American MACHINIST

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The future is here

The ever-broadening range of lasers have helped them make the leap from the lab to the production floor.

By Mike DelBusso, in cooperation with the Laser Systems Product Group of AMT—The Association For Manufacturing Technology

Edited by Patricia L. Smith

Although some might consider lasers pretty sophisticated, even futuristic, tools for the shop floor, they have quickly moved from the laboratory environment into prototype facilities, short-run production shops, and most recently, into high-volume manufacturers. In fact, over the past 15 years, as the general machine tool market has remained flat, the laser industry has grown steadily, increasing more than 400%. This growth has been fueled by technological advances — linear-drive motors, which provide faster speeds and better positioning accuracy, higher power lasers, better beam-delivery systems, and new, high-speed controllers — that have broadened laser applications while reducing costs.

Today, there are close to 150,000 laser systems doing a variety of material-processing tasks. Of these, about 40% are laser markers, and another 25% are being used for semiconductor applications, stereolithography, and rapid prototyping. This leaves approximately 50,000 units operating in traditional material processing, primarily cutting and welding in industrial applications. These cutting and welding applications are expected to increase, along with drilling, cladding, direct-metal deposition, bending, surface treatment, and rapid prototyping.

Laser cutting

Laser flat-sheet cutting. Laser cutting is already a mainstream technology for processing sheet-metal. Currently, there are 20,000 flat-sheet laser-cutting systems in operation, with roughly 9,000 in Europe, 6,000 in North America, and 5,000 in Japan. But even with this installed base, the number of flat-sheet cutters should more than double in the next 10 years to 50,000 units, a figure comparable to today's population of punch presses. The main reasons for this surge are that the systems are faster, more powerful, and more flexible than ever. They also offer good cut quality, narrow kerf widths, small heat-affected zones, and excellent accuracy and repeatability.

Many of today's flat-sheet laser-cutting systems use linear-drive motors to routinely reach speeds of 6,693 in./min, with some systems capable of up to 11,811 in./min. Linear motors also permit acceleration rates up to 2 G, with 4 G on the horizon. With such high positioning speeds, these laser systems can handle long rapid traversing, narrow contours, and indexing between multiple features.

Higher speeds also make laser systems more cost competitive versus nonflexible methods such as die stamping and castings. And compared to punch presses, lasers can slash cycle times — if users look beyond holes per minute and consider pitch factor, material, and material thickness. In addition, as laser power increases, these systems can tackle a wider range of materials and thicknesses, making them comparatively better than plasma cutting or punching.

In thin stainless steel and aluminum sheets, high-power lasers deliver up to 250% faster feedrates than lower-power systems. Welding speeds are also up, in some cases 4.5× faster than lower-power lasers.

Laser blanking. Laser blanking is rapidly replacing conventional die-stamp blanking for mid to short-volume production runs. In the automotive industry, for instance, a growing number of models of cars and trucks with lower production volumes per model and more frequent model changes is driving the demand for cost-effective alternatives to press die blanking. Typically, initial costs for blanking dies range from $25,000 to $250,000, which, on average, is tripled over a five-year life due to engineering changes, blade maintenance, storage, and transportation costs.

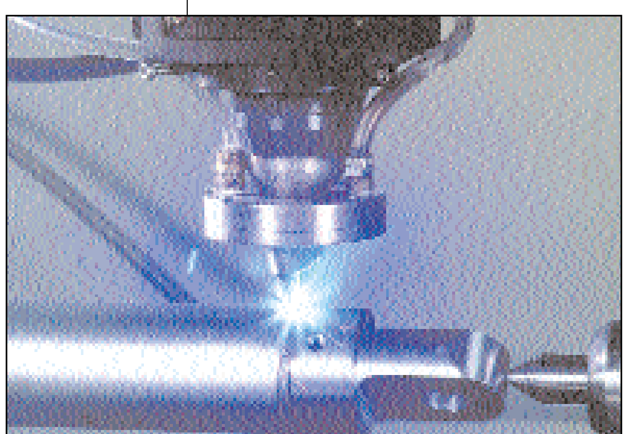
As with laser flat-bed cutting systems, high laser power, better beam quality, use of linear motors, and high-speed CNCs have given rise to laser-blanking systems. With typical cutting speeds running from 1,000 to 1,200 ipm, this process is not only competitive in terms of cycle time per part, but it also resolves the problem of high die cost per part at volumes of less than 60,000 vehicles per year.

