One Machine Does It All for Laser Beam Welding and Cutting

This combination system can help you boost flexibility and productivity in sheet metal fabrication

BY DIRK PETRING AND FRANK SCHNEIDER

Three-dimensional laser material processing has benefited in recent years from the developments in high-brightness disk and fiber lasers. The advantages of these lasers are fiber-coupled beam guidance, high beam quality, high laser efficiency, good pulsability, small size, and decreased investment costs. Additionally, the inherent advantages — shortened process chains, high flexibility, and accuracy — of combination processing in which cutting and welding are accomplished with the same processing head make 3-D laser processing ever more attractive (Ref. 1).

What makes brightness relevant for combined cutting and welding is the enlarged operating window allowed for changing head distance. A "slim" focal zone of a bright enough laser allows for cutting narrow kerfs with a small nozzle standoff and for excellent welding conditions with a larger standoff with the same nozzle — even without changing the focal distance relative to the nozzle exit (Ref. 2).

A new combi-head design for machines with integrated beam guidance is presented in this article. The design results in improved features for optimized 3-D processing. Furthermore, a programmable laser modulation control allows a high variation of speeds in 3-D contours and leads to burr-free cuts in the complete speed range of the application.

A typical application of the 3-D combi-head technology is illustrated by means of trimming, aperture cutting, and welding operations on automotive B-pillars.

Added Value by Combi-Processing

The possibility of carrying out laser cutting and welding operations on one machine without changing the process head offers many benefits in laser processing (Refs. 1–4). The combi-head is the key to this flexible production, allowing the quick change of the processes just by automatically changing the gas type and flow rate, focal and nozzle position, and laser power and speed. The so-called "autonomous nozzle" provides the gas jet for cutting and the shielding gas for welding (Ref. 5). The unique concept of the coaxial nozzle design permits an open space between the optics and nozzle (even during cutting) for the integration of a cross-jet. This jet is essential in order to protect the optics from smoke and spatter during the welding process, when we require only a low volume, smooth gas flow from the coaxial nozzle.

Combi-processing has several economic advantages compared to individual cutting and welding systems. These include short, integrated process chains; high machine utilization; flexible and cost-efficient production of variants; and savings in handling, positioning, and clamping of parts.

Also, the following technological advantages can be listed: identical tool center points (TCP) for both cutting and welding; and the free choice of an optimized sequence of cutting and welding operations with respect to technical and economic criteria. These features enable higher accuracy and shorter tolerance chains. For example, no tracking system is needed for welding because the edges can previously be cut with the combi-head and thus the coordinates of the weld track along these edges are perfectly known by the system. Since the TCP remains the same when welding, the path for the weld joint is precisely defined within the machine coordinates.

The Identical Path Concept

Whenever cutting and welding operations in combi-processing can use an identical path with the same clamping, the precision in repeating the cut/weld contour is perfect for achieving good and reliable results. Thus, even machines with moderate accuracy such as articulated robots can operate at higher speeds than usual.

Nonlinear tailored blanks processed with the combi-head demonstrate the identical path concept. Figure 1 shows a specimen machined with a 6-axis robot. As shown in the figure from left to right, the edges are first prepared by laser cutting, then put together, and welded along the same path. Finally, cuts in the welded blank are precisely positioned to each other. Even the limited accuracy of a robot at a cutting and welding speed of 8 m/min provides constant good weld joints, because only the reproducibility of the same path is required. Besides tailor-welded blanks, another application of the identical path concept is the processing of coils to produce "endless" coil material by laser trimming the ends of coils and laser welding them together. Figure 2 shows cutting and welding speeds on automotive sheets with 4.0-kW laser power from a fiber laser with a 150-μm-diameter fiber. With smaller fiber diameters, i.e., higher beam quality, even higher speeds are possible. On the other hand, if an application does not require or cannot handle such high speeds, a laser with lower power can be used, with corresponding cost reductions.

