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BDX-613-820 (Rev.)

LASER REMOVAL OF DIELECTRIC
FROM FLAT CABLES

PDO 6984790, Topical Report

R. T. Horn, Project Leader

Project Team:
W. C. Rutherford

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**Kansas City
Division**

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LASER REMOVAL OF DIELECTRIC FROM FLAT CABLES

BDX-613-820 (Rev.), UNCLASSIFIED Topical Report, Published April 1974

Prepared by R. T. Horn, D/812, under PDO 6984790

Use of a carbon dioxide laser for removing dielectric from flat flexible cables was investigated. Material reaction to pulsed and continuous laser modes of operation was analyzed. Microscopic examinations and electrical continuity inspections were used to evaluate results.

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THE BENDIX CORPORATION

KANSAS CITY DIVISION

KANSAS CITY, MISSOURI

A prime contractor for the
Atomic Energy Commission
Contract Number AT(29-1)-613 USAEC

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SUMMARY

Removing dielectric material from flat cables with a carbon dioxide laser was investigated. This application was successful on similar parts processed by laser vendors.

Four types of cable sections were processed: three thicknesses of copper electrodeposited on 0.002-inch-thick (0.005 cm) Kapton, and 0.0029-inch-thick (0.0073 cm) aluminum chemically bonded to 0.002-inch-thick Kapton. A rectangle 0.255 inch wide (0.648 cm) and 0.420 inch long (1.067 cm), located at one end of each cable section, was exposed to laser scanning. The laser beam was focused to a 0.005-inch-diameter (0.013 cm) spot at the dielectric surface. To determine optimum scan speeds and laser power levels, material reaction to single-shot pulses of known pulse length and the calculated peak power levels was analyzed. Those values which gave the desired dielectric removal were used to extrapolate power levels required for various scan speeds. For the majority of the sections processed, the laser was operated in the continuous wave (CW) output mode at an average power of 27 watts, and the part was scanned at a speed of 9.4 in./sec (23.9 cm/sec). The basic process utilized one axis of a numerically controlled (NC) X-Y table and a rotating drum on which the part was mounted. The drum was rotated at an equivalent linear speed of 9.4 in./sec, and was indexed through the focused spot 0.002 in./revolution. Average time to strip one panel containing eight cable sections was 300 seconds, or less than 40 seconds per section.

Microscopic inspections and electrical continuity examinations were performed on each cable section. Microscopic inspection immediately after processing revealed a black char on the surface of the metallic substrate. An alcohol-soaked cotton swab applied gently to the area removed this char and exposed any unaffected Kapton residue. Electrical continuity between randomly-selected points in the exposed area was used to indicate if any thin transparent film of material remained. No Kapton residue was detectable on panels processed by the methods covered in this report.

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DISCUSSION

The purpose of this work was to develop a dielectric removal process applicable to flat cable fabrication as an alternative to chemical or mechanical removal methods. This activity involved the removal of dielectric from flat surfaces using a carbon dioxide laser as a heat source. Parameters such as scan speed, laser power level, and effective focused spot size were to be optimized to achieve these results.

Concurrent studies on curved surfaces and insulation removal on multiconductor flat wire tapes are in progress. These will be covered separately in later reports.

PRIOR WORK

The investigation of carbon dioxide lasers for dielectric removal began at Bendix some time ago. Information acquired from a literature search* indicated that the carbon dioxide laser output wavelength of light ($10.6\text{ }\mu\text{m}$) would be readily absorbed by various dielectrics and would be almost totally reflected from metals. Given enough laser energy at this frequency, it was expected that a dielectric could be vaporized from a metallic substrate, leaving the substrate undamaged. Various samples of metal-dielectric laminates processed at laser vendors supported this theory.

Some time ago, work began at Bendix Kansas City Division on in-house dielectric removal studies. Initial dielectric samples were passed manually through the focused spot of laser light to determine approximate power ranges for processing. The laser system was subsequently interfaced with a numerically controlled X-Y table, and samples were processed with precision and repeatability.

*R. D. Hann, Jr., and others, "The Applications of Lasers to Industry," in IEEE Transactions on Industry and General Applications. Volume IGA-4, Number 4, July-August, 1968.

ACTIVITY

Equipment

A carbon dioxide laser was used to remove dielectric from panels of eight cable sections (Figure 1). The energy of the focused laser beam was used to vaporize the dielectric and expose the metal substrate. The amount of energy delivered to the work area was to be enough to vaporize the dielectric in one pass without causing discoloration or deformation of the metal substrate.

