Applications of High Power Lasers

Ralph R. Jacobs

Chairman/Editor

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APPLICATIONS OF HIGH POWER LASERS

Volume 527

Conference Committee

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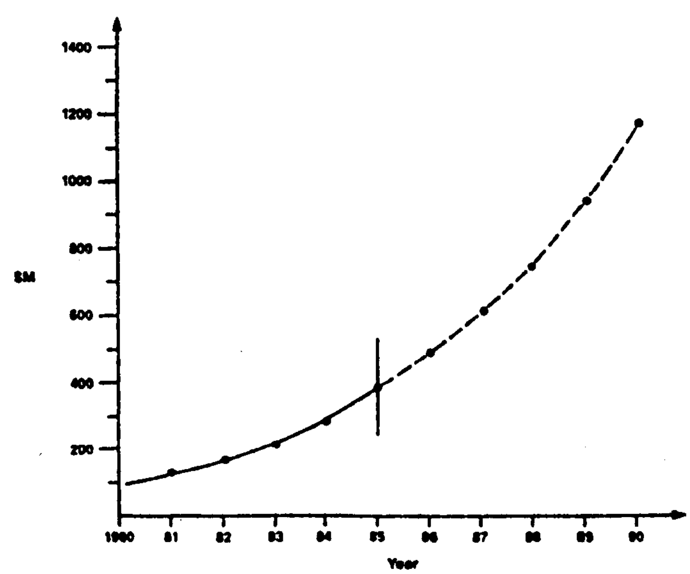
Ralph R. Jacobs
Spectra Physics, Incorporated

INTRODUCTION

High power lasers are finding acceptance in a broad spectrum of materials processing applications. As testimony of this acceptance, the figure shows laser system sales during the decade of the 1980s.

LASER SYSTEM MARKET FOR MATERIALS PROCESSING



The estimated growth rate from 1985 to 1990 is 25% per year. As seen in the figure, the 1985 market should approach $375M; the 1990 market size is estimated to be about $1200M.

Such strong appeal of lasers is due to their cost effective performance in a wide variety of materials processing applications. Accordingly, this critical review features papers that focus on the eight generic applications areas for high power lasers: cutting, welding, heat treating, drilling, cladding, scribing, trimming, and marking. Additionally, each of the four sessions is opened by one of the following general presentations: overview on the applications of high power laser systems, economic justification of industrial laser applications, overview of laser system integration, and the design of parts for laser processing.

Every author is to be commended on the excellent and comprehensive account for his particular topic. Taken in their entirety, these conference proceedings represent a snapshot of the state of the art in the various high power laser applications. The proceedings also help outline the "shape of things to come" in materials processing with lasers.

The chairman is indebted to Jim Hopkins and Tom Liolios of the Industrial Laser Division at Spectra-Physics for valuable assistance in the organization of this conference.

Ralph R. Jacobs
Spectra Physics, Incorporated

APPLICATIONS OF HIGH POWER LASERS

Volume 527

Contents

Laser Beam Processing -- A Manufacturer's Viewpoint

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Abstract

The ability of continuous wave high power CO_2 Lasers to generate power densities of up to 10^8 watts Cm^2 makes them useful for a variety of material processing tasks. Deep-penetration laser welding, high precision laser cutting, surface heat treating by martensitic phase transformation hardening, and surface alloying are the four major areas which are accepting laser processes.

This paper will cover these four primary laser applications existing in production within a variety of industries. Each individual area will be discussed in detail, describing the advantages and various parameters to achieve maximum productivity and quality. Beam configuration, integration, and manipulation are included also. Production examples of laser welding, cutting, surface hardening and surface alloying, are examined to demonstrate the laser processing advantages.

This paper also reviews the present and future status of the laser metalsworking industry in respect to the growth potential, research and development, manufacturers responsibilities etc.

Overview of laser process and primary applications

The laser provides a method for developing unique ways of material processing on the production line and is gaining wide acceptance by the metalsworking industry. The two major advantages of using a high power CO_2 Laser are the high speeds of operation and the localization of the process. Additionally, wear or corrosion resistant properties can be enhanced and applied precisely where required on components. Simple tooling can be used in laser processing because of its non-contact energy transfer form. Also, the process can be accomplished with high repeatability and reliability. For most applications, post-process machining and re-finishing is unnecessary. In some cases, laser processing can even save energy compared to conventional processes.

