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LASER WELDING OF ELECTRICAL INTERCONNECTIONS

By F. R. Bauer

Published December 1978

Topical Report
D. E. Stittsworth, Project Leader

Prepared for the United States Department of Energy
Under Contract Number DE-AC04-76-DP00613.

Bendix **Kansas City Division**

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Processes and equipment have been developed for welding thin aluminum and copper foils using a Nd:YAG laser. Laser welding provides an alternate technique with improved quality for welding these types of electrical terminations.

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SUMMARY

Laser welding consists of high intensity monochromatic light focused on metals to melt and fuse the materials. It is a preferred method for joining thin metal foils. Light energy, and therefore heat densities, can be accurately controlled through the input electrical characteristics and the optical system. The weld components are completely isolated from the welder since there is no physical contact with any electrodes as in ultrasonic welding. In addition, there is no need to complete any electrical circuit as in resistance or pulse arc welding.

A 70 W rated, single pulse, Nd:YAG laser was used to develop a method of welding 0.051-mm-thick aluminum foil backed with Kapton to an aluminum crimp sleeve (0.254-mm wall thickness) for electrical interconnections. Appropriate tooling, fixturing, and other process developments have resulted in a production process.

Seam welding copper foils requires a laser with higher power and automatic, rapid pulse rates. Welding a 0.038-mm copper element to a 0.203-mm Kapton-backed copper foil has been done using a higher powered YAG laser on a preliminary basis. The machine was rated at 400 W average power with a maximum pulse rate of 200 pulses/second. At this rate, a series of spot welds can be overlapped to form a continuous weld.

The problems encountered in welding aluminum connections were "blowouts" and stress cracking. Improper energy focused on the part caused the weld joint to explode and leave a hole known as a blowout. Stress cracking is a metallurgical condition occurring when a weld separates because of excessive heat and stresses in the material. Proper adjustments to electrical and optical systems, tooling, equilization of component thicknesses, and stress reliefs were the primary solutions to these problems.

DISCUSSION

SCOPE AND PURPOSE

Laser welding was investigated as an alternative to resistance, pulse arc,[1] and ultrasonic welding[2] for joining thin aluminum or copper foils. Initial development work was done with pulsed YAG lasers. Although the unit available proved capable of spot welds, a higher power, rapid pulse rate laser was needed to develop seam welding capability of copper foils. Work with this type equipment has been done only at a laser vendor's site.

PRIOR WORK

A literature search was conducted for all pertinent information related to laser welding of electrical terminations. Some initial Bendix Kansas City development work was done with laser systems at Mound Facility and Los Alamos Scientific Laboratory.

ACTIVITY

The Nd:YAG laser (neodymium doped yttrium aluminum garnet) emits coherent light radiation at the wavelength of 1.064 μm. The raw beam is expanded and refocused for the correct spot size for welding. This spot size can be varied with adjustments to the optical system and the use of beam attenuators and aperture control.

Figure 1 shows the optical system of a YAG laser. The aperture control allows only a certain central portion of the beam to pass while the attenuator blocks the light in a grid type pattern. This controls the energy density as well as the overall size of the beam. In thin foil welding, this is an important aspect of control.

Once a correct spot size has been chosen for the welding application, a corresponding energy and pulse length must be determined. For thin foil welding, pulse lengths are set for the longest possible duration to avoid blowouts or burning away the foil. A typical 7.5 ms pulse is shown in the lower portion of Figure 2. The output pulse of the laser is shown in an inverted mode, along with the input pulse to the flashlamp. The photograph was taken with the use of a photodetector diode and oscilloscope. The initial pulse spike will break down the reflectivity of the metal, and the remaining pulse length will cause the metals to

