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Seam tracking for fillet welds with scanner optics

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Abstract

Fillet welding requires a high positioning accuracy of the laser beam in respect to the joint. Workpiece manufacturing tolerances and variations of the clamping require the individual positioning for every workpiece, i.e. an online seam tracking is needed. The proven concept of simultaneous observation of the joint and the laser spot by a coaxial camera sensor and real-time image processing are adapted to the PFO 3D scanner optics. Light-section measurement of the joint ensures robust detection and insensitivity to workpiece surface attributes and to variations of the workpiece cut shape. The system has shown excellent performance at different workpieces and different weld configurations (e.g. incident angle) and is presently under industrial qualification

Keywords: Laser fillet welds; seam tracking; online sensor system; real-time image processing; light-section measurement;

1. Introduction

Laser welding has become widely uses practice in car body manufacturing because of its high productivity and flexibility. Typical weld joint configurations in body-in-white production are overlap joints of sheet metal. Here, line segments of various length and figures, e.g. circles or c-shaped cramps, are used and the shape of the weld segment is tailored to the required joint strength. Frequently these laser welds are carried out by a remote welding process with a scanner welding optics[1]. The processing beam is deflected across the workpiece surface by a set of scanner mirrors in the welding head and also small and complicated figures can be welded at high speed and great accuracy. The scanner welding optics is moved by a robot along a coarse path across the workpiece – the fine positioning of the laser spot is done by the scanner.

Compared to resistive spot welding (RSW) which has been used earlier, and which is still use in different cases, laser welding enables a narrower seam and allows a smaller flange which reduces the weight of the part. This is becoming ever more important in modern car production and is one key to save fuel and reduce CO_2-emissions.

The flange size can be reduced further by applying laser fillet welds of the partially overlapping sheets (see fig. 1), which gives potential to further weight reduction. Additionally, for car doors fillet welds allow smaller window frame size and larger windows without compromising the strength. But, fillet welds require a high positioning accuracy of the laser spot on the workpiece to ensure a good fusion: the edge or corner must be hit exactly. Consequently, an active seam tracking process is needed, because workpiece tolerances and clamping technology are not accurate enough.

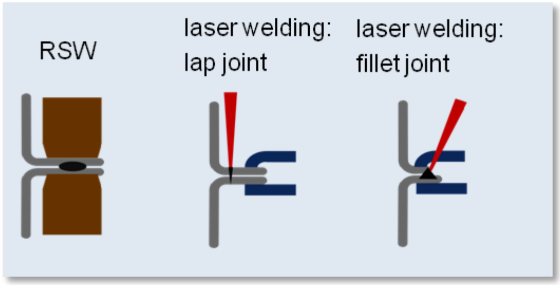

Fig. 1: Scheme of welding position and required flange size for laser welds in comparison to resistive spot welding (RSW). Laser welding requires additional clamping (dark blue).

2. Seam tracking

2.1. General principle

Active seam tracking in laser welding processes is well established and has been used for more than a decade in combination with fixed welding optics. Usually, the laser spot position is manipulated by moving the welding optics or by a dedicated deflection mirror that is built into the optics [2].

Most seam tracking systems for laser beam welding use camera sensors that measure the joint position in forerun to determine the lateral deviation from the desired position. This deviation is transferred to the control axis and the offset is corrected. For a robust and reliable joint detection, a controlled illumination is essential. Basically two different types of workpiece illumination are used: Vertical lighting to generate grey scale images, or laser line projection for triangulation using light-section measurement. Sometimes both types of illumination are implemented in the sensor system and the most appropriate type can be chosen.

2.2. Vertical lighting

Grey scale image evaluation with vertical lighting is well suited when the workpiece shows features of high contrast, like gaps, definite edges with no material beneath, holes, etc.

It fails if the contrast to be detected is too low or varies strongly e.g. by changing material surface attributes, or when the detection feature disappears or is mimicked by another feature: a small gap and a scratch on the workpiece may look identical. Also, vertical lighting does not highlight any height structure, like a step or chamfer.