The primary applications of laser processing in production are cutting, welding, surface hardening and surface alloying or hardfacing. Laser cutting is adopted mainly in fabrication shops for cutting sheet metal up to one-half inch thick. The narrow kerf width, minimum heat affected zone, great accuracy and flexibility make the laser cutting process a valuable method to compete with oxygen and arc cutting processes. Laser welding is utilized in components up to one quarter inch thick. The minimum heat input and distortion, higher production rate and quality make this new welding process very attractive for various component manufacturers. Laser surface hardening of iron base alloys generates a hardened surface which provides increased wear resistance and fatigue strength. Because of its low heat input, ease of automation, ability to accomodate inaccessible areas, complex geometries and energy savings, this laser process has already demonstrated its success on the production floor. The surface alloying and hardfacing processes are still in the testing stage. Several major advantages such as low usage of alloying material, low distortion, minimum dilution and possible control of microstructure, strongly implies that this process will be successful in the industry in the near future.

Laser cutting

High power CO_2 Laser cutting is a process by which material is removed by means of melting and vaporization. This process can be accelerated if a gas jet is directed onto the key hole area as an assist cutting jet -- it is usually directed coaxially to the laser beam. Laser cutting of sheet metal with its significant advantages over nibbling and punch has been recognized by industry and has made it an established process. Figure 1 shows laser cutting of different materials and thicknesses versus speed with a 1200 W CO_2 Laser.

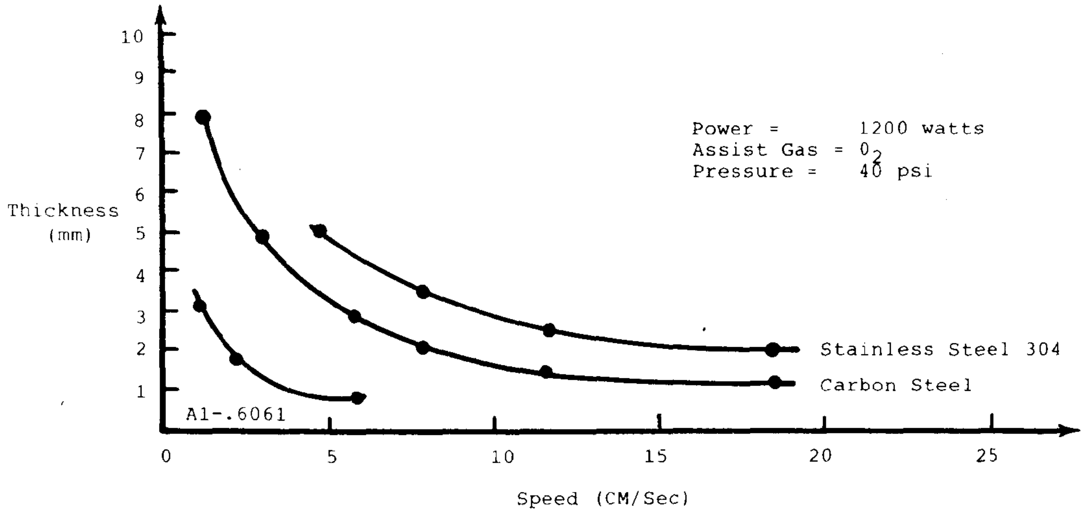

Figure 1

The very high cutting quality and flexibility are the strong points of this process. The accuracy of parts produced by the laser cutting system is dependent upon the accuracy of the parts or beam handling equipments. Usually, the tolerance can be controlled to less than 0.1 mm for a 6 mm thick plate. The straightness of the cutting edge is a function of the power and speed. When all the parameters have been optimized, there should be about one degree or less taper along the edge.

The kerf width and heat affected zone along the cutting edge are extremely narrow and small. The comparison of the kerf width and the heat affected zone (HAZ) of material among lasers, oxygen, and plasma arc cutting processes is shown in Table 1.

Table 1

The kerf width and HAZ of Laser
Oxygen and plasma cutting of low carbon steel

Thickness	10 mm		6 mm		3 mm	
	Kerf Width	HAZ	Kerf Width	HAZ	Kerf Width	HAZ
Laser	0.4 mm	0.075 mm	0.3 mm	0.05 mm	0.3 mm	0.05 mm
Oxygen	1 mm	0.8 mm	0.9 mm	0.6 mm	0.7 mm	0.5 mm
Plasma	3.2 mm	0.5 mm	3.2 mm	0.4 mm	3.2 mm	0.3 mm

Recent experiments have shown that slight vibrations or unsynchronized movements of the axes of the NC equipment will increase the edge roughness of the cutting. Programs or special pattern designs with sharp corners and tight turns will increase the heat input at local areas resulting in excess burning. Smoothly run NC equipment and proper pattern designs are two new factors needed for a successful laser cutting process.

Examples of industrial cutting applications will be discussed, along with the reasons for selecting laser processing in those instances.

Laser welding

Multikilowatt Laser welding is a process of joining metal by the fusion of a deep, narrow, parallel-sided seam. The process is energy efficient and capable of fabrication with minimum distortion. Furthermore, this capability is afforded without the generation of any harmful x-rays in the air.

