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Laser Applications

By R. T. Horn

Published July 1980

Final Report

Prepared for the United States Department of Energy
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**Kansas City
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LASER APPLICATIONS

By R. T. Horn

Published July 1980

Final Report
R. T. Horn, Project Leader

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**Kansas City
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LASER APPLICATIONS

BDX-613-2448, Final Report, Published July 1980

Prepared by R. T. Horn

Processes were developed that use lasers as manufacturing tools. These processes were stripping of insulation from cables and wires, machining of quartz, microdrilling and welding of reflective metals, and precision alignment of curved surfaces before machining. A technological basis also was formed which resulted in a process for automatic surface inspection of parts and aided development of machining processes for Kevlar parts.

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SUMMARY

Laser processing in production is a recent approach that is complementary with existing manufacturing methods. The work on this project consisted of identifying feasible production applications of laser processing and providing a technological basis for development work in other laser related studies.

From these efforts, basic methods for successful laser applications have been established. These methods require an understanding of the power and focusing parameters of lasers. Using these methods, processes for welding, drilling, cutting, alignment, and inspection have been developed. In particular, high speed laser stripping and contouring of flexible cables has become a major production application. Laser welding of cast aluminum cases and gold-plated integrated circuit containers also has been shown as a viable backup process for present techniques. Alignment schemes for power lasers and positioning techniques accurate to less than $2.5\text{ }\mu\text{m}$ also have been proven.

DISCUSSION

SCOPE AND PURPOSE

The purpose of this project was to identify feasible applications of lasers as manufacturing tools. A technological basis also was established to aid other departments in laser related efforts.

PRIOR WORK

Investigations involving lasers in welding and holographic interferometry at Bendix Kansas City had been started when this project was initiated.

ACTIVITY

The purpose of this project was to develop processes that effectively use laser systems as manufacturing tools and to assist other departments in related development efforts by providing any technological basis required.

The application of laser systems at Bendix Kansas City can be broken into two categories. The first category includes applications where the laser system is used to remove material or physically alter it (Power Applications). Examples are laser welding, drilling, and slicing. The second category includes applications where the laser's optical properties, such as coherence and chromaticity, are more important than its intensity (Optical Applications). Examples are holographic interferometry, precision alignment, and surface inspection.

This report is divided into three sections. The first section provides a basic description of lasers and an explanation of laser operating parameters. This knowledge is essential in comprehending the limits and advantages of laser processing. The second and third sections describe actual power and optical applications resulting from this effort.

Laser Basics

The basic model for a laser consists of a housing which contains the lasing material. The lasing material absorbs energy from the exciting source and reemits it at a different frequency. The majority of lasers used at Bendix can be divided into two categories--gas and solid-state. The gas lasers basically work on the same principle as a neon light. A tube containing the required mixture of gases is fed energy by the current flow between internal electrodes (Figure 1). The main types of gas

Figure 1. Basic Gas Laser System

lasers are carbon dioxide (CO_2), helium-neon (He-Ne) and Argon (Ar). Gas lasers can be operated in a chopped mode (switched on and off rapidly) or continuous. The solid-state lasers use a flashlamp for their exciting source. This flashlamp can take any of several configurations and is operated in a pulsed type mode (Figure 2). The main types of solid-state lasers are neodymium doped yttrium aluminum garnet (Nd-YAG), ruby, and neodymium-glass. They can be operated normally in just a pulsed mode. The difference between a chopped and a pulsed mode is illustrated in Figure 3. In the chopped mode, the laser achieves a preset power level rapidly, stays at that level for a specific time, then

Figure 2. Basic Model for a Solid-State Laser

Figure 3. Comparison Between Chopped and Pulsed Mode of Operation

returns to zero. In the pulsed mode, the laser achieves an initial high peak output. This is a result of the high initial output of the flashlamp as it first fires. The laser output then decays to a level determined by the average output of the flashlamp. When the flashlamp shuts off, the laser output decays to zero.