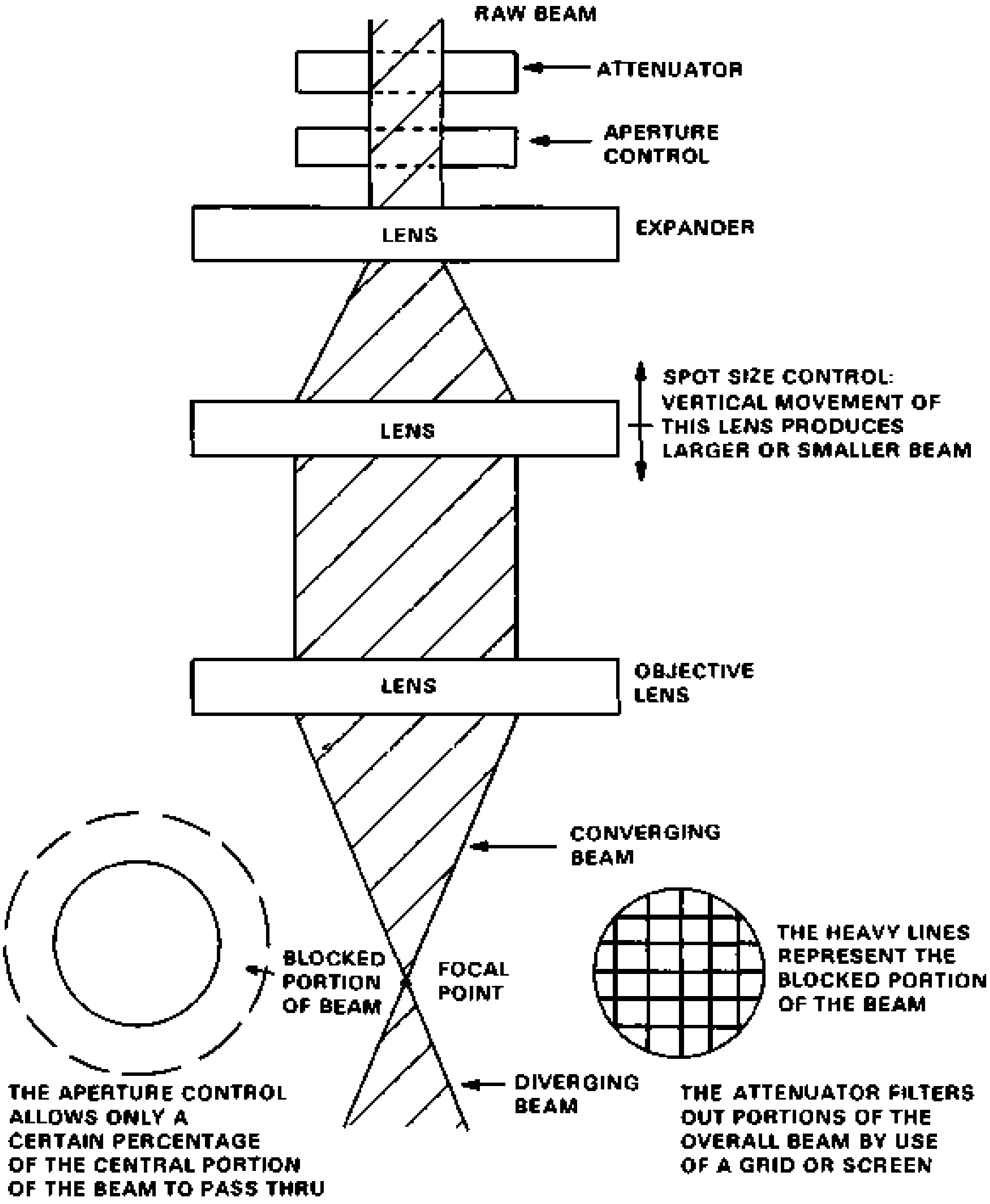


Figure 1. Laser Optical System

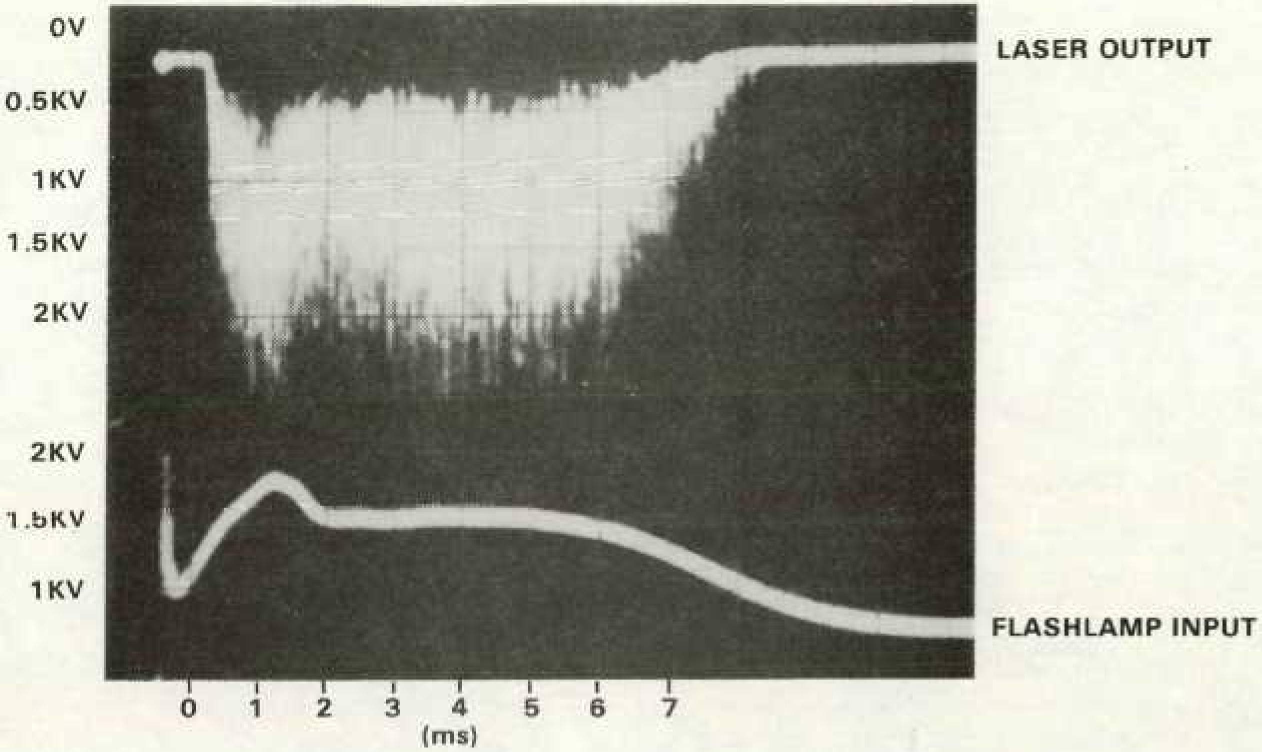


Figure 2. Welding Pulse

melt and flow together. Should the weldments be non-reflective, as is the case with severely oxidized metals, a much lower initial spike is needed. Energy, in the form of lamp input voltage, controls the height of this spike and the overall average power applied to the metals.

Since there is no physical contact between the welder and the metals, inherent electrical resistance of the materials is not a factor in this process. Reflectivity, the variable in this case, can be controlled through different surface finishes and treatments. For thin aluminum foils, a highly reflective surface resulted in the best welds. Parts that had been vapor blasted to dull the finish had a higher rate of unacceptable welds. In contrast, the copper foils welded required more heat and subsequently less reflectivity. Preliminary studies have shown that a dull finish on the copper gives the best results.

In laser welding, heat affected zones and thermal damage to adjacent materials are minimized. Heat conductivity in the weld zone can therefore be accurately controlled. Adhesives, polyimide backings, or other components would not be severely affected by welding in the vicinity of these materials. This is important for Kapton-backed flat cables that would be hipot tested for possible breakdown at extremely high voltages.

Equipment

After comparative attempts with CO_2 and YAG lasers and because of its shorter wavelength and increased efficiency in metal welding, the YAG laser was chosen as the most suitable to perform thin metal foil welding. Weld samples were sent to several vendors, and welding was attempted using a CO_2 laser at Bendix. Best results were obtained using a low power YAG laser welder with an energy output rating of 15 J at a maximum rate of 1 pulse/second. Figure 3 shows the system installed in its present production location. After installation in an engineering laboratory and some minor modifications to the unit's electronic controls, process development work was begun on welding aluminum flat cables.

Aluminum Foil Welding

For the aluminum flat cable application, an 0.254-mm wall thickness crimp sleeve is spot welded to an 0.051-mm-thick aluminum foil conductor (Figure 4). Important criteria for this type of thin foil welding is intimate contact of the surfaces and equilization of the mass and size of the two materials to be joined. Tooling and fixturing designs are based on these requirements.

The crimp pliers (Figure 5) are used to provide the intimate contact required. After the crimp sleeve is slipped over the tab, it is tightly crimped in place. In addition, another smaller crimp (Figure 6) is made with the "dimple crimp" pliers (Figure 7) to further equalize the thicknesses of the two foils to be welded.

A 30 degree tilt fixture and a three-axis controlled table are used to position the part for obtaining proper weld energy and orientation with respect to the beam (Figures 8 and 9). The 30 degree angle was determined a practical compromise between a 45 degree tilt, which was inconvenient for handling parts, and a 20 degree tilt, which was not a large enough angle to avoid blowouts. As in the illustration in Figure 10, the beam is fired incident to the edge of the material joint. By focusing more energy on the crimp sleeve, the thicker aluminum melts and flows onto the simultaneously heated thinner aluminum. The height of the part, as controlled by a Z-axis (vertical axis) movement, corresponds directly to the amount of energy applied. As the part moves toward the focal point, a hotter and smaller beam is encountered; as the part moves away from the focal point, a cooler and larger beam is encountered.