The laser has demonstrated its capability for high-speed welding in thin sheet steel as well as narrow welds in thicker materials. The penetration profile exhibits the characteristic high depth-to-width ratio which is due to the laser power concentration. Laser welding has produced quality weldments in many metals and alloys. In certain materials, the mechanical properties of laser welds have exceeded those of the present material. Simultaneous increases in yield strength and impact properties have been reported. Because of the high welding speed and narrow fusion zone, the HAZ is also narrow. For example, a 6.5 mm thick 304 stainless steel weld made at 5 KW and 21 mm/sec has a HAZ which extends only 0.8 mm into the parent material on each side of the fusion zone.

Plasma is formed by ionization of shielding gases and metal vapor emitted from the keyhole during laser welding, and it will absorb some of the laser energy. A plasma disruption device can be adapted to minimize this absorption.

In partial penetration laser welding, there is a tendency for root porosity to occur, but by proper selection of the ultimate welding parameters, this problem can be minimized. Fit-up of the parts is another important factor for successful production laser welding. For butt and lap joints, it is best to have the gap along the seam or between the lap to be less than 5% of the thickness of the plate. Excessive gap will lead to either heavy undercut along the sides of the welds or no welding at all. Generally speaking, if a welding application requires any of the following criteria, then laser welding may be the best process. 1) High precision joint 2) Minimum dimensional change 3) Minimum change in material properties 4) Weld cannot be performed by any other process 5) High production rate 6) Joint magnetic material.

Examples of production welding applications will be described, along with the reasons for selecting laser processing.

Laser surface hardening

Laser surface hardening of iron base alloys uses the laser energy to heat the surface above the phase transformation temperature while allowing the part to self-quency by its mass. The critical parameters for laser surface hardening are: 1) power density, 2) energy distribution, 3) coating, 4) cooling characteristics of the parts. For laser surface hardening a uniform intensity beam is desired. Sometimes this can be obtained by defocusing the laser beam from a lens or mirror. In many cases, when a special geometry and pattern are involved, a laser beam integrator is required to match the pattern and insure the uniformity of the beam in the pattern. One such method is a segmented mirror with a fixed shape. The other, which offers greater flexibility, is a one or two axis scanning device. The effective material absorptivity during the process is another important factor. When the metal surface is cold, a small percentage of the laser beam can be absorbed. Therefore, a uniform coating is needed as an absorbing surface layer. Black low cost spray paint is often chosen over phosphate or graphite coating because of its moisture resistance and ease of application and removal. The uniformity of the coating is essential for laser surface hardening production applications. The optimum thickness of the coating is around 0.02 mm to 0.04 mm. Extremely thin coatings will reduce case depth. Excessively thick coatings will cause both shallow case depth and surface melting. Figure 2 shows typical surface hardening data for 1045 Carbon steel.

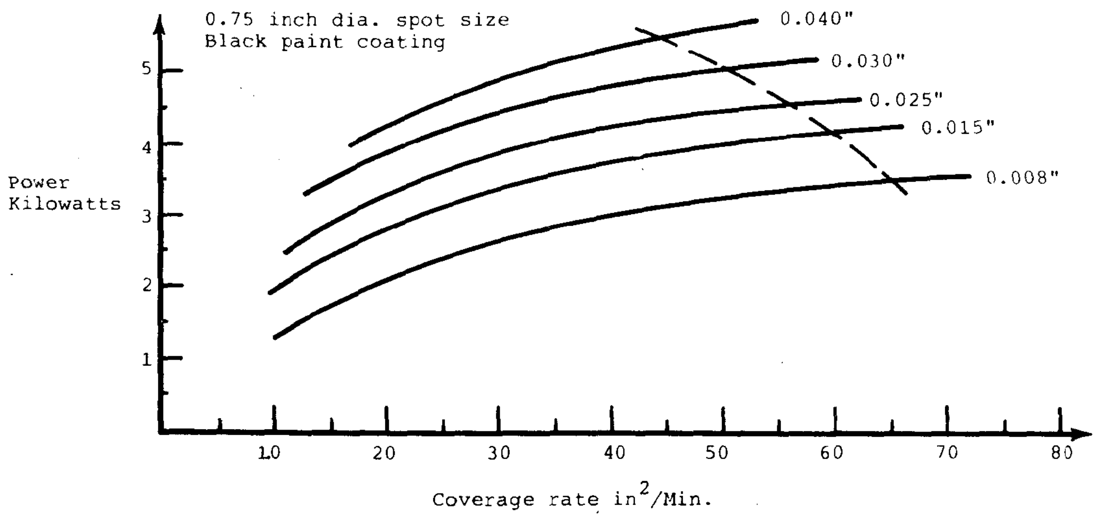

Figure 2
Laser surface hardening of 1045 steel with different case depth

The major advantages of using a laser for surface hardening are 1) lower distortion on the parts, often eliminating finish grinding, 2) energy savings, because it can selectively harden the desired area, 3) may allow the use of lower cost material, 4) increased production rate because of rapid heating and cooling cycle time, 5) hard to reach places may be heat treated by bending the laser beam with mirrors, 6) complex geometries can be heat treated with NC equipment and Robots. A good example which is in production is that of laser surface hardening for fatigue strength the ball race seat area on a light weight truck axle housing. Previously, the induction heating process introduced high distortion and low hardness because of gross heat input. Additional post heat-treat machining was required to meet the final dimensional tolerance (Figure 3).

