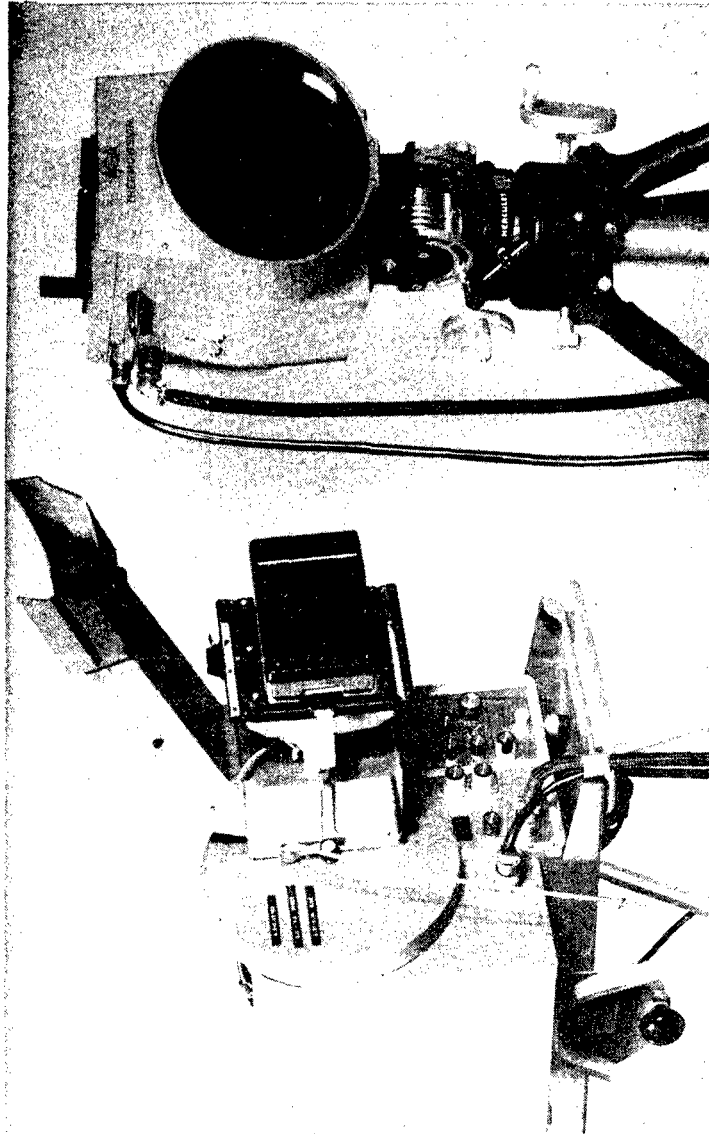
Rectangular Scanning Pattern

FIGURE 5