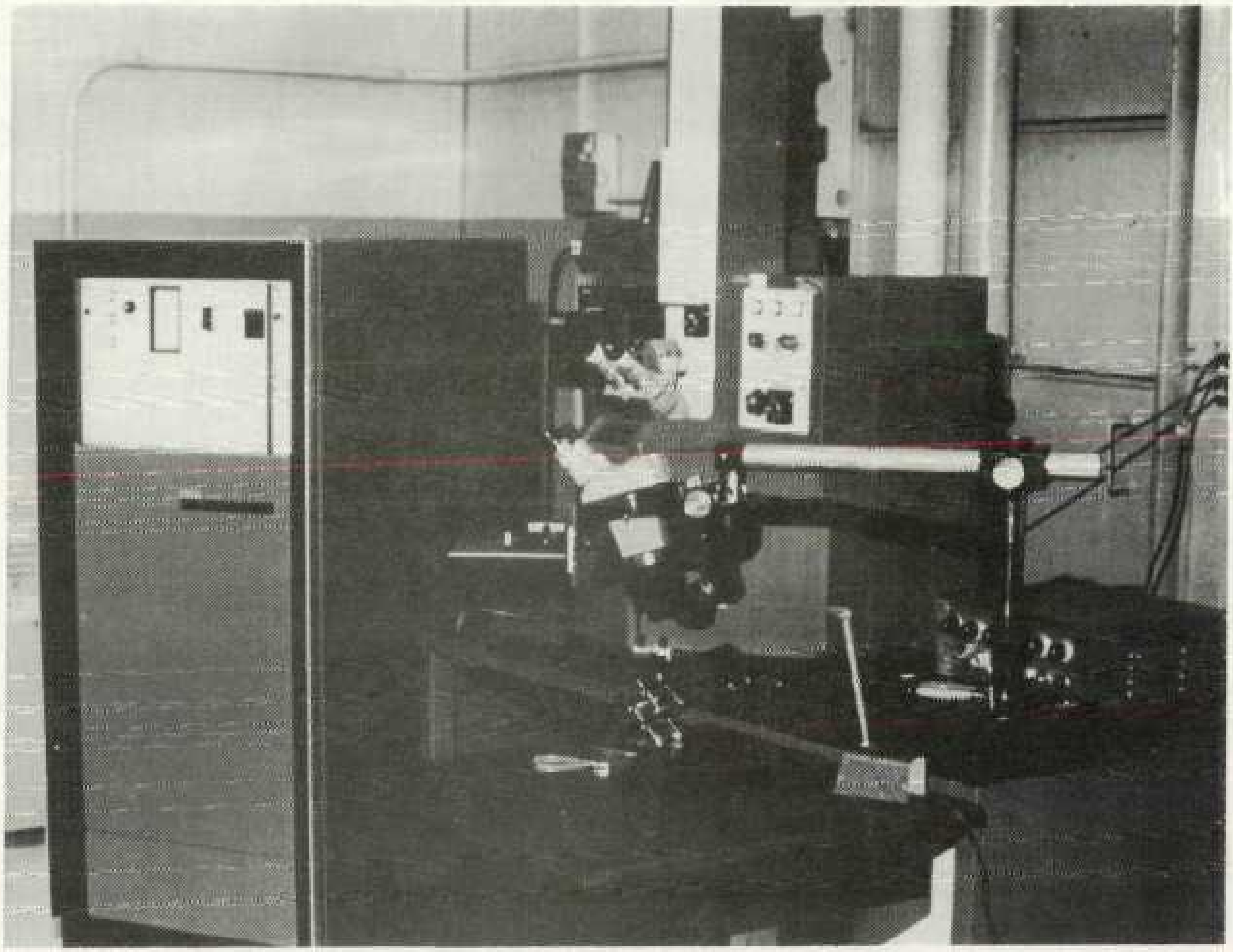


Figure 3. YAG Laser

Quality welds can also be achieved using a diverging beam as compared to a converging beam (Figure 10). In instances where thin foils are concerned, the frequency of blowing holes in the material may depend upon the use of a converging or diverging beam. The aluminum foils appear less susceptible to blowouts when a diverging beam is used.

Aluminum Wire Welding

A less critical aluminum welding application is shown in Figure 11. A 22 AWG wire is inserted through the hole of the connector shell (6061-T6 aluminum), cut 0.254 mm above the surface, and