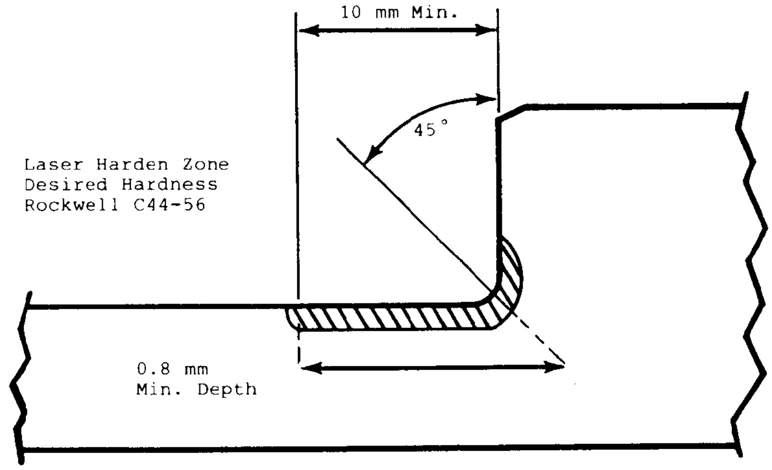

Figure 3
Surface hardening specification of truck axle housing
(material carbon steel 1035)

A 5 KW laser system utilizing a segmented mirror beam integration system is now used in this application. The only measurable dimensional change is about 0.02 mm increase in diameter of the hardened zone. Fatigue testing has shown about five to eight times longer life compared to unhardened parts. The advantages of laser processing in this application are: 1) material cost is reduced, 2) post-heat-treat machining is eliminated, 3) process speed is increased, 4) product quality is improved.

Laser alloying/hardfacing

Laser surface alloying or hardfacing is employed when localized wear or corrosion resistance is required on a part which does not have these properties. Surface alloying or hardfacing alloys are usually cobalt, nickel or iron base, and various carbide materials which are commercially available, such as rods, wires or powders. Conventional methods for example, flames, Arc welding or plasma, require excessive heat input and may cause distortion. Additional machining, which is usually needed when using conventional methods, will waste labor and expensive alloys. A fully automated laser system associated with the controllability of the heat will have the following advantages: 1) optimization of coating geometry so that additive usage and distortion are reduced, 2) because of the reduced distortion and stress, the laser process will save energy by allowing lower preheat temperature to be used which sometimes is an essential step to prevent cracking and porosity defects, 3) minimize melting of substrate so that dilution is reduced, 4) fast heating and cooling rates which offer possible control of microstructure or prevention of the breakdown of the carbide materials.

A manufacturing company has a requirement to surface alloy with a cobalt base alloy for metal wear resistance. Manual gas tungsten arc welding process with filler wire is adopted in production at the present time. Human factors, welding defects, distortion, high dilution, long machining time, short tool life and material waste up to 50% of the very expensive alloy are the motivations for them to switch to laser processing.

Three different thicknesses of power coating (1.38 mm, 1.77 mm and 2.36 mm) were thermal or plasma sprayed on 3 inch square carbon steel stainless steel coupons and the actual parts. However, these processes can only mechanically bond the powder to the base metal. A 7.6 mm x 15.2 mm rectangular laser beam was needed to produce a metallurgical bond. Because of the fast heating and cooling of the parts, the depth of the melting from the surface and the dilution of the coating and the base metal were easily controlled. A preheat and post-heat procedure was adopted to prevent the cracking and pinhole defects.

Because of the very low heat input and low distortion to the parts, a lower preheat temperature on the parts is also important. Otherwise, localized defects can occur. Part of the test results are listed in Table 2. Some post-treatment machinery is required because the final products need a flat machine finished surface. The laser processed parts need removal of 0.4 mm of the material as compared to 1.6 mm for TIG process.

Table 2. Laser Surface Alloying With Cobalt Base Alloy

TYPE	COATING THK. (mm)	POWER (KW)	TRAVEL SPEED (CM/min)	PREHEAT TEMP. (C°)
1	1.38	5	25.4	150
2	1.77	5	10.2	230
3	2.36	5	5.1	320

Base Metal: 316l stainless steel. Coating material Stellite 6 powder

Status of laser metalsworking industry

The potential of the laser metalsworking market is tremendously high. For a conservative estimate, it represents about 8-10% of the total metalsworking machine tool market if lasers were fully accepted and utilized for those applications where they offer real production economic advantage. The near term metalsworking laser system market has shown a market size of approximately 25 million dollars in 1980 growing to 100 million dollars by 1985. This annual growth rate of over 35% demonstrates the laser metalsworking market segments are among the most rapidly growing in the material process field.

