9th International Conference on
Photonic Technologies LANE 2016

Industrial Paper

Optical coherence tomography for remote laser welding

N. Deyneka Dupriez[a,]*

[a]*Lessmüller Lasertechnik GmbH, Gollierstraße 12, D-80339 Munich, Germany*

Abstract

Optical coherence tomography (OCT) is an innovative technology in modern industrial laser processing in particular in laser welding. Performing coaxially to the processing laser and supplied with the OCT scanner, OCT enables not only the tomographical keyhole depth measurements but also precise omnidirectional seam tracking. By acquiring a 3D surface topography, the profile of the joint can be recorded with high axial and lateral resolution. Thus the exact welding position can be detected in real-time regardless of the viewing angle, a change of the focusing distance or the welding direction. Frequency analysis of the measurement data makes OCT immune to the intensive process light. Performing with high acquisition rate and accompanied by high processing rate analysis software, OCT can provide "on the fly" tracking and is a promising technique for fast accurate and cost-effective remote laser welding. Simple maintenance-free solution, robust and small-sized, OCT is easy adaptable to any conventional laser head, it does not require sophisticated alignment and any additional cross jet.

Keywords: optical coherence tomography; remote laser welding; laser processing; noncontact tracking; real-time monitoring; online quality control; high acquisition rate; high resolution

1. Introduction

The advances of remote laser welding in terms of enhanced production speed and flexibility are of special interest of automotive industry. The variety of application fields of this technology is continuously increasing. It is mainly applied in the mass production of flat assembly groups with a high number of welding seams at different locations on the workpiece [1].

The modern industrial remote laser welding stands for reduced unproductive positioning times and efficient production. The laser welding spot can be displaced in milliseconds with a scanner, with a scanner-less approach or "on the fly" (with a robot guided scanner). Accomplished by higher welding speeds, cycle times can be dramatically reduced at simultaneously low heat input into the workpiece [2].

Up to now, the lap joints are often favorited in series production since they need a less accurate positioning of the laser beam on the workpiece (0.2-1 mm) than fillet welds (typically 50 µm) [1]. However, vehicle mass and costs may be reduced by diminishing the flange size needed for laser lap welding and therefore enabling edge welding. It requires precise fully automated and high dynamic detection and adjustment of the seam joint position over the total scan area and in any welding direction. Even in case of a programmable welding the exact processing beam positioning is important since tolerances and operating gap changes are influencing the weld quality. Thus the welding optics must be extended by a high-precision seam tracking system.

Effective laser processing requires also a precise online process monitoring including automated readjustment, realized, e.g., by FILLET SCAN from Lessmüeller Lasertechnik GmbH. This is an example of a system permitting automated closed loop controlled seam tracking, visualization of the welding process, and the monitoring of the correct laser welding progress. It enables fast "on the fly" and position controlled omnidirectional welding by online detection of the laser beam position, the location of the fillet joint, and fast on-line correction of the welding location. This technology is based on live camera imaging and real-time gray-scale image processing. The combination of the dynamic WELDEYE camera and an external coaxial planar unstructured illumination with a high power light source is a key technology for the visualization of the welding

* Corresponding author. Tel.: +49-89-3609048-104; fax: +49-89-3609048-29 .
E-mail address: nd@lessmueller.de

process area and its surrounding along the entire scanning range [3]. The actual position of the processing beam and the seam joint are revealed in real-time by image analysis with high processing rate in terms of evaluation of the intensity distribution (brightness) of the reflections from the joint. Via the direct and fast communication interface the determined values are transferred to the robot steering software to adjust the welding location. Since this technique is an indirect determination of joint location it may pose some difficulties while evaluating the joints with imperfect edges. Additionally, at certain robot-workpiece configurations luminosity acquired for accurate gray-scale image processing had to be readjusted.

Another efficient tracking system available for remote laser welding is laser-based, structured- light automated pre-process inspection [2, 4], based on the triangulation principle. A laser line is projected onto the workpiece surface and the joint position is recognized as a discontinuity in the line observed in the camera image. This seam-tracking concept is robust, reliable, and marked by high temporal resolution [2]. However, the seam inspection with the laser triangulation can be performed only in the direction where the line projector is installed and cannot measure sharp changes of the joint trajectory without rotation of the welding head. The interfering contour of the welding head containing projectors is also bigger. Moreover, the line projector requires an additional cross jet and a time consuming set-up and alignment.