Essentials for 3-D Capability

Those examples show that there are reasonable 2-D applications for combi-processing, but typically the welding in combi-processing is used to manufacture 3-D assemblies from 3-D raw parts such as deep-drawn sheets, blanks, profiles, or tubes. Hence, the following 3-D capabilities from the machine, the processing head, and the process are required:

- Appropriate machine kinematics, pro-

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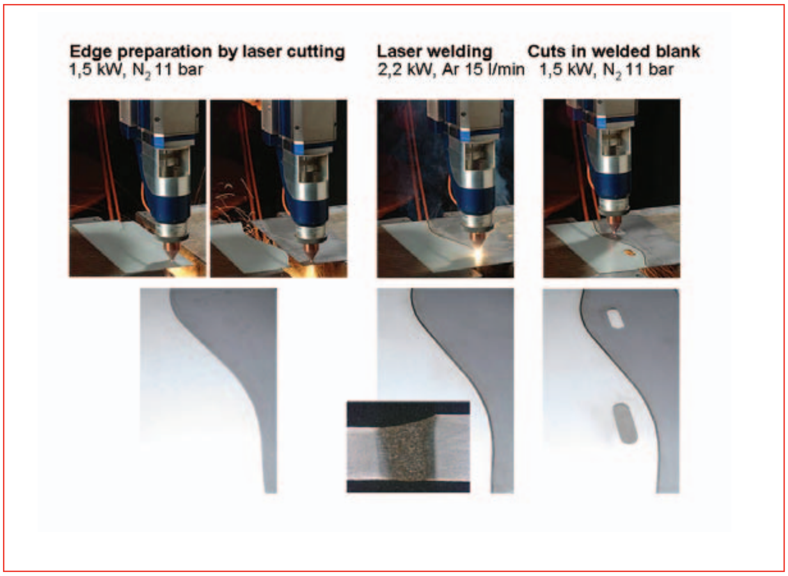

Fig. 1 — Specimen of nonlinear tailor-welded blanks from coated steel (1 mm/1.2 mm), combi-processed with the identical path concept on a 6-axis articulated robot without teaching or joint tracking in a moderate power range of 1.5–2.2 kW and at a processing speed of 8 m/min.

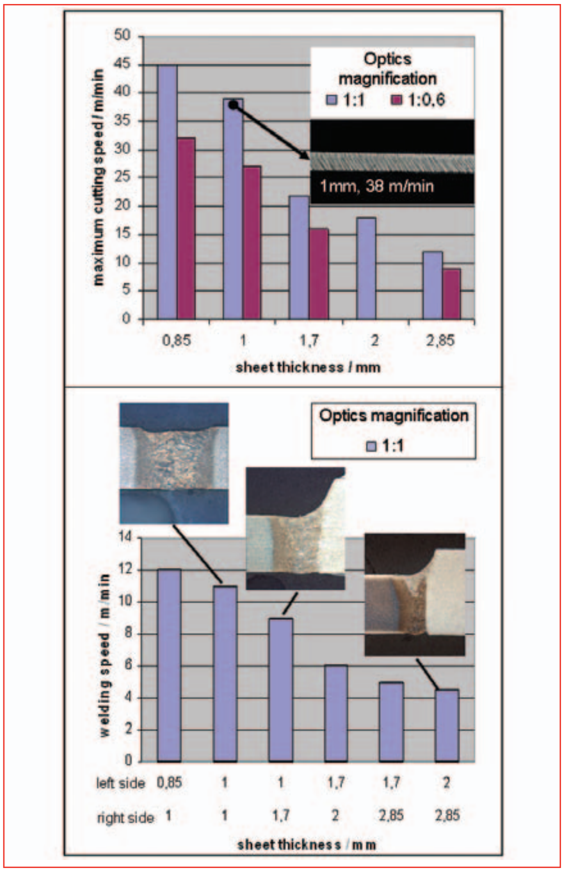

Fig. 2 — Maximum cutting speeds (top), and adapted welding speeds for a sound root formation (bottom). (Laser power: 4 kW; fiber diameter: 150 μm; material: galvanized steel.)

viding the application-oriented requirements in accessibility, speed, acceleration, and accuracy.