From the laser processing point of view, there are still many factors concerned with the welding, cutting, surface hardening and hardfacing which are not quite understood. Additional research and development are needed to refine these points. Laser assist machining and laser welding with filler metal are also very interesting concepts which need more fundamental exploration. NC table and parts handling equipment are sometimes the drawback of the laser process. Therefore, the table and parts handling equipment manufacturers need to do more development so that the laser and its associated equipment can advance together to service the industry needs.

As a laser machine manufacturer, our present priorities are:

1) To continue to advance the state-of-the-art in available laser tools, particularly aimed at improving the ease of operation, reducing capital and operating costs, and improving productivity.

2) To educate the industry that the laser machine is a safe, clean, powerful tool which can help them solve tough problems in the production line.

3) To assist in the set-up of uniform worldwide laser and process standards.

4) To help industry make a smooth transition from the testing lab to the production line.

The laser metalsworking industry has a very bright future.

Why a laser cutting system: a comparison with more conventional cutting systems

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Abstract

Marketing a laser cutting system usually requires a comparison with plasma-arc cutting, Wire EDM (Electrical Discharge Machining), and oxygen-acetylene flame cutting. Each system has its own advantages and disadvantages, however because of its versatility and adaptability, laser is becoming the more sought-after system.

A new company

U.S. Amada was formed in 1972 as the United States distributorship for Amada Company, Ltd. in Japan. The parent company began in 1946 with a single bandsaw and is today the second largest machine tool manufacturer in the world. The primary type of equipment produced is geared for precision sheet metal working.

Through the years, Amada has been known for bringing innovation and insight to old forms of processing. Two examples of this would be our press brakes, which bend material using force applied from the bottom of the part instead of the top as is traditional, and the turret punch press, which has a closed frame (Bridgeframe) instead of the more familiar "C" shaped or open frame.

A new product

In 1982, Amada began marketing a laser cutting system. This system combines an Amada material movement table with a Spectra-Physics laser. At that time, and still today, the ideal machine would combine a laser with a turret punch press. However, upon testing such a combination, it was found that the vibration of the punch consistently upset the alignment of the mirrors, rendering the laser virtually useless until an alignment was performed. This problem, even seen in combination machines of recent manufacture, led engineers at Amada to the conclusion that the only way they could provide a machine possessing the same reliability as others bearing the name Amada would be to build a stand-alone laser. In other words, a machine whose only tool for cutting material would be a beam of light.

In marketing this system, it became obvious that we were going to be competing with several other types of cutting systems on the market. Specifically, oxygen-acetylene, plasma-arc and wire EDM (Electrical Discharge Machining). In order to compete with these systems, we naturally had to gain a good understanding of their function, abilities, faults and potentials. It is the purpose of this paper to establish these variations in laymen's terms.

Oxygen-acetylene

In actuality, oxygen can be combined with any of a number of combustible gases, such as natural gas, in this process. The combination of oxygen with acetylene is probably the most common. In addition, this combination produces the hottest flame. Therefore, our comparison will be made using these two gases.

Because of the relative simplicity of the system, hoses that supply the gases to a cutting head and ignition of the gas at that point, it is a simple process to mount several cutting heads and accompanying supply hoses together and use a simple numerical control to guide the combined heads in identical patterns at different areas of the material to be cut to produce several cut-outs at the same time for very little cost. Being able to cut several parts at the same time increases the relative cutting speed of the operation, which is quite slow when considering actual feed rate of a single cutting head. Generally, the maximum cutting speed would be around 30 ipm (inches per minute) with the minimum being around 2 ipm when cutting maximum material thickness.

It is in the area of material thickness that oxy cutting leads the others. Plate with a thickness of eight feet is about the maximum material thickness capable of being cut by oxy-acetylene, and while the probable cutting speed of 2 ipm seems extremely slow, proper perspective returns when remembering the size of the sheet being cut.

This process, however, cannot really be considered for anything along the lines of a precision cut, meaning cuts made with the need for accuracy, maximum material usage and minimum damage to the material due to heat build-up. In fact, the area of material affected by the heat of the process, referred to as HAZ (heat affected zone), is quite large and the material suffers a considerable amount of warpage. Material lost during cutting is considerable and the accuracy is far less than any of the other processes.

All in all, the comparison of oxy cutting to laser is not close because of the difference in their applications. Oxy cutting is generally for cutting thicker plate when tolerances and heat affect are not major concerns.