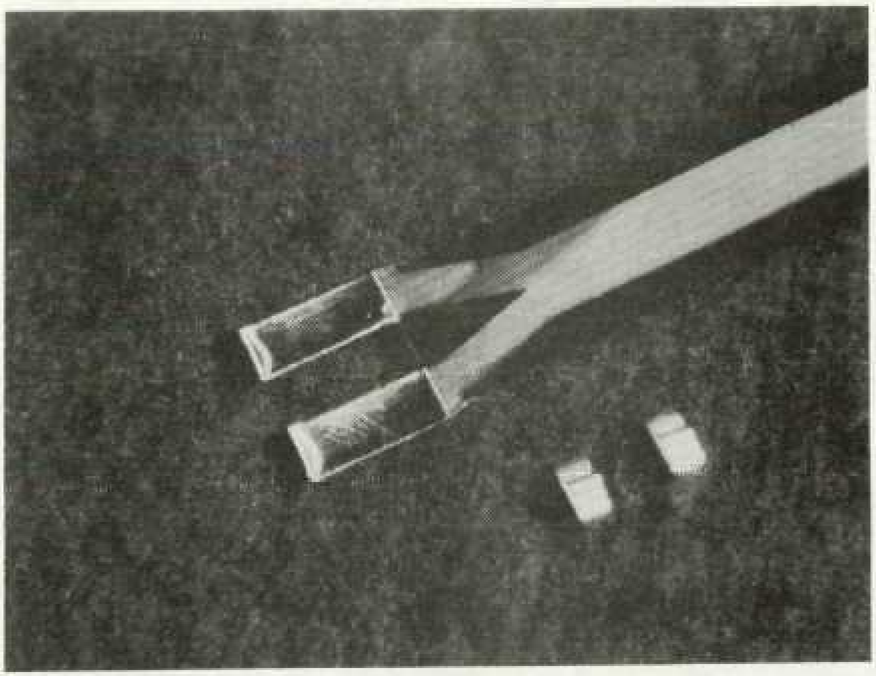


Figure 4. Crimp Sleeves and Cable Tab

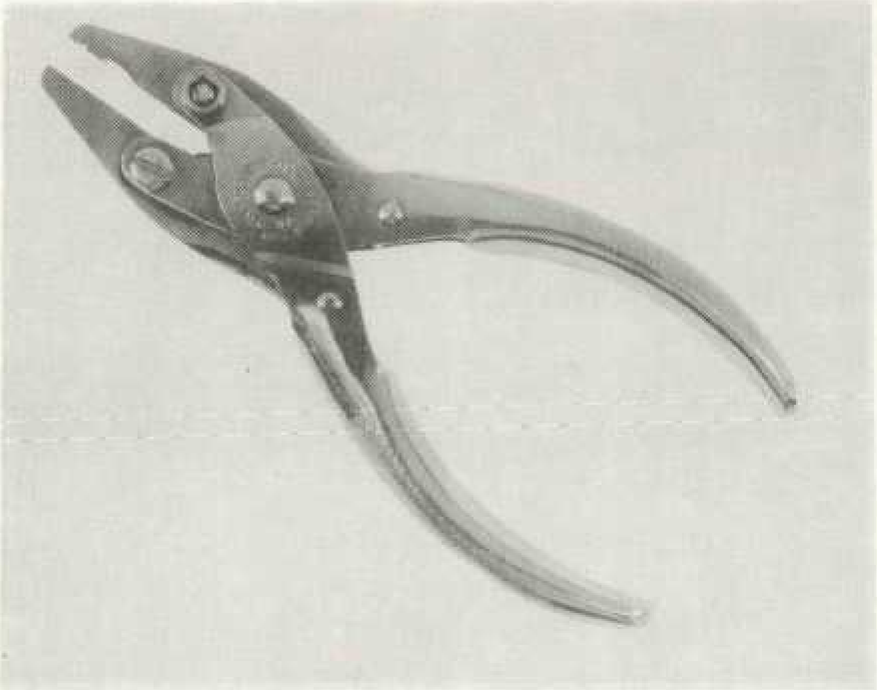


Figure 5. Crimp Pliers

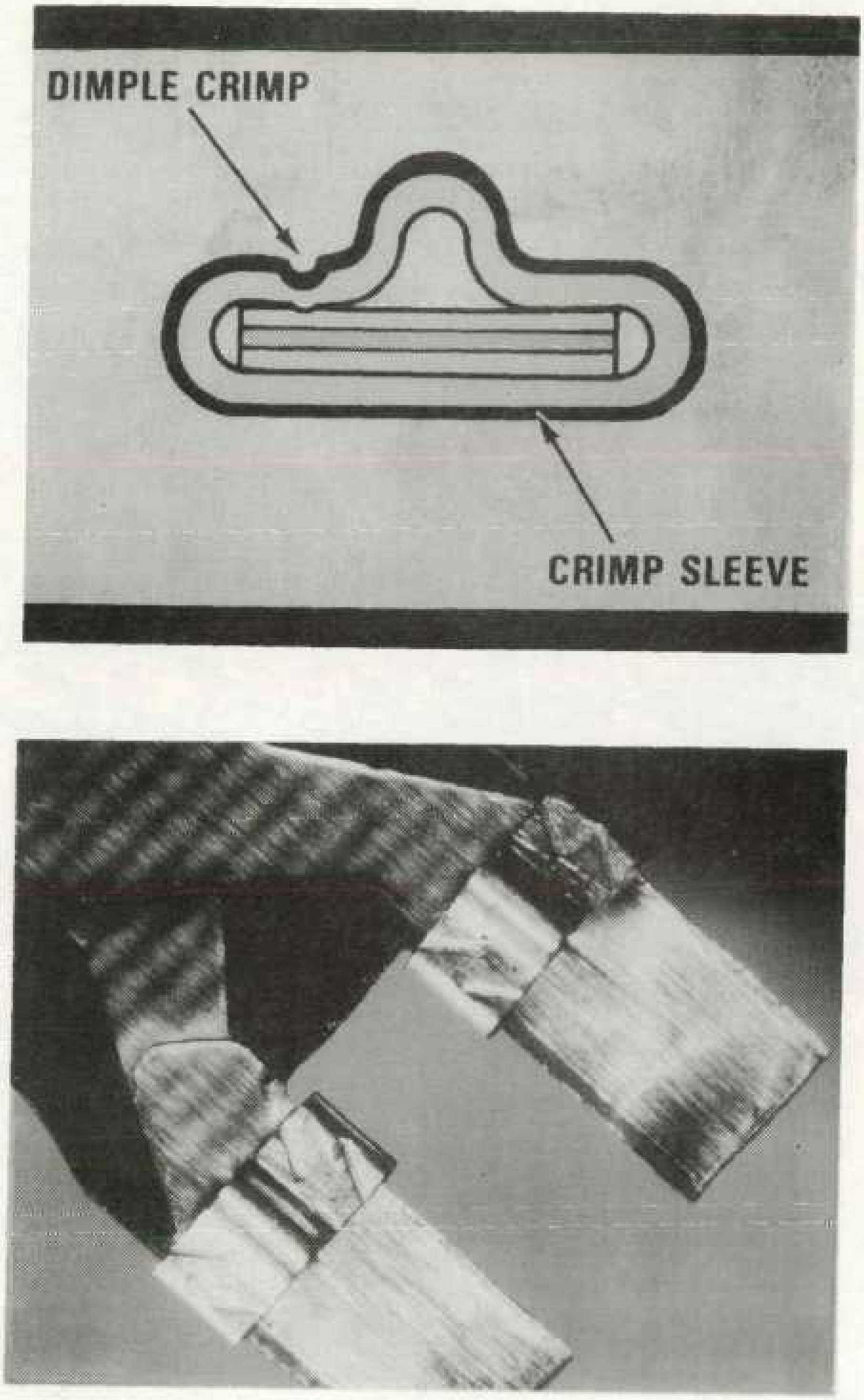


Figure 6. Dimple Crimps

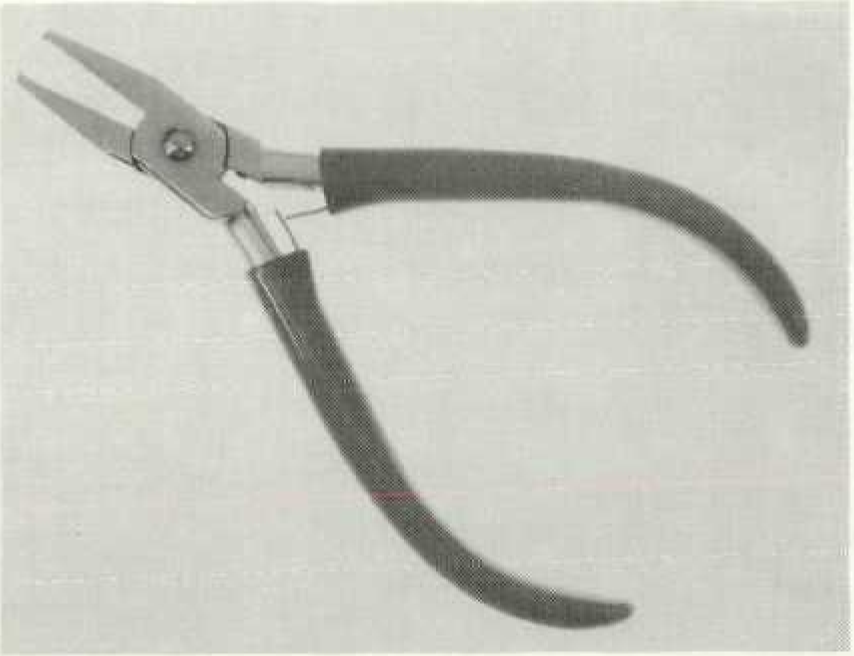


Figure 7. Dimple Crimp Pliers

welded. Z-axis position, angle of the part, and spot size are not as critical as with foils; however, more power is needed for the larger materials. Because the welding parameters are not critical, the probability of burning away significant amounts of the shell or wire is reduced. Stress cracking of the weld did, however, present a problem.

Figure 12, a cross section of a completed wire-to-shell weld, shows stress cracks formed due to the mismatch of masses of the weldments. Separations are caused by a faster cooling rate of the lighter wire with respect to the heavier shell. To compensate for this, two stress relief slots were cut into the shell to effectively equalize masses. Figures 13 through 15 show these slots, the weld achieved, and its cross section.

Weld Schedule Development

A weld schedule development procedure is used incorporating the parameters of spot size, Z-axis distance from the beam focal point, and weld energy (lamp input voltage). Spot size is adjusted for a practical size weld determined by the part geometry. The Z-axis distance from the beam focal point is set to control blowouts and energy density in general. This distance will also

