

PROGRESS IN CUTTING AND WELDING OF SHEET METAL ASSEMBLIES IN ONE MACHINE WITH THE LASER COMBI-HEAD

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Abstract

Flexibility is an often proclaimed property of laser tools and normally adverted to flexibility in geometry, material or lot size during the application of a certain laser process (e.g. cutting *or* welding). With the laser combi-head, even the processes themselves can flexibly be changed within the manufacturing procedure– in this case between cutting *and* welding. The gain in flexibility is accompanied by a shortened process chain, a more integrated production facility and higher accuracy of the resulting products at a high cost-effectiveness. Further improvements of the equipment for combined cutting and welding with a multifunctional laser combi-head are described by means of new examples from research projects and latest industrial implementations with CO₂ lasers as well as with fiber coupled solid-state lasers.

Introduction

3-D-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 [1,2].

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 stand off and for excellent welding conditions with a larger stand off with the same nozzle – even without changing the focal distance relatively to the nozzle exit [3].

A new combi-head design for machines with integrated beam guidance is presented in this article. Improved features for optimized 3-D processing are the result. 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 and profile-flange connections.

Cutting and Welding with a Multi-Functional Laser Combi-Head

The possibility of carrying out laser cutting and welding operations on one machine without changing the process head offers a lot of benefits [1-3]. 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, laser power and speed. The so-called “autonomous nozzle” provides the gas jet for cutting and the shielding gas for welding. The unique concept of the coaxial nozzle design permits an open space between the optics and the 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.

In principle, there are no differences between the capabilities and parameters of standard cutting and welding heads compared to cutting or welding with the combi-head. Nevertheless, some details are worth to be mentioned 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 for

special applications, 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. Less optical and mechatronical 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 automatically 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 during the setting-up of the system.

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.

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

Constand TCP and Identical Path Concept

The constant tool center point (TCP) and unchanged clamping situation for both cutting and welding and the free choice of an optimized sequence of cutting and welding operations enable higher accuracy and shorter tolerance chains. For example, no tracking system is needed for welding, if the edges are previously cut with the combi-head. 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 seam is precisely defined within the machine coordinates.

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 to achieve good and reliable results. Thus even machines with moderate accuracy such as articulated robots can operate at higher speeds than usually.

2-D tailored blanks, processed with the combi-head, demonstrate the benefits of the identical path concept. Particularly in the production of nonlinear tailored blanks, lack of precision in the prefabrication of the

blanks causes gaps to form between the edges being joined. This can lead to either increased costs during the prefabrication phase, greater demands being made on the accuracy of seam tracking and gap measurement during the welding process, or even the use of filler material. In this context, integrated cutting and welding with the combi-head opens up new possibilities.

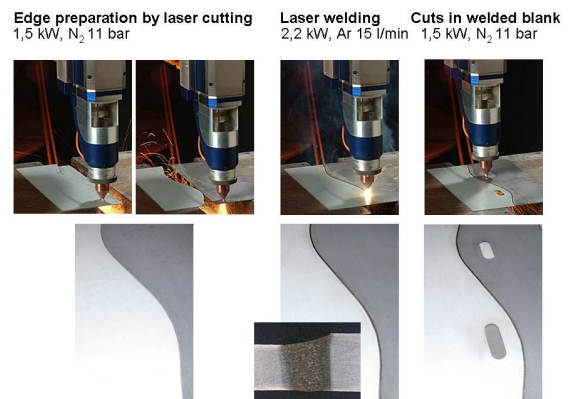


Fig. 1: Specimen of 2-D tailored welded blanks from coated steel (1mm/1.2mm), combi-processed with the identical path concept on a 6-axes articulated robot without teaching or seam-tracking in a moderate power range of 1.5-2.2 kW and at a processing speed of 8m/min.

Fig. 1 shows a specimen machined with a 6-axes robot. From left to right: the edges are first prepared by laser cutting, pushed together, and welded along the original cut 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 8m/min provides constant good weld seams, because only the reproducibility of the same path is required.