The light radiated by these lasers has several unique characteristics. It is normally monochromatic and to some degree coherent. There are two types of coherency--temporal and spatial. Temporal coherency implies the output beam does not shift phase (Figure 4). Spatial coherence implies the intensity distribution of the output beam does not shift considerably over distances (Figure 5). These intensity distributions are determined by the lasing material and the type and placement of the internal mirrors. The most common intensity distribution produced by gas lasers is also the simplest. It is a single spot that is defined by the equation

$$I = I_0 e^{-2r^2/w^2} \quad (1)$$

where

I = intensity at a radius r from the axis of the beam,

I_0 = intensity on the axis of the beam, and

W = radius of the beam where the intensity drops to $1/e^2$ of the axis value.

This and other types of intensity distributions are shown in Figure 6 and are described in several references.¹⁻³ The solid-state laser usually has a beam intensity distribution which is a combination of the terms of Equation 1. The energy distribution of a typical solid-state laser beam is illustrated in Figure 7.

Because most of the applications discussed later in this report involve the simple single-mode intensity distribution, a more detailed review is required.

When the laser beam intersects with a material, the response of the surface is directly proportional to the input intensity at any particular point. It is of some value to know the equal intensity zones about the focal point of a converging laser beam.

When the beam is focused, it normally takes on the shape illustrated in Figure 8. This sketch represents the optical definition of focal plane and focal depth. The intensity distribution⁴ of this shape can be determined from the equation

Figure 4. Temporal Coherency (Constant Phase Difference)

Figure 5. Spatial Coherence

Figure 6. Various Types of Laser Beam Intensity Distributions

Figure 7. Typical Solid-State Laser Beam Energy Distribution

Figure 8. Focal Beam Shape

$$W = W_0 \left[1 + \left(\frac{\lambda z}{\pi W_0^2} \right)^2 \right]^{1/2} \quad (2)$$

where

W_0 = radius of the beam at the beam waist or focal point (measured from the beam axis to where the intensity drops to $1/e^2$ of the central value),

z = linear distance from the beam waist,

λ = wavelength of the laser light, and

W = radius of the beam at a distance (z) from the beam waist, (again where the intensity drops to $1/e^2$ of the beam axis value at this z).

Integrating the gaussian equation given previously out to a radius r determines the power $P(r)$ which would pass through an aperture of radius r

$$P(r) = \int_0^r 2\pi r I dr = I_0 (\pi/2) W_0^2 (1 - e^{-2r^2/W_0^2}). \quad (3)$$

If the aperture is set at the beam waist, the equation becomes

$$P(r) = I_0 (\pi/2) W_0^2 (1 - e^{-2r^2/W_0^2}). \quad (4)$$

If the aperture radius r is extended to infinity

$$P(\infty) = I_0 W_0^2 (\pi/2) \quad (5)$$

which is total power that for all practical purposes can normally be measured by a power meter with an aperture of 25.4 mm or larger. If the power meter is offset along the axis of the beam, an amount z , the total power measured must be the same; therefore,

$$I_0 W_0^2 (\pi/2) = P(\infty) = I_{0z} W_z^2 (\pi/2) \quad (6)$$

where

I_{0z} = intensity at the beam axis a distance z from the beam waist,

W_z = radius of beam at z from the beam waist, and consequently

$$I_{0z} = I_0 W_0^2 / W_z^2 \quad (7)$$

For a specific intensity, I therefore equals

$$I = I_{0z} e^{-2r^2/W_z^2} = I_0 \frac{W_0^2}{W_z^2} e^{-2r^2/W_z^2} \quad (8)$$

where from before

$$W_z^2 = (1 + \lambda^2 z^2 / \pi^2 W_0^4) W_0^2 \quad (9)$$

Using Equations 8 and 9, a plot of constant intensity profile was made (Figure 9). An exploded view of these same profiles is shown in Figure 10. In this case, I_0 is assumed to be 1 and W_0 is a constant value that was picked to fit the illustration. As shown in Figures 9 and 10, the profile takes on a slight peanut shape at low relative intensities. This means that if 10 percent of the intensity at the center of beam waist was desired over the largest area possible, then the material should be at the point indicated. These profiles also can be used in an empirical approach to determining the true location of the focal point. First, a pulse width is picked that will effect a homogeneous block of material with one shot. The power level is set and measured at some P_1 . The material is put in place at some unknown position z_1 from the focal point and shot. The radius of the spot on the surface is measured and will be called r_{11} . The

Figure 9. Equal Intensity Profiles

process will be repeated, but with another power level P_2 . This time the radius of the spot on the surface is r_{12} . The material is now moved to another position z_2 along the beam axis so that

$$z_2 = A + z_1 \quad (10)$$

is the distance from the new location to the focal plane. The process is repeated with the same power levels P_1 and P_2 netting new radii r_{21} and r_{22} . Assuming it requires the same intensity for the same period of time to cause the same effect. In all the shots the distance from the new position z_2 to the focal plane can be determined as follows.