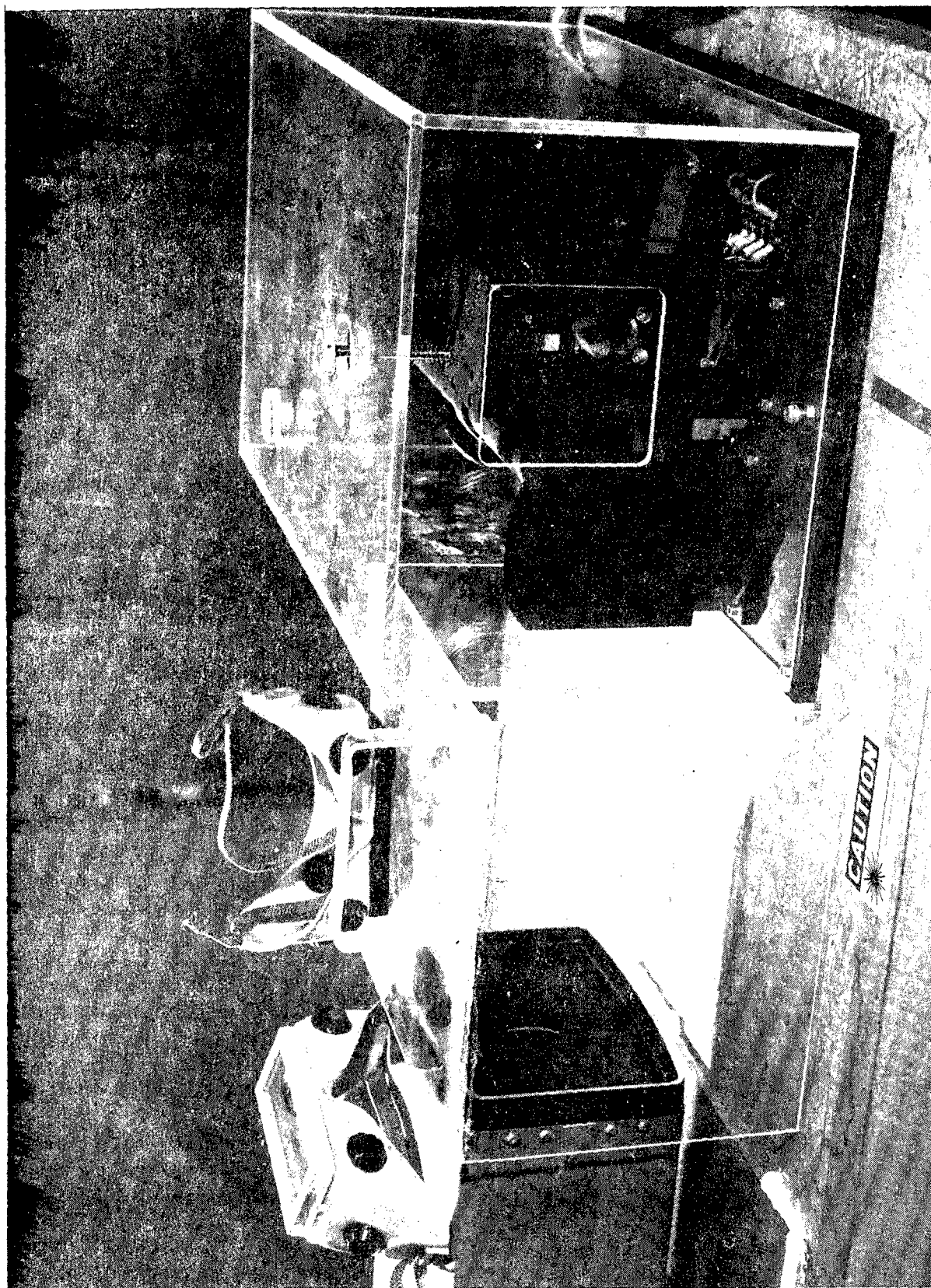
Elliptical Scanning Pattern

FIGURE 6