2.3. Laser line projection

Projecting a laser line on the workpiece at a dedicated angle is the basis for a light-section measurement, which is a type of triangulation. It allows measurements of vertical distance and distance variances, and thus enables the measurement of workpiece topology. Light-section measurement is an ideal method to measure edges and steps, their position and height. As only the position and shape of the laser line reflection are evaluated, a light-section measurement is widely insensitive to changes of the workpiece surface attributes.

2.4. Optimum illumination for overlap fillet welds

Regarding the workpiece illumination of car body sheets in fillet weld configuration (fig. 1 right) we have investigated vertical lighting by LEDs for grey value imaging and laser line projection for light-section measurement. It turns out that simple grey image processing is not suitable to reliably detect the joint position at the overlapping sheets of the investigated configuration. Variations of the reflection from the cut edge, e.g. angle, roughness, varying shadowing at non-vertical observation, and scratches on the workpiece surface prohibit the robust and precise edge detection.

The light-section measurement, on the other hand, allows the robust detection of the joint position, widely independent of the surface and cut quality. The step at the overlapping sheets can be measured in a wide range of incidence angle (0° to 45°). This may be necessary for a high-quality weld or may be caused by limited accessibility to the workpiece because of its shape or clamps. In addition, interpolation of the surfaces of the lower and upper sheet also helps to determine the joint position. As the light section triangulation provides absolute height measurement, the gap size can be determined (when the thickness of the upper sheet is known) and may be considered in the welding process.

The laser line illumination and light-section measurement predetermines the weld direction: The laser line is in forerun and perpendicular to the feed direction. These restrictions could be overcome by several or adjusting laser lines.

3. Adaption to the PFO scanner optics

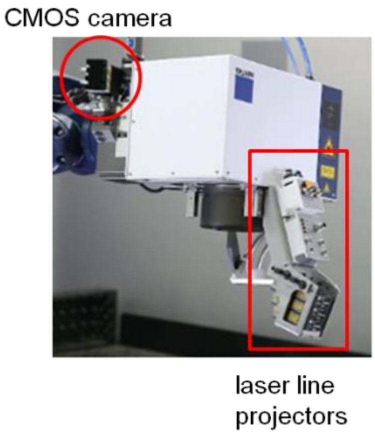

Fig. 2: TRUMPF PFO 3D scanner optics with coaxial CMOS-camera of process zone imaging and laser line projectors for light-section measurement of the joint.

TRUMPF has introduced the advanced seam tracking sensor system SeamLine Pro with the fixed processing optics BEO D70 several years ago [3,4]. This process sensor system observes the processing zone with a CMOS-camera coaxially to the processing beam. In the *pre*-process zone the weld joint is detected either by light-section or by grey-value image evaluation at only 5 to 10 mm forerun to the welding position. Simultaneously, the actual weld spot position is measured in the *in*-process window by the same camera. And finally, the system measures the seam geometry by a second light-section measurement in the *post*-process zone.

The camera images are processed in real-time at a rate of some hundred Hertz. From the deviation of the measured joint position to the weld spot the welding position is corrected in a closed-loop control by dedicated axes.

We have transferred this concept to a TRUMPF PFO 3D scanner: In an experimental setup the CMOS-camera is mounted to the camera port of the PFO and allows on-axis observation of an area of approx. 22 mm around the processing beam. Processing and monitoring light path are separated by a dichroitic beam splitter.

For light-section illumination purpose we have mounted laser line projectors to the PFO and adjusted the laser line at approx. 8 mm forerun to the welding spot (fig. 2). The actual laser spot is measured in the *in*-process window, and serves as the reference point for the seam tracking.

Real-time image processing and closed-loop position control is adapted from the SeamLine Pro system with minor changes. The position control sets via an internal bus the scanner mirrors for fast and accurate positioning of the laser spot.

