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Laser Cutting Plastic Materials

By R. A. Van Cleave

Published August 1980

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Topical Report
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LASER CUTTING PLASTIC MATERIALS

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A 1000-watt CO_2 laser has been demonstrated as a reliable production machine tool for cutting of plastics, high strength reinforced composites, and other nonmetals. More than 40 different plastics have been laser cut, and the results are tabulated. Applications for laser cutting described include fiberglass-reinforced laminates, Kevlar/epoxy composites, fiberglass-reinforced phenolics, nylon/epoxy laminates, ceramics, and disposable tooling made from acrylic.

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SUMMARY

The CO_2 laser cutting process has proven to be a viable technique for material removal, first in Kevlar/epoxy laminates and now in other plastics and reinforced composite applications. This project is intended to advance and improve the manufacturing capability in plastics machining, based on the successful development of Kevlar/epoxy cutting conducted on a previous project. A part of this goal is the familiarization and development of a unique three-axis laser cutting system purchased to cut contoured Kevlar/epoxy laminates.

The project is divided into three sections: material processability, configuration capability, and production applications. Various thicknesses of more than 40 different thermoplastics, thermosets, and reinforced laminates have been laser cut. Cutting power, kerf width, edge taper, and feasibility of processing these materials have been determined. Little or no detrimental effects to the many materials have been caused by laser cutting. In general, most plastics and composites can be laser cut within certain thickness, configuration, and edge quality limits. The effect of nozzle design and beam mode on cutting performance is not understood fully at this time, but suitable setup conditions have been developed to process those specific needs which have surfaced. Feasibility of pocket cutting has been demonstrated on Kevlar/epoxy laminates and certainly will add to the laser cutting capability in processing other plastics.

The most meaningful accomplishment of this project is the application of laser cutting in manufacturing production parts and development hardware. Five different products, in addition to Kevlar/epoxy laminates, currently are or will be processed by laser cutting. In these applications, the laser provides either a higher quality cut (nondelaminated and fuzz free) than machining or a significantly more efficient cutting process. This cutting technique offers a method of plastic material removal that undoubtedly will provide new applications in the future.

The advantages of laser cutting include high feed rates (3000 mm/min); cheaper fixtures; elimination of cutting tools; fuzz-free, nondelaminated edges; and low operating cost. Disadvantages are limitations on material thickness; charred surfaces; tapered edges; and high initial equipment costs.

DISCUSSION

SCOPE AND PURPOSE

The purpose of this project is to develop and provide a laser cutting manufacturing capability with the three-axis CO_2 laser system and to establish nonmetal cutting applications. Previous work in cutting Kevlar/epoxy laminates proved the laser cutting technique is a cost-effective approach to producing high quality, nondelaminated edges; therefore, similar performance on other plastic materials and composites seemed reasonable. The activity is directed towards selecting various plastic materials and composites and evaluating the cutting performance of the laser on each material. This effort will be followed by cutting various shapes and configurations to determine the flexibility and capability of the three-axis laser system. Along with this development, potential cutting applications will be explored.

PRIOR WORK

A significant amount of laser cutting of Kevlar/epoxy laminates had been performed previously on a two-axis system.[1,2] (Because the fixed position of the focusing lens during laser cutting seemed to be a drawback for cutting on contours, the need for a three-axis system became apparent.) Only a limited amount of work in cutting other than Kevlar/epoxy laminates had been performed before this project.

ACTIVITY

This work was conducted on a Model 1003 CO_2 laser system (Figure 1) designed and built by Photon Sources, Inc. (Livionia, MI). The laser has a rated output power range of 125 to 1350 W and will perform in continuous wave (CW) or pulsed mode. The beam produced has a wavelength of 10.6 μm, measures about 25 mm in diameter, and has a Gaussian distribution mode (TEM_{00}). The beam is reflected to the work station and is focused to a spot size near the range of 0.1 to 0.2 mm in diameter using a 127-mm-focal length focusing lens. The work station (Figure 2) encloses a 600 mm square work table which is capable of numerical-control two-axis contouring over a travel of 600 mm in both the x and y directions. A third axis moves the focusing lens simultaneously with the work table to allow contour following of the focal point during a cutting operation.

The three axes of motion are controlled with a computer numerical controller (CNC) made by Vega Servo Control, Inc., and provide

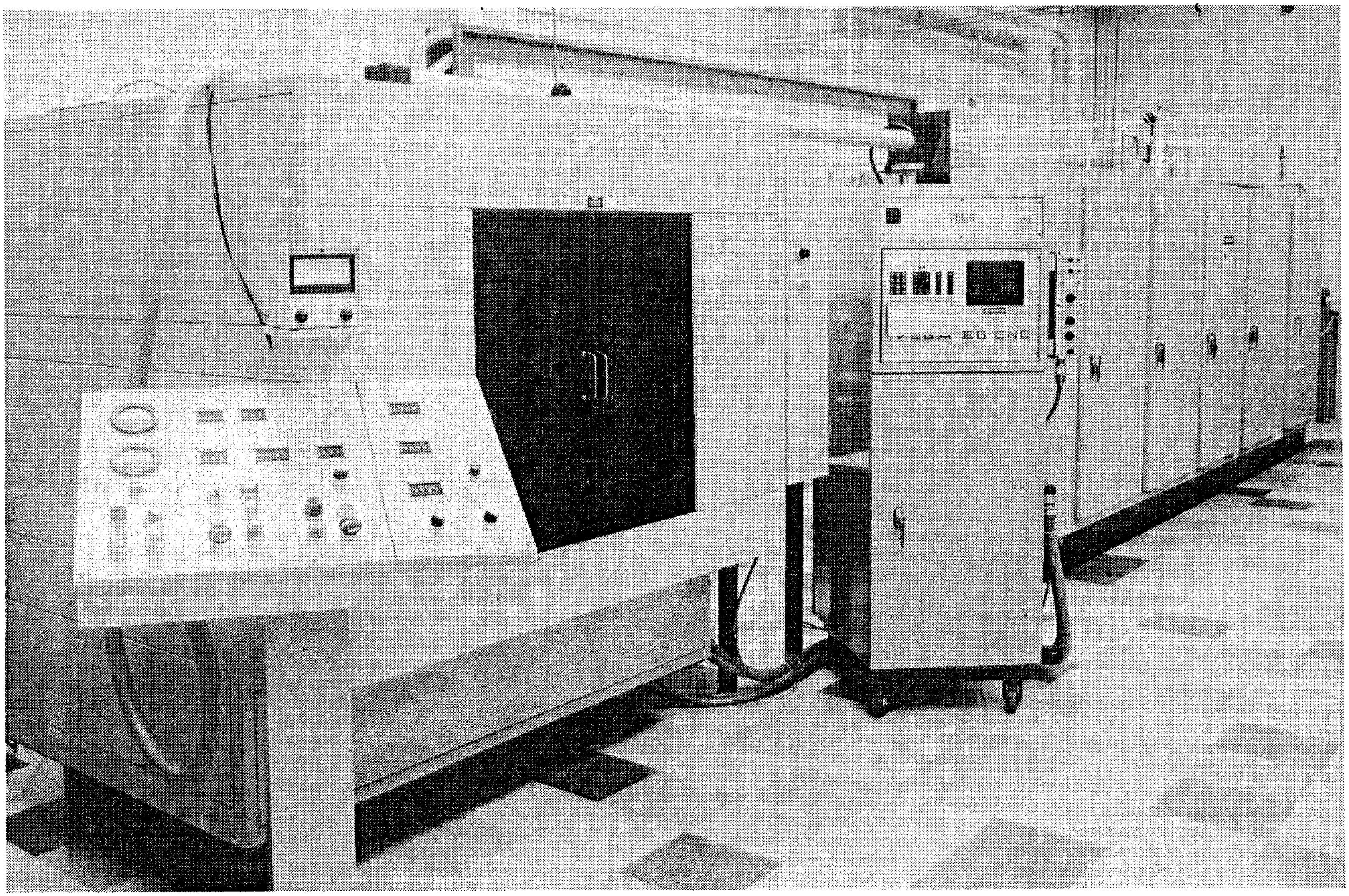


Figure 1. Three-Axis CO_2 Laser Cutting System

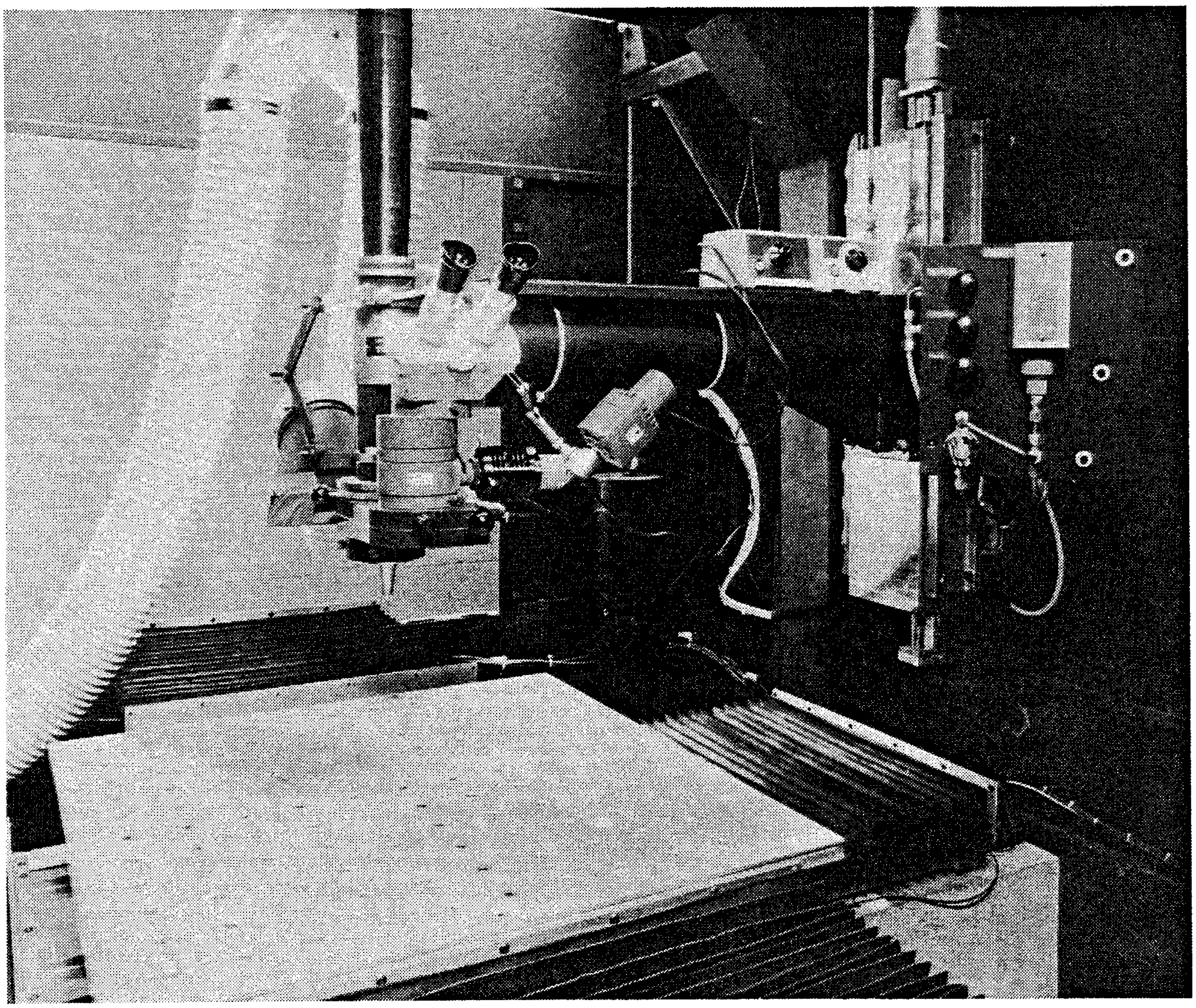


Figure 2. Laser Work Station

cutting speeds up to 3000 mm/min with a system resolution of either 0.001 mm or 0.0001 inch. The work station also houses an exhaust system for fume removal during the cutting process.

Material Cutting Results

Various types of plastics and plastic composites were selected from materials available from stores inventory and other engineering projects. The cutting power, edge taper, and kerf width (Figure 3) were established for many of these materials, and the results are given in Table 1. (The materials given in the table were categorized on the basis of information given in References 3 and 4.) Figure 4 shows two typical samples cut in Kevlar/epoxy.

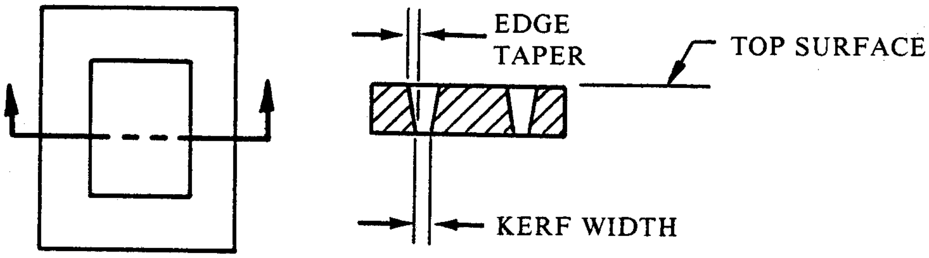


Figure 3. Kerf Width and Edge Taper Definition

In general, the thermoplastics were easier to cut and did not char. Most of the thermosets contained a reinforcing material which, when laser cut, left a layer of char, usually less than 0.05 mm per side. The char can be wiped clean to the touch using a paper wiper and alcohol, and the remaining discoloration can be removed by a glass bead vapor blast operation. Earlier studies[1] with Kevlar/epoxy have shown little or no detrimental effects with laser cutting, as compared to conventional machining.