Figure 1. Flat Panel Containing Eight Cable Sections

Four types of cable sections were processed: copper in thicknesses of 0.0028 in. (0.0071 cm), 0.0007 in. (0.0018 cm), and 0.00035 in. (0.00089 cm) electrodeposited on 0.002-inch-thick (0.005 cm) Kapton; and 0.0029-inch-thick (0.0073 cm) aluminum chemically bonded to 0.002-inch-thick Kapton. A rectangle 0.255 inch wide by 0.420 inch long (0.648 by 1.067 cm), located at one end of each cable section (Figure 1), was exposed to laser scanning.

Each panel was mounted on the aluminum cylinder and rotated through the focused laser beam. For each revolution of the cylinder, a microswitch was tripped, causing the numerical control table to move the cylinder assembly a specified amount parallel to the rotational axis. A metallic ring was used to mask areas on the cable which were not to be exposed. The laser beam

emerged from the laser cavity and was reflected to the focusing lenses with a gold mirror (Figure 2). The lens assembly focused the beam on the top side of the cylinder.

Figure 2. Carbon Dioxide Laser System With Cable Panel Mounted

Power Level Determinations

No information was available on the mechanics of the dielectric removal process by laser energy; therefore, the determinations of laser power levels that efficiently removed the Kapton were based on empirical results. These were determined by analyzing the effects on unused panel areas of single-shot laser pulses of known length and calculated peak power levels.

Several physical assumptions formed the basis of this analysis. The first was that a laser pulse length of t seconds would result in the same amount of

energy being absorbed by the Kapton and metal substrate in one spot as that absorbed by the same spot when it takes t seconds to move across the focal spot. Therefore, the same effects are achieved firing the laser in single shots with the cylinder fixed as running the laser continuously and rotating the cylinder. The second assumption was that a focal spot of diameter d with successive scans X distance apart must allow enough scan overlap to compensate for irregularities in Kapton thickness. If the Kapton is thicker, more laser exposure would be required for complete removal. Three variables also were considered: the pulse length (t), the diameter of the spot of metal exposed by the shot (d), and the peak power level of the pulse (P). The variable motor drive and cylinder assembly are capable of an effective maximum linear speed at the surface of a mounted panel of 9.4 in./sec (23.9 cm/sec). The pulse length should therefore be the time it would take to travel across a focused spot of diameter d , or

$$\frac{d}{9.4 \text{ in./sec}} = t \text{ sec.} \quad (1)$$

Through experimentation, it was determined that the maximum diameter spot of metal that could be cleanly exposed was 0.005 inch (0.013 cm). Substituting 0.005 inch for d in Equation 1 yields

$$\frac{0.005 \text{ in.}}{9.4 \text{ in./sec}} = 0.0005 \text{ sec pulse length.}$$

The remaining variable (P , or peak power level) can now be determined by trial and error. With the lens assembly focused on an unused part of the panel, the laser was fired in single-shot pulses of 0.0005 sec pulse length. The shots were spaced 0.030 inch (0.076 cm) apart on the panel and were of increasing amounts of power (Figure 3). After a power level was reached that cleanly exposed a 0.005-inch-diameter spot of metal substrate, a power meter was inserted between the beam bender and focusing lens. The power meter averaged the amount of energy delivered to it in 1 sec. The laser was fired at a pulse rate of 200 pulses per sec with the same power settings and pulse length as before because the meter is not fast enough to register the power in a single pulse. The peak power of the individual pulses could then be calculated from this average power (AP), using Equation 2.

$$\frac{AP}{200} \frac{1}{t} = P \quad (2)$$

Figure 3. Single-Shot Pulses at 50X (Dielectric: 0.0002-Inch-Thick (0.0005 cm) Kapton on 0.0028-Inch-Thick (0.0071 cm) Metal Substrate)

The first term in Equation 2 gives the energy delivered in each pulse; to find the peak power (P) of the pulse, this value must be divided by the pulse length (t). The result is the rate of transfer of energy during the pulse or the peak power. Theoretically, this is the power output level that the laser should maintain continuously during processing.