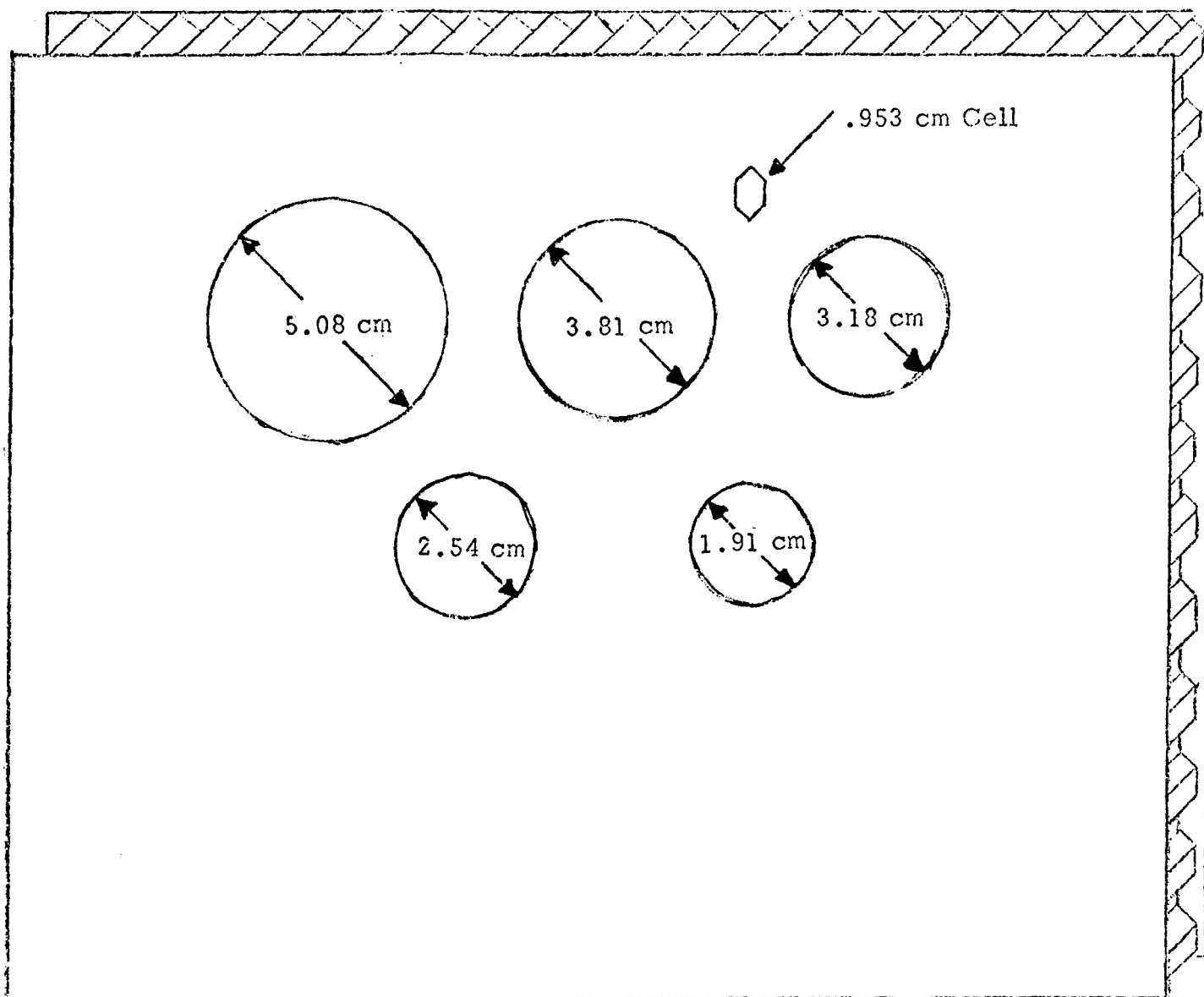
Thermal Imaging System

FIGURE 7



