© 2012 THOSS Media & DE GRUYTER DOI 10.1515/aot-2012-0040 — Adv. Opt. Techn. 2012; 1(5): 397–402

Letter

Oliver Pütsch*, Jochen Stollenwerk, Markus Kogel-Hollacher and Martin Traub

Annular beam shaping system for advanced 3D laser brazing

Abstract: As laser brazing benefits from advantages such as smooth joints and small heat-affected zones, it has become established as a joining technology that is widely used in the automotive industry. With the processing of complex-shaped geometries, recent developed brazing heads suffer, however, from the need for continuous reorientation of the optical system and/or limited accessibility due to lateral wire feeding. This motivates the development of a laser brazing head with coaxial wire feeding and enhanced functionality. An optical system is designed that allows to generate an annular intensity distribution in the working zone. The utilization of complex optical components avoids obscuration of the optical path by the wire feeding. The new design overcomes the disadvantages of the state-of-the-art brazing heads with lateral wire feeding and benefits from the independence of direction while processing complex geometries. To increase the robustness of the brazing process, the beam path also includes a seam tracking system, leading to a more challenging design of the whole optical train. This paper mainly discusses the concept and the optical design of the coaxial brazing head, and also presents the results obtained with a prototype and selected application results.

Keywords: annular beam shaping; automotive industry; coaxial wire feeding; complex optics; high-power laser; laser brazing.

***Corresponding author: Oliver Pütsch,** Chair for Technology of Optical Systems (TOS), RWTH Aachen University, Steinbachstr. 15, Aachen 52074, Germany, e-mail: oliver.puetsch@tos.rwth-aachen.de
Jochen Stollenwerk: Chair for Technology of Optical Systems (TOS), RWTH Aachen University, Aachen, Germany
Jochen Stollenwerk and Martin Traub: Fraunhofer Institute for Lasertechnology (ILT), Aachen, Germany
Markus Kogel-Hollacher: Precitec KG, Gaggenau, Germany

1 Introduction

Laser brazing technology exhibits both mechanical and optical advantages compared to other established joining technologies, e.g., welding. Besides increasing the mechanical stability, the directed energy coupling enables small heat-affected zones and, therefore, avoids the damaging of protective/functional layers, e.g., zinc on zinc-coated steel. Additionally, smooth seams satisfy the high requirements on optical appearance. The degree of rework can be efficiently reduced.

The above-mentioned advantages have given the laser brazing technology a firm position in the automotive industry for joining visible parts like trunk lids, roof seams, C pillars, and doors.

The recent brazing heads apply lateral wire feeding and, therefore, their application to braze complex-shaped geometries suffers from the following drawbacks:

- The obscuration of the intensity distribution in the working zone due to lateral wire feeding results in a dependence of direction.
- The lateral wire feeding constrains the free moving space of the brazing head, especially if small radii are involved.
- Complex-shaped geometries demand continuous reorientation of the brazing head and require an extensive programming of the peripheral equipment (robot control).

The frequent reorientation results in both geometry variations and defects of the brazing seam. This does not comply with the high demands on mechanical and optical quality. Furthermore, the processing speed is limited.

The current disadvantages with the utilization of the lateral wire feeding motivate the development of a laser brazing head with a coaxial wire feeding. The approach requires that the optical axis of the focused laser beam be collinear with the axis of the wire feeding. To take full advantage of the brazing head, a non-contact tracking unit has to be coaxially integrated to feedback the current position of the seam as well as the orientation of the brazing head. The combined development of both the processing optics and the seam tracking optics is the most challenging aspect to the optical design because no crossings of the optical paths with the wire feeding are allowed. By avoiding obscurations, an enclosed, rotational symmetric intensity profile in the working zone, without any energy losses due to parasitic absorption, is maintained. This enables the brazing head to function independent of direction. The following advantages can be identified concerning the new coaxial design [1]:

- High-quality brazing seams for complex, three dimensional brazing seams, sharp changes in brazing contours, and small radii;
- Less-demanding programming of the controlling axes and path correction;
- Increased melting efficiency and penetration depth of the brazing due to the symmetrical heating of both the brazing wire and the material;
- Higher accessibility to complex shapes due to the integration of the external wire feeder coaxially into the optics;
- Extended design options for the component parts;
- Reduced or no postfinishing work due to the high quality of the brazing seam.

