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Enhancing remote laser welding with OCT sensor support

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Abstract

In the past years optical coherence tomography (OCT) sensors have become available for industrial use. As this is still a new field, applications specific developments are required. One of the possible applications for OCT in laser remote welding is the omnidirectional tracking and welding of fillet seam on car doors. Simultaneously, the sensor can be used to evaluate the geometry of the welded seam and therefore eliminate the need for a separate quality control.
It has been shown that the oscillation of the laser beam is necessary to have a stable process when welding fillet joints. The combination of an oscillated laser beam and an OCT sensor for seam tracking and topology measurement provides technological challenges that have to be overcome before it can be used in industrial scale.
Different approaches to combine the oscillation and OCT are presented and discussed in respect of the addressed applications. Furthermore, first results of the Blackbird development on real parts will be discussed.

Keywords: OCT; laser remote welding; scanner welding; edge tracking

1. Introduction

In the past years remote laser welding gained popularity in the automotive industry, especially for the production of hang-on parts and seat structures. Nonetheless, to further improve the implementation of remote laser welding into a wide variety of processes and products, also the economic feasibility needs to be improved. To match this challenge especially two aspects can be regarded:

- Quality assurance can be integrated into the remote laser welding process to reduce subsequent processes.
- Welding of fillet seams can help to reduce the weight of cars and gives the opportunity to avoid a zinc degassing gap. But due to small deviations between parts and the need to very precisely guide the laser beam onto the edge, an edge tracking solution has to be implemented.

The state of the art for quality assurance tasks are the interpretation of camera pictures, process emissions or laser triangulation. Every method has its own assets and drawbacks and all come with severe restrictions, e.g. laser triangulation results in a forced welding direction and small working area, negating the big field size of a remote welding scanner and the possibility to weld omnidirectional. Camera and photo diode-based system may need some reteaching after small changes of the part quality or the process.

Seam tracking solutions based on laser triangulation have the same restriction as these systems for quality assurance tasks – but edge tracking and quality assurance can be performed at the same time during the process. Camera based seam tracking systems can be used for omnidirectional welds but are also limited to a certain area in the working field and are prone to changes in the quality of the cutting edge of parts. Variation in the edge quality can be caused by wear of the cutting tools or changing suppliers. These problems, especially frequent reteaching, may lead to a decreased acceptant at the end user.

It has been shown that with the extension of a remote laser welding scanner with an OCT-based sensor, quality assurance and edge tracking tasks can be performed while avoiding some of the restrictions mentioned

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above [Musiol 2017]. Additionally, the OCT-sensor can add new capabilities to the remote welding system, e.g. measuring the gap between metal sheets and adjusting welding parameters in real-time.

Blackbird Robotics is aiming to transfer the possibilities of OCT, that have been shown under laboratory conditions, into an industrial, robust solution and with this providing the user with a versatile and economic tool for a wide variety of tasks. Therefore, Blackbird started a development in 2015 with Precitec and Scanlab as suppliers of relevant components. While Blackbird's OCT-sensor platform is capable of full On-The-Fly welding across all dimensions of the working envelope, a major challenge is to enable the laser beam oscillation while edge tracking and performing quality assurance tasks.

Hereinafter the current technical status, application samples and challenges in the implementation of OCT-sensors in remote laser welding will be shown. Some possible solutions for enabling oscillation with edge tracking will be discussed.

2. Technical approach

In the following, the technical approach to implement the OCT into a remote laser welding system will be discussed in detail. The measuring principle of OCT will not be depicted, as it's been already widely published [Webster 2011] [Bautze 2015].

In order to allow for an omnidirectional use of the OCT within the full working envelope of the remote laser welding 3D scanner, the sensor is adapted coaxially to the welding head: by using a beam splitter in the collimated beam, the laser beam and the OCT measuring light are combined. Together, they are focused by means of a focusing optics, mounted between the beam splitter and the mirror galvanometers. This optical set-up, sometimes referred to as pre-focus scanner, prevents from any chromatic aberrations that would occur when using F-Theta optics, normally mounted after the mirror galvanometers [Thombansen 2015].

The previously described optical setup allows to displace the laser beam and the OCT beam in a curved, two-dimensional plane. In order to address the third dimensions, usually entitled as 'z', the laser beam's collimation can be shifted in order to move the focal plane. As the OCT beam needs to accurately follow the laser focus, it's also equipped with a motorized collimation that is moved synchronously to the laser collimation.

Additionally, the OCT measuring principle is based on comparing the length of two optical paths which only differ in a few millimeters. As the focal plane and therefore the distance to the object or workpiece to be measured is varied, the reference beam of the OCT needs to be varied in a similar manner. Therefore, the OCT reference path consists of an assembly of mirrors that can be manipulated in such a way to modulate the optical path length.