Gas Nozzle

Modification to a nozzle design has been completed by changing the nozzle to accept various orifice size tips (Figure 5). Openings can be made to various sizes, with 1.3, 2.5, and 3.8 mm diameters available. As the size of the orifice decreases, the gas jet increases, but alignment becomes more critical. If the opening is not coaxial with the beam or if the opening is too far above the focal point, power absorption or robbing by the nozzle results. This robbing will result in either less power for cutting or nozzle damage. Figure 6 shows the relationship of the nozzle to the focusing lens, and Table 2 gives recommended maximum clearances of the nozzle and the laser focus point. The nozzle adjusting details allow for convenient alignment in both directions. The locking ring acts as a jam nut to prevent movement of the orifice after it is positioned properly. Gas flow parallel with beam is available with a special mount which provides a gas shield in addition to a gas jet during cutting.

Pocket Cutting

While most of the development and applications require through cuts, some work has been directed to pocket cutting or cuts to a controlled depth. A contoured cutout has been made in a 6.2-mm-thick Kevlar/epoxy laminate to a depth of 3.3 mm (Figure 7). Penetration can be controlled to about ±0.25 mm. The cut was made by covering the area in increments of 0.25 mm and pulsing

Table 1. Settings and Results for Laser Cut Materials

Material	Power (W)	Feed Rate (mm/min)	Thickness (mm)	Edge Taper (mm)	Kerf Width (mm)	Char
Thermoplastics						
ABS						
Cycolac H	100	2000	3.4		0.3*	No
Cycoloy 800 (ABS/Polycarbonate)	350	2000	3.4		1.5	Slight
Royalite	100	3000	1.6		0.3*	No
Acrylic						
Plexiglas	100	3000	1.6	0.07	0.31	No
Plexiglas	125	3000	2.8	0.17	0.17	No
Plexiglas	275	3000	4.5	0.21	0.19	No
Plexiglas	700	2000	8.6	0.24	0.31	No
Plexiglas	700	1400	12.0	0.30	0.38	No
Plexiglas	700	600	17.8	0.39	0.39	No
Plexiglas	800	300	24.5	0.38	0.61	No
Cellulosics						
Cellulose Acetate Buturate	50	3000			0.3*	No
Fluorocarbons						
Teflon	325	3000	3.3	0.10	0.16	No
Teflon	425	1500	6.4	0.10	0.33	No
TFE/Glass	600	2500	3.1	0.13	0.30	Yes
Phenoxy	50	3000			0.4*	No
Phenoxy	225	2000	3.4		0.5*	Slight

Table 1 Continued. Settings and Results for Laser Cut Materials

Material	Power (W)	Feed Rate (mm/min)	Thickness (mm)	Edge Taper (mm)	Kerf Width (mm)	Char
Polyamide						
Nylon 6/6	30	2000	0.9		0.2*	No
Nylon 12	325	2000	3.3		0.6*	No
Nyatron (Nylon/Glass)	550	2000	3.2		0.2*	No
Polycarbonate						
Clear	50	2000	1.5		0.1*	Yes
Clear	325	2000	3.6		0.4*	Yes
Clear	700	2400	5.8	0.29	0.46	Yes
Black/Glass	400	2000	3.3		0.2*	Yes
Polyester						
Valox 420 (30 Percent Glass)	500	2000	3.2		0.3*	Yes
Mylar	50	3000	0.1	0.13	0.50	No
Polyimide						
Kapton	100	3000	0.4	(Pulsed Mode)		Yes
Polyolefins						
Polypropylene	325	2000	3.3		0.7*	Slight
Polymethyl-pentene (TPX)	300	1500	1.7		0.8*	Slight
TPX	300	2000	3.2		0.7*	Slight
Polyphenylene Sulfide (40 Percent Glass)	850	2000	3.3		0.1*	Yes

Table 1 Continued. Settings and Results for Laser Cut Materials

Material	Power (W)	Feed Rate (mm/min)	Thickness (mm)	Edge Taper (mm)	Kerf Width (mm)	Char
Polysulfone						
White	375	2000	3.6		0.5*	Yes
Polyphenyl Sulfone	550	2000	3.3		0.3*	Yes
Thermosets						
Allyl						
Diallyl Phthalate (DAP) With Glass Fibers	450	2000	3.3		0.2*	Yes
Epoxy						
Epon 828/DAP	500	1000	9.1		0.2*	Slight
Fiberglass/Epoxy	75	3000	0.3	0.09	0.17	Yes
Fiberglass/Epoxy	125	3000	0.7	0.14	0.18	Yes
Fiberglass/Epoxy	175	1500	1.5	0.17	0.25	Yes
Fiberglass/Epoxy	350	3000	1.5	0.2	0.21	Yes
Fiberglass/Epoxy	750	2000	3.3		0.2*	Yes
Fiberglass/Epoxy	850	750	6.7	0.2	0.6*	Yes
Prepreg	150	3000	0.3	(Pulsed Mode)		Slight
Kevlar/Epoxy	30	2000	1.1	0.6	0.11	Yes
Kevlar/Epoxy	150	2000	3.3	0.14	0.12	Yes
Kevlar/Epoxy	400	2000	6.2	0.17	0.14	Yes
Kevlar/Epoxy	940	2000	9.5	0.22	0.17	Yes
Prepreg	100	3000	0.3	(Pulsed Mode)		Slight
Graphite/Epoxy	950	1000	3.2			Excessive
Prepreg	100	1500	0.7			Excessive
Boron/Epoxy	950	1000	3.2			Excessive

Table 1 Continued. Settings and Results for Laser Cut Materials

Material	Power (W)	Feed Rate (mm/min)	Thickness (mm)	Edge Taper (mm)	Kerf Width (mm)	Char
Desiccant/Epoxy	225	2000	3.2		0.2*	Yes
Desiccant/Epoxy	850	2000	5.6		0.3*	Yes
Nylon/Epoxy	100	3000	1.3		0.2*	No
Prepreg	110	3000	0.3	(Pulsed Mode)		
Phenolic						
Nema H-1 (Nylon)	50	3000	0.8	0.07	0.17	Yes
Nema H-1	100	3000	1.5	0.08	0.17	Yes
Nema H-1	450	1500	3.0	0.14	0.27	Yes
Nema H-1	750	3000	4.8	0.14	0.25	Yes
Nema XXX (Paper)	100	3000	1.6	0.11	0.12	Yes
Nema XXX	250	3000	3.5	0.13	0.15	Yes
Nema XXX	800	3000	6.7	0.12	0.18	Yes
Fiberglass	200	3000	0.8	0.13	0.28	Yes
Fiberglass	850	2000	2.9		0.3*	Yes
Formica (Cotton)	200	3000	1.7	0.10	0.18	Yes
Formica	300	3000	3.5	0.08	0.23	Yes
Polyurethane Rigid Foam						
0.3 g/cm^3	100	2000	6.4		0.47*	Slight
0.3 g/cm^3	300	2000	15.0		0.60*	Slight
0.8 g/cm^3	400	2000	7.8		0.31	Slight
Others						
Cellular Silicone	150	2000	3.0			Yes
Cellular Silicone	800	2000	9.0			Yes
RTV	100	2000	1.0			Yes

Table 1 Continued. Settings and Results for Laser Cut Materials

Material	Power (W)	Feed Rate (mm/min)	Thickness (mm)	Edge Taper (mm)	Kerf Width (mm)	Char
TDI (Flexible)	100	2000	8.0			Slight
TDI (Flexible)	200	2000	13.0			Slight
PAPI Foam	200	2000	7.0		0.46*	Slight
PAPI Foam	550	2000	17.0		0.56*	Slight
Syntactic Foam						
Carbon Micro-balloon/Polyimide	450	2000	7.6			Excessive
Carbon Micro-balloon/Polyimide	820	2000	10.3			Excessive
Carbon Micro-balloon/Polyimide	600	2000	8.5			Excessive
Polyolefin-Based Rubbers						
TPR 1900	500	2000	6.3			No
TPR 1600	500	2000	6.3			No

*Approximate.

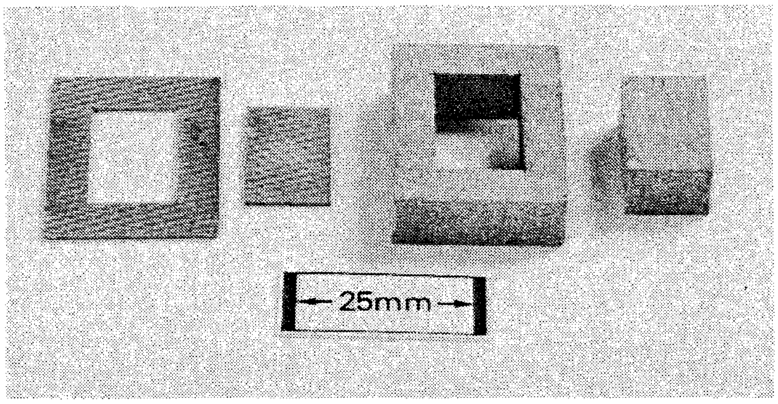


Figure 4. Kevlar/Epoxy Test Samples for Finding Edge Taper and Kerf Width

the beam 10 ms on and 5 ms off. The char developed was removed with a vapor blast of glass beads. Additional data on similar activity has been published.[1]

Beam Mode

The distribution of energy across the diameter of the unfocused beam is called the beam mode. Ideally, the majority of the beam energy would be located in either one spot in the center of the beam (Gaussian or TEM_{00}) or in a donut shape around the center (ring or TEM_{01*}). Mode stability can be a difficult condition to maintain in high power lasers, and as the mode shape drifts from the ideal cutting performance decreases dramatically. Aligning the mirrors in the laser cavity to return to optimum mode is a time-consuming and precise operation, because a slight movement of a mirror near the optimum position can result in a total loss of mode.

Mirror alignment for beam mode may be performed in at least two ways. One technique requires making a "mode burn" in an acrylic block and is a simple, fast procedure. This method is not convenient for tuning the mode, because a continuous feedback of a mirror fine tune adjustment is not provided. Another technique, developed at Bendix, uses a laser beam profiler which detects and converts energy levels across the beam to electrical impulse and displays the signal on an oscilloscope.[5] The display is continuously updated as the mirrors are adjusted. Figure 8 shows a display of a Gaussian mode, and Figure 9 represents a donut mode. The laser beam profiler has proven itself to be a fast, accurate method of establishing the optimum beam mode for either Gaussian or donut profiles.