2 Annular beam shaping system

2.1 Design of the processing optics

Figure 1 depicts the overall optical system of the laser brazing head [2].

The input distribution of the collimated fiber-coupled laser source is first transformed to an annular ring shape by an axicon. The ring is separated into two halves by a pair of refractive prisms, thereby, creating a gap. The gap allows to insert the coaxial wire feeding without causing an obscuration after the optical axis is deflected by 90° by a flat mirror. A second prism pair recombines the two halves of the beam, and finally, an aspheric lens followed by a protective window focuses the beam into the working plane.

The transformation of the beam into an annular ring shape is realized with conical optical components [3]. As depicted in Figure 2, the utilization of a mirror-axicon (Figure 2 left) benefits from a reduced space and complexity in production in contrast to the transmittive components such as a double glass axicon (Figure 2 right).

The main challenge for the optical design is the parameterization of the axicon, prisms, and asphere to match the given geometrical constraints:

- Fiber core diameter 0.6–1.0 mm, outcoupling NA 0.25
- Working distance (optics to workpiece) >100 mm
- Spot size at the workpiece 2–3 mm
- Utilization of commercially available collimation optics
- Diameter of the brazing wire: maximum 1.6 mm
- Free length of the wire (distance from the brazing nozzle to the working plane): 10 mm
- Gap for the coaxial wire feeding: 14 mm.

From the first-order approximation, the suitable parameterizations can be derived analytically. The focusing

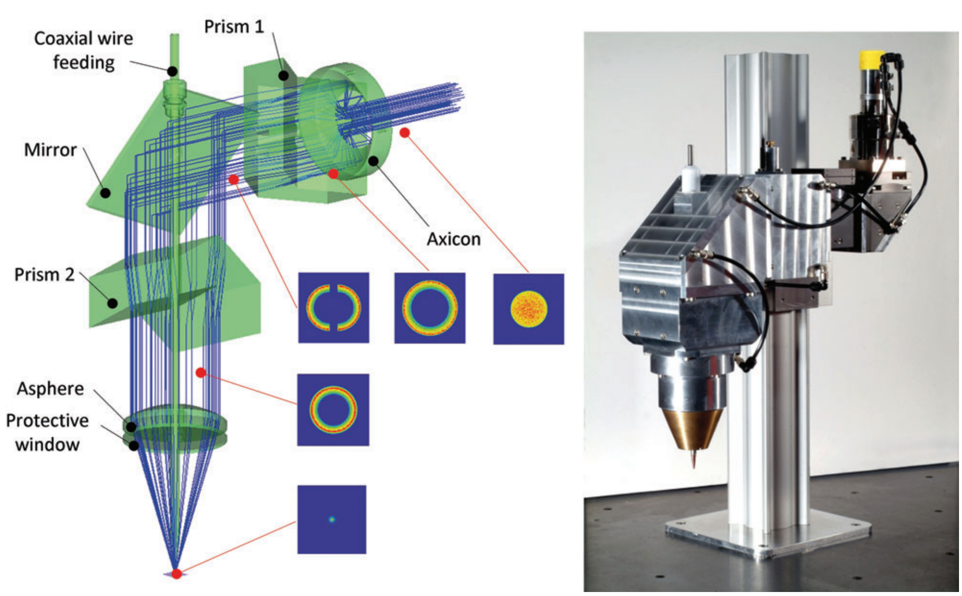

Figure 1 Concept of the annular beam shaping optic.

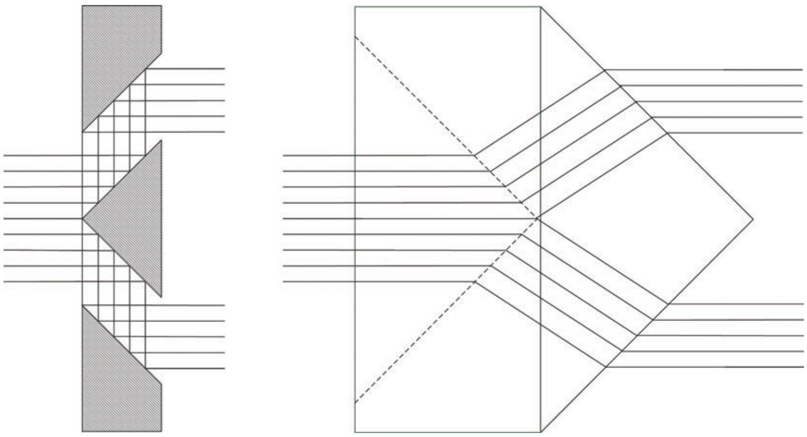

Figure 2 Annular beam shaping with an axicon.