In order to enable the OCT sensor to not only record the distance to a single point, the OCT beam is deflected by its own 2D scanner before being coupled with the laser beam. This allows to move the measuring light in the surroundings of the focal spot of the laser beam. Hence, the scan of the workpiece edge can be performed before the laser beam hits the workpiece. As for the seam inspection, the OCT beam scans the height profile of the welded seam right after the welding took place.

These four degrees of freedom of the OCT – the two mirror galvanometers, the motorized collimation and the adjustable reference path – require for a synchronous and real-time control in order to accurately position the OCT focal spot to the targeted place. To enable tracking and quality assurance with full On-The-Fly capability, especially for curved seams and in z-direction, the exact knowledge of every position and movement of all axes is essential. The three axes of the welding scanner, the four axes of the OCT-scanner and the six axes of the robot have to be perfectly synchronized. Also, the tracking error, acceleration and deacceleration times of the galvanometers has to be taken into consideration.

An additional challenge of implementing the OCT into remote laser welding is the exact calibration of the OCT scanner relatively to the welding scanner. The quality of this calibration is essential for achieving good tracking and therefore good welding qualities within a large part of the working envelope.

The calibration can be performed by marking a repetitive pattern on a flat surface, recording the pattern's topography with the OCT sensor and subsequently localizing the marked pattern. With this information and the knowledge of the exact position of the beforehand marked pattern in the scanners coordinate system, the working fields of the welding scanner and the OCT scanner can be exactly matched. This procedure has to be performed one-time after the installation of the system and after changing fibers. Once calibrated, further calibration is not required when using mirror galvanometers that allow an automatic self-calibration.

One of main issues to enable OCT-supported remote laser welding for a broad field of applications with high acceptance by the users is the usability. The system – although very complex itself – has to be easy to use, stable over a long time and should provide the user only with a manageable number of parameters.

A possible approach is a monolithic software: the OCT-scanner and the welding scanner are programmed in the same software. In this software (RSU8) the parameters for edge tracking and quality assurance can be programmed by the user just as every other welding parameter. The system places the OCT-lines automatically perpendicular to the 3D-welding seam. Although OCT adds a new level of complexity to remote laser welding, this can be handled easily be the user. In most cases it should be possible to work with the standard parameters for fillet seam edge tracking.

3. Preliminary results

As stated above, car doors are one of the main applications for remote laser welding. Therefore, Blackbird tried to demonstrated the possibilities of OCT enhanced remote laser welding with a car door demonstrator consisting of different fillet seam geometries and materials. The different seam geometries for edge tracking on this demonstrator are discussed in this chapter.

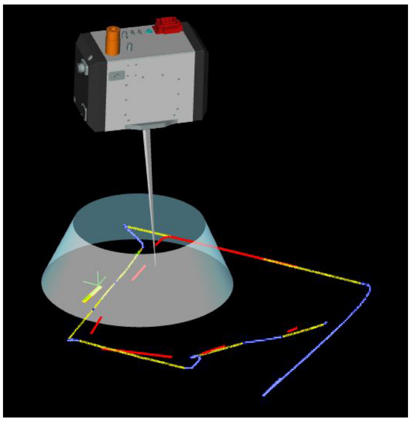

Fig. 1. complete On-The-Fly program that includes the path of the TCP (blue line) as it's performed by the robot, welding groups (yellow lines) and actual weld seams (red lines).

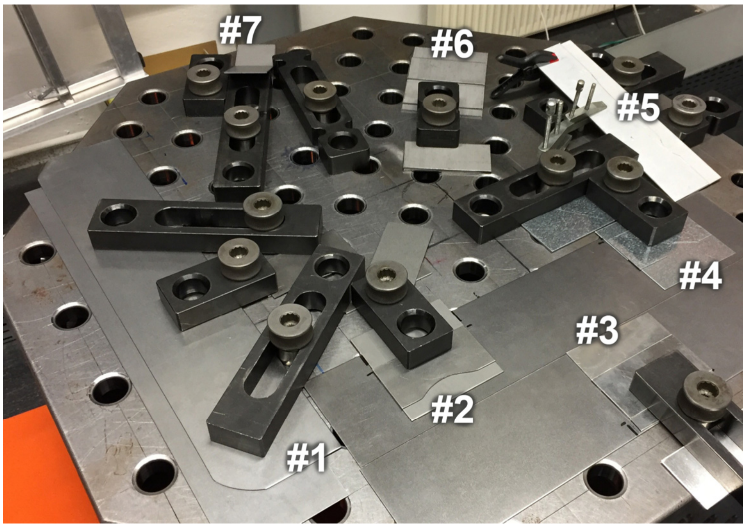

Fig. 2. exemplary setup of different weld configurations as they can be found in hang-on part and body-in-white applications, mounted on one welding bench.