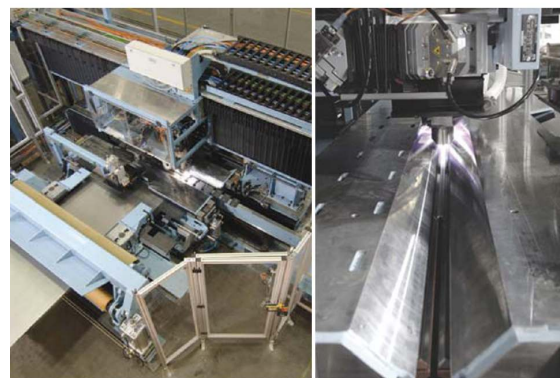


Fig. 2: Laser cutting and welding machine for coil processing (source: TKLT).

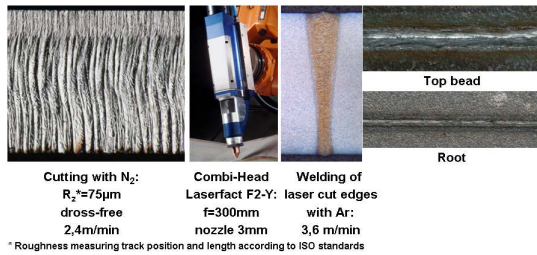


Fig. 3: Combined cutting and welding 8mm thick structural steel sheets with an 8 kW disk laser.

Another industrial application of the identical path concept is the processing of coils to produce 'endless' coil material in coating lines by laser trimming the ends of coils, laser welding them together and subsequent laser cutting of a smooth coil transition at the start and the end of the welded joint track (**Fig. 2**). ThyssenKrupp Steel is using a CO₂ laser combi-head for this application in coil production lines in Germany and in USA since 2009 [4]. With enough laser power the combined cutting and welding can also be managed with thicker plate or profile material, as demonstrated with an example in **Fig. 3**.

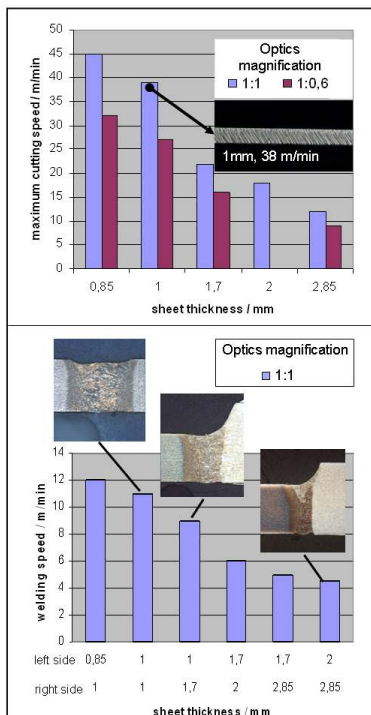


Fig. 4: Maximum cutting speeds (top), and adapted welding speeds for a sound root formation (bottom). (Laser power: 4 kW, fiber diameter: 150 µm, material: galvanized steel)

Fig. 4 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 then be used – with corresponding cost reductions.

Essentials for 3-D Capability

The above examples show that there are reasonable 2-D applications for combi-processing. Nevertheless, combi-processing is predestined to manufacture 3-D assemblies from 3-D raw parts: deep-drawn sheets, blanks, hydroformed parts, profiles or tubes etc. Hence, the following 3-D capabilities from the machine, the processing head and the process are required;

- appropriate machine kinematics, providing the application-oriented requirements in accessibility, speed, acceleration, 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 especially for the cutting process, because bended surfaces or lateral material and clamping tools 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 laser gantry robot with axes-integrated beam guidance and a therefore optimised combi-head as well as an appropriate choice of the beam parameters.

The applied gantry robot RLP16 from Reis provides three linear axes with linear direct drives and three rotational axes. The highly dynamical drives achieve an acceleration of 0.7 g. When following 3-D contours with small radii the hand axes of a robot can experience rapid changes in speed and orientation of the processing head. Accordingly, stresses in the fiber by bending, torsion and lashing movements would occur. This is avoided by employing an axis-internal beam guidance system with mirror optics. The fiber connection and the collimation optics are located above the last two rotational axes of the robot.