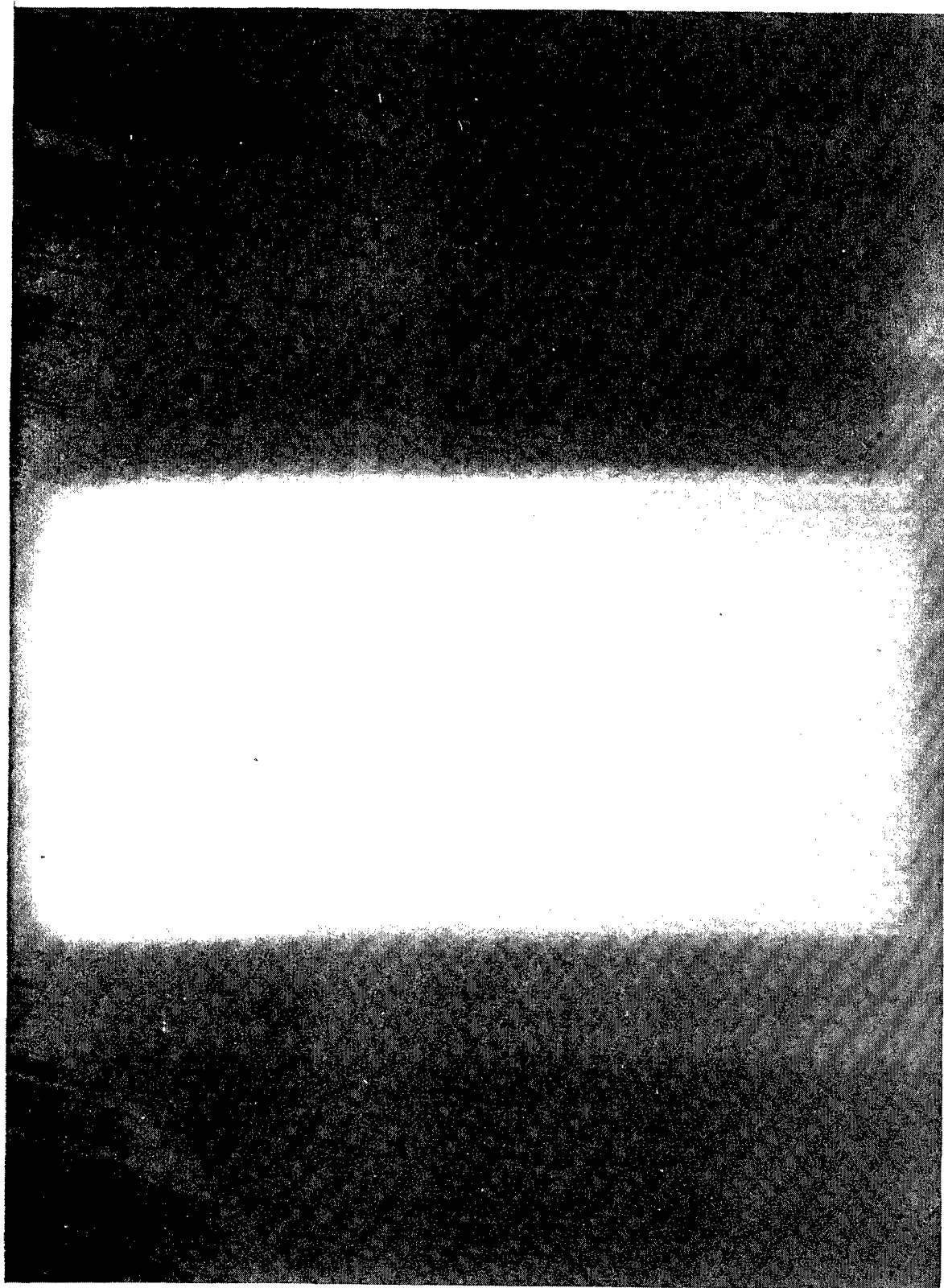
Laser Safety Equipment

FIGURE 8