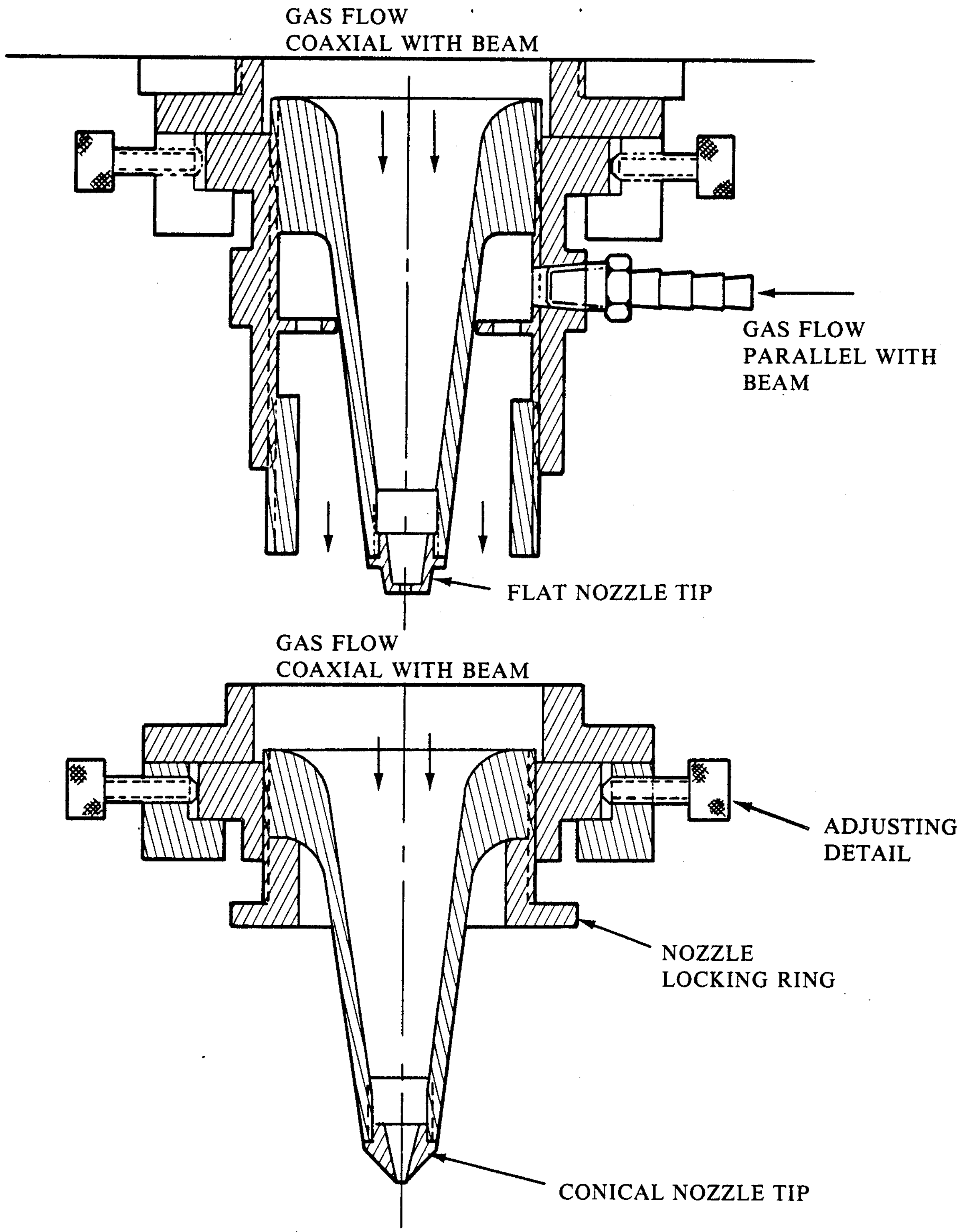


Figure 5. Cover Gas Nozzles

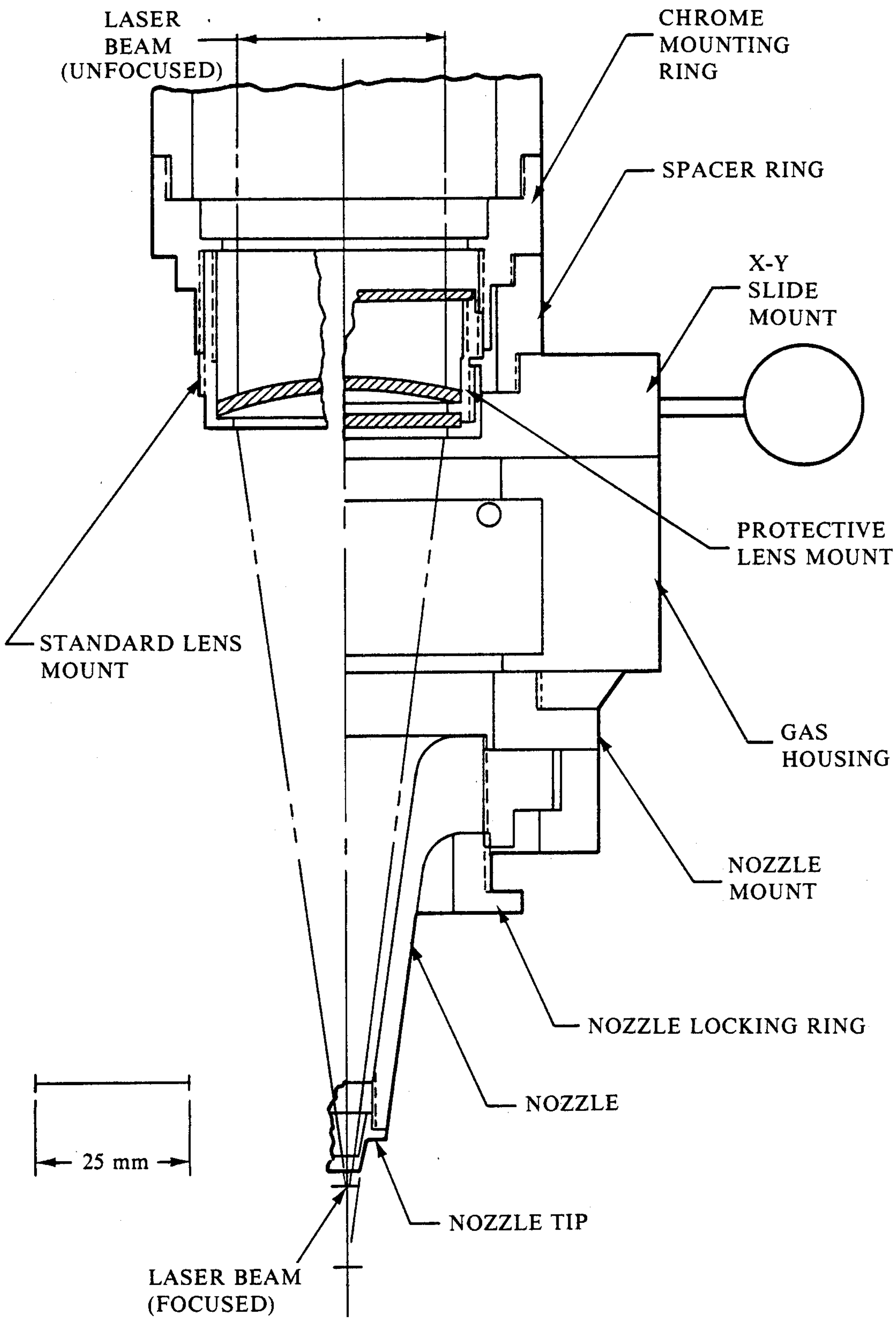


Figure 6. Gas Delivery System

Table 2. Maximum Nozzle Clearances

Nozzle Opening (mm)	Maximum Recommended Clearances From Focal Point (mm)
1.3	2.5
2.5	5.0
3.8	10.0

Applications

Fiberglass-Reinforced Laminates

Processes have been developed for laser cutting various types of fiberglass/epoxy laminates. The first example is a 1.0-mm-diameter pultruded rod made of fiberglass and polyester resin. Four holes, each 0.25 mm in diameter, must be drilled normally to the rod. A wire is placed through one hole, wrapped around the rod to form an inductor coil and placed through a second hole to hold the coil in place. The remaining two holes are located on either side of the coil and are used to mark and cut the end of the part (Figure 10). Each hole is drilled using 600 W of power and two pulses of 2 ms duration. The drilling time is about 2 seconds per part and 45 parts are drilled in one cycle. The hole produced is tapered about 0.05 mm per side, and the exit hole size is controlled to ±0.03 mm. After wire winding, parts are laser cut to separate each part from the rod stock.

Figure 11 shows two hand layups made from a fiberglass/epoxy prepreg material. The flange of one part is 3.2 mm thick and requires a 279 mm outer diameter and eight holes, 7.9-mm-diameter each, to be machined. The laminate is cut with a power of 400 W and a feed rate of 1500 mm/min for a total cycle time of 60 s. The char in the holes is removed with a hand-held reamer, and the outer diameter is hand sanded. The flange of the other part also was 3.2 mm thick and required machining an outer contour and eight holes 3.5 mm in diameter. The end of the part and two rectangular openings in the cylinder section also required machining. Cutting conditions were similar to the other hand layup. The end of the part was cut by rotating the part under the focused beam. The kerf width of 0.4 mm was narrow enough to permit reuse of the cut out piece of cylinder opening as a door in the same opening.

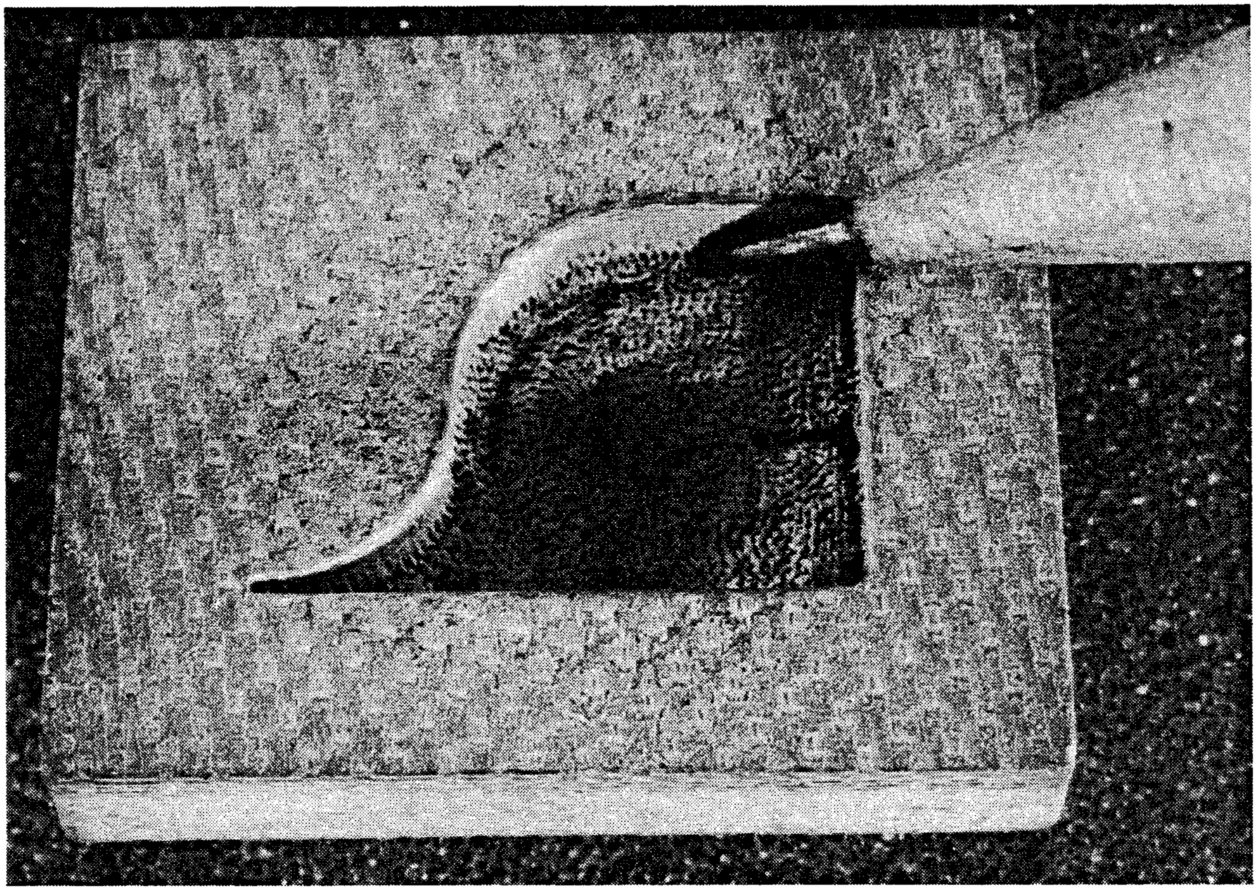


Figure 7. Pocket Cutting a Contour in Kevlar/Epoxy

An insulated terminal board has been cut from a 0.7-mm-thick sheet of fiberglass/epoxy (Figure 12). The holes were cut first, and then the outer contour. The material was cut in 45 s using 100 W at 3000 mm/min. A vapor blast operation removed the char. This technique is particularly attractive for cutting development hardware or for a small quantity of parts, because a minimum of tooling is required.

A 0.4-mm-thick molded part made from a short glass fiber and diallyl phthalate (DAP) presented chipping and breaking problems during machining. The first conventional machining effort yielded about 5 percent good parts. Laser cutting was substituted for the end mill operation, resulting in a yield of 90 percent. The slot and end of the part (Figure 13) were cut with 50 W at 1500 and 3000 mm/min. The carbon residue was removed with a glass fiber brush.