In general, with volumes of less than 1,000 vehicles, prototype laser cutting is warranted. From

The Laser Systems Product Group (LSPG) was founded 10 years ago as a membership committee within AMT—The Association For Manufacturing Technology. The group is comprised of representatives from laser manufacturers operating in North America, including Amada, GE Fanuc, Nuvonics Inc., Laser Machining Inc., Mazak, PRC, Process Equipment Co., Rofin-Sinar, and Trumpf. The group also collects and reports data on quarterly and yearly shipments from a total of 46 reporting companies in the laser industry, showing the trends within the industry in terms of laser type, application, system configuration, and markets.

The charter of the LSPG is to promote the general use of laser technology in manufacturing within the following four main areas of activities: promotion, education, standards, and statistics.

The statistical reporting is available only to those who participate. LSPG has published an educational booklet, entitled "An Introduction to Industrial Laser Processes," which is available free of charge by downloading it from the AMT website, www.mfgtech.org.



Welding continues to be a popular application for laser systems.

1,000 to 60,000 vehicles per year, low-volume laser blanking is the best choice. At more than 60,000 vehicles per year, high-volume die blanking remains the most economical option.

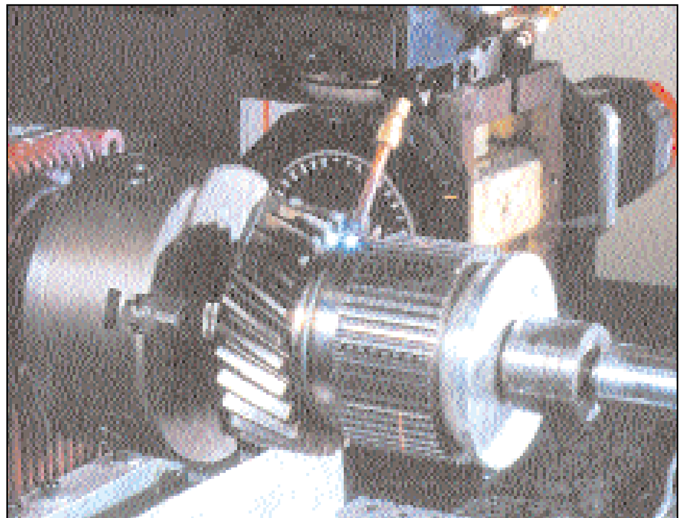
Other advantages lasers have over die blanking include nesting flexibility, less scrap, and smaller numbers of coil widths in inventory. In the case of blank designs, lasers can cut corner radii and strategically designed curvilinear features, yielding better formability, a need for less binder stock, and material savings. Also, when part dimensions or shapes change, shops simply change the laser CNC program instead of waiting for a new or reworked die.

Hydroformed part cutting and trimming. The automotive industry uses hydroforming, a method of producing shaped, hollow parts from tubing by use of water pressure, to produce rails, exhaust systems, motor mounts, pillars, and other components. It's projected that up to 30% of automobile chassis could be hydroformed, and lasers would play a significant role in the post-processing of these parts, both for trimming and for hole cutting.

Hydroforming reduces part counts (a hydroformed part can replace as many as eight separate stamped parts), and parts are lighter, stronger, and have less distortion. They also use up to 20% less blanking material.

Thick-plate cutting. The development of more powerful laser resonators, with higher beam quality, lets lasers cut into thicker materials than once economically feasible. Only a few years ago, 1.5 to 2.5-kW lasers, cutting thicknesses less than 1 in., were considered high-end. Now, 4 to 6-kW systems are the norm, and high-end, 12-kW lasers cut up to 4-in.-thick plates.

Today's 6-kW CO_2 laser cuts 1.6-in.-thick carbon steel, 1.25-in.-thick stainless steel, and 0.5-in.-thick aluminum. For joint configurations where a beveled edge is required, 4 to 6-kW lasers cut to 45° angles in up to 0.75-in.-thick carbon steel. Although other cutting methods, such as plasma cutting, process thicker materials, lasers have the advantage in edge quality and a low heat-affected zone. With these systems, shops can eliminate post-cutting work such as grinding or milling, reduce weld rework and burnout, minimize plate distortion, and reduce or eliminate complicated tooling and setups. Compared to beveled plasma cuts, laser cuts have no dross and do not exhibit bevel-angle rounding that requires additional finish work.