- A slim head with a small interfering contour for good accessibility of the workpiece.
- Process parameters that provide good quality over a wide speed range because in 3-D processing, the potential variance in the TCP processing speed is huge due to unavoidable low-speed phases during reorientation of the head, e.g., at bending edges.
- Distance-tolerant process parameters for the cutting process because bended surfaces or lateral material influence the signal of the capacitive distance control and cause higher variation of the nozzle distance than is usual in flat sheet 2-D cutting.

These requirements are met by a machine setup with a new combi-head design for robots with axis-integrated beam guidance and an appropriate choice of the beam parameters.

When following 3-D contours with small radii, the hand axes of the robot can experience rapid changes in orientation of the processing head and produce stresses in the fiber by lashing movements and torsion. This can be avoided by employing an axis-internal beam guidance system that directs the collimated laser beam with mirrors through the last two or three rotational axes of the robot. The latest version of the combi-head F2-X from Laserfact (Fig. 3) is adapted in this way with a mounting flange coaxial to the last rotational axis of a gantry robot (system RLP16 from Reis), which uses three linear axes with linear direct drives and three rotational axes.

Gantry kinematics profit from short tool lengths when circular paths around the workpiece are required. This is because a short tool reduces compensation movements and improves the dynamics around small radii. The combi-head meets this demand by a short overall length of 305 mm from the flange to the nozzle tip, including the additional z-axis for distance control. High acceleration is achieved by using high dynamic linear drives with 0.7-g acceleration in 3-D movements.

Taking advantage of a modular design, the lower part of the head, containing the protection window, cross-jet, distance sensor and nozzle, is unchanged in comparison to the other combi-head versions, except for an alternative nozzle design: For optimal workpiece accessibility, the cone angle of the nozzle can be reduced from 60 to 40 deg. A small angle also reduces interference of the distance control signal caused by lateral material proximity. Due to the modular head design, the modified nozzles are applicable for all existing combi-head versions.

The upper part of the head, containing the z-axis, the focusing optics with adjustment elements, and all media connections, has been redesigned for a short, compact length and to fit to connection flanges coaxial to the beam entrance aperture.

Switching between Cutting and Welding

In principle, there are no differences between the capabilities and parameters of standard cutting and welding heads and the combi-head. Nevertheless, some details are worth mentioning in order to avoid needless confusion or scepticism. It is sometimes believed that adaptive optics or motorized nozzles for changing nozzle distance and focal position independently are obligatory during switching between cutting and welding. Of course these are possible options, but with the autonomous nozzle for many applications, it turned out to be appropriate to use an identical focal distance from the nozzle tip for both cutting and welding. That means focal position and nozzle distance relative to the workpiece surface are changed simultaneously, simply by lifting the complete head, when switching from cutting to welding. Fewer optical and electrical elements reduce the complexity of the combi-head to the required minimum and ensure maximum robustness. Of course the head distance as well as gas type and flow rate, laser beam power, and processing speed can be adapted auto-