The first welding configurations is a very long seam that also leads around a corner [Fig.2, #1]. This resembles the welding of the door skin to the door structure. Another example shows a butt weld with reference edge [Fig. 2, #2]. This configuration demonstrates the ability to address but welds with a minimal flange width by keeping a constant distance of the seam to the edge of the workpiece. Also, a fillet weld with stainless steel [Fig. 2, #3], a fillet weld with aluminum [Fig. 2, #4] and a hardened steel with two edges [Fig. 2, #6] are part of the demonstrator. Another example with an aluminum fillet weld shows the ability to also track into z-direction [Fig. 2, #5]. As last example an aluminum fillet seam is shown where the upper sheet is inclined to the lower sheet by 30° [Fig. 2, #7].

All seams – except for the first example – are taught as straight lines and the metal sheets have been prepared to have severe distortions. These distortions shall demonstrate the potentials of OCT and the size of these defects is far bigger than normal defects that could appear in a production line. Additionally, the seams are very poorly programmed in terms of spatial orientation and the actual shape of the edge. Without activated seam tracking a misplacement of the pilot laser path and the nominal positions of the seams in the magnitude of 1-5 mm can be measured.

The OCT-seam tracking is activated within the user interface. As a first test run, the welds can be recorded without activating the edge tracking algorithm [Fig. 4]. All records are saved into a database with timestamp, serial number (if provided) and welding parameters and can be accessed via the software or be exported.

If the acquisition of height profiles through OCT can be confirmed, the edge tracking can be activated [Fig. 5]. For the above described door demonstrator, the same edge finding parameters are used for all seams apart from the butt weld. The pilot laser respectively the laser focus follows the edges of the part, regardless of edge geometry, material, scanner rotation and z-position.

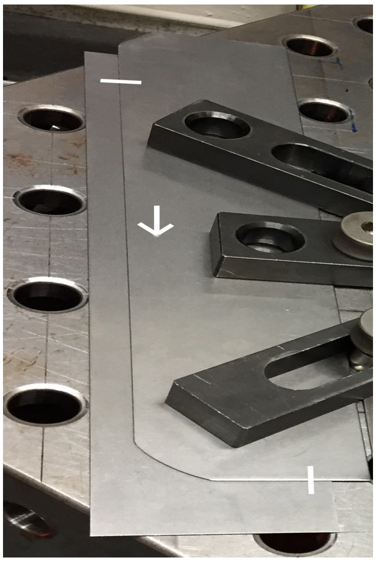

Fig. 3. close-up view of seam #1; the marks indicated the beginning and end of the seam.

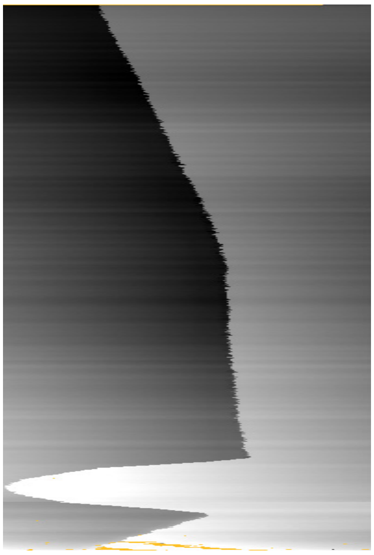

Fig. 4. OCT height profile for seam #1 as recorded without activated seam tracking.

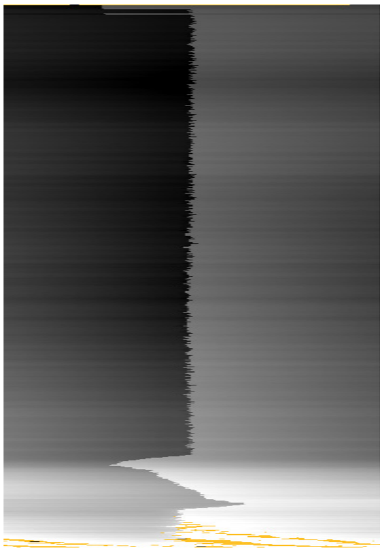

Fig. 5. OCT height profile for seam #1 as seen when the seam tracking is activated.

4. Oscillation with OCT based edge tracking

As shown in the previous section, applications for seam tracking without simultaneous oscillation of the laser beam can be addressed by the current state of development. Nevertheless, the oscillation is a key factor for achieving good welding results in fillet weld configurations with aluminum, as the spatial laser power distribution is critical for avoiding hot cracks [Weberpals 2015]. Also, for welding of steel fillet seams, the oscillation can provide a gap bridging capability. Therefore, synchronous seam tracking and oscillation is mandatory for welding most fillet welds configurations.