The calculated power levels for the four types of cables were 25 watts (0.0028 inch-thick copper), 22.5 watts (0.0007-inch-thick copper), 18 watts (0.00035-inch-thick copper) and 23 watts (0.0028-inch-thick aluminum). With the laser operating at the predicted power level, rotating the panel through the beam should produce a 0.005-inch-wide path of exposed metal. The parameters determined thus far do not allow for variations in the cylinder rotational speed or irregularities in Kapton thickness. Increasing the power level enough to provide for these situations dumps too much energy into one area in too short a time and causes discoloration of the metal (Figure 4). It was found that

Figure 4. Copper Discoloration From Exposure to a High Energy Laser Pulse

scanning the same path more than once allows the metal substrate to cool enough between scans to prevent discoloration. Therefore, the distance between scans (X) was determined to provide optimum scan overlap and still process the part in a minimum amount of time. (This determination was based on the NC table positional limitation of steps of 0.001 inch (0.0025 cm).) If, as in Figure 5, two 0.005-inch-wide paths are separated by 0.001 inch, then 80 percent overlap occurs between successive scans and every point would be scanned five times. If the distance X is increased to 0.002 inch, the paths overlap 60 percent, and there are alternating bands which are scanned twice or three times. If the distance X is increased to 0.003 inch, the paths overlap 40 percent, and bands 0.001 inch wide are scanned once and alternate with bands 0.002 inch wide which are scanned twice. It is evident that the maximum value for X which ensures that every point is scanned twice is 0.002 inch.

Process Results

The panels were mounted on the tooling and the steel masking ring was positioned so that the eight uncovered areas were on unused parts of the panel. The laser was fired at the calculated power level while the cylinder was

0.001 IN. (0.0025 cm) OFFSET

↓ DIRECTION OF SCAN

→
FROM HERE ON
EVERY POINT IS SCANNED
5 TIMES

0.002 IN. (0.005 cm) OFFSET

2 3 2 3

EVERY OTHER POINT
SCANNED TWICE, OTHERS
SCANNED THREE TIMES

0.003 IN. (0.008 cm) OFFSET

1 2 1 2

ALTERNATING AREAS OF
1 SCAN (0.001 IN. WIDE) AND
2 SCANS (0.002 IN. WIDE)

Figure 5. Overlap Scan Offsets

rotating at 9.4 in./sec. In all cases, the power had to be increased to remove the Kapton efficiently. The final values for the four types of cables (Table 1) were 27 watts (0.0028-inch-thick copper), 24 watts (0.007-inch-thick copper), 20 watts (0.00035-inch-thick copper) and 27 watts (0.0028-inch-thick aluminum). When the laser was operated 5 watts below these levels, insufficient vaporization of the Kapton occurred and a heavy black char formed on the metal surface (Figure 6). When the laser was operated at 5 watts above these levels, discoloration occurred similar to that shown in Figure 4. The highest quantity of char was produced when processing the aluminum panels bonded to Kapton with a 95 percent nylon, 5 percent epoxy adhesive. It is believed that this adhesive contributed to the greater amount of char present.

Figure 6. Copper Cable, 0.0028 Inch Thick (0.0071 cm),
Scanned at 5 Watts Below Optimum Power, 7.5X

Process Inspection

All cables had to be cleaned of char with an alcohol wash after processing. Microscopic inspections and electrical continuity examinations were used to evaluate process results. When cables were processed at the values shown in Table 1, no dielectric could be detected in the exposed area at 100X

Table 1. Powers Predicted and Used For Dielectric Removal

Cable Section	Single-Shot Pulse Length (sec)	Avg Power For 200 Pulses (watts)	Calculated Peak Power Level (watts)	Empirically Determined Power Level (watts)	Deviation Of Emperical From Calculated Power Level (percent)
0.0028-inch-thick (0.0071 cm) copper on 0.002-inch-thick (0.005 cm) Kapton	0.0005	2.5	23.5	27	8
0.0007-inch-thick (0.0018 cm) copper on 0.002-inch-thick Kapton	0.0005	2.25	21.1	24	6.67
0.00035-inch-thick (0.00089 cm) copper on 0.002-inch-thick Kapton	0.0005	1.8	17	20	11
0.0028-inch-thick aluminum on 0.002- inch-thick Kapton	0.0005	2.3	21.6	27	17.4

magnification, and the conductivity between randomly selected points on the surface was that of the base metal.

ACCOMPLISHMENTS

A process for using a carbon dioxide laser to remove dielectric from flexible flat cables has been developed. Test results show the metallic surfaces exposed are clean of dielectric residue and exhibit conductivities between randomly selected points to be the same as the base metal.

The time required to process cables was less than 40 seconds per cable, or 5 minutes for a panel of eight cables, as compared to the 45 minutes required in studies on chemical and mechanical dielectric removal. A method was also developed for determining optimum scan speeds and power levels utilizing single-shot pulses.

FUTURE WORK

Efforts are continuing in developing dielectric removal process for cables of different configurations. Should there arise a need for large scale production of these or similarly designed parts, this development work can be used as a basis to develop the required manufacturing production processes.