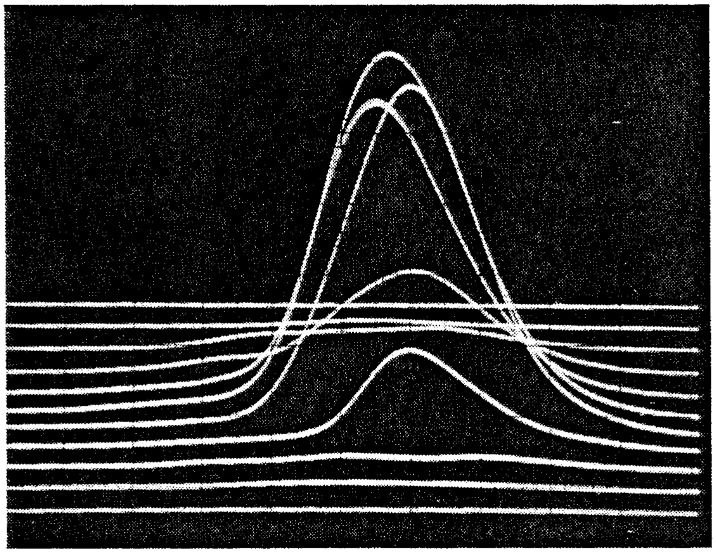


Figure 8. Gaussian Mode Profile Made With a Profiler

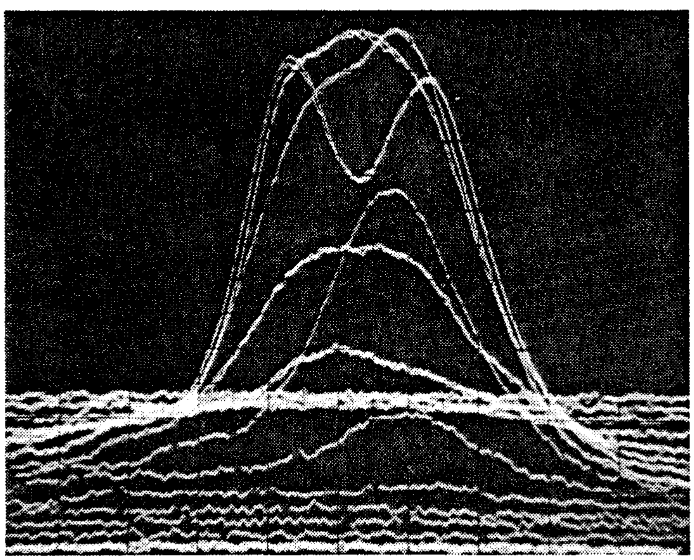


Figure 9. Donut Mode Profile Made With a Profiler

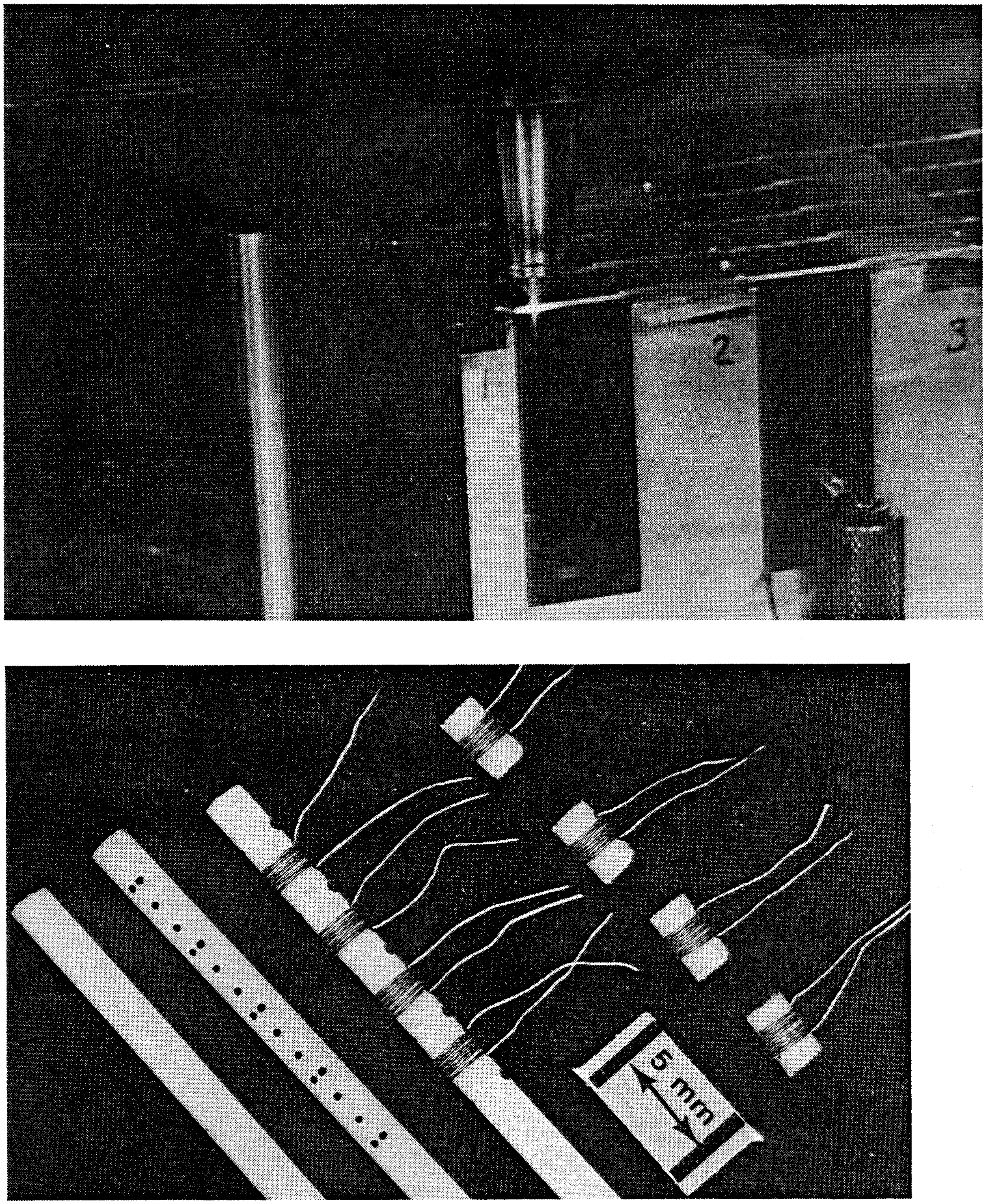


Figure 10. 0.25-mm-Diameter Holes Drilled in 1.0-mm-Diameter Fiberglass-Polyester Rods

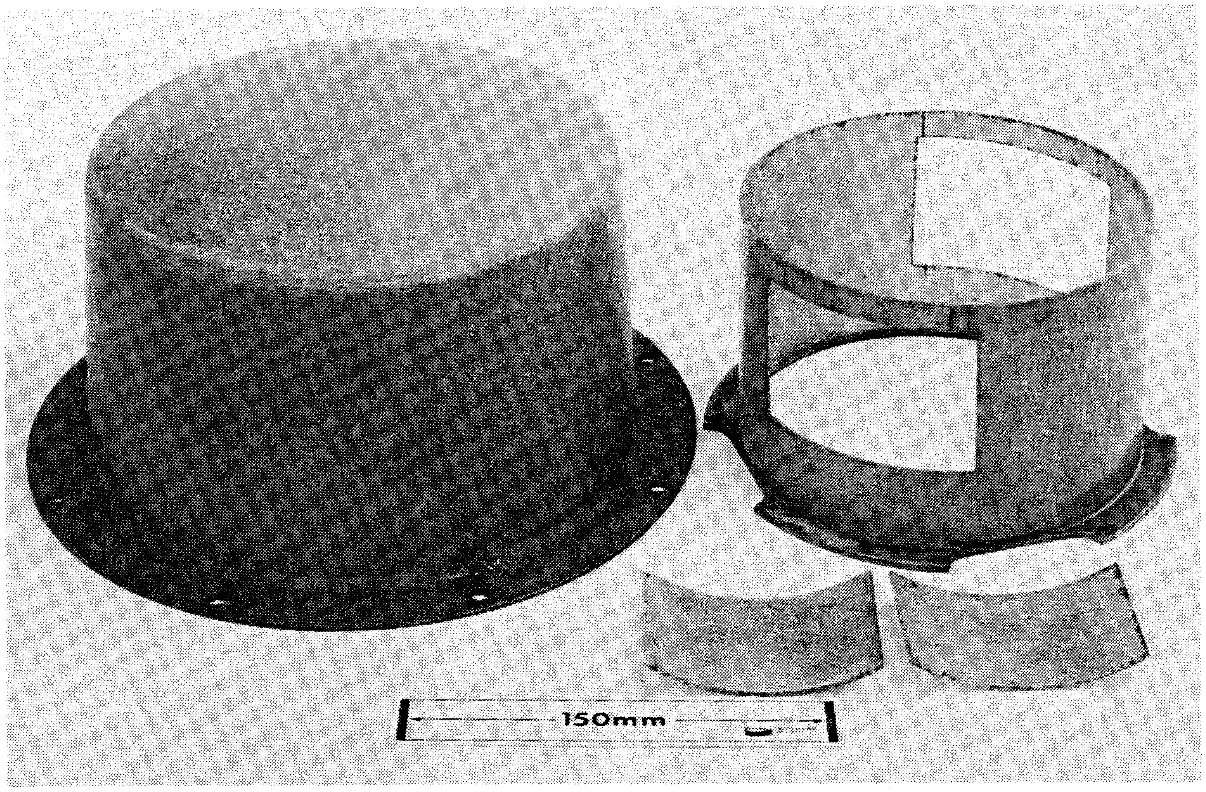


Figure 11. Fiberglass/Epoxy Prepreg Laminates

Kevlar-Reinforced Laminates

Kevlar cloth, prepreg, and laminates are cut routinely with the laser. The "toughness" of the cloth, the loose weave required to allow contour molding, and the various contours needed make cloth cutting with scissors, rotary shears, or stamping dies impractical. The laser cutting system offers a noncontact, rapid method for producing various repeatable shapes to allow for good control for the laminating process. The numerical control system also permits a software change approach to developing a pattern as opposed to the more inconvenient and costly hardware technique of stamping dies or templates. Cutting rates vary from 1500 to 3000 mm/min, depending on the shape and accuracy required. Cutting power is only 100 W, and the laser operates in a continuous pulsed mode of 2 ms on, 1 ms off to reduce the char or discoloration to an insignificant level. Various laser cut shapes are shown in Figure 14. Cutting normally is performed on one layer of cloth rather than a stack to eliminate the discoloration which occurs between the layers.

The high cutting speed and the narrow heat-affected zone of the laser makes cutting Kevlar prepreg (cloth previously impregnated

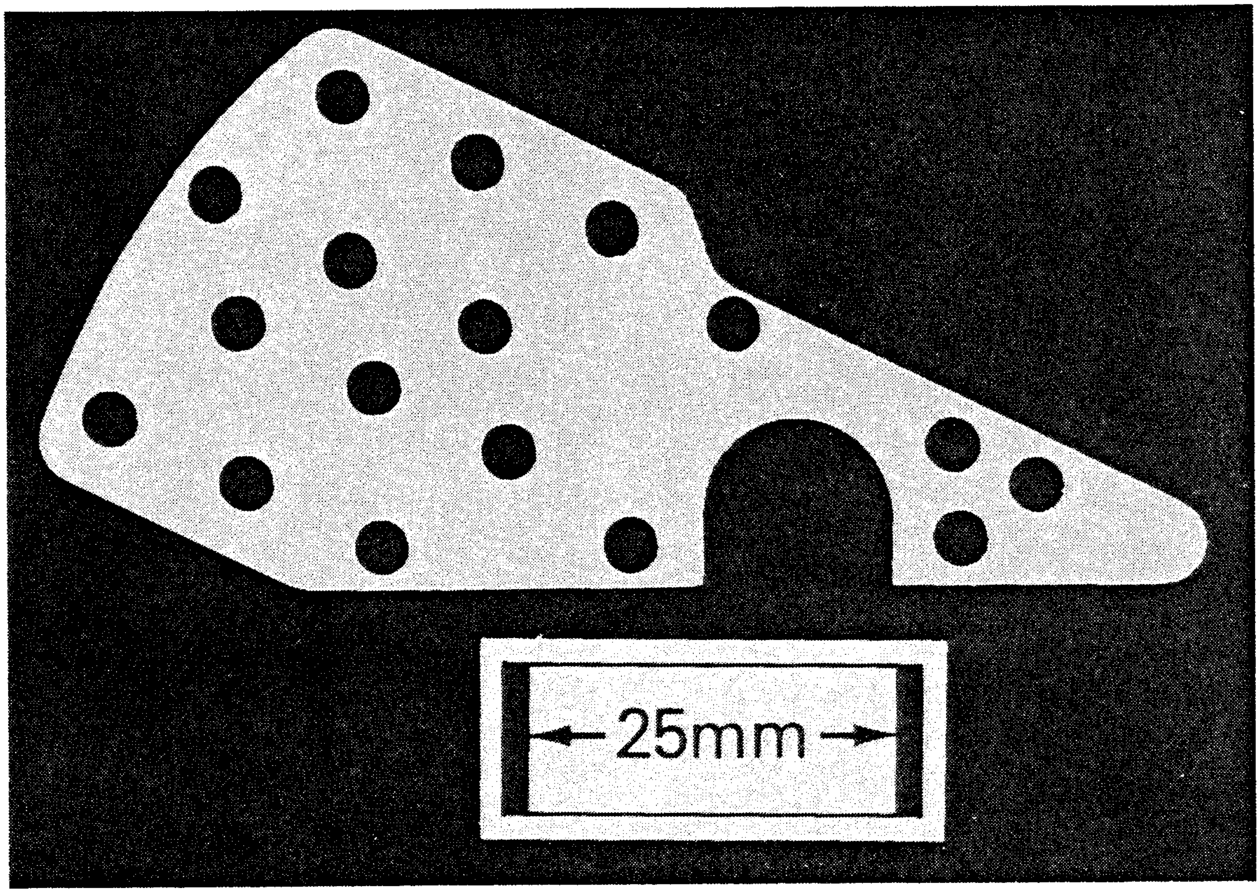


Figure 12. 0.75-mm-Thick Laser Cut Fiberglass/Epoxy Part

with resin) as easy as cloth cutting. Prepreg cutting conditions are the same as cloth cutting. Even though temperatures high enough to vaporize the material are reached, the area heated is sufficiently small for a short enough period of time that the epoxy does not cure or "set up," which permits laminating layers of the laser-cut prepreg. Nylon and fiberglass prepregs can be cut with equal ease.