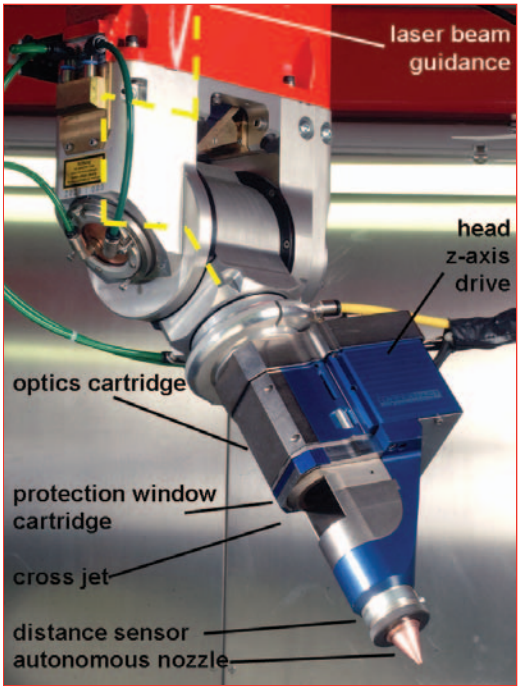

Fig. 3 — Combi-head on a gantry robot with axis-integrated beam guidance.

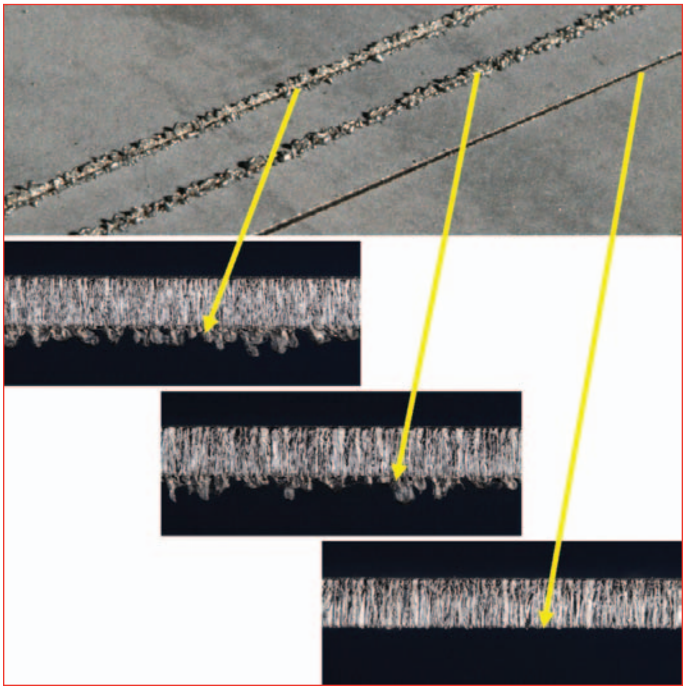

Fig. 4 — Low-speed cutting affects quality: backside of a sheet with three cuts and photos of corresponding cut edges, all cut at a speed of 1 m/min. Top: laser power 2 kW, cw; middle: laser power 0.5 kW, cw; bottom: laser power 0.5 kW (average), peak power 2 kW, pulsed with f = 250 Hz, duty cycle 0.25.

matically by the machine control being programmed accordingly. And, of course, the combi-head allows precise manual adjustment of the laser beam focus in lateral and axial direction.

A suitable beam quality and the correct layout of the collimation and focussing optics according to the demands of the combined processes are the crucial boundary conditions to be successful with the above-described concept.

Laser Power Modulation

Depending on the contour involved, the speed of the tool center point (TCP) can vary dramatically in 3-D applications. A factor of 10 or 20 between speeds on straight paths and around small radii is not unusual. Reduced quality occurs in low-speed sections in the form of burrs when cutting and irregular joints during welding. In combi-processing, as in standard cutting or welding, a simple laser power control with respect to speed is an effective answer for some of the problems due to speed variation. However, to achieve a burr-free cut quality over the whole speed range, an adaptive laser power modulation is necessary — Fig. 4. A programmable laser modulation control has been developed that allows us to adapt modulation frequency, duty-cycle, and amplitude of the laser power to the effective speed. By the control of pulse frequency and duty cycle, it is possible to adjust both the average power and spatial overlapping of pulses individually for each velocity. In addition, by adapting the amplitude, the depth and level of the modulation are tuned according to the required process characteristics.