A laser welding system processes a gear.

Laser welding

Remote welding. The automotive industry is currently using remote welding systems with galvanometer scanning assemblies to weld the most frequently used joint types in automotive underbody and framing components. But until recently, such assemblies were limited to beam-steered laser-marking systems. In this setup, small mirrors attached to high-speed galvanometer motors quickly and accurately direct a laser beam onto a part. This is accomplished without any other motion devices on either the part or the laser. An *XY*-axis setup of two galvo mirrors allows the formation of virtually any 2D pattern, creating shapes, alphanumeric characters, and even logos and pictures.

Improvements in beam quality on the latest generation of multi-kilowatt CO_2 lasers lets this technology be scaled to applications beyond laser marking. Better beam quality also permits the use of long focal lengths and depths of focus, both beneficial for laser welding.

A long focal length keeps laser optics further from the part and from contamination, while a long depth of field creates a wide weld seam that overcomes gaps and makes the process more tolerant in part fitup. Although the power density is not as intense in a longer, larger spot, it is consistent in the beam waist and, hence, is consistent over a longer distance with a longer depth of field. Studies have shown that even with only 5% of the power density, welding speed needs only to be reduced to 40% to achieve the same penetration as a shorter focal-length weld. In addition, the slower weld time can be made up with the high-speed galvo motors steering the beam from point to point. Reportedly, remote welding systems boost overall cycle times up to 6×, with greater weld strength and quality.

With remote welding systems,

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a four-post structure holds the laser and optics box over an open space that accommodates part loading and unloading. The part can be kept stationary if all welds fall within the galvo working envelope (approximately 1 m^3), or it can be mounted to a positioning system to increase the working range.

Tailored blank welding. Shops use laser welding to produce tailored steel blanks of differing material thickness and grades. In butt welding 0.315-in.-thick plates, for instance, a 3.5-kW, fiber-delivered Nd:YAG laser can provide welding speeds of up to 748 in./min. The same laser can join 0.0394 to 0.0787-in.-thick sheets at speeds up to 394 in./min with excellent qualities (tensile strength equal to the parent material, acceptable weld-bead face and root, and elongation of 94% to 96%).

Welding speeds are impeded by gaps between sheets. A gap of 0.0079 in. or less is required for maximum weld speeds with acceptable quality; however, various methods have been developed to overcome larger gaps, such as increasing the weld spot size and using special optics to produce twin spots. These methods can bridge gaps of up to 0.0138 in., albeit at slower welding speeds. Another alternative to producing twin spots is to use two lasers — in which case, maximum welding speeds are generally maintained.

In aluminum welding, lasers are processing aluminum tailored blanks at speeds equal to, or greater than, welding steel (433 in./min in joining 0.0394 to 0.0787-in. sheets with a 4.6-kW, dual-beam Nd:YAG laser).

Conventional tailored-blank welding systems have been geared towards mass production and simple, rectilinear welds. This has limited their use in smaller-volume niche vehicles and non-linear or complex shapes. But this is changing. One laser manufacturer, in fact, is taking advantage of the laser's flexibility to both cut and weld. Its system

Diode lasers offer another choice

Laser users have long debated the merits of CO_2 and Nd:YAG (or solid-state) lasers. CO_2 is the older, more dominant technology, with higher available output power, typically superior beam quality, higher efficiency in terms of electrical conversion, and lower capital and operating cost. Nd:YAG lasers, on the other hand, have a shorter wavelength and couple more efficiently with metals, thereby negating some of the advantages of CO_2 lasers, particularly in thinner sections. For example, a 4-kW Nd:YAG laser can typically achieve the same welding speed in some materials as a 6-kW CO_2 laser.

The most significant advantage of Nd:YAG lasers is the ability for beam delivery through fiberoptic cables. This eliminates beam tubes and turning mirrors, which require frequent cleaning and re-alignment. Fiberoptic cables also provide a flexibility suited to robotic manipulation while also maintaining a constant beam-path length.