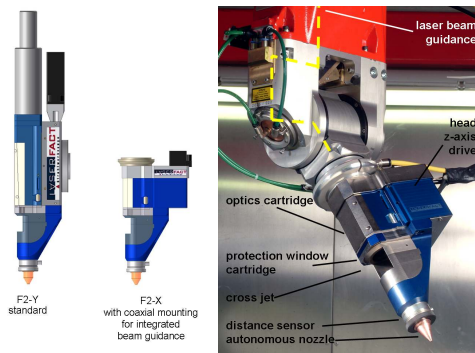


Fig. 5: Combi-head on a gantry-robot with axis-integrated beam guidance

The newly developed version of the combi-head F2-X from Laserfact (Fig. 5) is equipped with a mounting flange for an optically and mechanically coaxial mounting to the last rotational axis of the gantry robot. 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 the coaxial mounting flange.

Gantry kinematics profits from short tool lengths when paths around bended workpiece corners with small radii are required. This is because a short tool reduces compensation movements and improves the dynamics around the 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 the distance control.

Taking advantage of a modular design, the lower part of the head, containing the protection window, the crossjet, the distance sensor and the autonomous nozzle, is unchanged in comparison to the other combi-head versions. For optimal workpiece accessibility an additional nozzle version with a cone angle of 40° has been developed. The 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 functional scope of the combi-head control unit was extended, too. For example, not only can both, the distance and the absolute z-axis coordinate, be set by the operator as well as be measured, closed-loop controlled and conveyed to the superordinated machine control, but the distance control system also includes an auto-calibration mode and can monitor whether a pre-defined tolerance band is being complied with.

Laser Power Modulation

Depending on the contour involved, the speed of the Tool Center Point (TCP) can vary significantly in 3-D applications. 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. 6). 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.

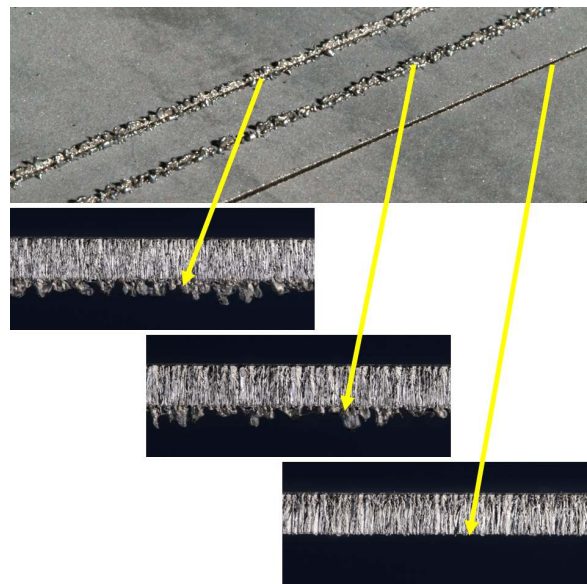


Fig. 6: Low speed cutting affects quality: backside of a sheet with three cuts and photos of corresponding cut edges, all cut at a speed of 1m/min:

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

3-D Applications

An increasingly important laser application is the processing of ultra-high-strength steels because those materials are difficult to cut mechanically and also conventional joining techniques are not suitable. The trend is driven particularly by the use of modern hot formed high-strength MnB-steels for crash-relevant car body components. Main objective is the reduction of vehicle weight as well as improvement of strength and stiffness of its structure. A well established automotive application example is laser trimming of the outer contour and cutting of apertures of B-pillars made from 22MnB5 steel. With the availability of 3-D combi-processing it becomes even possible to integrate welding operations into the process chain with the same setup leading to the benefits discussed already.

At first, several holes are cut into the B-pillar. Secondly, 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. 7**).



Fig. 7: Combi-processed B-pillar with cross-section of the welded reinforcing sheet and details of the cut contours, max. laser beam power 2.5 kW.

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 gantry robot RLP16 from Reis is equipped with a Laserfact combi-head F2-X (**Fig. 8**). An IPG fiber laser YLR4000 SS is connected to the integrated beam guidance with a 100 μ m 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 used was 2.5 kW. The lap-weld only takes about five seconds. The combi-head avoids the need to switch to another processing station and hence saves all operational and investment costs that this entails. Depending on the details of the cut contour, the overall processing time for cutting and welding a B-pillar as in **Fig. 7** is in the range of 1 min.