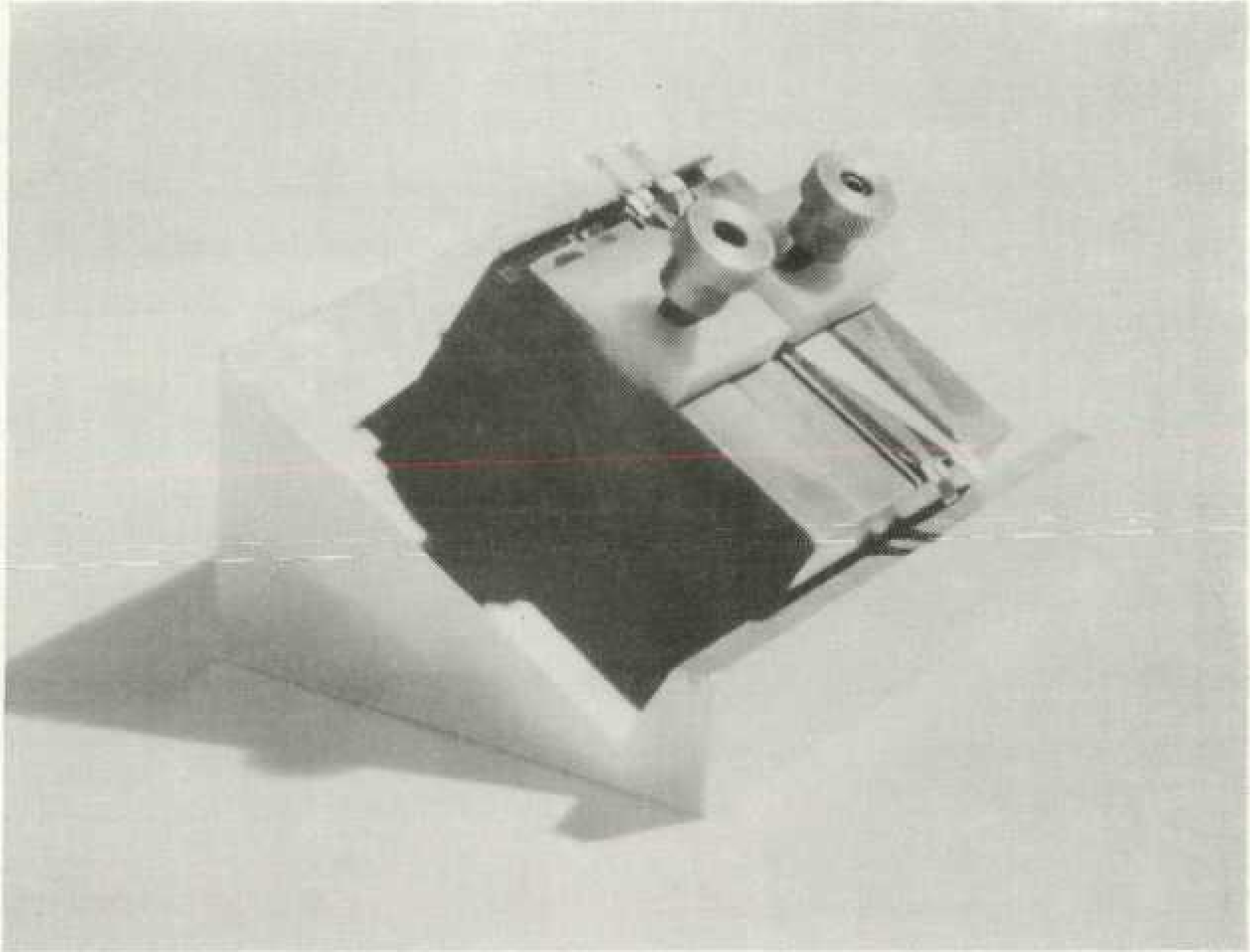


Figure 8. Tilt Fixture

affect the spot size adjustment. When spot size and Z-axis distance have been correlated for best welding, lamp input voltage is varied until consistent lasing takes place and the number of blowouts is minimized.

After proper settings have been found, 25 samples are welded, visually inspected, and tested for resistance. A crimp-sleeve-to-foil-weld will have a resistance of about 1 mΩ; the wire-to-connector shell about 3 mΩ. If all samples meet the requirements, the schedule will be used for production parts.

Copper Foil Seam Welding

Seam welding 0.038-mm copper foil to 0.203-mm copper foil backed with Kapton required a higher powered laser with a more rapid

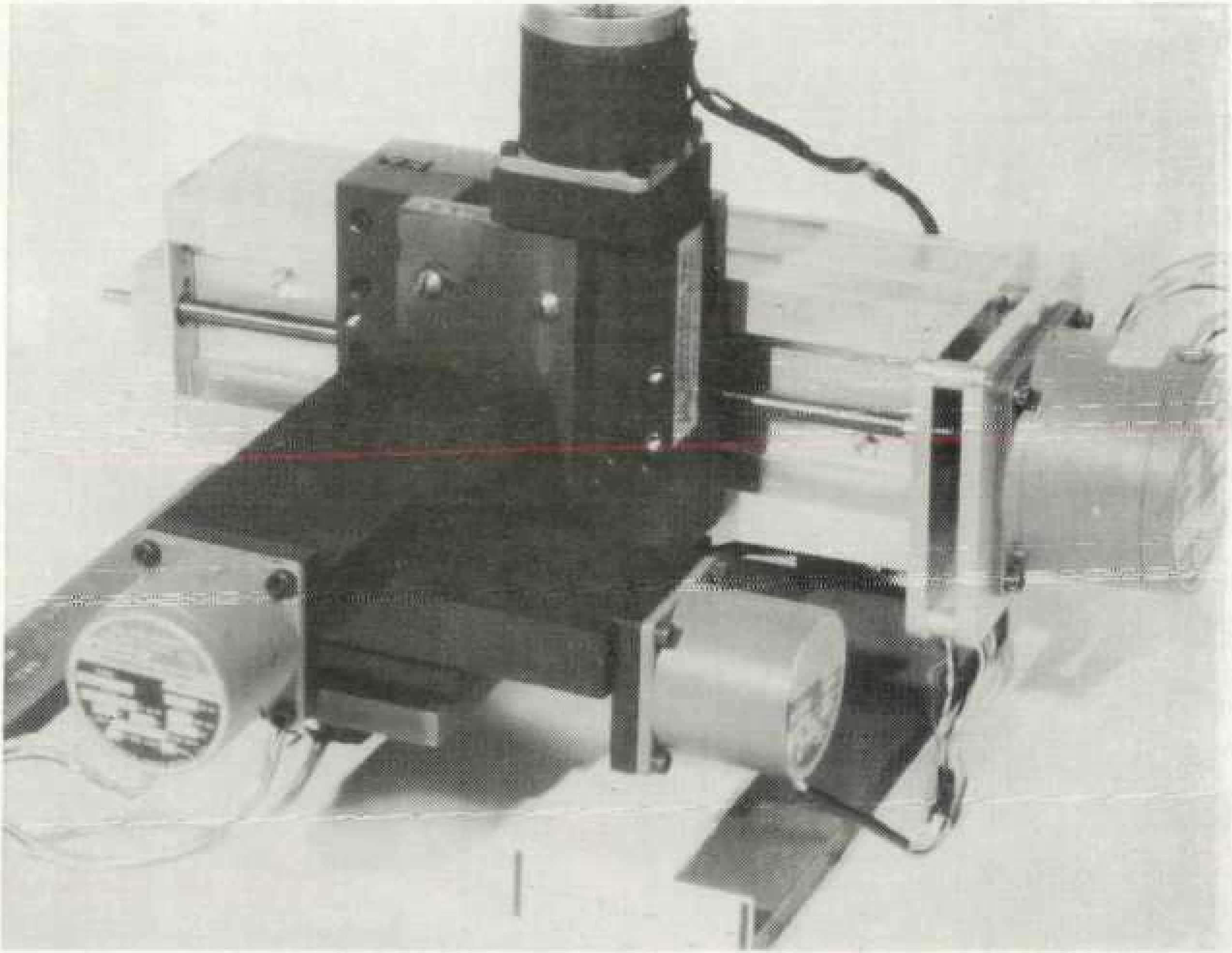


Figure 9. XYZ-Axis Table

pulse rate than the 70 W laser used for aluminum spot welding. This material combination was sent to several laser vendors for welding evaluation. The greatest success was achieved using a 400 W laser.

The requirements for this weld were: good quality electrical continuity in the form of a seam weld, absence of any holes in either foil, and minimal delamination of Kapton from the 0.203-mm foil.

The higher powered laser was better for this application because of its 400 W average power output and its capability of 200 pulses/second. The weld in Figure 16 was done at an average of 100 W and 50 pulses/second.