Flat composites generally are made by heating and pressing layers of prepreg or cloth/resin material. One example of this laminate is shown in Figure 15. This part is 3.5 mm thick by 75 mm outer diameter and has a 5 mm and a 1.8 mm hole. The two holes and outer diameter are cut using 250 W at 1500 mm/min. One part takes 20 s; a panel yields 16 parts and requires about 5 minutes to cut. Char is removed with a vapor blast operation. Two other parts are shown in Figure 16. The flat part is 6.3 mm thick and is cut using 700 W at 1500 mm/min. The outer contour char is wiped clean to the touch by rubbing with alcohol, and the holes

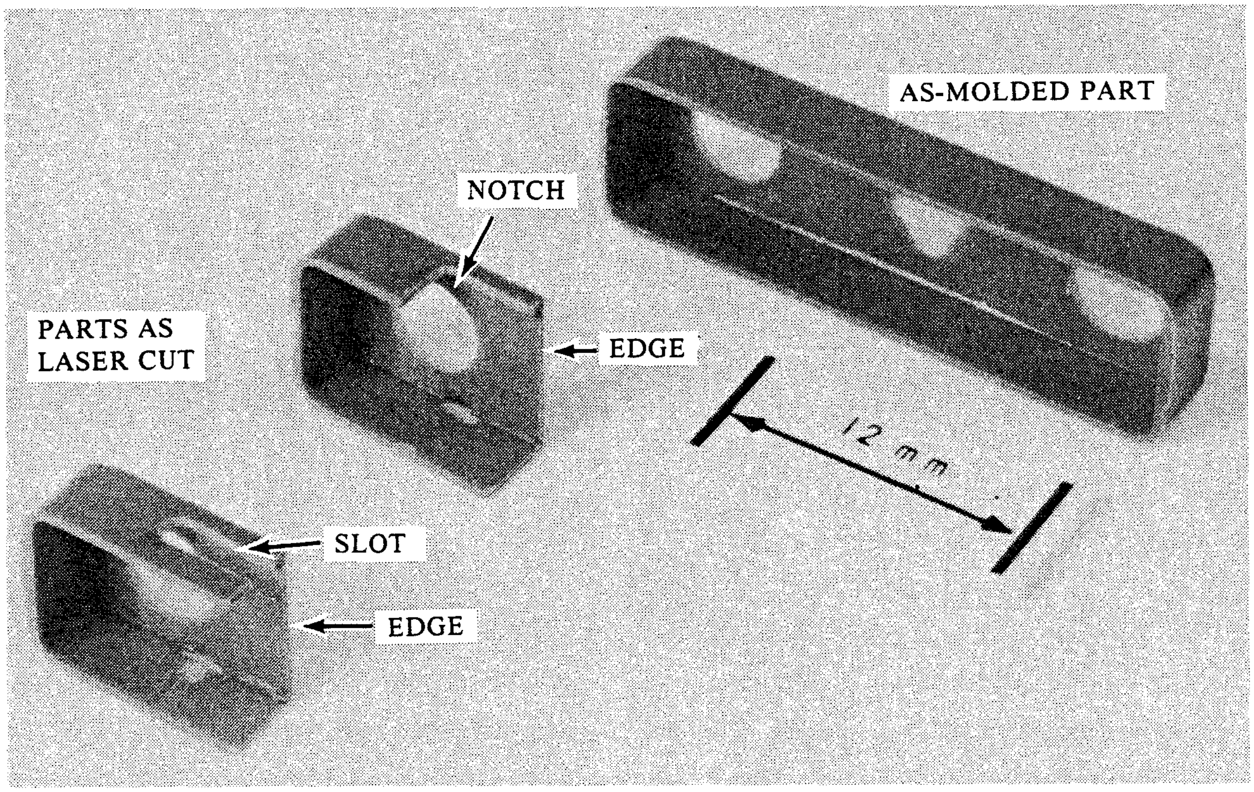


Figure 13. 0.4-mm-Thick Laser Cut Fiberglass/Diallyl Phthalate Molded Part

are reamed by hand. The contoured part is 5.0 mm thick and was processed in a similar manner, except that the focusing lens was repositioned continuously during laser cutting to maintain position with the top surface.

Fiberglass-Reinforced Phenolic

Two products molded from 91LD, a fiberglass-reinforced phenolic, have been laser cut. The part shown in Figure 17 requires removal of the center section molding core (a result of the compression molding process) from the outside of the molded part. The part is about 200 mm long and the material thickness at the gate area is 1.5 mm. It is cut using 800 W at 3000 mm/min, and cycle time is about 20 s. The remaining char can be removed by vapor blasting.

The other part (Figure 18) requires a serial number to identify each part from the mold through subsequent machining operations. Ink stamping or vibratory pencil marking is not suitable to survive the final operation of vapor blasting. The 6-mm-high characters are scribed about 1 mm deep, and the four-digit number

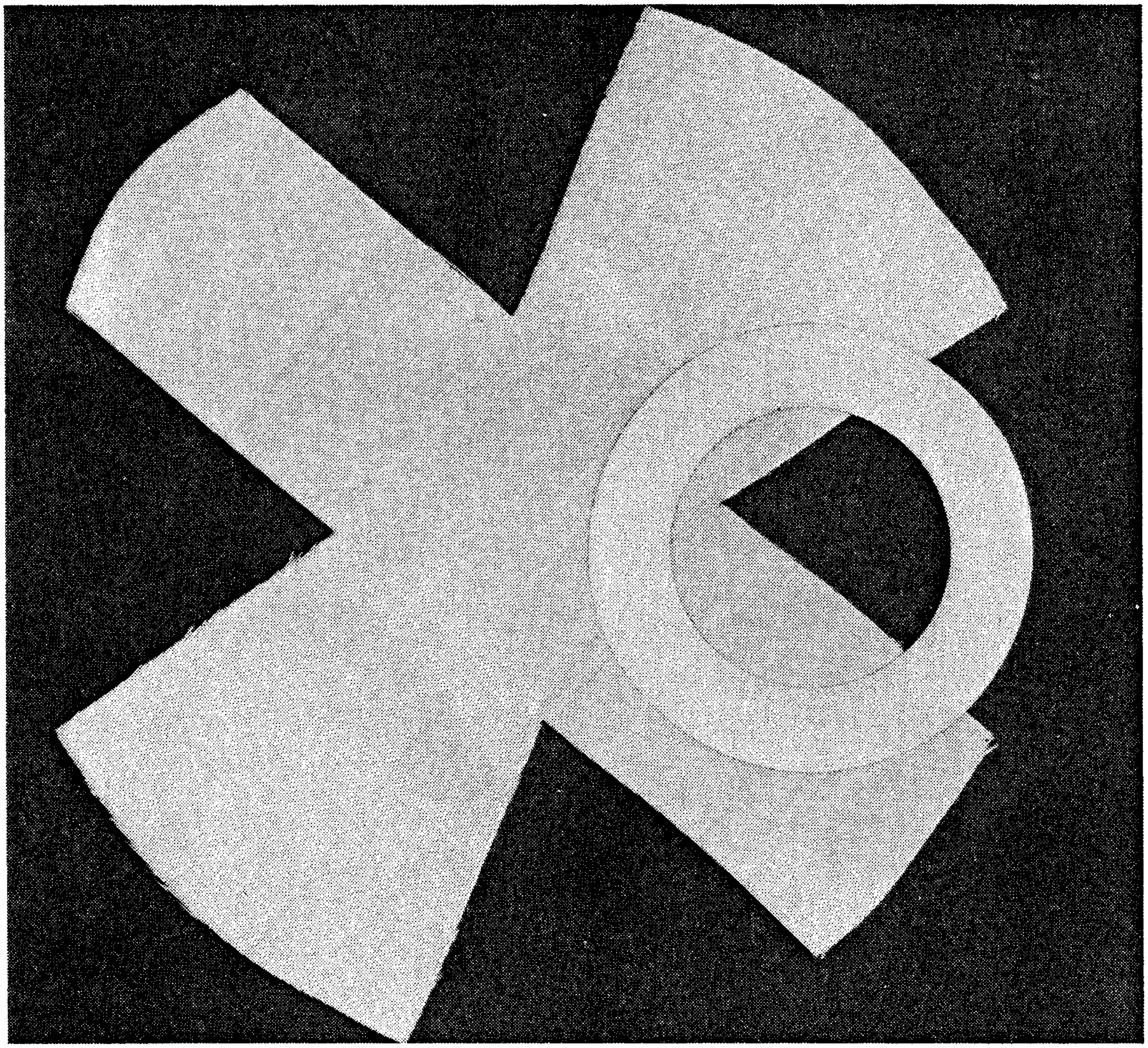


Figure 14. Typical Shapes Laser Cut in Kevlar Cloth

requires a total time of 20 s. Scribing power is 200 W, and speed is 1500 mm/min.

Nylon/Epoxy Laminate

Three sheets of nylon/epoxy prepreg are compression molded into a 1.3-mm-thick laminate which is 170 mm wide by 980 mm long; the laminate then is formed into a 294-mm-diameter cylinder. The formed laminate is rotated at 10 rpm under the beam to cut both sides of the part to establish the width. The fixture then is pinned into two positions, one to cut the length of the part and another to cut a keyway slot (Figure 19). The rotation cutting speed is equivalent to 9000 mm/min, and the fixed position speed

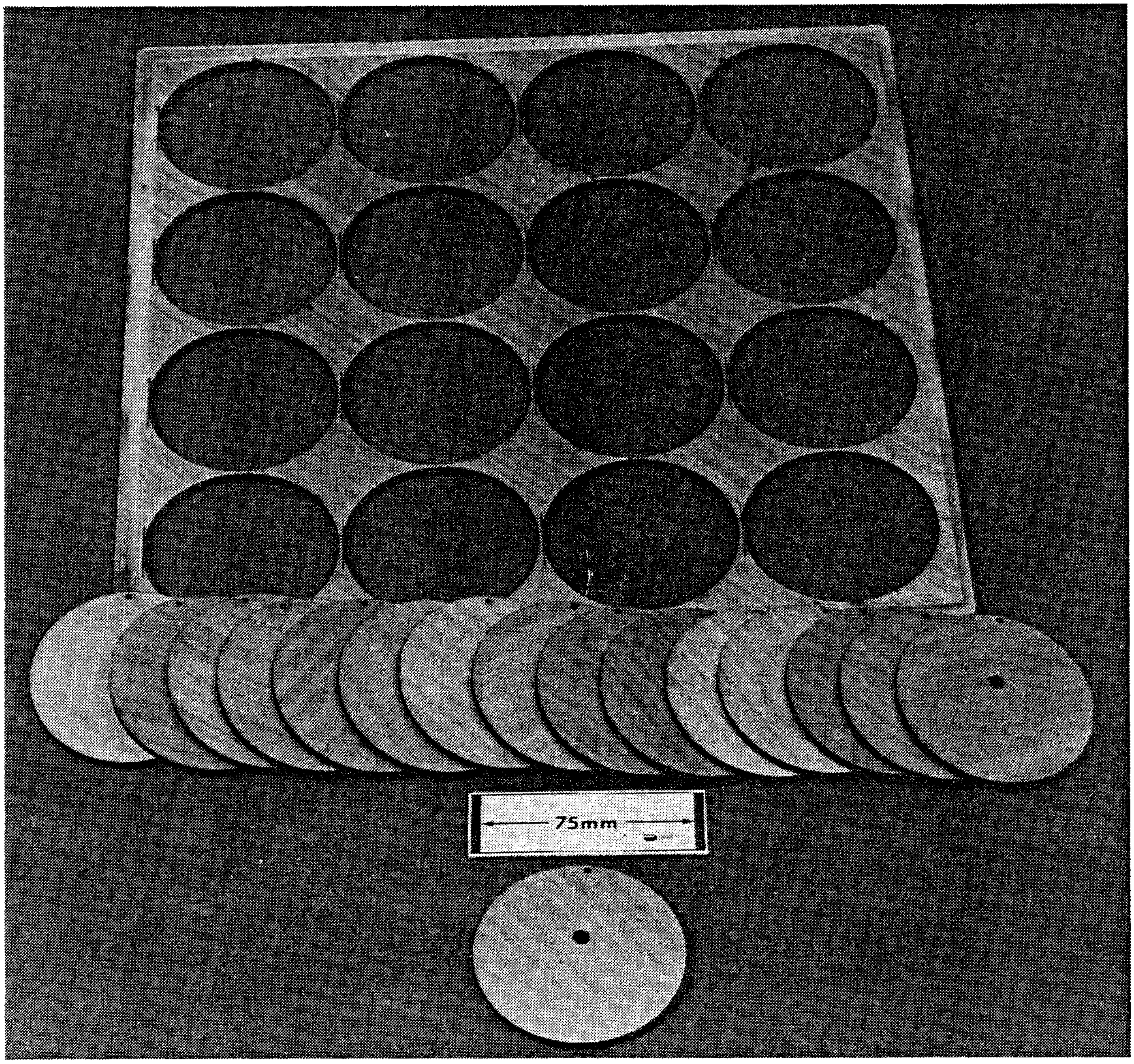


Figure 15. Kevlar/Epoxy Part Cut With Laser

is 3000 mm/min; 100 W of power is used. No char is developed, and the edge is fuzz free and not delaminated, eliminating the delamination problem existing with conventional machining methods.