First, find the beam diameter at position z_1 from Equations 11, 12, or 13

$$P_1 = I_{o11} W_1^2 (\pi/2) \quad (11)$$

and

$$P_2 = I_{o12} W_1^2 (\pi/2) \quad (12)$$

Figure 10. Exploded View of Equal Intensity Profiles

$$P_1/P_2 = I_{o_{11}}/I_{o_{12}} \quad (13)$$

and since the edge of the spot was produced by the same intensity, I therefore equals

$$I = I_{o_{11}} e^{-2r_{11}^2/W_1^2} = I_{o_{12}} e^{-2r_{12}^2/W_1^2} \quad (14)$$

or

$$I_{o_{11}}/I_{o_{12}} = e^{2(r_{11}^2 - r_{12}^2)/W_1^2} = P_1/P_2. \quad (15)$$

To simplify, let

$$C = W_2^2 W_1^2, \quad (16)$$

$$E = W_2^2 + W_1^2, \text{ and} \quad (17)$$

$$D = \lambda^2 A^2 / \pi^2. \quad (18)$$

Then the above equation becomes

$$W_0^4 (E^2 + 4D - 4C) + W_0^2 (-2DE) + D^2 = 0. \quad (19)$$

And using Laplace's equation

$$W_0^2 = \frac{2DE \pm \sqrt{4D^2 E^2 - 4D^2 (E^2 + 4D - 4C)}}{2(E^2 + 4D - 4C)} \quad (20)$$

which reduces to

$$W_0^2 = D \left(\frac{E \pm 2\sqrt{C-D}}{E^2 + 4D - 4C} \right). \quad (21)$$

Solving for W_1

$$W_1^2 = \frac{2(r_{11}^2 - r_{12}^2)}{\ln(P_1/P_2)} \text{ and} \quad (22)$$

$$W_1 = + \sqrt{\frac{2(r_{11}^2 - r_{12}^2)}{\ln(P_1/P_2)}}. \quad (23)$$

From a similar development, W_2 is found to be

$$W_2 = + \sqrt{\frac{2(r_{21}^2 - r_{22}^2)}{\ln(P_1/P_2)}}. \quad (24)$$

Therefore, knowing W_1 and W_2 , W_0 at the focal point can be determined.

From before,

$$W = W_0 \sqrt{1 + \lambda^2 Z^2 / \pi^2 W_0^4}, \quad (25)$$

which can be solved for Z to arrive at

$$Z = \sqrt{\left(\frac{W_2^2}{W_o^2} - 1\right) \frac{\pi^2 W_o^2}{\lambda^2}} \quad (26)$$

Since the displacement A between z_1 and z_2 is known, this relationship can be used to find W_o

$$z_2 - z_1 = A = \sqrt{\left(\frac{W_2^2}{W_o^2} - 1\right) \frac{\pi^2 W_o^2}{\lambda^2}} - \sqrt{\left(\frac{W_1^2}{W_o^2} - 1\right) \frac{\pi^2 W_o^2}{\lambda^2}} \quad (27)$$

Solving for W_o produces

$$W_o^4 \left[\left(\frac{W_2^2 + W_1^2}{W_o^2} \right)^2 + \frac{4\lambda^2 A^2}{\pi^2} - 4W_2^2 W_1^2 \right] + W_o^2 \left[-2 \left(\frac{W_2^2 W_1^2}{W_o^2} \right) \left(\frac{W_2^2 + W_1^2}{W_o^2} \right) \right] + \frac{\lambda^4 A^4}{\pi^4} = 0. \quad (28)$$

Using this equation to find W_o^2 and the one for z shown earlier,

$$Z = \sqrt{\left(\frac{W_2^2}{W_o^2} - 1\right) \frac{\pi^2 W_o^4}{\lambda^2}} \quad (29)$$

the z offset can be calculated.