In order to address these applications, technical constraints need to be solved. On small field scanners, the laser beam and the sensors have different optical paths; therefore, a laser beam oscillation does not affect the optical sensors. In case of large field 2D- and 3D-scanners – as the Scanlab intelliWELD PR that was used for above mentioned tests – the laser beam and the sensors are deflected by the same galvanometer mirrors. An oscillation therefore also affects the optical sensors. In case of coaxial use of OCT, where every measurement spot needs to be positioned with an accuracy of 50 µm or better, the high frequent oscillation of the main galvanometer mirrors causes a serious constraint. Different possibilities to solve this circumstance will be discussed hereinafter.

One way to handle oscillation is the “two-step OCT” with a time separation of OCT and oscillating welding laser: in a first step, the seam is scanned with the OCT system and in a second step the weld seam is placed with oscillation by knowledge of the previously recorded position of the seam. As a disadvantage, this method is not applicable for robot-based systems and has limited gap bridging capabilities, it needs a more complex programming and comes with longer cycle time.

Another strategy is a software based online compensation. In this case, the OCT scanner would compensate the oscillation movement of the working laser. The calculation is complex and is only possible for low oscillation frequencies and simple patterns. The scanner dynamics are the main limiting factor in this case. Also, the user would have to deal with a reduced resolution due to jitter effects.

The third strategy oscillates the OCT beam and the laser beam in the same manner. In this solution, the OCT beam has a small offset in direction of the weld seam. Disadvantages are limited post-process capabilities, it is only applicable for straight welds or welds with large edge radius and a continuous sinusoidal oscillation pattern is required.

All three solutions above have the common advantage that they do not need additional hardware. Three more solutions are possible, but they need additional hardware in terms of drives, mechanical and optical components.

In a solution that can be named as “post-scan beam splitter”, the laser and OCT have distinct scanners for high-frequent oscillations, followed by a beam splitter that superimposes both beams. The laser and the OCT light may have their own focusing optics or a common lens after the beam splitter. This enables a very flexible beam oscillation and OCT application, but comes with a field of view by the size of the beam splitter and, if applicable, focusing optics.

Another possibility is a “wobbling collimation”. In this lean solution, a rotating collimation unit deflects the laser beam in a circular shape. Also, two rotating optics may be used in a risley prism configuration to deflect the beam in any direction. Still, this results in either inflexible oscillation patterns or the complexity to control to rotating lenses.

The most versatile approach is the “triple scanner”. The Laser and OCT have distinct 2D scanners for high-frequent oscillations, then being combined through a beam splitter and then followed by a common scanner. This would be the most flexible solution, but it requires a large number of opto-mechanical components and leads to a large size and comes with the costs of three scanner units.

5. Future challenges

The next generation of industrial OCT-engines will come with sampling rates of up to 500 kHz. First systems with more than 1 MHz have been demonstrated in combination with scanning units [Wieser 2015]. These high sampling rates are necessary to enable tracking and quality assurance done at the same time with decent resolutions. Compared with the current generations in the range of 100 kHz sampling rate, improved solutions for data transferring and real time calculations are mandatory.

To be able to actually benefit from such high measurement rates, it is also very important to further optimize the speed of the OCT-scanner galvanometers. Considering today’s state of the art, the acceleration and deceleration at high frequencies leads to a loss of time available to perform distance measurements.

For some applications the measurement of the keyhole depth can be valuable. This has already been shown on fixed optics [Bautze 2014]. The implementation on a 3D scanner comes with additional challenges. Especially the quick changes of direction and the high processing speed make it very difficult to get a stable signal from the keyhole bottom. In case of sequential pre-, in- and post-OCT scans, the keyhole depth measurement would be interrupted, complicating the interpretation of the keyhole depth signal.

On the software side, the GUI has to be user-friendly and enable the end-user to monitor and adjust all process parameters and all the pre-, in- and post-process parameters of the OCT.

6. Summary

The depicted OCT solution can be deployed for stable and easy to use edge tracking tasks if the process doesn’t require a simultaneous laser beam oscillation. An acquisition of post-process seam profiles allows the subsequent use of tools to compare the seam’s geometry against pre-defined boundaries and quality measures.

To address processes with oscillation and high-resolution quality assurance tasks, further development has to be done. Especially, the next generation of OCT engines with higher sampling rates for quality assurance tasks and a suitable solution for oscillation will be needed to develop OCT-enhanced remote laser welding into a technology that can be used for a wide variation of processes and products.

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