3-D Applications

The impact of the features that support 3-D performance (high beam quality, an optimized combi-head, and the modulation control) is demonstrated in an automotive application example, namely combi-processing of a B-pillar. Driven by the use of modern hot-formed high-strength steels for crash-relevant car body components, laser trimming and cutting of apertures in these parts is well established because those materials are difficult to cut mechanically. With the availability of combi-processing, it even becomes possible to integrate welding operations into the process chain with the same setup leading to the benefits already discussed.

First, several holes are cut into the B-pillar. Second, the final dimensions are cut. Next, a reinforcing sheet is welded on the pillar and, finally, holes are cut through the reinforcing sheet and the B-pillar — Fig. 5.

All operations are performed in one clamping, thus high positional tolerances between the outer contour and the holes, including those in the weld-on part, are guaranteed.

The processing was done on a gantry robot (RLP16 from Reis) with a Laserfact combi-head F2-X — Fig. 6. The laser source was an IPG fiber laser YLR4000 SS with a 100-µm-diameter process fiber. The large contours were cut at 15 m/min, the holes at 3–9 m/min, depending on their diameter and the material thickness. For the smallest radii, the pulsed mode was used. The welding speed was 3 m/min for the lap weld through the reinforcement plate (1.3 mm) and the pillar (1.4 mm). The maximum laser power was 2.5 kW. Depending on the details of the cut contour, the overall processing time for cutting and welding a B-pillar as in Fig. 5 is in the range of 1 min.

Another demonstration of combi-processing capabilities is the possibility of welding a circular joint just before precisely cutting the holes at the edge of the weld joint to produce a gap-free, sealed hole, preventing subsequent crevice corrosion — Fig. 7. The coordinates of the weld are known in the machine and with an identical path plus an offset, a precise position of the cut relative to the weld is possible thanks to the common TCP for cutting and welding. As both processes can be done one after the other, there is no additional positioning. Another option is the welding on of additional functional parts such as nuts, studs, or mounting plates.

In fact, there are many possibilities for intelligent process chains opened up by the integration of laser cutting and welding processes in a flexible manufacturing

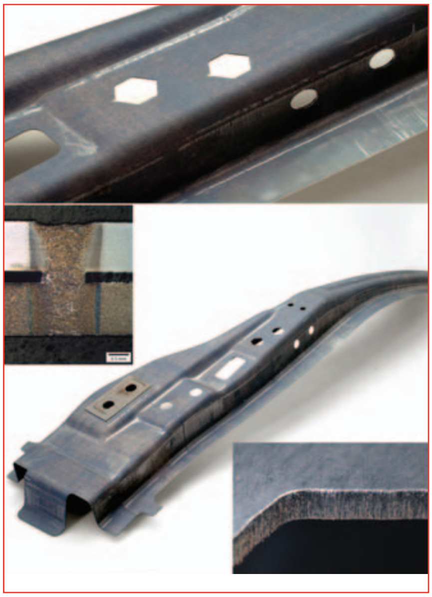

Fig. 5 — Combi-processed B-pillar with cross section of the welded reinforcing sheet and details of the cut contours. Maximum laser beam power is 2.5 kW.

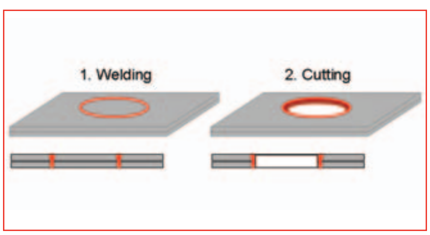

Fig. 7 — Cutting a sealed aperture along a previously welded circular overlap joint through two sheets.