If W_2 is greater than W_1 , then position 1 is between the true focal point and position 2.

Data from an actual sample is shown in Table 1. A CO₂ laser whose output wavelength is 10600 nm was used at two power levels, 40 and 20 W. A sample was placed in the focused beam path at two different positions 2.54 mm apart and fired at with both power levels. The results are shown in Table 2; however, since the focal plane determined earlier was 2 mm from position 1, this approach appears to agree within 0.01 mm.

This approach proved more accurate and more repeatable than the common method of using a microscope focused on a desired material position. Each part is then moved until it appears in focus at the same position. With the same operator, the microscope method was found to produce positions off by as much as ± 0.5 mm.

Table 1. Measured Spot Radii

Position	Power (W)	Radius of Spot (mm)
1	40 (P_1)	0.2591 (r_{11})
1	20 (P_2)	0.2375 (r_{12})
2	40	0.2785 (r_{21})
2	20	0.2542 (r_{22})

This empirical method, which is based on spot size, was used consistently in the power applications that were developed.

Power Applications

Probably the best known laser power application is welding. The process involves focusing the laser beam on the joint to be welded long enough to cause flow but not cause evaporation. High power CO₂ gas lasers and Nd-YAG lasers are used for welding at Bendix. In the case of the Nd-YAG laser, the welds are normally either tack or overlapping spot welds. The CO₂ laser, however, is capable of continuous welds in metals such as steel, nickel, and Kovar. An example of an Nd-YAG laser weld is shown in Figure 11. The part is a container for a hybrid integrated circuit. It is made of gold-plated Kovar and the leads exit through glass beads which are hermetically sealed to the case. The lid must be welded in place after the circuit is installed. The seal must be hermetic and mechanically strong. The weld was made with overlapping spots approximately 0.5 mm in diameter. The part was positioned such that the focal plane of the focused laser beam was 0.25 mm below the surface. The laser was pulsed at 200 pps at 250 W average output. The lid of the part was recessed to aid in aligning with the wall. The beam was focused on the top surface of the lid and the wall. The corners were tacked down with the laser previous to the seam weld. Figure 12 shows a photomicrograph of a cross section of a similar weld. The black spot near the bottom was not a void, but an illusion caused by reflection. Another type of weld on the same type part is shown in Figure 13. Here the lid was not recessed and the beam was focused at the lap interface. A photomicrograph of a cross section is shown in Figure 14. No voids are present and leak tests on both types of welds showed them tight to within 133.3 nPa of helium. These welds were performed to show feasibility and provide a backup process to present soldering techniques. Another seam weld made with a Nd-YAG laser is shown

Table 2. Calculated Variables When Offset Between Positions 1 and 2 (A) Is 2.54 mm

Variable	Value
W_1	0.1759 mm
W_2	0.1933 mm
D	7.3448×10^{-2}
E	6.8306×10^{-2}
C	1.1561×10^{-3}
W_0^2	2.9395×10^{-2}
z_1	1.9978 mm
z_2	4.5364 mm
Actual z_1	2.00 mm $\pm$ 0.01 mm

in Figure 15. The lid is 1.63-mm-thick, 6061 aluminum and the box is cast 356A aluminum. The part has been cross-sectioned and a photomicrograph of one of the weld areas is shown in Figure 16. The weld was nonporous and attempts to break the weld by prying the lid invariably broke the casting first. The laser was focused 2.54 mm below the surface and was operated at 15 pps with a pulse length of 6.2 ms. The power was set at an average of 240 W. Other examples of CO₂ laser welding can be found in the References 1 and 2.

Power lasers probably have even a greater application in drilling or slicing material. Figure 17 shows an example of CO₂ laser drilling. The hole is about 0.5 mm in diameter through 0.58-mm-thick fired ceramic. The tooling arrangement for this process is shown in Figure 18. The part is mounted on a small vacuum box and the laser is focused from above. The air flow from the room through the hole as it is being drilled forces the vaporized ceramic and molten material into the box and out of the beam path. To assist in definition of the hole edges, a rough copper mask is placed over the ceramic to prevent the beam from striking in the wrong place. The copper mask scatters the beam by reflection. The copper is rough so that the reflected light is no longer coherent and greatly reduced in intensity. For holes larger than can be drilled by a single focused spot, the part is mounted on a rotary table with the laser spot tracing the perimeter of the hole. Holes up to 25 mm in diameter have been made this way with no subsequent cracking of the ceramic.