Ceramics

Fired ceramic substrates made from both 96 and 99.5 percent alumina have been laser drilled and contour cut. Shown in Figure 20 is a 0.7-mm-thick substrate which contains 150 holes

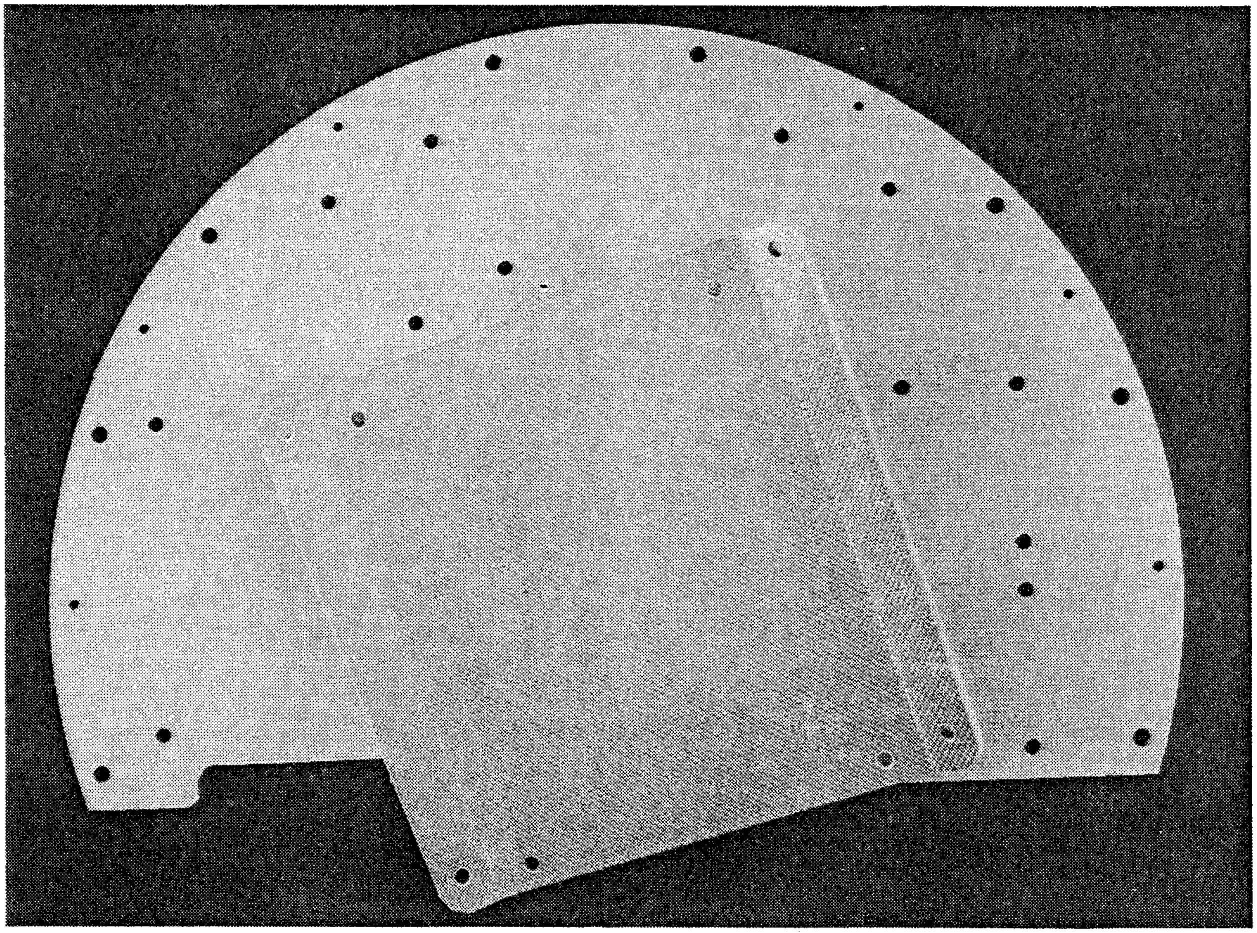


Figure 16. Typical Laser Cut Kevlar/Epoxy Products

0.7 mm in diameter, 12 holes 7.3 mm in diameter, and 6 rectangular cutouts. The material is cut at 150 mm/min with 800 W and a duty cycle of 3 ms on, 42 ms off. A gas jet of argon is supplied coaxial with the beam through a 1.3-mm-diameter orifice. Cycle time to cut the entire pattern is 8 min.

The keyboard entry of data and the subroutine call capability of the Vega control system has reduced response time to design changes from weeks and months to hours and days. The laser cutting process replaces an ultrasonic operation which would have required an estimated 8-h cycle time per substrate.

A second ceramic application requires pocket contouring instead of cutting through the material. A 17-mm-thick fired ceramic block had been fired with wire channels and electrical component cavities molded in place. Design changes required adding additional channels and pockets up to 3.8 mm deep. Laser cutting was

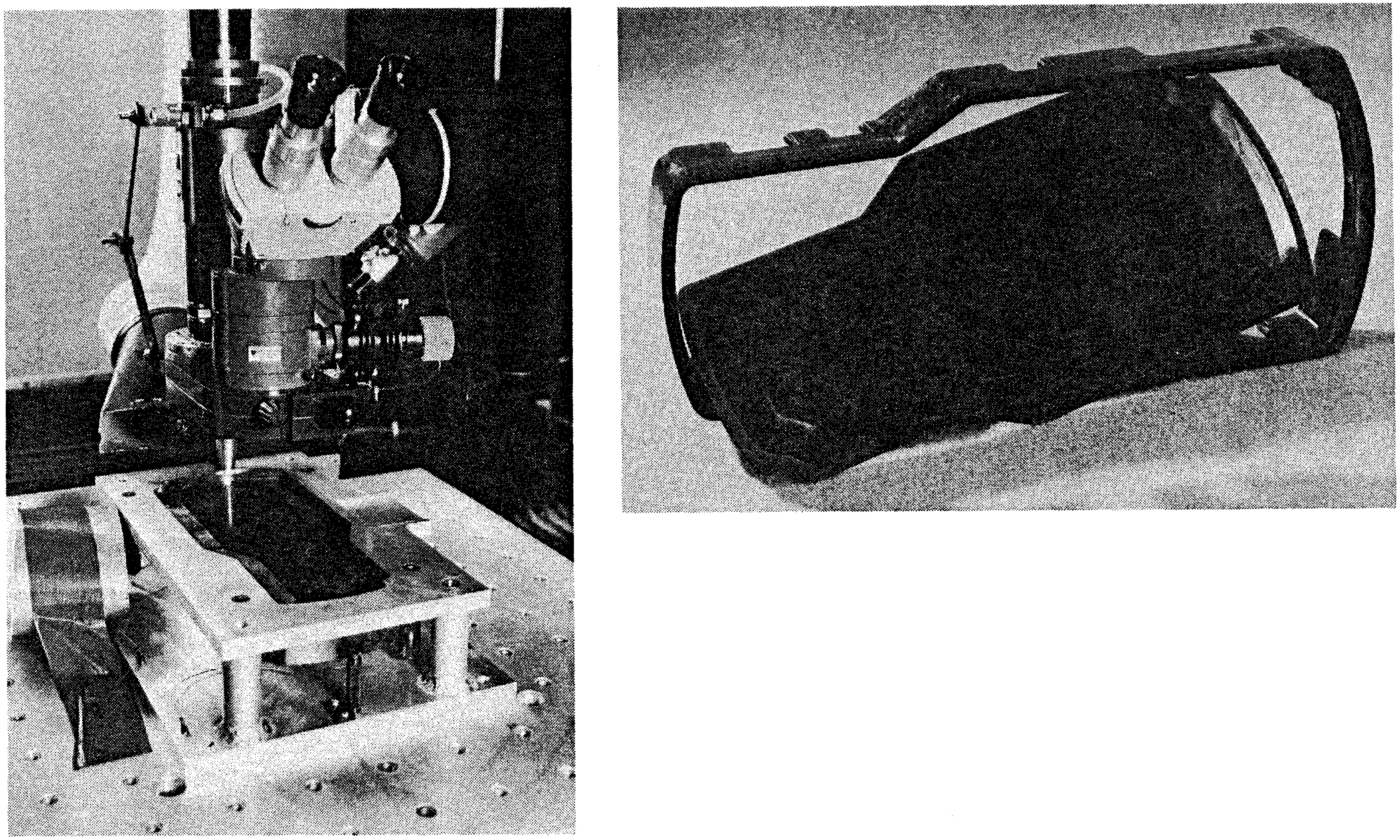


Figure 17. Fiberglass-Phenolic Part With Center Molding Core Removed by Laser Cutting

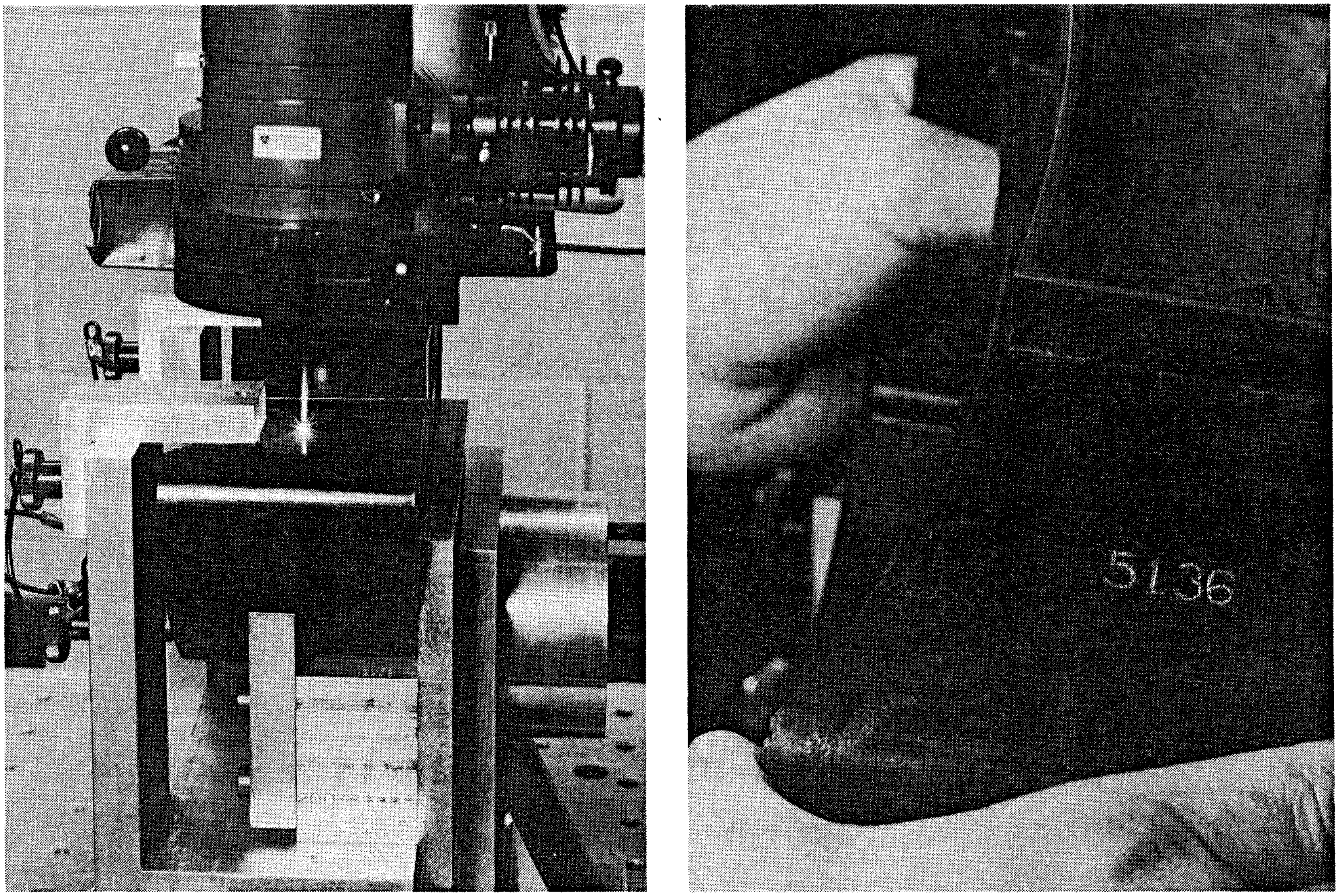
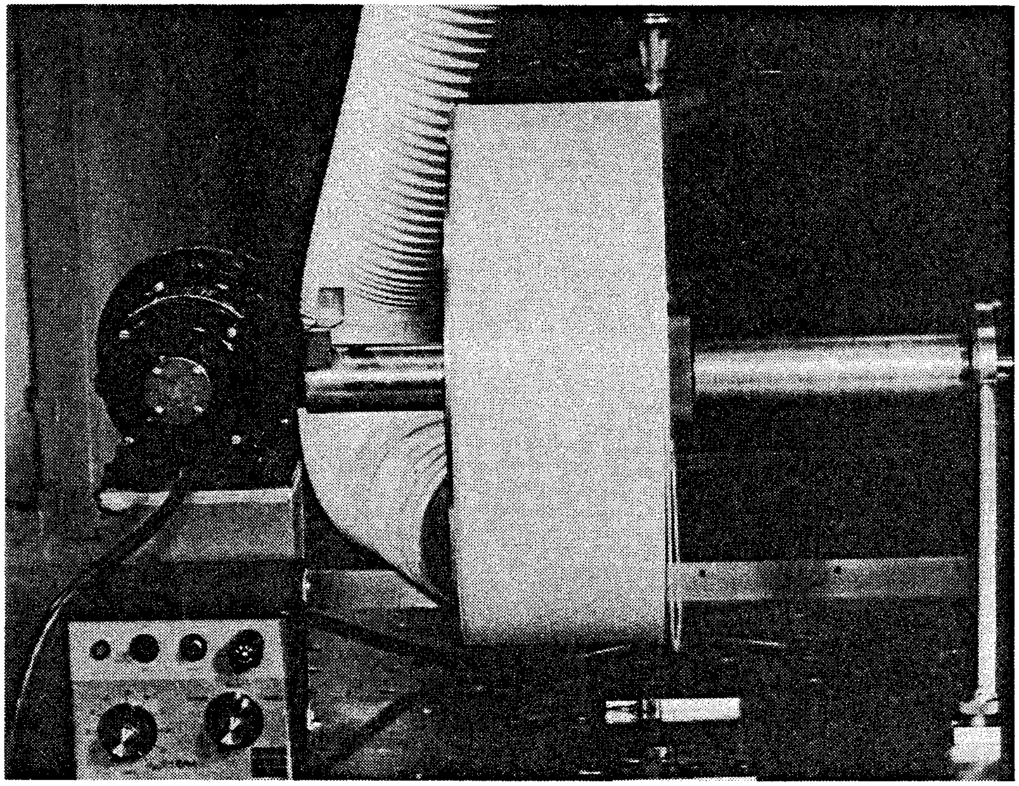