With the advent of CW (continuous wave) Nd:YAG lasers, solid-state lasers reached output-power capabilities of up to 5 kW, making them technically competitive to CO_2 in a variety of applications. Issues of poor reliability, however, have plagued some of these lasers, and the equipment and operating costs remain higher than for CO_2 lasers. Also beam quality and energy conversion aren't as good.

Now, diode lasers are providing another choice. Even though the sales of diode lasers dwarf the sales of non-diode lasers — driven primarily by the telecommunications market — they aren't as common in material-processing applications. This is quickly changing, however, on two main fronts.

The first is direct-diode lasers, which are delivering higher output powers, currently 6 kW. These systems are being used in thin-metal welding and brazing. At this point, direct-diode lasers are fairly expensive and have not proved their long-term performance and reliability. However, their high efficiency and low operating costs make them attractive. Laser diodes convert electrical-to-optical energy at greater than 50% efficiency, as compared to CO_2 lasers at around 12% and Nd:YAG at only 2% to 3%. With reduced demands for electrical consumption, chilling water, and consumables, hourly operating cost is around $1.50 for direct diode, compared to $10 per hour for CO_2 and $30 per hour for Nd:YAG.

Another advantage of the direct-diode lasers is their compact size. A 4-kW laser, for example, fits in a 8-in.-wide package and weighs only 14 lb, allowing it to be mounted on the end of a robot without any beam-delivery components.

Unlike CO_2 and Nd:YAG lasers, direct-diode lasers do not produce a focused spot, but rather a line of focus, or a linear-shaped beam, that can be dimensionally adjusted. The shape of this beam is advantageous for energy distribution along the seam in welding. In fact, this welding process provides conduction heating rather than the keyhole formation found with CO_2 and Nd:YAG, creating a less violent reaction with no spatter or plume. The wavelength of direct-diode lasers is in the near infrared, and it couples well with metals — particularly aluminum — giving them significant absorption-rate advantages over CO_2 and Nd:YAG.

The main drawback of direct-diode lasers may be in terms of power density, which is lower than needed for high-speed cutting and deep-penetration welding. Their inherent advantages, though, can not be overlooked, and the initial applications in plastic welding, conduction metal welding, brazing, soldering, and surface treatment will lead to further improvements in what could prove to be a breakthrough technology for laser material processing.

Diode-pumped lasers are also gaining momentum in the industry. These lasers are an adaptation of Nd:YAG lasers, replacing the flashlamps with laser diodes to excite the laser rod. Although diode-pumped lasers are currently more expensive than lamp-pumped lasers, they offer a twofold improvement in beam quality and a threefold increase in efficiency.

More promising yet, using laser diodes to pump non-rod type lasers, such as disk or slab lasers, offers even greater efficiency and beam quality. Efficiency is near that of direct-diode lasers and beam quality is near, or better than, CO_2 lasers. Some industry analysts predict a widespread, mass substitution of CO_2 lasers by diode-pumped lasers over the next 4 to 10 years.

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first laser trims the edges of two sheets and then welds them together. This ensures a high edge quality with virtually zero gap and allows for irregular, nonlinear joint patterns. Furthermore, the system eliminates the costs of blanking dies and shearing machines normally required for edge preparation. Smaller shops can now create low-volume and custom-tailored blanks.

Other applications and developments

Hybrid processes and dual-beam welding. Although not exactly a hybrid process, the combination of laser welding with filler-wirefeeding mechanisms has expanded the range of parts and materials that can be successfully laser welded. Although laser welding usually doesn't require adding filler wire to the weld joint, some laser applications are using it to bridge unattainable gap tolerances or overcome certain metallurgical properties. Some filler metals, for instance, can enhance weld-metal chemistry to reduce porosity.

Another example is the 6000 series of aluminum, which cannot be laser welded without solidification cracking in the welds. Filler wire not only takes care of this problem, but the wider and longer weld pool resulting from its addition can relax fitup tolerances between parts. These are important considerations in industries such as automotive. In shipbuilding, where thick plate cutting is most economically done with a flame torch, a laser/filler-wire weld can compensate for poor edge quality and air gaps that prohibit laser welding alone.