Figure 11. Nd-YAG Laser Weld of Recessed Lid to a Hybrid Integrated Circuit Container.

Figure 12. Cross Section of Laser Weld of a Recessed Lid to a Hybrid Integrated Circuit Container

Figure 13. Nd-YAG Laser Weld of a Full Lid to a Hybrid Integrated Circuit Container

Figure 14. Cross Section of Laser Weld of a Full Lid to a Hybrid Integrated Circuit Container

Figure 15. Nd-YAG Laser Weld of Cast Aluminum Container (356A) to 6061 T6 Aluminum Lid

One of the techniques to laser processing is to keep the plume of vaporized and molten material from blocking the beam. This becomes a major consideration during laser slicing of materials like quartz. Because quartz is a very difficult material to slice, the normal method is to use a diamond saw. A laser method was developed and the setup is shown in Figure 19. The material is fed through the beam in the direction of the air flow. The air flow moves the material plume from the cutting area. In Figure 20 are three views that illustrate the difference focal point placement makes in cutting depth. These views are photographs of the edge of a 6.35-mm-thick quartz plate that was fed into the beam. In view 1, the laser was focused at the surface; in view 2, 1.57 mm below the surface; and in view 3, 3.18 mm below the surface. The focal position used in view 2 is preferred because it provides a deeper cut and less taper and kerf. The rounded area bordering the cut is a fused region of optically clear quartz caused by the heating action of the laser. This fused area has some residual stresses which become visible

WELD
AREA

20X

Figure 16. Cross Section of Laser Welded Container

under polarized light inspection (Figure 21). This stress, in many cases, must be removed with the annealing cycle shown in Figure 22. Without this annealing, the samples will, in time, relieve the stress through gradual relaxation, or in some cases by cracking. Figure 23 illustrates the cutting spreads that were determined for two CO₂ lasers. In particular, test results showed that a 1 kW laser could slice a 6.4-mm-thick quartz sheet at 6.4 mm/s.

During the determination of material slicing parameters, techniques for "single point" milling also were investigated. In this application, the laser optics were as shown in Figure 24. The axis of the output lens is offset from the beam axis. The beam is still focused through to the axis of the lens. The lens is then mechanically rotated about the beam axis. This causes the focal spot to transcribe a circle. If the material is not moved, a hole with a radius equal to the lens offset is cut. If the material is fed through the focal plane, a slot is formed much like that produced by a single point mill (Figure 25). The difference in this case is the mill depth is not just a function

of the focal plane of mill point, but is a direct function of how much energy a particular point on the surface receives by multiple crossovers of the focal spot and slow movement of the material. For example, if the laser output is constant, the focal plane is held constant, and the material feed rate is held constant, the edges of the mill slot receive more energy than the middle. This effect and the effect on the shape of the mill slot bottom are illustrated in Figure 26. This effect can be controlled by modulating the laser output power or selective masking.

The principles discussed above for quartz machining are applicable to most dielectrics. They use processes similar to those developed for cable and wire stripping and flexible cable contouring.⁵⁻⁷ One application of these processes calls for the stripping of a polythermalize insulation from each wire of a

90-conductor wire tape. Mechanical and chemical stripping techniques were undesirable because they can nick and weaken the wire and leave unwanted contaminations. Figure 27 shows 33-AWG copper wire tape scanned at 15.24 cm/s with a 0.152-mm-diameter focal spot and 50 W continuous power output from a CO₂ laser. The wires are tied together in a flat tape and are scanned twice, once on each side of the tape. Because the copper almost totally reflects the beam, no mechanical damage is incurred by the wire. The insulation is directly vaporized, leaving only ash that can be rinsed off leaving no contamination.