Both, the video recording of processing area with FILLET SCAN and the laser triangulation approach involve an intensity based analysis of 2D camera images. Therefore the white-hot process glow or speckle as well as, spatters, fixtures and clamping may obstruct during high speed remote welding.

To obviate these shortcomings, improve the accuracy of remote laser welding and make a remote laser welding system capable of three-dimensional surface inspection for reliable online automatic determination of seam joint location and the actual the beam position the OCT system is proposed. The benefit of OCT over other inspection techniques is that it enables not only multidimensional visualization of the welding process but also direct real-time height measurements with high degree of accuracy.

2. Measurement setup

The principles of optical coherence tomography (OCT) are used to provide a real-time optical detection of the joint during remote laser welding. A basic measurement setup of this instrument with emphasis on laser welding is described elsewhere by Deyneka Dupriez et al [5]. Fig. 1 represents a particular remote laser welding setup including, e.g., scanner head assembled with OCT components. It combines a coaxial measurement concept of OCT with a laser positioning system. Red line in Fig. 1 shows the pathway of the processing laser. OCT system consists of a 3D scanner connected through the camera port to the welding optics. Other OCT components like sensor, length modulator and a control unit are located in the control box at the operator side. OCT beam (blue line) is then fiber-guided to the laser processing side.

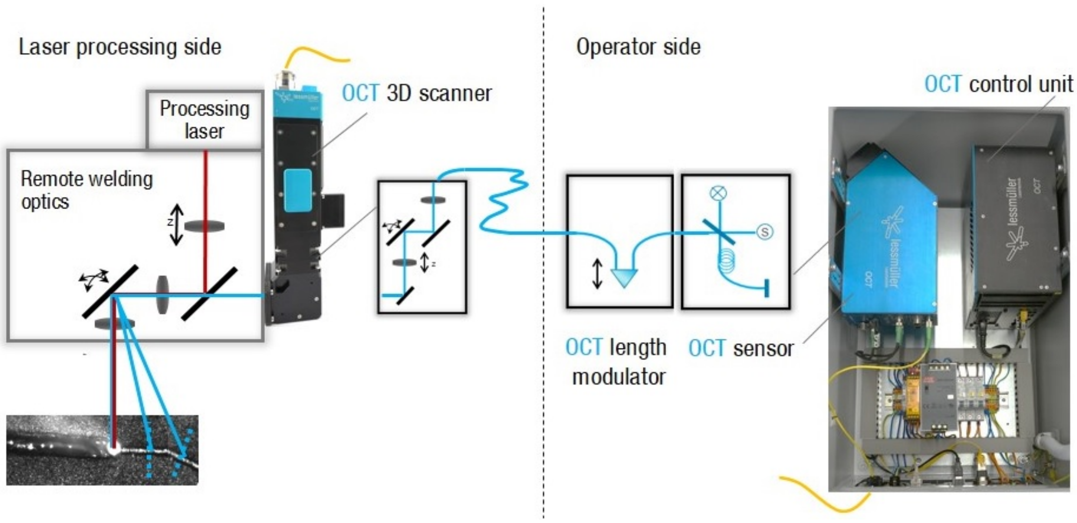

Fig. 1. Remote laser welding setup with active beam guidance by coaxial OCT approach. Photograph of the workpiece surface shows that OCT beam (blue line) can be freely positioned within the scan field irrespective the welding direction.

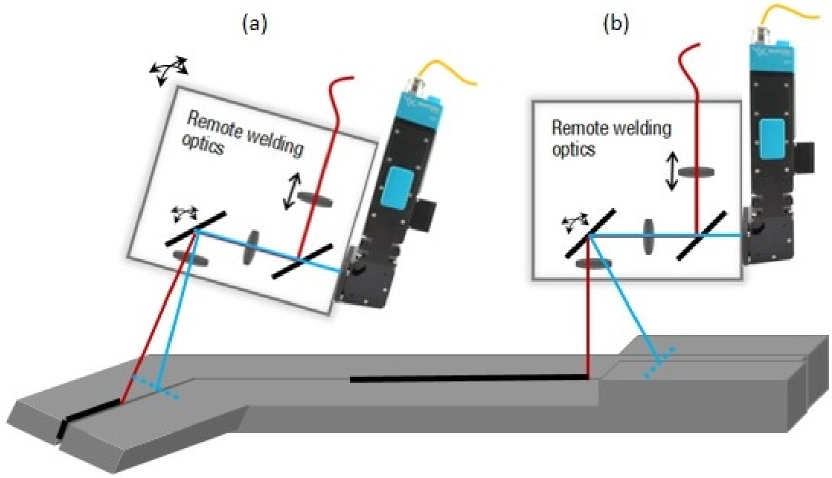

Fig. 2. Schematic presentation of self-guided seam tracking with OCT at different viewing angles, working distances, and welding directions ((a) and (b)).