Figure 18. Fiberglass-Phenolic Molded Part With Laser Cut Serial Number



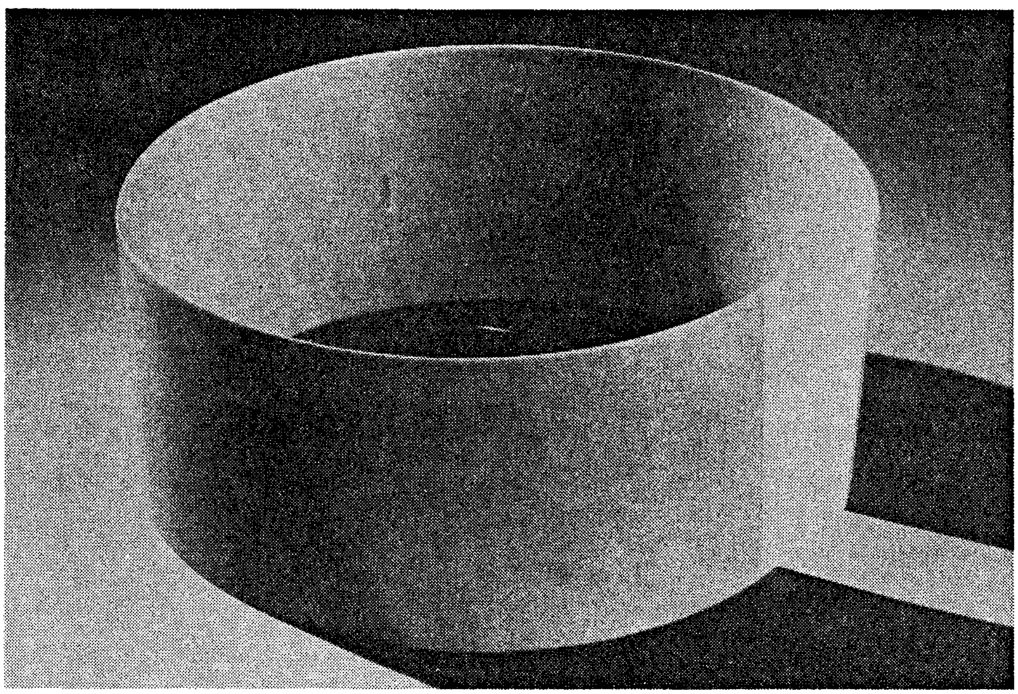


Figure 19. Nylon/Epoxy Laminate With Laser Cut Features

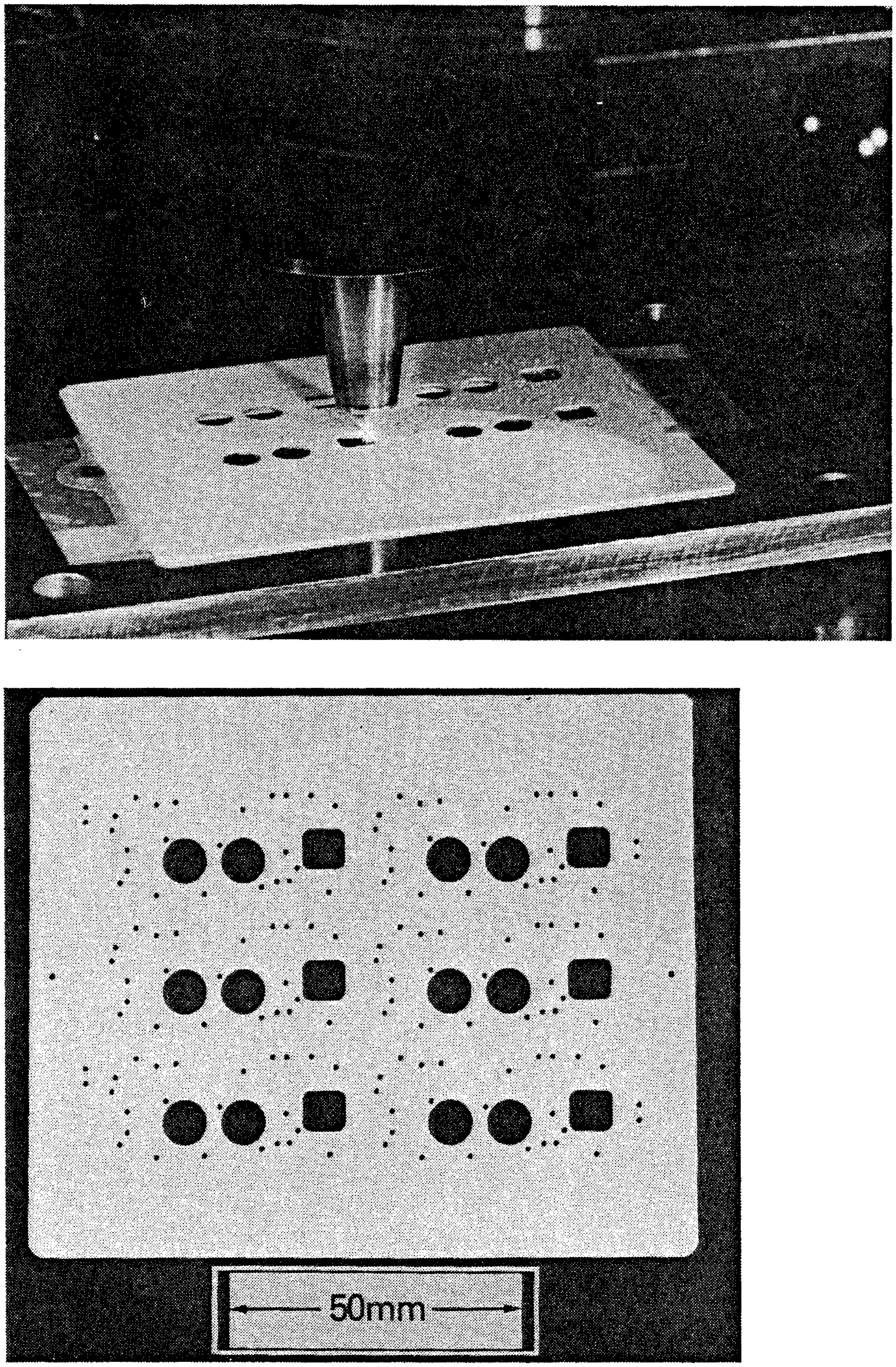


Figure 20. Ceramic Substrate Laser Drilled; Cutting Time About 8 Min

used as an interim process to allow alteration of existing parts (Figure 21). Cutting conditions were as above, except the duty cycle was changed to 4 ms on, 100 ms off. Two and three passes were required, depending on the depth, and the debris that remained in the pocket was scraped away with a sharp tool. A nonconductive black residue remaining in the cavities can be removed with a diamond-tipped rotary deburring tool. Laser cutting time was about 30 min per part, as opposed to a diamond grinding process which required 8 to 12 hours.

Another ceramic application also was a rework operation. A clearance notch had to be added to the inside diameter of several thousand 6.4-mm outer diameter by 1.1-mm thick ceramic washers (Figure 22). A 0.7-mm-thick ceramic substrate was laser cut to serve as tooling by cutting 50 holes to position and hold the washers. Cutting time for the washer rework was about 1 s per part, with 800 W of power in the pulsed mode of 3 ms on, 42 ms off.

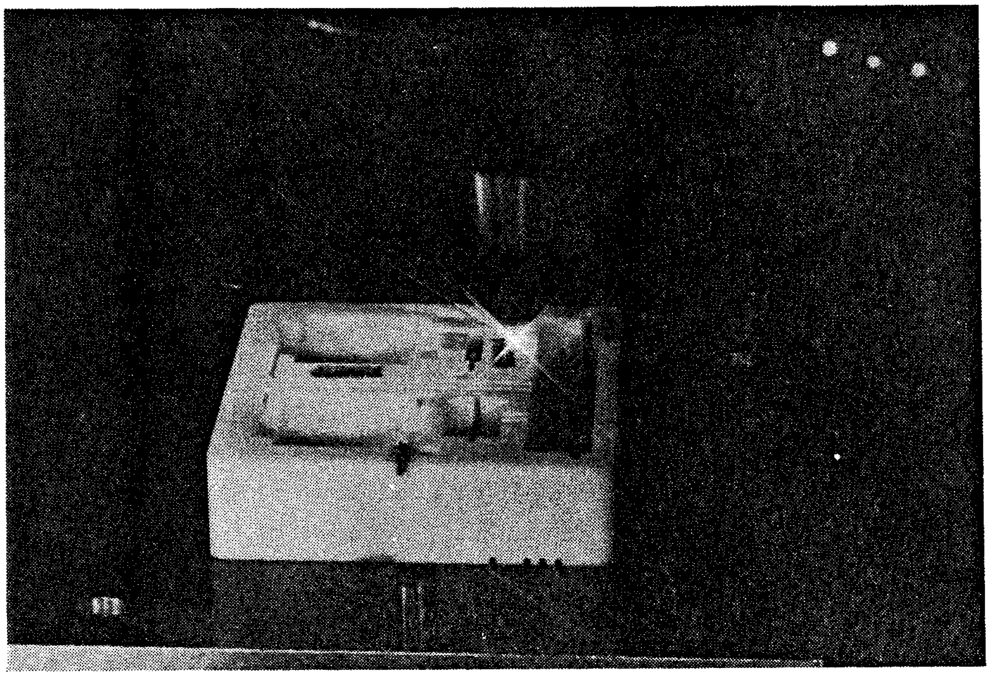
Polymethylpentene (TPX)

A cylindrical part made from TPX measuring about 200 mm in diameter has been injection molded. The material is injected into a runner reservoir which feeds the mold cavity through a 1.0-mm-thick ring gate around the entire inner diameter. The gate has been laser cut using 100 W at 3000 mm/min and a cycle time of 20 s per part. The quality of cut may not permit cutting to the finished dimensions, because the material melts and reflows easily. Development will continue, using a pulsed mode in an attempt to reduce material damage.

Laser Cut Tooling

Techniques for laser cutting two different types of disposable tooling have been developed. The first involves cutting a 0.03-mm-thick roll of material, called Tedlar, which is used as a release sheet to separate layers of prepreg prior to a lamination process. The square sheets measure 380 mm per side and have four 7.0 mm holes for alignment purposes during stacking. The roll was rough cut into squares, stacked 20 sheets thick on a fixture, and laser cut. A continuous pulse schedule of 1 ms on and 3 ms off, 200 W of power, and a speed of 3000 mm/min were used to cut the material. Cutting time was 45 s/cycle. The edges fused together much like the gummed edge of a tablet, which, rather than being a problem, eased handling and storage.