More of a hybrid process is the combination of an Nd:YAG laser with a direct-diode laser. Most components in car bodies are made of galvanized materials to

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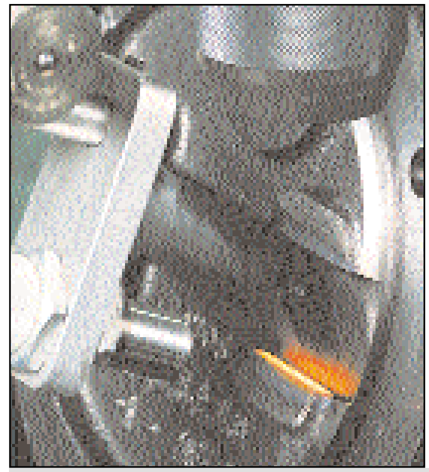

Lasers have been useful tools in heat-treating applications.

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prevent corrosion. The galvanized coatings, however, have long been a nemesis to laser welding because of differing melting temperatures to base materials, vaporization in the weld keyhole, and rapid cooling, all of which can cause porosity. Similar problems exist in aluminum welding, based on the alloy and metallurgical composition of certain grades.

One solution is to expand the size of the weld keyhole and lengthen the cooling time (while maintaining the weld feedrate). This is done by combining the high-intensity focused beam of an Nd:YAG laser with the lower-density, rectangular-shaped beam of a direct-diode laser. The Nd:YAG laser initiates the weld with the normal keyhole and keeps the feedrate high, while the direct-diode laser expands the size of the keyhole and keeps it open longer, delaying solidification and easing the process. Another advantage of this technique is that each laser is individually controlled, allowing adjustments to optimize the process.

Other results can be obtained by the placement of the two beams, either making one of the lasers the leading and one the trailing beam or by having them centered together. Similarly, Nd:YAG and CO_2 lasers have been combined to negate, or control, undesirable reactions with a weld pool or cut kerf.

Hybrid processes can also combine the laser with other thermal technologies, such as MIG, TIG, and plasma. A demonstration with automotive-body welding showed a weld speed of 39.37 in./min with MIG alone and a weld speed of 78.74 in./min with a laser. The combined speed was 236.22 in./min. The laser, in this case, brought stability to the MIG process, while the MIG technology provided filler material in the form of its weld pool. In addition to the increase in welding speed, the hybrid process allowed a greater tolerance range in gap size and provided greater focal lengths and material compatibility.

Process monitoring. Process assurance is becoming critical as lasers move increasingly into full-production environments. Therefore, the laser industry is developing a multitude of process monitors, inspection techniques, and process safeguards. These may be on-line, off-line, or performed in real-time, but they are all aimed at improving quality and manufacturing efficiency by detecting defects and prompting, or even providing, corrective action.

For many years, laser manufac-

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turers have provided built-in power monitors by simply having one of the mirrors in the laser resonator (generally the rear mirror) leak a small portion of the beam onto a sensor. These sampling sensors have also been externally attached to the resonator, at the laser output, at fiber inputs, and at the workpiece location. Some of them even provide closed-loop control back to the laser so it can self-compensate for such things as flashlamp degradation.

But the problem with these sensors is that they only monitor the laser-output performance. There are many aspects of the process, such as the weld plume, part temperature, and part gaps, that adversely affect the laser beam and the overall performance. Recently, sampling monitors, which fit within the final focusing assembly, have been designed to monitor both the source laser beam and the generated process radiation coming back off of the material.

Ultrasonics are another method to inspect welds in tailored blanks and other components. By generating electromagnetic waves into a finished part, these devices capture the entire length and volume of a weld joint at speeds of up to 2,362 in./min. The system can detect defects including pinholes, porosity, lack of fusion or penetration, inclusions, concavity, and mismatch. The process can be integrated in-line and automated to provide a complete inspection record and immediate disposition of the part.

Essential parameters for detection vary from process to process, but they commonly include laser power, beam focus, part fitup, feedrate, shield-gas pressure, weld porosity, weld-bead shape, and edge-cut roughness. While collection devices and recording methods exist for all of these, the ultimate goal of a truly intelligent laser system will require further development in assessing these parameters, assigning significance to the readings, dismissing extraneous or conflicting signals, pinpointing masked effects, and determining, or even executing, corrective actions. ●

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