Plasma-arc and wire EDM

An arc of electricity is constricted into a small space in the shape of a nozzle. A fast-moving stream of ionized gas (plasma) is directed through the nozzle. Upon contact, the gas is heated to a high temperature by the arc. As the gas flows through the nozzle and is directed towards a piece of metal, the arc is conducted to the material with the gas as a medium. The combination of the arc and the high gas temperature cause the material to melt and the molten material is blown away by the force of the gas. This process is called plasma-arc machining. Depending on the current output of its power supply, the plasma-arc can cut through material up to three inches thick. Again depending on the current output, the material type and thickness, cutting speeds upwards of 300 ipm have been attained.

The process known as wire EDM (Electrical Discharge Machining) also bases its ability to cut material in electricity. In this case, a wire is used as the medium to conduct electricity to the material surface. The material in closest proximity to the wire is "eaten away". Wire EDM is capable of cutting through material or stacked sheets up to six inches thick, however the speed of the cut is very slow, obtaining speeds of nearly sixty inches per minute only in very thin material.

Aside from cutting speed and thickness of material, consideration must be given to the accuracy of the cut, the amount of material lost during the cut and the extent to which the material is affected by the heat generated during the process. Again, as oxy cutting was intended more for cutting very thick sheets of material without concern for the speed of the cut, the accuracy or the material loss, comparisons between it and the other three processes are of little value to the purpose of this paper.

Accuracy

This is as much a function of the machine control the process is using as it is of the process itself. Going with the standard forms as they exist in the industry today, consideration will be given to each process in terms of accuracy in best case situations.

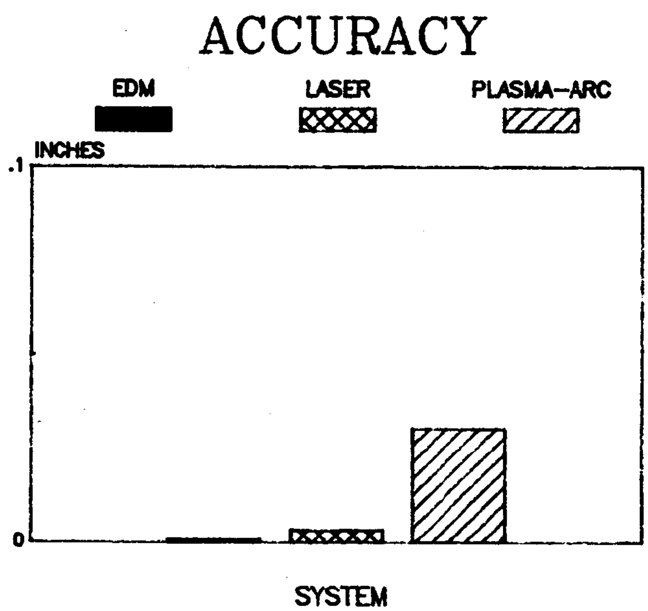

Figure 1. Accuracy

In the case of plasma-arc machining, tolerances of around 0.030 inches can be held. The variances seen are a result of the fluctuations of the diameter of the gas stream as it travels from the nozzle to the material surface. When considering laser beam machining, the beam diameter will vary somewhat depending on the distance of the focusing lenses to the surface of the material. Generally, there are three different focus lengths commonly used in the industry; 2.5 inches, 5 inches and 7.5 inches. Taking the middle ground with the 5 inch length, 0.003 inch tolerances can be held. In the case of wire EDM, the accuracy can vary with the thickness of the wire being used. The smaller the wire, the higher the tolerance that can be held. Holding tolerances of 0.0005 is not uncommon. (See Figure 1.)

Kerf

The width of the cut, which can also be referred to as the amount of material removed during the actual process, is frequently called kerf when talking about these types of systems. This can be critical to justifying a system when considering the hidden cost of wasted material that is lost during the cutting operation or the material left in the sheet being processed because the parts being cut cannot be nested or grouped close enough together.

In the case of plasma-arc, the kerf is also directly related to the diameter of the nozzle being used. Again, using best case examples, the width of the cut on a plasma-arc machine would be no less than 0.030 inches. When considering the laser, the height of the focusing lens again has an effect. Taking the middle ground with the 5 inch lens, the kerf for laser cutting would be 0.010 inches. Turning to EDM, we find that the kerf will vary with the diameter of the wire being used. Wire as small as 0.001 inches can be used, resulting in a kerf of 0.002 inches. However, wire that thin is extremely fragile and has a very short life expectancy. (See Figure 2.)