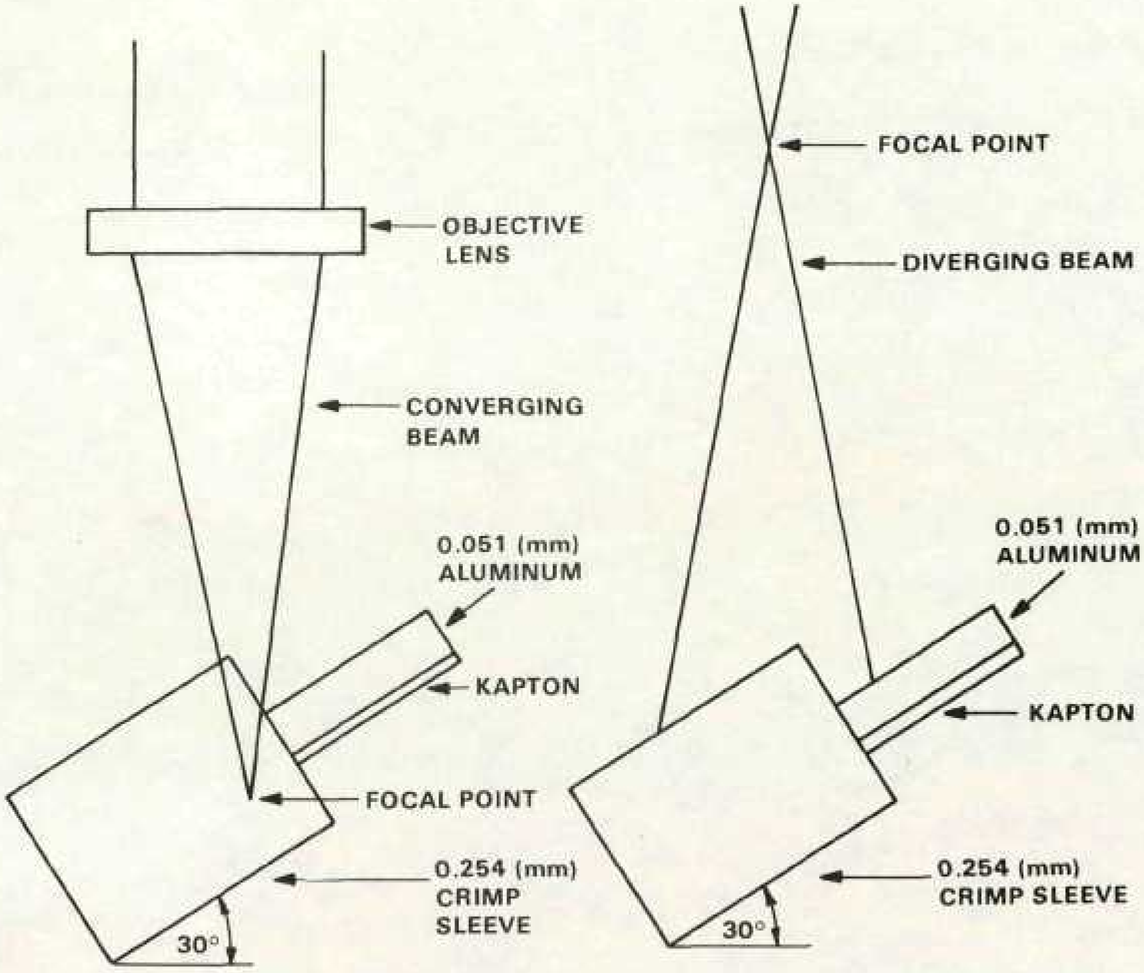
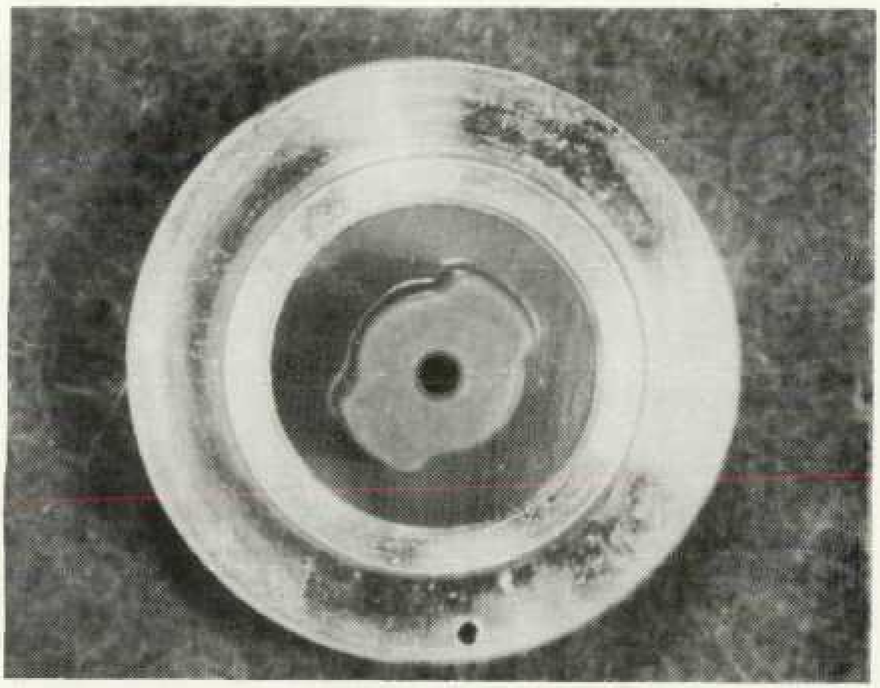


Figure 10. Converging Beam and Diverging Beam

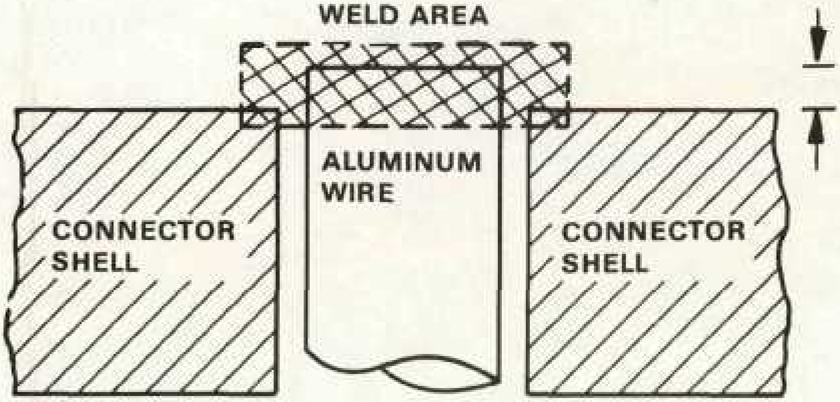
Again, a 30 degree tilt fixture was used and an edge weld was made. Delamination of the Kapton behind the weld was barely perceptible (Figure 17). This exemplifies the small heat affected zone inherent in laser welding. In comparison, Figure 18 shows the same view of a weld made with a resistance welder. The heat damage to the adhesive and Kapton is more significant. Additional work on this process is underway.

ACCOMPLISHMENTS

Weld schedules and procedures have been established for welding an 0.051-mm Kapton-backed aluminum foil to an 0.254-mm wall