The processing laser guidance along the joint contour on the workpiece is realized by the tilting of the scanning mirror of the welding head whereas the customer defined OCT scanning for surface topography inspection arises from tilting of mirrors of OCT 3D scanner. Fig. 1 demonstrates an example of OCT scanning performed along a line across the joint (see blue dotted line). The height measurements at any point in time are performed by means of interferometry with OCT sensor [5, 6].

Since the probe beam is coaxial to the processing beam, it guarantees measurements in machine coordinates irrespective of the welding direction (Fig. 1). The photograph of the workpiece surface during welding in Fig. 1 shows that due to the alteration of the joint trajectory the OCT beam (blue line) is fast displaced to operate within the new coordinates and the orientation of the OCT scan figure (dotted blue line) is changed respectively.

OCT offers the flexibility in choosing the scan region and in positioning of the beam within the scan region. OCT has a long working distance and is therefore not influenced by the focus changes caused by tilting of the scanner mirrors (Fig. 2(a)) or changes in the focusing distance (Fig. 2(b)). Additionally, the system utilizes a length modulator that allows determining the distance to every single point on the workpiece surface at variable focusing of scanner-integrated remote welding system in the working range of 390 mm. OCT affords a relatively wide tilt tracking angle without requiring any recalibration. Thus it can provide “on the fly” tracking and height based image analysis in particularly for the geometries that create problems for traditional structured light measurements. OCT can be applied at any orientation and any user defined distribution of weld seams. Moreover, the accuracy of the OCT system is not limited by the process glow. Obstacles like fastening fixtures in process surrounding do not have any influence on the tracking results and the cycle times. Thus positioning welding with OCT offers maximum precision and operating reliability and can be also realized for butt-welding or other high accuracy applications.

Moreover, the tool geometry has a minor influence during the manufacturing of various welding patterns in limited space since only the OCT scanner being light and compact is connected to the camera port of the welding head. Measurement, evaluation, and control facilities are at the operator side (Fig. 1) and coupled to the OCT scanner receiving optical signals. The need for a special illumination or projectors is eliminated. This permits to minimize the size and weight of the entire welding head and to avoid discrepancies due to mechanical and thermal distortions.

The OCT control unit supplied with WELDEYE software is responsible for numerical analysis of the OCT image and closed-loop feedback carried out in real time. It provides the detailed information about the axial and lateral seam joint position that is used for steering and control the scanner/robotic devices. Processing speed is compatible with high welding speed permitting to realize time efficient “on the fly” processing and enabling flexible production.

3. Remote laser welding with OCT

OCT was used to follow a two-dimensional joint remotely. Real-time seam tracking with Lessmüller Lasertechnik OCT was performed during the welding tests with Scanlab intelliWELD 30 FC V scanner optics (Fig. 3). The height sensing and joint profiling was done by scanning with OCT along a line of 5 mm length