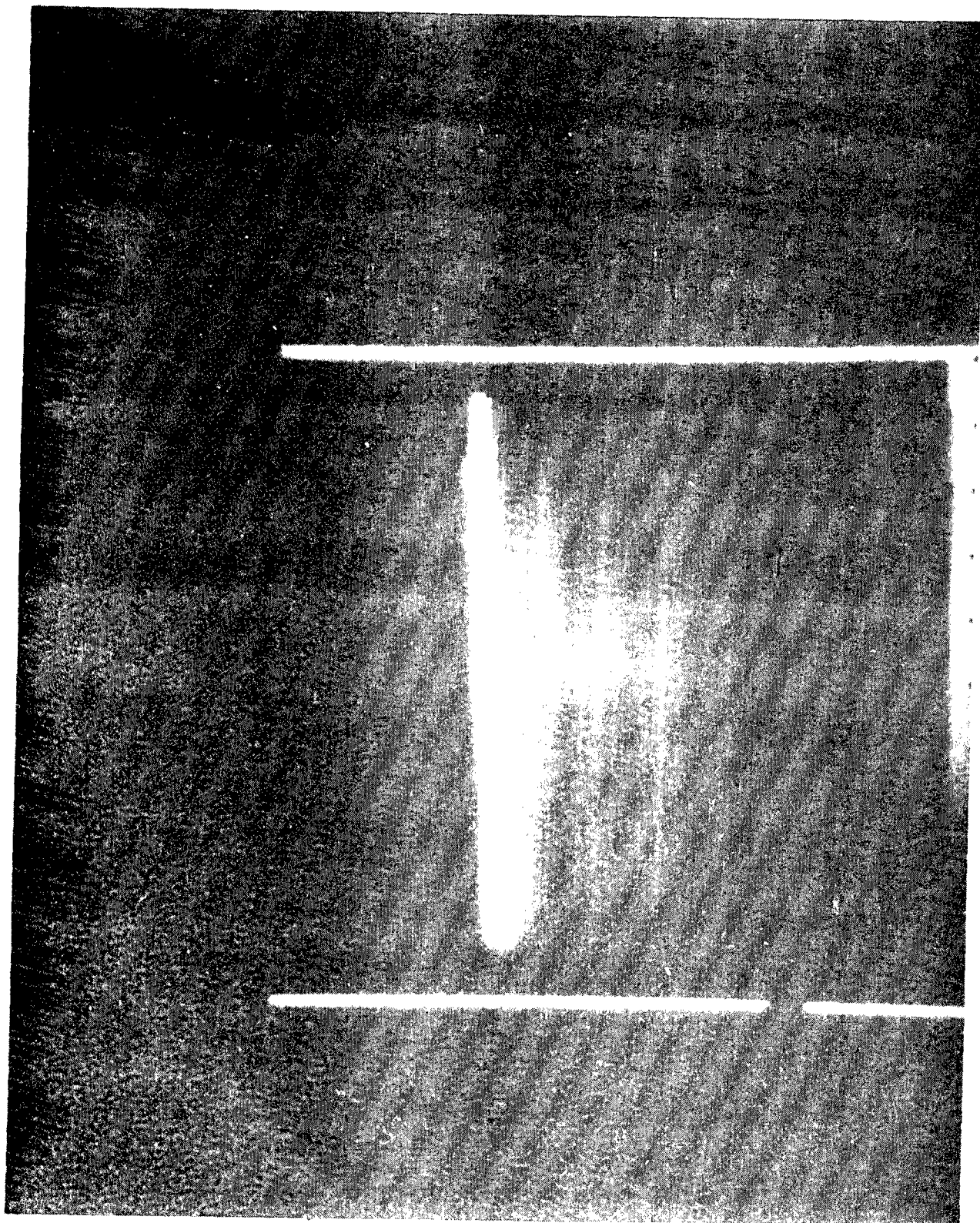
Arrangement of Simulated
Defective Specimen