ALUMINUM WIRE NOT SHOWN



SIDE VIEW

Figure 11. Original Connector Shell

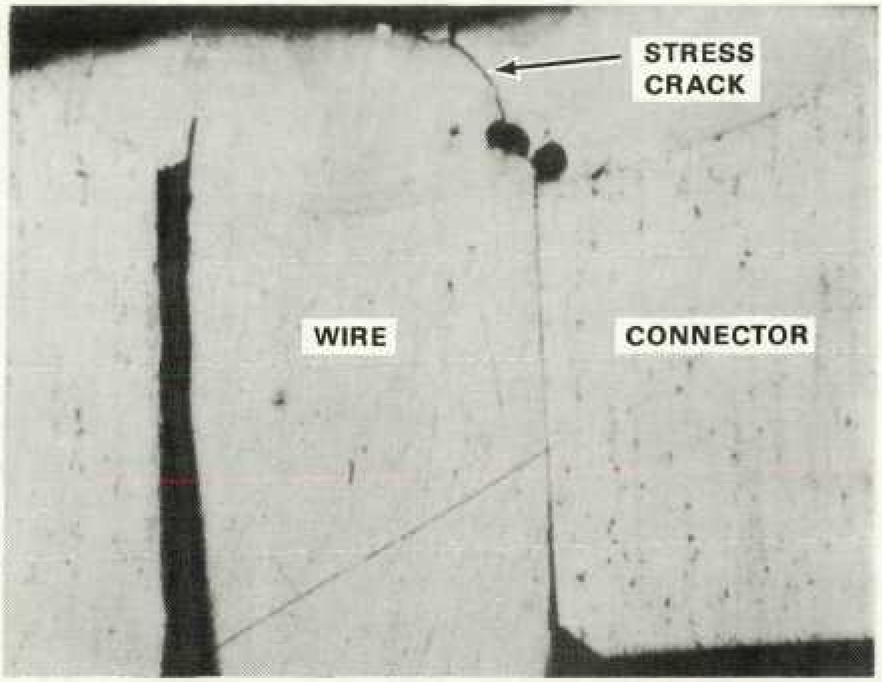


Figure 12. Cross Section of Stress Cracking in a Weld

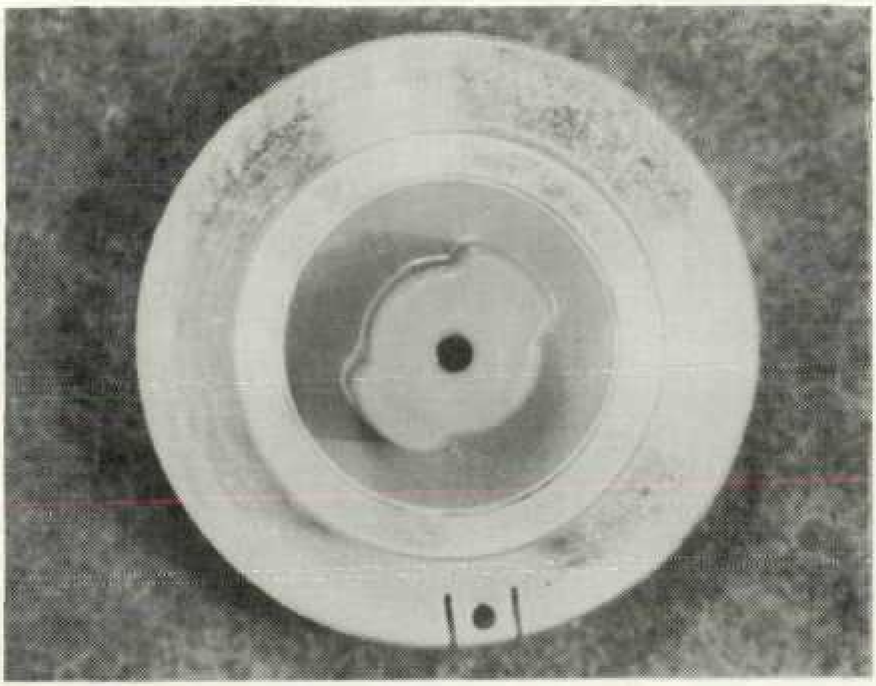
thickness crimp sleeve, and a 22 AWG aluminum wire to a 6061-T6 aluminum connector shell. Problems such as stress cracking and blowouts have been reduced in process development work. These welding applications, both considered to be outside the capabilities of YAG laser welders in the 1974 era, are currently involved in relatively high rate production of aluminum flat electrical cables.

YAG laser welding has also proved itself a successful method for joining thin copper foils for electrical interconnections. Preliminary work has shown that a seam weld with apparent higher quality than conventional methods can be made in joining 0.038-mm copper to 0.203-mm Kapton-backed copper.

FUTURE WORK

A higher powered, rapid pulse rate YAG laser is expected to be obtained. Upon availability, development in the following areas is planned:

- Seam welding different thickness copper foils will continue to be studied for possible future production applications,



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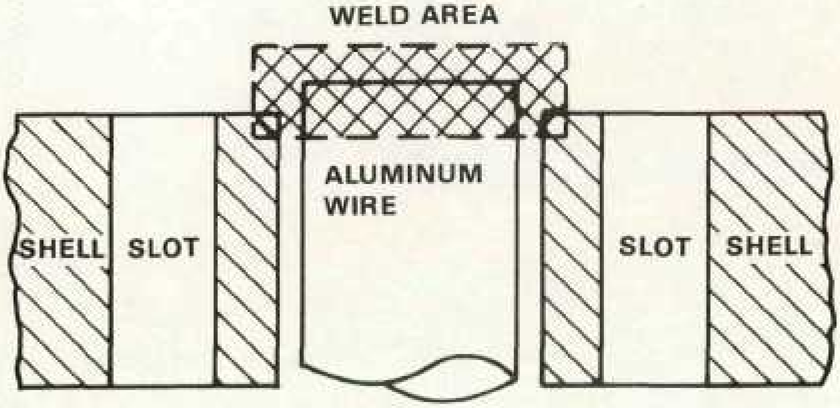

SIDE VIEW

Figure 13. Modified Connector Shell

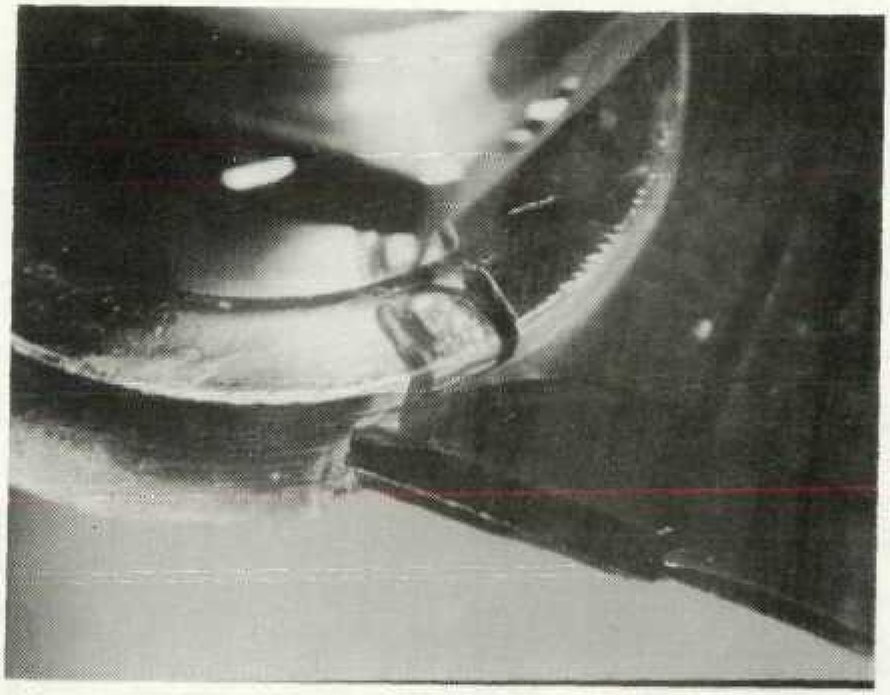

Figure 14. Wire-to-Shell Weld

- An 0.051-mm to 0.051-mm aluminum foil weld will be evaluated as an application for flat cable electrical terminations,
- A search for material combinations suitable to laser welding will be conducted and recorded for future reference, and
- High rate production of large quantities of aluminum flat cables could be made possible with the addition of a numerically controlled table. The possibility of using this positioning system is being investigated.
- The YAG laser will be evaluated for use in miniature electrical interconnections on applications other than foils and the aluminum connector discussed in this report.