Another disposable tool was fabricated from 6.35-mm stock acrylic (Plexiglas) which functioned as a combination positioning template/holding fixture to fabricate a structural support assembly (Figure 23). The purpose of the tool is to locate



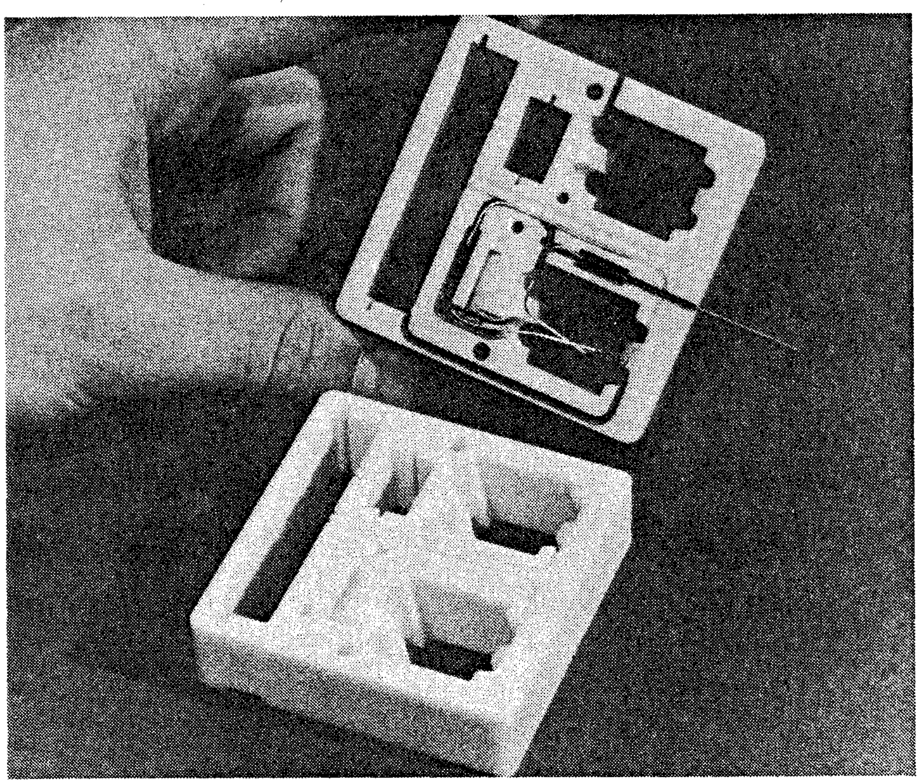


Figure 21. Ceramic Block Modified by Adding Laser Cut Channels

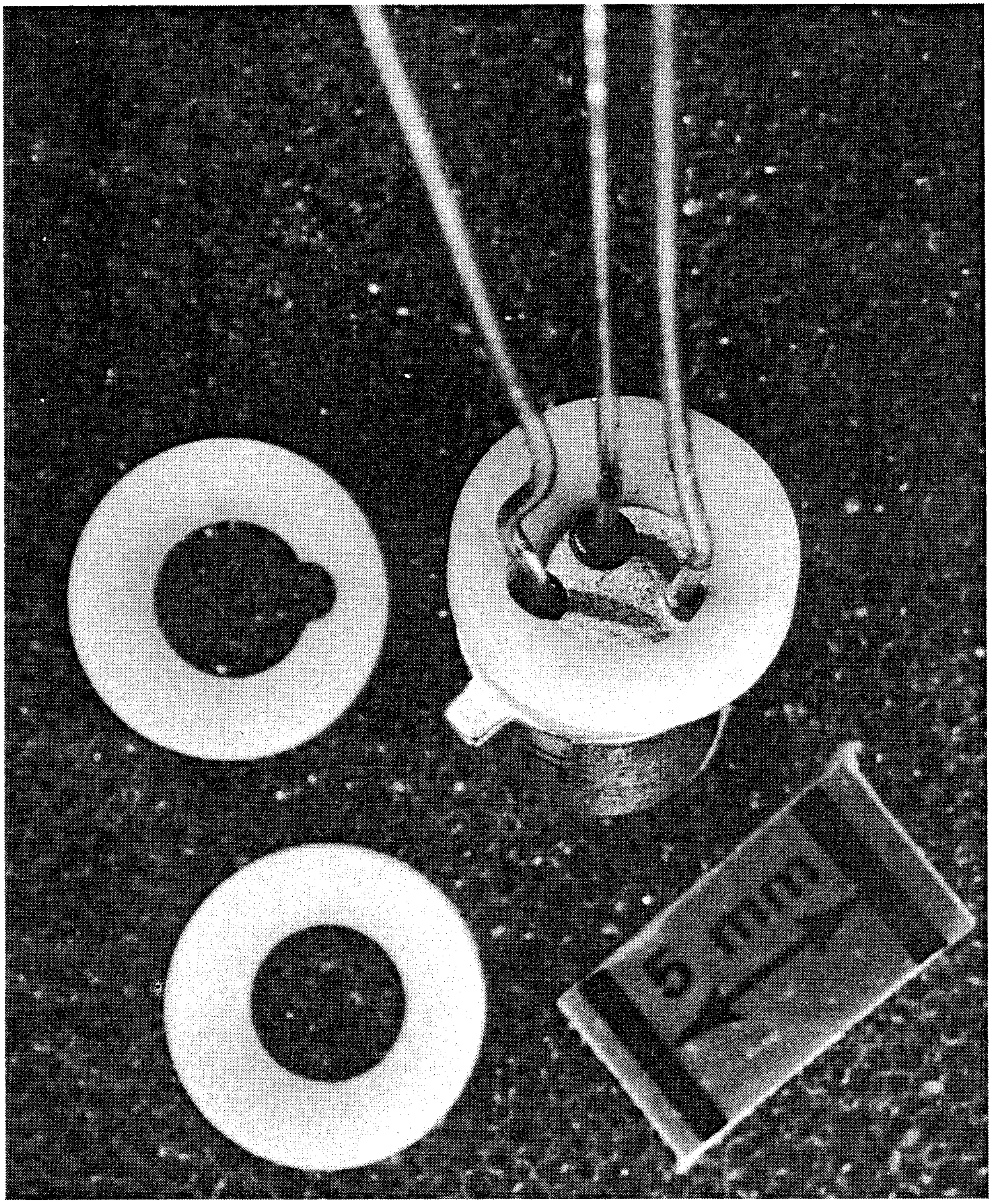


Figure 22. Ceramic Washer Reworked by Laser Cutting Notch; Cutting Time About 1 s

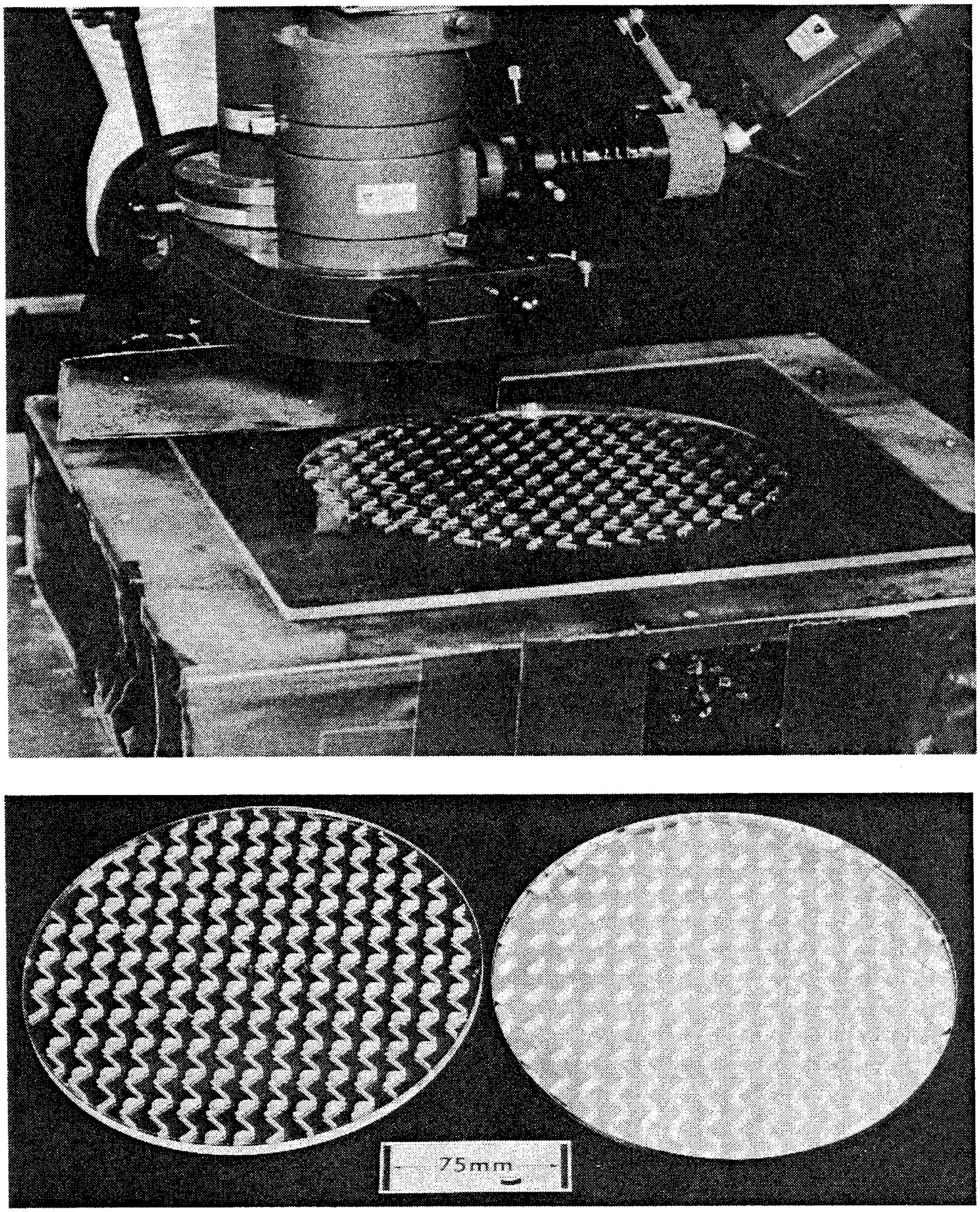


Figure 23. Laser Cut Acrylic Positioning Template

0.13-mm-thick stiffening strips of stainless steel on a 0.26-mm-thick bottom plate for a spot welding operation. The narrow kerf width produced with the laser permitted this template to be made as a single unit, rather than the unsuccessful multipiece aluminum tooling originally built. Half moon cutouts in the Plexiglas permit access of a welding electrode for the spot weld operation at each tab. Power was 300 W at a speed of 3000 mm/min and a cycle time of 5 minutes per tool. Handling fixtures of the same Plexiglas also were laser cut for storage of the strips prior to assembly.

ACCOMPLISHMENTS

Various thicknesses of more than 40 different thermoplastic and thermosets have been categorized and laser cut to establish the feasibility of this type processing. Material properties from this cutting technique have been compared to machined surfaces, and little or no evidence of any detrimental effects has been seen. Cutting power, kerf widths, and edge tapers have been established for most of the materials. A gas nozzle has been developed to allow more flexibility in orifice size selection and easier alignment of the opening coaxial with the beam.

Probably the most significant result of this project is the development of several applications that prove the laser to be a practical method for processing plastic materials. At least five of these applications are currently supporting or are planned to support production activities. These applications include cutting a nylon/epoxy laminate, a fiberglass/phenolic molding, a fiberglass/polyester rod, an acrylic material, and a ceramic substrate. In all cases, the laser provides either a higher quality product (nondelaminated, fuzz-free edges), a product that would be very difficult to manufacture in any other way (acrylic position template), or a more efficient technique to replace existing methods (ceramic drilling). This cutting technique offers an alternate method to removal of plastic material by conventional machining tools which will provide further applications. Some advantages of laser cutting are as follows:

Speeds to 3000 mm/min can be attained;

Fixtures are cheaper with this noncontact method because fixtures generally can be made from aluminum, less rigidity is needed, as cutting tool forces need not be absorbed, and restraining the part from tool force deflection is not required;

No cutting tools are required, which is particularly significant when cutting abrasive materials such as Kevlar/epoxy or ceramics; and

Operating cost generally is as low as a few dollars per hour.

The method does have some disadvantages and limitations, as listed below:

Thickness is limited by depth of focus of the focusing lens and the type of material processed (Kevlar/epoxy to 9 mm);

Most thermosets and some thermoplastics are charred when laser cut, which requires at least a solvent wipe and perhaps a vapor blast operation for char removal;

Initial cost of an N/C high power laser cutting system can exceed $250,000, and replacement of mirrors and lenses, which usually survive for many months, typically are several hundred dollars each; and

Edge tapers of up to 0.2 mm per side, depending on material and thickness, result in nonstraight sides.

FUTURE WORK

Additional work is planned in the following areas:

Pocket cutting in materials other than Kevlar/epoxy;

Material removal by rotating the work under the beam and slicing a layer of material (similar to a lathe operation);

Evaluation of the effects of gas flows on pulse shapes for the various power ranges to gain better control of the laser energy;

Determination of the effect on cutting performance for ring mode versus Gaussian mode, type of cover gas, and nozzle design and orifice size;

Improvement in hole cutting techniques;

Continued investigation of further applications;

Refinement of cutting TPX material to reduce material effects; and

Cutting typical shapes in cylinders and cones to determine flexibility in cutting contours.

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BDX-613-2476

LASER CUTTING PLASTIC MATERIALS, R. A. Van Cleave, Topical, August 1980.

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