FIGURE 9



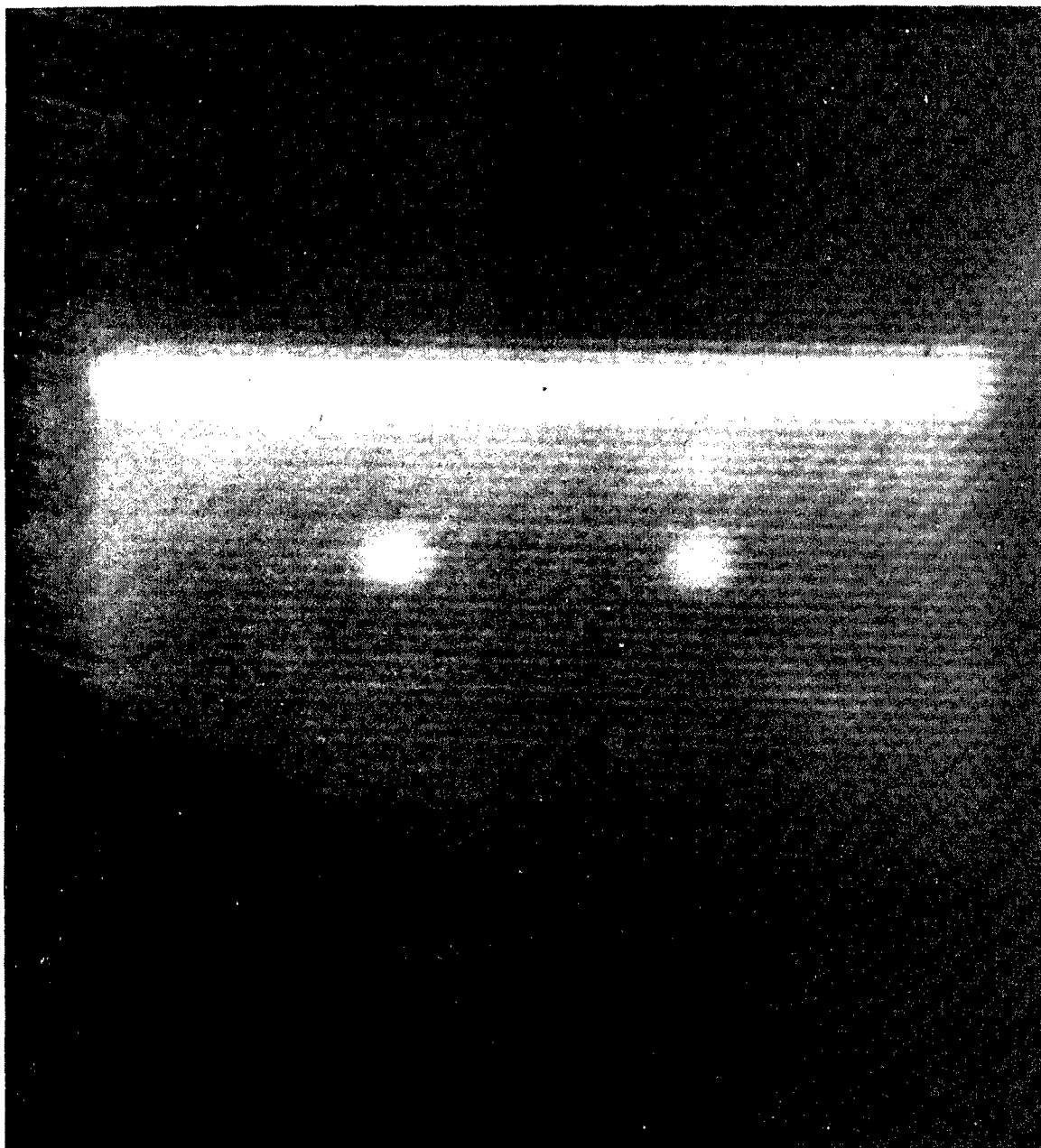
Thermal Image of Fiberglass/
Aluminum Honeycomb

FIGURE 10



Thermal Image of Titanium/
Aluminum Honeycomb

FIGURE 11



Thermal Image of Rubber/
Aluminum Bond

FIGURE 12

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2. "Investigation of a Laser Illuminator-Thermal Imaging System for the Detection of Voids and Disbonds" U.S. Army TACOM, Report # 11169, January 1971.
3. "Application of Infrared Inspection Techniques to the Inspection of Artillery Shells for Unseated Rotating Bands and Improperly Processed Mechanical Joints" unpublished paper presented by J. Pasman, Picatinny Arsenal at 1970 Materials Testing Meeting, Watertown, Massachusetts.
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5. "Infrared Physics and Engineering" Jamieson et al McGraw-Hill 1963.

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RECOMMENDATIONS

Scan laser heating is recommended for infrared non-destructive testing applications where excessively long heating times would be required if conventional methods were to be employed to obtain thermal contrast. The technique is particularly applicable to the testing of large specimens where uniform specimen heating is difficult to achieve, or where the configuration requires that the heat source and thermal imager be positioned on the same side of the specimen.

SUMMARY AND CONCLUSIONS

The development of scan-laser heating provides an effective method for uniform heating of specimens which can be inspected by thermal imagery. This technique provides a real time nondestructive testing capability for a variety of materials and structures such as bonded honeycomb structures.

In order for the two-dimensional scan laser technique to have maximum versatility as a heat source for infrared nondestructive testing, it was necessary to allow for adjustment of scan speed, vertical and horizontal beam travel, and scan line spacing. In addition, safety precautions are necessary in all applications to insure that personnel are not subjected to burns by direct or reflected invisible radiation from the CO₂ laser. The addition of a coincident visible beam from a low power laser was found to be beneficial in adjusting all scanning parameters, and determining the location of the invisible laser beam.