An example of cable contouring and stripping is shown in Figure 28. The edges indicated were trimmed with the same 50-W CO₂ laser that stripped the area indicated. A further example of the laser's selectiveness is shown in Figure 29. The part is a minitransformer board of photoetched copper circuit leads (0.07-mm-thick) laminated with 0.025-mm-thick Kapton, 0.038-mm-thick adhesive, and 0.127-mm-thick Kapton backing. The laser is used to vaporize the L-shaped cuts shown without blowing off the copper leads. These L-shaped cuts facilitate mounting of the small transformer leads. The laser scanned the part at 15.24 cm/s and 50 W power.

64X

ENTRANCE

64X

EXIT

Figure 17. CO₂ Laser Drilled Holes
Through 0.584-mm-Thick
Fired Ceramic

Figure 18. Tooling Arrangement for Laser Drilling Holes Through Ceramic

Many other examples exist that use the same basic principles illustrated by these examples. In fact, power applications of laser processes have become a common consideration in present manufacturing operations.

Technical Support of Power Applications

This project supplied technical support in the Power Applications area to other laser related activities. These included Kevlar machining, cable connector welding, and laser safety.⁸

Optical Applications

Lasers tuned for optical applications approach the ideal conception of a light source. Their output is usually monochromatic to a high degree and with a divergence (beam spread) measured in milliradians. The main variety used at Bendix are gas lasers, which use He-Ne as the laser medium. This type of laser has an intense red beam. One of the earliest applications for this

Figure 19. CO₂ Laser Setup for Slicing Quartz

laser was in the alignment and beam locating for infrared power lasers like the Nd-YAG and the CO₂. In the case of the Nd-YAG laser, the He-Ne is mounted as shown in Figure 30. The frequency of the He-Ne beam is high enough to pass freely through the special dielectric mirrors and crystal rod and is focused by the same optics. The focused He-Ne spot coincides within a few micrometers of where the invisible focal spot of the Nd-YAG will strike. This slight difference is caused by the dependence of the index of refraction of some optics to the frequency of the light being focused. This type of laser also is used to align the mirrors of a CO₂ laser. The mirrors are removed from the CO₂ laser and replaced with an aperture a little larger than the He-Ne beam diameter in one end and a tube with a translucent white screen over the opening at the other end. The He-Ne laser is positioned to shine through the aperture and strike the screen in center. The screen is removed and replaced with a mirror. The mirror is adjusted until the He-Ne light is reflected back on itself. This condition is determined using the setup shown in Figure 31. The laser beam travels through the beam splitter with approximately 50 percent of it split off to the first detector. The beam then propagates to the mirror and is reflected back along its original path. When the beam reenters the beam splitter, it again divides with approximately 25 percent of the original beam going to the second detector. The detector signals

Figure 20. CO₂ Laser Slicing Profile in a 6.35-mm-Thick Quartz Plate With the Focal Plane of the Beam

Figure 21. Polarized Light Scattered by Stressed Areas in Laser Sliced Quartz

Figure 22. Annealing Cycle for Quartz Stressed From Laser Processing

Figure 23. Quartz Slicing Speeds With a CO₂ Laser as a Function of Material Thickness and Laser Power

are then electronically divided. This is performed to eliminate the effects of power fluctuations in the laser. The mirror is then adjusted until the ratio of detector signal two to detector signal one is as close to 1 to 2 as possible. The He-Ne system is then removed and the second mirror is reinstalled. The CO₂ laser tube is refilled with gas and final adjustments are made on the second or rear mirror to optimize the power output from the first.

Figure 24. Diagram of Laser Optics
for Milling of Quartz

This same approach was used in an optical tachometer for measuring the speed of rotation of very small drill bits. A lens was added to the beam splitter to focus the laser light to a spot on the drill shaft. A thin line of reflective silver paint was painted on the drill shaft. The amount of laser light reflected from the drill shaft was greatly increased whenever the silver line revolved through the focal spot. This burst of light produced a pulse in the output of the detector. This pulse was fed to a frequency counter which recorded directly drill bit revolutions per second.