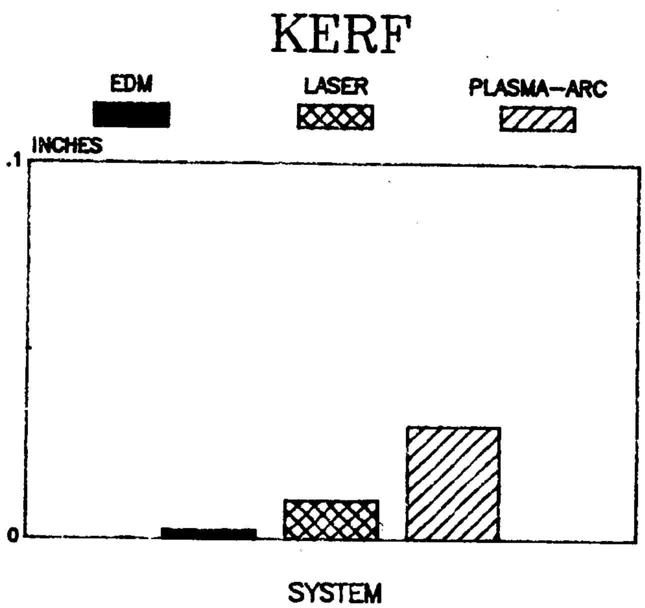

Figure 2. Kerf

Heat-affected zone

In special applications, with certain special materials, the amount the material is affected by the heat generated during cutting is very critical. To much heat can cause surface cracks in the edge, will definitely cause some hardening and possibly result in the edge becoming brittle. These results are unacceptable when considering certain applications in aerospace and high-technology industries. For plasma-arc, laser and EDM, the depths of heat-affected zone, or HAZ, is 0.060, 0.008, and 0.002 inches, respectively. Figure 3 on the following page shows a bar graph detailing these figures.

Cutting speeds

Comparing the three remaining systems in terms of how fast they can cut is not an easy task. Each process has different cutting tendencies for different materials. Case in point. The laser (it should be noted here that figures for laser through-out this paper are for a Carbon Dioxide laser with a maximum power output of 1500 watts, continuous wave,

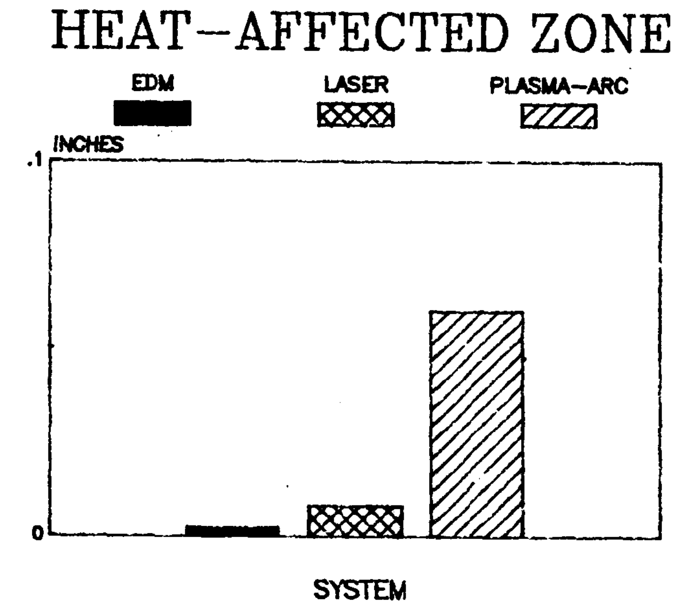

Figure 3. HAZ

in the typical 10.6 micron wavelength for CO2 lasers) cannot cut aluminum very well. This is due to the fact that aluminum is highly reflective to the 10.6 micron wavelength and dissipates the heat of the beam so well. The end result is that aluminum cut on a laser has a very rough edge, the cutting speed is very slow in comparison to other materials and the thickness that can be cut is much less than other materials. In contrast, the other processes cut aluminum very well. However, to establish a good general base for comparison of the processes on a bar graph, we will consider maximum cutting speeds of each system for mild steel that is, say, 0.030 inches thick. (See Figure 4.)