3.1. Experimental results

The in-process evaluation algorithms have been adapted and expanded to recognize and measure the joint position at incident angles of 0° to 45°. Also, the incident angle and the gap width are determined from the light-section measurement.

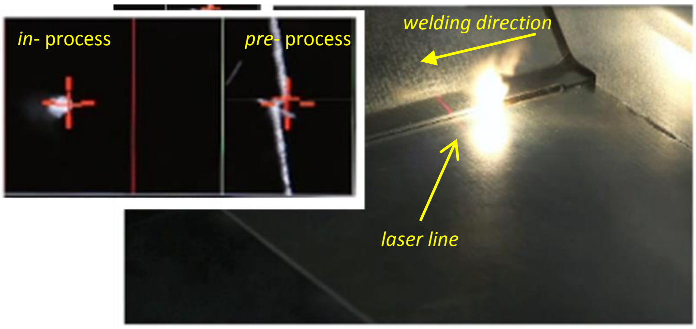

Fig. 3: Fillet seam welding with active position control.

The left insert image shows the *in*-process window with the laser spot and the *pre*-process window with the laser line for precise and robust joint detection.

The right picture shows the actual welding process with the laser spot and the red laser line in forerun.

Fig. 3 shows the welding of a flat fillet seam at an incident angle of 20°. But, real workpieces are not as flat as this laboratory example. Therefore, we have tested the system at various “industrial” workpieces of different material and under various configurations. Fig. 4 shows some examples with small flanges that continue into bent sheets. In all case the joint position was detected and the weld position was corrected by control of the scanner mirrors. The influence of material, surface and edge quality of the workpiece were negligible and seam tracking was possible in almost every case.

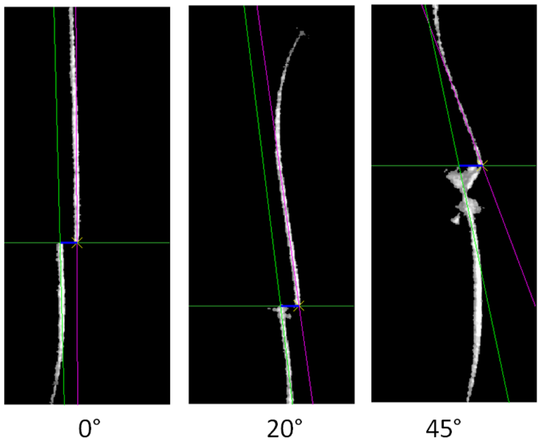

Fig. 4: Light section measurement of joints from "real" workpieces, which are not perfectly flat but show only small flanges that continue in a bent sheet. Also, the incident lateral angle is varied between 0° and 45°.
The green and violet lines show interpolation lines that are used to determine the joint position.

4. Summary

We have demonstrated an online seam tracking system for a PFO 3D scanner optics that detects partial overlap sheet for fillet joints accurately. The joint position is measured using light-section triangulation at little forerun to the weld position. This makes the measurement insensitive to changes of the workpiece surface or the cut quality. It is robust in a wide range of incidence angles of 0° to 45° without changes to the system and, thus, different incident angle can be used on the same workpiece.

The coaxial sensor system simultaneously measures the laser spot position as the reference.

In the present configuration, where we use only one laser line projector there are some limitations to the system: There is a distinct forward direction given by the laser line to be in forerun, and because of the laser line length of 20 mm, the joint has to be near the center of the optical axis of the scanner optics. Despite these limitations, there are a lot of applications in car body production, where scanner usage is state-of-the-art and our sensor systems expands the area of use to fillet welds.

The system has been tested successfully with various configurations and at workpieces in the laboratory. Industrial tests are ongoing. The sensor system allows a new laser welding process that reduces the flange width by approx. 40%, reducing the weight of the workpiece in body-in-white production.

Further development and improvements will reduce the limitations – restricted field of operation to the center of the scanner, and distinct welding direction – and expand the area of use even more.

References

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