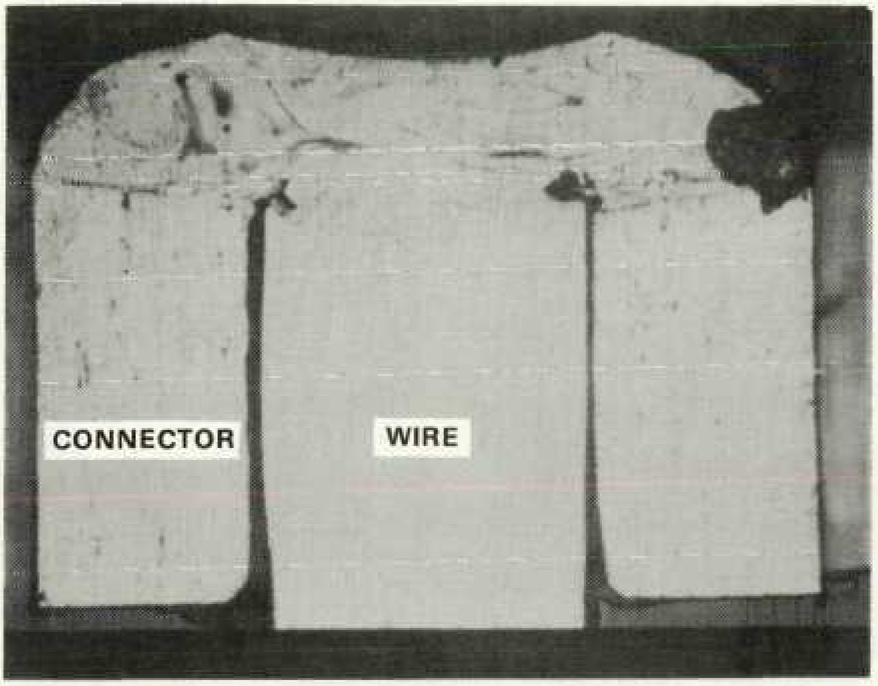

Figure 15. Cross Section of Modified Connector Shell

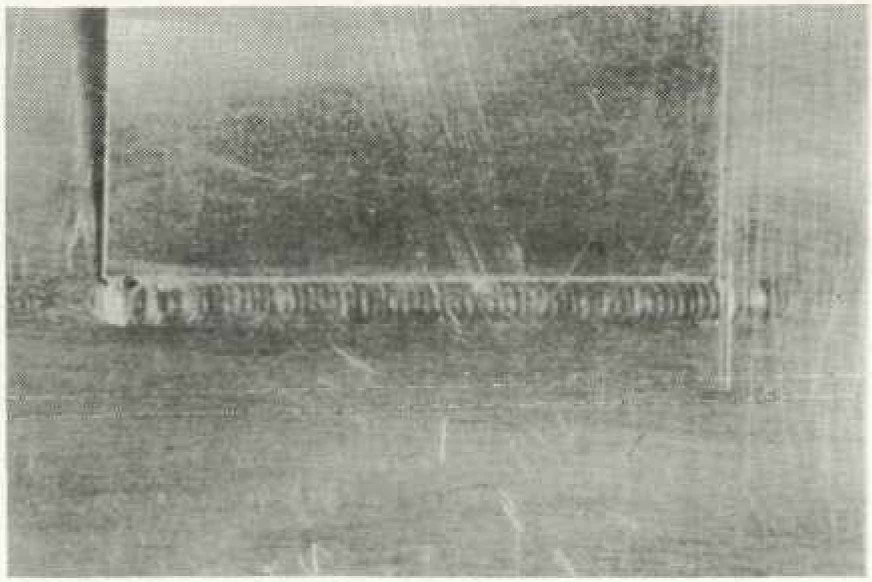

Figure 16. Copper-to-Copper Seam Weld

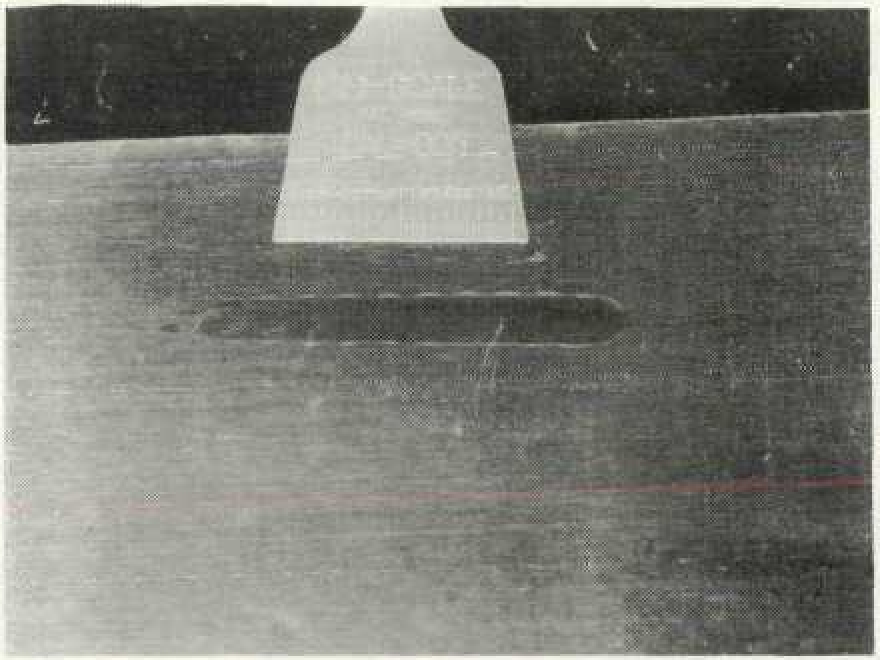

Figure 17. Kapton Side of Copper-to-Seam Weld

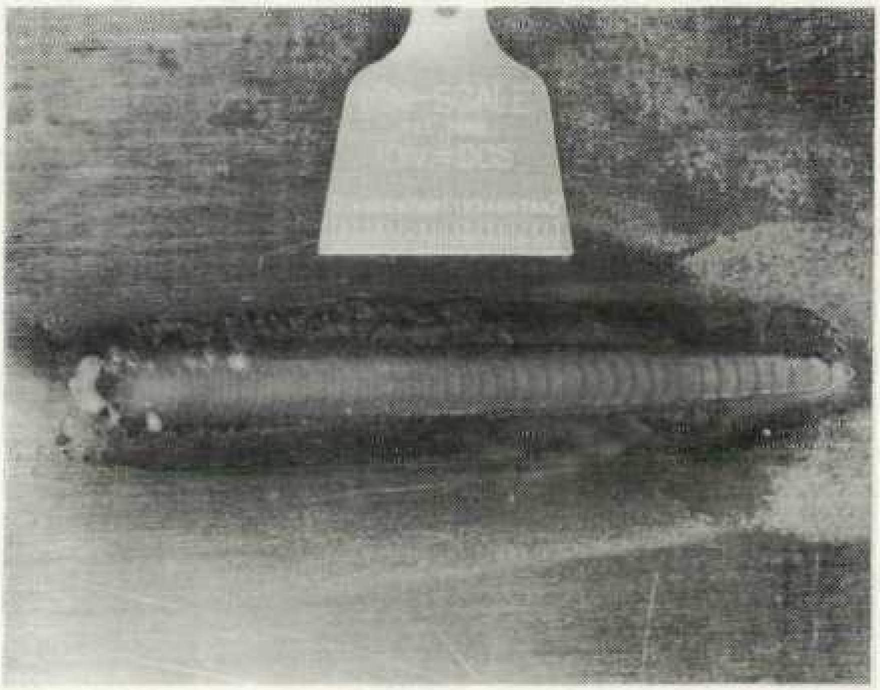

Figure 18. Kapton Side of Resistance Weld

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[2] Kent Thoeni and others, Bendix Kansas City Electrical Termination Welding Handbook, (Manual). Bendix Kansas City: BDX-613-637, May, 1972 (Available from NTIS).

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