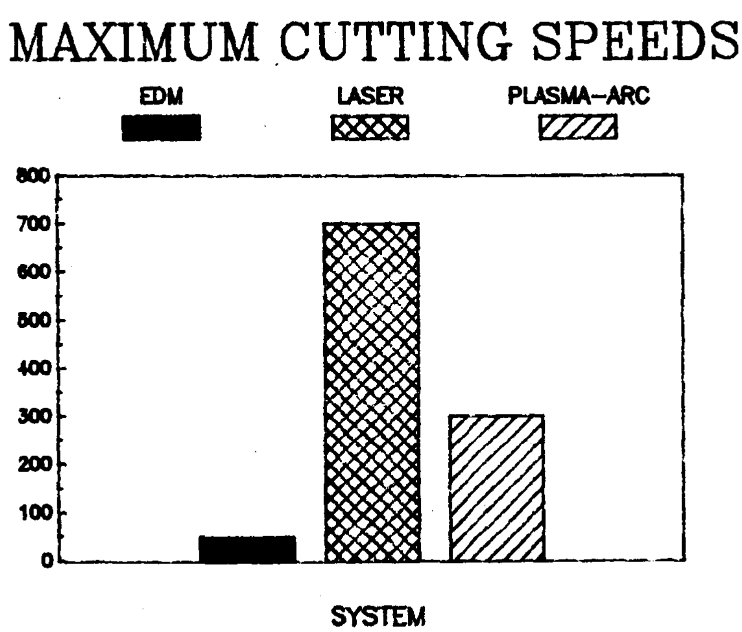

Figure 4. Cutting Speeds

As can be seen, EDM does not really compare to the other two systems in terms of actual cutting speeds. Depending on the material and thickness being cut, plasma-arc and laser vary back and forth as to which is fastest. Figure 5 shows a more detailed graph of cuttings speeds for varying thicknesses of mild steel. Again, cutting speeds are also dependent on the power of the device being used as they are the specifics of the material. In this case, we are looking at maximum power for both systems.

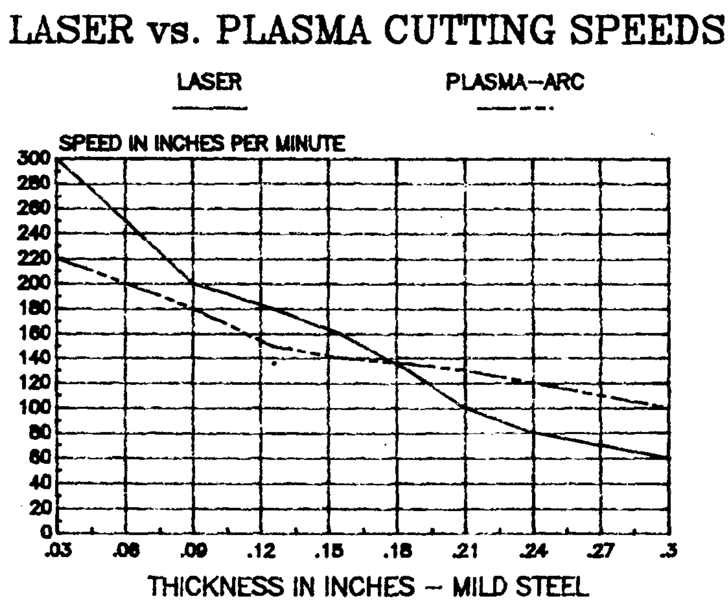

Figure 5. Laser vs. Plasma cutting speeds

Conclusions

In the final analysis, any system can be judged the best available over all others depending upon the details of the requirements. Examples have shown lasers to be less accurate than EDM but more so than plasma-arc. Comparisons of kerf and HAZ have revealed the same ranking of results. However, when looking a cutting speeds we found lasers to be superior to both in most cases, falling behind plasma-arc only in thicker materials. So what conclusions were reached as to the best way to compare these systems so that lasers were shown to be the correct choice for today's market? Versatility!! Both plasma and EDM are only able to cut electrically conductive material. EDM cuts extremely slow in most cases, to the extent that some machines are left running over a weekend. Start the part cutting of friday afternoon and return to work monday morning to find the machine just finishing. Plasma-arc leaves a beveled edge in material, sometimes as much as 15 degrees from the vertical, in all thicknesses of materials. The edge of the material will approach the vertical only after a depth of 0.60 to 0.75 inches. Plasma is ineffective in certain applications because of its poor accuracy, large material loss and high depth of HAZ. Because the wire is continuous in an EDM application, holes within the perimeter of the part or inside contours must either have a start hole drilled (and then have the wire threaded through the hole) or else must be done in a secondary operation.

Laser, in contrast, is continually increasing the speed of cutting. Certain materials have been cut at up to 700 ipm. In many materials, the edge of the cut material is very clean and requires no post cutting clean-up. Laser's accuracy is well within the tolerances for most any kind of work, from job shop to aerospace. The kerf is so small, some parts are bent and welded without the need for filler material for the weld. The HAZ has been checked by companies doing work military high-technology work and found to be again within tolerance. And finally, the varieties of material that can be cut by the laser far surpass the other two. The materials include mild steel, stainless steel, titanium, iconel, brass, aluminum, felt, wood, rubber, plastic, glass, ceramics, concrete, granite, marble, brick and a number of other materials.

Again, the key word is versatility. And the impact that lasers have made in the industrial field to this date, which is really the sum of only three to five years of use, is felt by many to be minor to the impact that lasers will make in the future.

Acknowledgments

Most of the information contained in this paper is the combined accumulation of data obtained through actual hands-on experience with the equipment mentioned. The author wishes to thank Jay Maechtlen, Micheal Palmer and Dale Davis of U.S. Amada and Kenneth Perry Of Adamation, Inc. for useful information. In addition, some of the information was confirmed through the Tool and Manufacturing Engineers Handbook, Volume One - Machining.