From results obtained in the laboratory, it can be concluded that scan laser heating is a valuable tool for infrared nondestructive testing of composite or bonded structures which have a thermally insulative outer surface over a thermally conductive core. Under these favorable conditions, it is possible to resolve defects as small as .95 cm on the thermal imaging display. The scan laser heating technique, however, does not show promise for real-time front surface heating for thick specimens or those with a thermally conductive outer surface over a thermally insulative core.

Solid metal specimens are much more difficult to evaluate. Here, the heat tends to be distributed evenly throughout the specimen and all thermal gradients caused by a subsurface defect are rapidly lost if indeed they ever appear at the surface. However, since the scan laser heating technique does offer a method for real time NDT, it could be advantageously employed for many structures, and warrants further study.

EQUIPMENT DESCRIPTION

The basic equipment may be divided into four broad categories for consideration: a. laser, b. beam positioner, c. thermal imaging system, and d. safety equipment.

a. Laser:

The laser employed in this evaluation was a Coherent Radiation Model 42 CO₂ with a 50 watt CW output. The beam diameter was 6.3 mm with a 2.2 mr beam divergence. The laser head is shown in Figure 1. It consists of a water-cooled glass plasma tube and an optical resonator. The laser medium is a continuous flowing mixture of nitrogen, helium, and carbon dioxide. The gas flows to the middle of the plasma tube and is pumped out the ends as shown in Figure 2. The total pressure in the tube is maintained at 25 to 35 mm of mercury.

The laser power supply controls the laser gas supply, water supply and electrical power. These are located in a cabinet which is safety interlocked. An umbilical tube connects the power supply cabinet to the laser head. The laser beam control circuit supplies a constant current to each of the two laser tube cathodes, and switches the laser beam current for precise on and off control.

b. Beam Positioner:

The laser beam positioner normally scans the 50 watt CO₂ laser beam in a rectangular raster format. The complete positioner consists of an optical unit and an electronic control unit. It is designed to scan a wide variety of area patterns over a field of view of variable size at widely adjustable scan rates.

The optical unit of the beam positioner is shown in Figure 3. For safety purposes, a visible wavelength laser (Ne-He) is used to illuminate the area irradiated by the CO₂ laser. This is accomplished through the use of a dichroic element which permits the axial combination of the 6328A NeHe laser radiation and the 10.6 micrometer CO₂ laser radiation. The two beams meet at the dichroic element and form a scan pattern by the two scan mirrors shown. Small torquers drive the first surface scanning mirrors. One mirror scans the coincident laser beams in the X direction, and the other produces scanning in the Y direction. The torquers follow the waveform of the driving signal voltage and can be offset by an amount proportional to any DC voltage.

The beam positioner control unit, Figure 4, consists of two independent but synchronized electronic waveform generators. These operate individual driver amplifiers, one for each scan mirror. The electronic control also contains the on-off and scan start switches as well as adjustments for frame time and line resolution. A pulse output is provided that permits the CO₂ laser to be turned off during vertical retrace of the scanner.

Electrical modulation of the X and Y scan signals can produce a scan pattern of almost any desired shape for variable target coverage to 20° with a scan sweep speed up to 40 Hz. Figure 5 illustrates a rectangular scan normally employed for specimen heating. Figure 6 shows the scanner versatility by generating a circular scan.

c. Thermal Imaging System:

The thermal imaging system is an AGA "thermvision" as shown in Figure 7. The equipment consists of an infrared camera and an oscilloscope which displays the thermal image on its screen. A recording camera attachment allows permanent photographic records to be taken while the screen is being viewed. In the normal mode of operation, the thermogram displayed is a picture of the object viewed in a continuous range of gray tones, with a warm area appearing lighter than a cold area.

d. Safety Equipment:

The direct or reflected laser beam is capable of igniting materials or causing serious eye or skin burns, and care must be exercised to prevent unwanted exposure of materiel or personnel. Since plexiglas is an efficient absorber of the 10.6 micrometer laser radiation, it becomes a convenient visually transparent material for the fabrication of laser safety goggles and instrument covers (Figure 8). An additional 1.2 m x 2.4 m plexiglas sheet mounted on a movable stand is also used for protective screening.