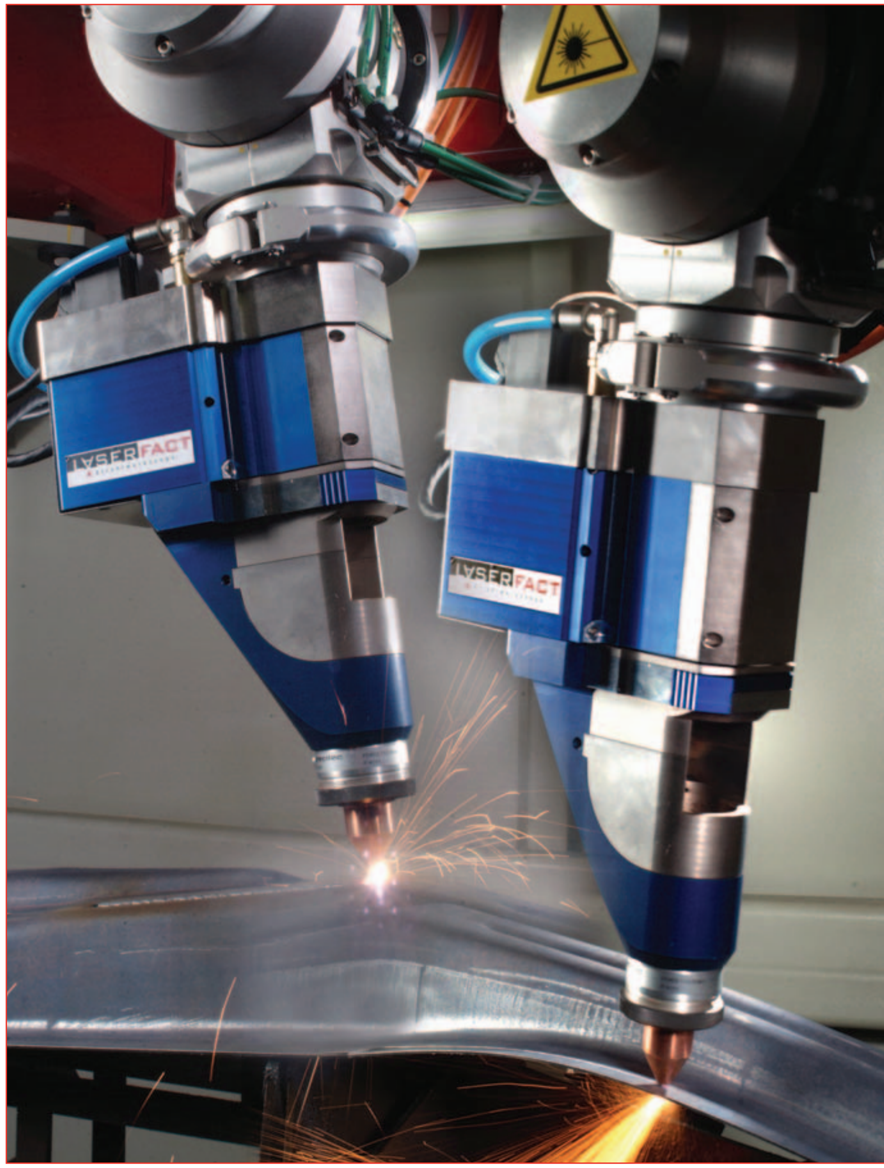

Fig. 6 — Combi-head at work. Cutting and welding process on the B-pillar with a gantry-robot. (Photo courtesy of Laserfact GmbH.)

environment. And beside the improvement of existing processes, completely new product designs are also possible and can be cost-efficiently manufactured.

Conclusions

For 3-D combination processing with high-quality results at economically attractive processing times, the following elements are essential:

- A 3-D machine or robot with high dynamic response and accuracy, such as a gantry robot with linear direct drives and integrated beam guidance.
- A laser with a fiber-coupled beam delivery and good beam quality such as a fiber or disk laser.
- A combi-head, featuring optimized 3-D capabilities as a result of its slender design, short length, and fast distance control with a dynamic z-axis.
- A speed-adapted laser power modulation control.◆

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