A setup very similar to this was used to align curved parts before drilling. The equipment consisted of a helium-neon laser whose beam passes through a biconvex lens. The part was positioned such that the focused laser beam was reflected from its surface back through the lens. The beam returning through the lens was deflected by a beam splitter to a photodiode detector. The detector used is sensitive to the position of the laser spot on its surface. This spot generated a current flow between a ground connection and two electrical contacts on the surface at opposing edges of the detector. The amount of current flowing

Figure 25. Mill Slot in Quartz Produced by Rotating Laser Spot

DEEPER CUTS RESULT FROM
THE HIGHER PERCENTAGE
OVERLAP OF THE LASER SPOT,
NOT THE SLOT EDGES.

Figure 26. Expected Profile of Laser Mill Slot in Quartz
When Laser Power Held Constant

Figure 27. Multiconductor Wire (33 AWG) Tape
With Insulation Vaporized by CO₂
Laser Stripping Process

through each of the contacts was proportional to the focused spot position with respect to the contacts and the power of the incident light. With the spot between the two contacts, the difference between the currents divided by the sum gave a ratio solely dependent on the position of the spot and independent of laser power fluctuations. A current-to-voltage converter circuit was used to convert the respective difference and sum of the currents into voltages. A ratio meter was then used to display the ratio of the two voltages. An optical system of this type is called a thick mirror, and the positions of the lens, part, and the detector were determined by standard power equations. This system was capable of a positional repeatability of 2.5 μm for highly reflective curved parts.

In some applications, the ease of controlling the laser beam also proved to be a major advantage. For example, one such application was used to inspect thin metal-Kapton laminate for pinholes. The previous method was to try to hold the part to a bright light and try to manually count the pinpoints of light that shined through. The laser process used the equipment arrangement shown in Figure 32. The laser beam first struck a front surface mirror

MATERIAL
LASER STRIPPED
FROM COPPER
CONTACT

EDGE OF CONTOUR

2X

Figure 28. Example of Cable Contouring With 50-W, CO₂ Laser

mounted on the shaft on an oscillating servo. The servo was driven by a sine wave signal generator at about 100 Hz and a deflection of about 15°. The reflected beam from the first mirror struck a second mounted also on a similar type servo. This second servo was driven to about the same deflection but at a frequency of 0.1 Hz. The part was positioned directly over a photographic plate and in the path of the raster scanning of the laser. The light from the laser exposed the photoplate right under a pinhole. The advantage of the laser to a conventional light source is that the pinhole image produced was much more defined and more directly proportional to the actual pinhole size. The photoplate, once developed, provided a permanent record of the number, approximate size, and location of the pinholes. They could be counted manually or with digitizer available on the Bendix computer system. They could also be compared with photos of other parts and possible trends could be identified.

Technical Support of Optical Applications

This project supplied technical support in the Optical Applications area to other laser related activities. These included laser safety, holographic interferometry, and precision surface inspection.

Figure 29. L-Cuts in Minitransformer Board Made by CO₂ Laser Without Blowing Off Copper Leads

Figure 30. He-Ne Laser Alignment Arrangement for Nd-YAG Laser System

Figure 31. He-Ne Alignment Setup for CO₂ Laser

ACCOMPLISHMENTS

Specific processes that effectively use laser systems as manufacturing tools to weld, drill, cut, and inspect have been developed. These applications have demonstrated the basic considerations essential to a quick development of a laser process. They also illustrate how some lasers can be used to weld hardened metals and others can be used to inspect surface irregularities.

FUTURE WORK

Recommendations for future work in power applications include the modulating of a CO₂ laser output during a milling operation setup to control the shape of the mill slot cross section. New lasers, such as chemical and dye based systems, also should be included in future power or optical laser process evaluations.

In optical applications, the effect of lasers on alignment and inspection techniques is rapidly increasing and should be followed. The application of ultraviolet lasers also should be considered for precision light sources in photoresist exposure applications.

Figure 32. System for Laser Scanning Thin Metal-Kapton Laminate Parts for Pinholes

such as chemical and dye based systems, also should be included in future power or optical laser process evaluations.

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LASER APPLICATIONS, R. T. Horn, Final, July 1980.

Processes were developed that use lasers as manufacturing tools. These processes were stripping of insulation from cables and wires, machining of quartz, microdrilling and welding of reflective metals, and precision alignment of curved surfaces before machining. A technological basis also was formed which resulted in a process for automatic surface inspection of parts and aided development of machining processes for Kevlar parts.

SPECIAL PROJECTS: Laser Applications

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