angle (focal length) of the asphere is matched to the geometry of the brazing nozzle (Figure 3). The free length of the wire and the working distance define the inner radius of the annular shape (r_i) directly before its focusing. The radius of the collimated beam and the spot diameter in the working plane defines the outer radius of the annular profile (r_a) and enable the particular parameterization of the axicon.

The parameterization of the prism pairs results from the requirements for the space of the coaxial wire feeding. The degree of separation results from the index of refraction, thickness, and inclination angle [3].

2.2 Design of the seam tracking optics

The integration of a seam tracking control enables the utilization of the coaxial brazing head in an automated production environment and enhances the benefits in automotive applications. In contrast to the tactile sensing techniques that are often applied with lateral wire feeding [4], the new coaxial design requires a non-contact and rotationally symmetrical sensing technique.

Both the evaluation of the orientation of the brazing head relative to the working zone and the true position of the seam are based on laser triangulation. Currently, two independent optical paths are used for that and denoted as projection and detection path (Figure 4).

The projection path creates a ring-shaped focal profile with a diameter of 10 mm in the working zone. Radiation from a fiber-coupled laser diode (660 nm) is collimated and shaped into a ring by a shallow axicon. By coaxial integration, the illumination path uses the same optical components as the processing optics but is focused to a ring in the working zone.

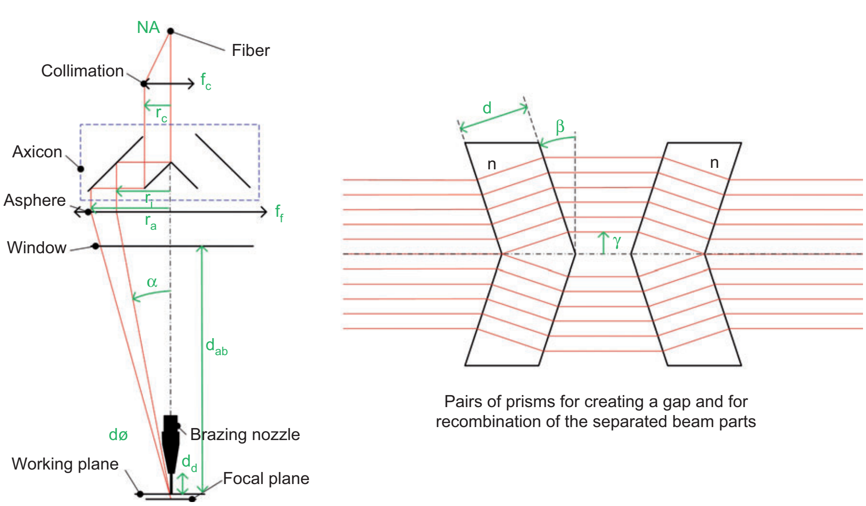

Figure 3 Geometric consideration for the optical design.