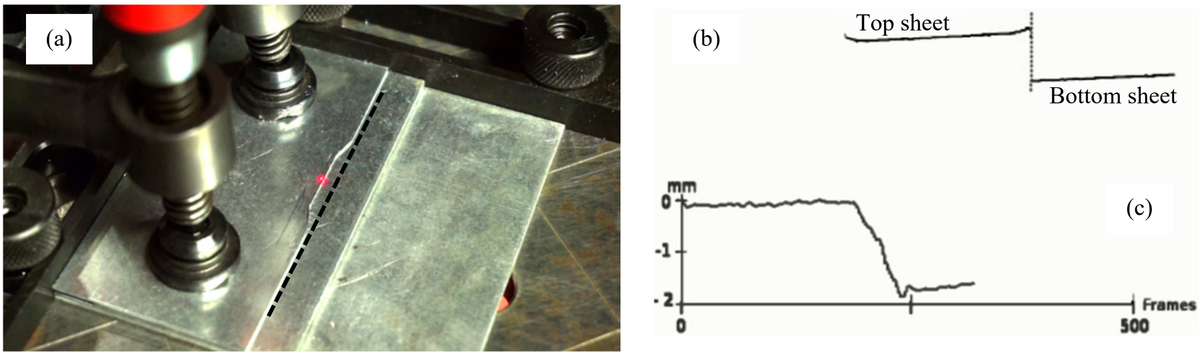

Fig. 3. Welding test performed with Scanlab intelliWELD 30 FC V scanner optics and with real-time seam tracking by means of OCT. (a) photograph of seam tracking performed on fillet joint of zinc coated sheets used in automotive industry, dotted line marks programmed robot path, red point represents the laser position that corresponds to the joint position detected by OCT; (b) joint profile measured with OCT at the actual laser position, dotted line marks the automatically detected joint position; (c) profile of the OCT guided scanner/laser pathway from the starting point up to the actual laser position in terms of frames.

across the joint (like the blue dotted line schematically presented in Fig. 1 and 2) with 100 measurement points per line. OCT was operated at the sampling frequency of 100 kHz. The WELDEYE software was applied to determine joint position. To adjust the welding position the scanner optics was manipulated by Blackbird steering software. The laser beam only needed to be moved within one horizontal plane of the scanner field (Fig. 3(a)). Welding speed was set to 3 mm/min. During welding, the active OCT beam guidance unit performed seam finding and closed-loop feedback. As a result, the laser beam "found its way." Fig. 3(a) demonstrates that laser beam deviated from the programmed robot pathway (dotted line) and followed the tracked by OCT trajectory of the joint (red laser point). Fig. 3(b) and (c) represent numerical OCT results. Fig. 3(b) shows the surface topography profile of the fillet joint along one line measured with OCT at the moment when the laser is located at the red point in Fig. 3(a). OCT software automatically detects the position of the joint marked in Fig. 3(b) as a dotted line. The joint trajectory was also derived from OCT measurements and presented in Fig. 3(c). Thus, using OCT a processing head is capable to follow joints or traces on the workpiece self-guided, which means independent of the actual movement of the processing head and without any prior calibration or information of the trajectory.

4. Summary and outlook

It is demonstrated that OCT is a unique and valuable technique for real-time diagnostics to guide and therefore optimize the laser welding process since OCT offers non-destructive 3D measurements irrespective of weld trajectory and welding angle. OCT system enables omnidirectional online topography acquisition of the workpiece during laser processing. Owing to the long working distance OCT offers no limitation either in resolution or in the field of view. Simple in construction, free of additional assemblies on the laser head, immune to process light and temperature, non-sensitive to fixtures or clamping devices, it has a potential to spread out in its industrial use.

An advantage of seam tracking with OCT is that by more accurate positioning of the laser remotely it enables precise laser edge welding. Thus, it permits to reduce investments, operating costs and to achieve high output quantity. Moreover, OCT may be easily assembled to the existing remote laser optics through the existing camera port.

Tracking facility of OCT can also be accomplished by simultaneous optical inspection of the weld bead. Thus, simultaneous precise tracking and quality assurance of randomly oriented seams makes OCT a potential tool for customer individual industrial applications with high quality requirements.

References

[1] Zaeh, M.F., Moesl, J., Musiol, J., Oefele, F., 2010. Material Processing with Remote Technology – Revolution or Evolution? Physics Procedia 5, 19-33.

[2] Regaard, B., Kaierle, S., Poprawe, R., 2009. Seam-tracking for high precision laser welding applications – Methods, restrictions and enhanced concepts, Journal of Laser Applications, 21, 183-195.

[3] Truckenbrodt, Ch., 2013. Mit dem Auge zurück an die Schweißnaht. Laser Technik Journal, 10, 46-50.

[4] Reichert, C.T., 1998. Pre- and post-weld inspection using laser vision, Proceedings SPIE 3396, Nondestructive Evaluation of Materials and Composites II, 244 - 254.

[5] Deyneka Dupriez, N., Truckenbrodt, Ch., 2016. OCT for efficient high quality laser welding. Laser Technik Journal. 3, in press.

[6] Brezinski, M., 2006. Optical coherence tomography – Principles and Applications. Elsevier, pp. 130-134.