Fig. 8: Combi-head at work. Cutting and welding process on the B-pillar with a gantry-robot (photo: multiple exposures).

Another unique capability of combi-processing is the lap welding of a circular seam just before cutting the holes precisely at the inner edge of the weld circle. This process sequence produces a gap-free, sealed hole, preventing subsequent crevice corrosion between the overlapped sheets via the hole (**Fig. 9**). 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 right 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.

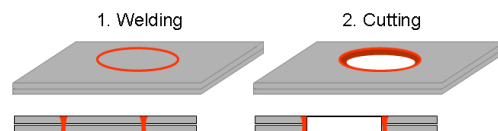


Fig. 9: Cutting a sealed aperture along a previously welded circular overlap seam through two sheets.

Distance Sensor Recorded Coordinates

In 3-D processing the above described identical path concept has to be extended to the third dimension. While in 2-D processing the cut path is well-defined by the cut edge coordinates laterally to the sheet surface, 3-D processing additionally involves a height contour of a shaped surface. Frequently, this shape is not well-defined but varies from part to part due to tolerances of the pre-manufacturing deep-drawing or bending processes or of the clamping device. This can cause non-fitting joints with unacceptable edge misalignment particularly in the case of I-butt or stake-welded T-butt joints.

Due to the constant TCP and the unchanged clamping situation in combined cutting and welding, there is also an effective solution in this case. For the compensation of part tolerances, the required information about the height contour deviations of the part is recorded during cutting via the distance sensor of the combi-head. The coordinates are conveyed to the machine control in order to specify the corrected program for the subsequent welding procedure. In **fig. 10** the concept of distance sensor recorded coordinates is demonstrated by means of a complete process chain for a profile-flange connection. It comprises the laser trimming of the U-shaped profile with simultaneous recording of the height coordinates via the distance sensor, the subsequent stake-welding of the T-joint for the profile-flange connection and finally the cutting of a circular aperture into the flange with a well-defined position relative to the profile cross section based on the recorded profile coordinates.



1. Trimming the profile and recording height coordinates

2. Welding the flange plate

3. Cutting the flange aperture

Fig. 10: Manufacturing of profiles with flange plates by combined cutting and welding with distance sensor recorded coordinates

As a matter of fact, there are many possibilities for intelligent process chains opened up by the integration of laser cutting and welding processes in a flexible manufacturing environment. And beside the improvement of existing processes also completely new product designs become possible and can be manufactured cost efficiently.

Conclusion

- A 3-D gantry robot with high dynamic response and accuracy due to linear direct drives, and an integrated mirror beam guidance in the rotational axes provides a solid machine basis for multifunctional laser processing with fiber coupled lasers.
- A new combi-head, featuring optimised 3-D capabilities as a result of its slender design, short length, coaxial mounting flange and fast distance control with a dynamic z-axis allows for flexible and efficient cutting and welding.
- A speed-adapted laser power modulation control ensures continuous quality also in critical 2-D and 3-D contours.
- The extended combi-head control unit manages signal inputs/outputs e.g. for/from distance sensor setting and signal, additional z-axis drive setting and position, the machine control program and parameters, and the user interface.

The identical path concept (2-D applications) and the use of distance sensor recorded coordinates (3-D applications) are processing strategies for high precision and accuracy in an integrated process chain of cutting and welding procedures.

Acknowledgements

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References

- [1] Petring, D. (2005). One Head Does It All – New technology allows 3-D laser beam cutting and joining. *Welding Journal*, August 2005, 49-51
- [2] Petring, D. (2005). Laser cutting and welding with one tool. *The FABRICATOR*, October 2005, 40-41
- [3] Petring, D., and Schneider, F. (2009). One Machine Does It All for Laser Beam Welding and Cutting. *Welding Journal*, March 2009, 38-41
- [4] Spöttl, M. (2010). Contact Free and Flexible Cutting and Welding – Coil Joining with Combined Laser Processing Head. To be published on the International Laser Technology Congress AKL'10. Aachen, Germany, 5-7 May 2010.