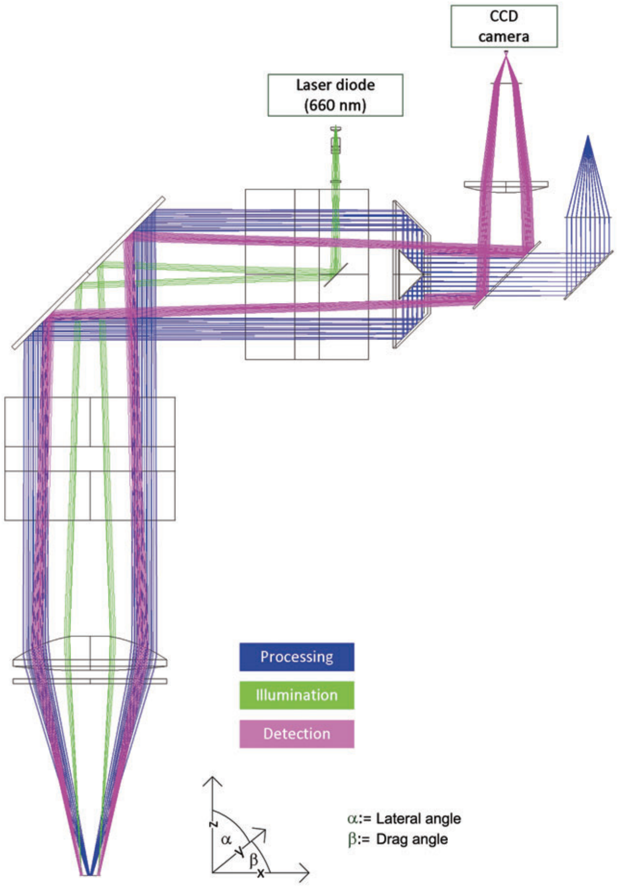

Figure 4 Optical paths for processing and seam tracking.

The ring spot is viewed by a CCD camera via the laser processing optics. The axicon is bypassed from left to right to avoid any obscurations.

3 Results

The brazing quality, which comes from the independence of direction with the coaxial wire feeding, is verified with the processing of the most common joint designs in car body manufacturing. The applied materials are $CuSi_3$ brazing wire with a diameter of 1.0–1.6 mm and zinc-coated steel plates (0.8–1.0 mm). Figure 5 depicts samples of the processed fillet-weld lap (Figure 5, left) and the flange weld joints (Figure 5, right) utilizing a fiber-coupled (NA 0.1, diameter 600 μm) 10-kW Nd:YAG disc laser at a reduced output power of 3.8 kW and in conjunction with an industrial-grade push-pull wire feeding system.

The experiments demonstrate a high tolerance against the variations in focus position and inclination angles. Although the brazing head is handled by a five-axis portal robot, only three axes (x,y,z) have to be controlled to process the complex 3D topologies with small radii as shown on the left-hand side of Figure 5. Owing to the annularly shaped intensity distribution, the independence of direction allows for large drag angles (±45°) without reorientation of the brazing head. Figure 6 shows the cross section of a flange weld joint. The deep penetration of the brazing metal into the seam accounts for a high mechanical stability without affecting the zinc coatings, and the smooth surface satisfies the demand of the optical appearance of the final result.

The brazing process is optimized, varying a quantity of parameters such as processing and wire feeding speed, initial wire length, laser power, and spot diameter. Table 1 summarizes the results of recent experiments with the coaxial brazing head.

Figure 5 Brazing of fillet-weld lap joint (left) and flange weld joint (right).

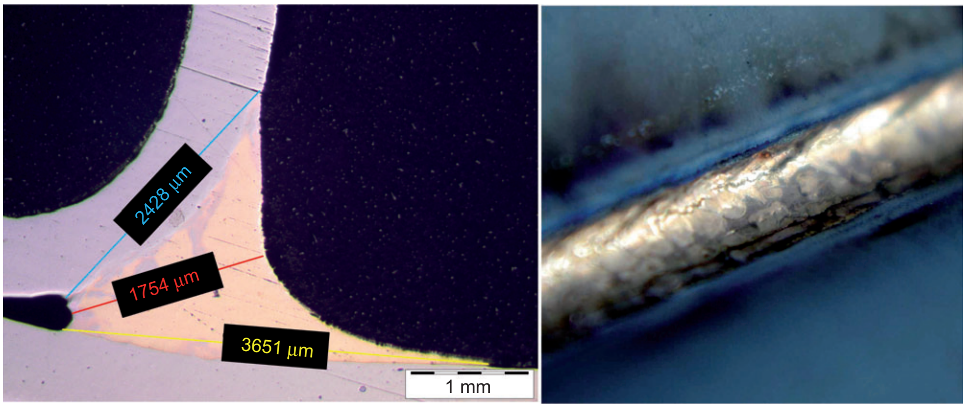

Figure 6 Cross section and surface of a flange weld joint (P_L=3.2 kW, v=3.3 m/min).