The high voltage power supply necessary for operation of the laser also constitutes a potential safety hazard. The power supply cabinet and scanner controller cabinets contain interlock circuits to prevent accidental access to the electrical connections while operating. The door of the controlled access laser area also contains electrical switches to activate warning lights when the laser power supply is energized.

TEST SPECIMENS

A variety of materials and structures was used in the evaluation of the laser scan heating technique for the detection of sub-surface defects:

A. Honeycomb Structures:

1. Titanium skin, aluminum honeycomb aircraft structure. This structure was 1.9 cm thick. The outer titanium skin was 0.05 cm, and the honeycomb hexagon structure was .32 cm.

2. Fiberglass skin, phenolic honeycomb structure. This structure was 1.27 cm thick. The outer fiberglass skin was .32 cm, and the honeycomb structure was .95 cm hex. Circular disbond areas were created in preparing the panel. These were 5.08 cm, 3.81 cm, 3.18 cm, 2.54 cm and 1.91 cm in diameter. Figure 9 illustrates the arrangement of simulated defects in the bonded specimen.

3. Fiberglass skin, paper core structure. The structure was 3.81 cm thick. The outer skin was .32 cm thick, and the wave configuration paper core had a .64 cm wave to wave spacing. Disbond areas consisting of circular unbond areas 5.08 cm x 6.35 cm were also used to simulate defect areas.

4. Fiberglass skin, aluminum honeycomb core. The structure was 3.81 cm thick. The outer skin was .32 cm thick, and the honeycomb had a .95 cm hexagonal cell. Circular unbond areas were created in fabricating the structure. These were 5.08 cm, 3.81 cm, 2.54 cm and 1.91 cm diameter.

B. Metal Structures:

1. Solid Aluminum Panel

A 2.54 cm section of aluminum 30.5 cm square .32 cm, .64 cm and .95 cm holes drilled parallel to and .32

cm to .64 cm beneath the surface. These were used to simulate various size voids beneath the surface.

2. Bonded Aluminum Panel

An aluminum sandwich structure was constructed of a .64 cm aluminum plate sandwiched between aluminum plates .32 cm thick. 3.81 cm, 2.54 cm, 1.91 cm and .64 cm holes were drilled in the .64 cm plate to simulate voids, and the entire sandwich was bonded with two part epoxy adhesive.

C. Other Specimens:

1. Tank Track Pads

A tank track pad which consists of approximately 5.08 cm of rubber bonded to a .32 cm steel base was used as a typical automotive component requiring nondestructive testing.

EXPERIMENTAL PROCEDURE

Test specimen structures were painted to increase absorptivity of the laser radiation and to provide some uniformity in the comparison of various specimens. A specimen-to-laser distance of 4 meters was maintained for the investigation. This allowed an area up to 1.4 meter x 1.4 meter to be covered with the scan laser. The infrared camera head was placed 4.65 meters from the specimen. At this distance, a thermal image of an area .36 m by .46 m could be obtained.

Prior to activation of the CO₂ laser scan, the visible beam from the neon helium laser was used to establish the desired scan pattern. Horizontal and vertical scan distances were adjusted to cover the specimen without extensive overlap. The speed of scan was also selected to provide the desired degree of heating for each type of specimen examined.

The thermal image of the heated specimen was observed, and photographic records were made of the specimens under test.

RESULTS

Figure 10 illustrates the thermal imagery obtained with scan laser heating of a fiberglass skin aluminum honeycomb structure. The defects, which are unbonded areas, range from 1 cm to 5 cm in diameter. The hexagonal cell structure was 1 cm. These defects were readily seen under a wide variety of scan speeds and laser beam power. Similar results were obtained with other fiberglass/aluminum structures.

A section of an aircraft panel consisting of .05 cm titanium skin over 1.9 cm aluminum honeycomb was also examined. Figure 11 shows a defect caused by de-bonding the skin from the core. In this case, photography of the thermovision screen enhanced the detection of the defective area since the rapid dissipation of heat in