Spot diameter in working zone	3 mm
Maximum variation of focus position (along optical axis)	±3 mm
Maximum variation of lateral focus position (Δz)	±0.4 mm
Maximum variation of lateral angle (α)	±45°
Maximum variation of drag angle (β)	±45°
Maximum process speed (filled-weld lap joint), $CuSi_3$ ø1.2 mm	2.7 m/min (P_L=2.3 kW)
Maximum process speed (flange weld joint), $CuSi_3$ ø1.6 mm	3.8 m/min (P_L=3.8 kW)

Table 1 Experimental results with the coaxial brazing head.

4 Conclusion

An optical system for laser brazing is developed, which allows coaxial wire feeding without obscurations and with integrated non-contact seam tracking control. The processing of the common joint designs in the automotive industry takes full advantage of the independence of direction of the new brazing head. Recent results demonstrate a high tolerance to the varying process parameters and show the ability to process complex-shaped geometries with constant brazing seam quality.

To increase the applicability in the automotive industries, future work will mainly focus on higher process speeds of up to 5–8 m/min. To this end, the brazing head design has to be adapted to work at higher laser output powers.

Received August 8, 2012; accepted August 24, 2012

References

[1] H. Hornig, in ‘Praxis des Laserstrahlhartlötens im Fahrzeugbau, 5th Laser Anwender-Forum LAF’ (Bremen, 2005).
[2] C. Schnitzler, M. Traub and J. Diettrich, ‘Optisches System für einen Laserbearbeitungskopf’, Patent DE 10 2007 018 40 (Munich, 2009).
[3] H. Gross, in ‘Handbook of Optical Systems Volume 1: Fundamentals of Technical Optics’ (Wiley-VCH, Weinheim, 2005).
[4] R. Poprawe, P. Loosen and F. Bachmann, ‘High Power Diode Lasers for Material Processing, Principles and Application’ (Springer Verlag, New York, 2005).

Oliver Pütsch received his diploma in Mechatronics Engineering from Aachen University of Applied Sciences, Germany in 2008 and his MSc in Mechatronics in 2010. During his masters course, he worked at the Faculty of Mechanical Engineering and Mechatronics at Aachen University of Applied Sciences in the subject area of Microtechnology. He is currently pursuing a PhD in engineering and has been working as a research scientist at the Chair for Technology of Optical Systems at RWTH Aachen University since 2011. His research interests are the application and development of active and controlled optical devices.

Dr. Jochen Stollenwerk received his Diploma degree in Physics at the RWTH Aachen University in 1996. He was a scientific employee at the Fraunhofer-Institute for Laser Technology in Aachen (ILT) and received his PhD in the area of Laser Materials Processing in 2001. After his PhD examination, he moved to TRUMPF Laser Marking Systems (Grüsch, Switzerland), where he was responsible for the Application department. In 2004, he became the Vice Director at the newly founded Chair for 'Technology of Optical Systems' at RWTH Aachen University and additionally took over the responsibility for the group 'Thin Film Laser Processing' at the Fraunhofer-Institute for Laser Technology.

Markus Kogel-Hollacher began his activities in the area of lasers working for his MS degree at the Fraunhofer Institute for Laser Technology in 1994. Since then, the focus of his work has been in the field of monitoring and control of laser processes. After earning his MS degree in physics in 1996 from the RWTH Aachen University in Germany, he joined Precitec Optronik GmbH (formerly Jurca Optoelektronik GmbH) in Rodgau, Germany, continuing the work with the emphasis on transferring R&D results to industrial solutions. This work has been discussed extensively in several technical journals and presented at various conferences. In his position as the head of the department's R&D projects in the Precitec Group, he oversees national and international governmentally funded projects. Working together with RTD performers and end users, his guiding principle is to continuously increase the reliability and the use of process monitoring and process control devices in laser materials processing.
In 2008, he obtained his PhD at the Technical University of Berlin, Germany. Dr. Kogel-Hollacher has been a member of the Laser Institute of America (LIA) since 2002. At present, he is a member of the board of directors at the LIA and recently has served as a jury member of the Innovation Award Laser Technology.

Martin Traub studied mechanical engineering at the RWTH Aachen and Michigan State University. He received his diploma in 1999 and started working as a research scientist at the Fraunhofer ILT. He gained a diploma in Industrial Engineering from RWTH Aachen in 2003. Since 2008, he leads the group 'Optics Design and Diode Lasers' at the Fraunhofer ILT.