WELDING HEAD FOR 'SELF GUIDED' LASER WELDING
Paper #2309

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Abstract

Precise positioning of the laser beam on the workpiece is crucial for high quality laser welds; e.g. for butt welding the focal point of the laser beam with respect to the joint must be maintained within an accuracy better than 20µm - 150µm, depending on the focused beam radius. These stringent accuracy requirements call for high precision robots, a repeatable workpiece profile and precise clamping. To compensate for insufficient repeatability of workpiece or clamping, seam-tracking devices are used. A sensor measures the joint position and computes a correction vector to follow the actual joint trajectory. The deviation is compensated either by robot trajectory adjustment or by an additional tracking axis. Disadvantages of this approach are complex installation of the devices due to interfacing with the robot control, the need of teaching and calibrating the sensor and principle based accuracy restriction that limit the usability in more complex 2D contours and with low accuracy robots.

We recently introduced a more flexible and precise approach that utilizes an advanced camera-based sensor that is capable of measuring seam position, relative displacement between workpiece and sensor and melt pool of the process with one single device. This paper describes a realized 'self guided' welding head, which uses this approach in combination with an integrated high power scanner. The result is a welding head that follows a curved or linear butt weld with high precision and independent of the actual robot trajectory; without the need of calibration, robot interfacing and alignment.

Introduction

Laser welding allows high precision welds with aspect ratios of up to 1:10; far superior to any traditional welding approach. However, the process also calls for precise positioning of the ‘laser tool’: The working distance has to be maintained typically within 200µm-500µm; and for butt or fillet welds the focal point has to be positioned on the joint within the focused beam radius (typically 50µm – 150µm) /SCHULTZ1997/. In overlap welding applications, the lateral position accuracy requirement is lower, usually within 0.2mm – 1mm.

To provide the needed accuracy, seam tracking devices are widely used in butt and fillet weld applications. The predominant seam-tracking sensor concept is based on the triangulation principle, Fig 1. Older sensors of this type use a deflecting mirror to scan the workpiece surface around the joint /BOGEL1990/; present systems use light section sensors, e.g. /FALLDORF-SENSOR2009/, /SERVOROBOT2009/, /PRECITEC2009/, /META-SCOUT2009/.

Fig. 1: Seam tracking sensor based on triangulation /light section principle

A less widespread principle for joint position measurement is gray image recognition, Fig. 3. This approach uses a high speed camera to observe the joint. A bright field illumination provides good contrast of the joint to the surrounding material, Fig. 2.

Fig. 2: Bright field illumination
Additional illumination
 Beam splitter
 Camera

Fig. 2: Optical setup for gray image recognition based seam tracking sensor

Standard image processing algorithms are available to increase contrast and remove fragments (e.g. Threshold, Dilation and Erosion filter), extract edge positions (Sobel filter) and determine the coordinates of the joint contour (Hough transformation).

An advantage of this sensor concept is that it measures very narrow butt joints with high reliability, whereas light section sensors work best on surfaces with height changing profile (fillet-, V-groove-, flange-weld) /STARKE1983/, /HORN1994/.

Fig. 3 Seam tracking sensor based on gray image recognition

Seam Tracking Control Principle

As a matter of principle, seam tracking sensors measure the joint position with a forerun to the laser beam position (Tool Center Point TCP). For correct tracking, this forerun has to be considered as a time delay $T$, which is dependent on the average feed rate $v_{robot,x}$ and the actual forerun of the sensor $s_x$:

$$T = \frac{s_x}{v_{robot,x}}$$

(1)

It is obvious that an incorrect time delay setting – due to a difference of the actual feed rate to the set feed rate – leads to positioning errors, as shown in Fig. 4.

Fig. 4: positioning error caused by an actual feed rate below the set feed rate

The target value for the tracking axis $p_{cor,y}$ at a given time $t$ is calculated by the sum of the sensor reading value $s_y$ and the tracking axis position $p_{axis,y}$ under consideration of the time delay $T$:

$$p_{cor,y}(t) = s_y(t - T) + p_{axis,y}(t - T)$$

(2)

This simple control approach is sufficient if

- the feed rate is constant within an acceptable tolerance
- the feed direction is linear within the required position accuracy (no transversal robot movement)
- the head is not tilted in either direction during the robot movement.
- No work piece movement occurs
These requirements can be sufficiently met for many 1d – applications that use a linear axis or gantry robot. Most articulated robots however do not meet the linear and rotational accuracy. Formula (3) expands formula (2) by a lateral movement of the robot $r_{robot,y}$:

$$p_{corr,y}(t) = s_y(t - T) + r_{robot,y}(t - T) + p_{axis,y}(t - T)$$

It is apparent that a control algorithm based on formula (2) gives correct results if the lateral robot position remains constant, but results in a position mismatch whenever the robot moves transversal to the feed direction. The mismatch value equals the lateral movement of the robot $r_{robot,y}$; the mismatch length equals the sensor forerun $s_x$. Similar conditions occur if the welding head is tilted to the feed direction.

Coaxial Seam Tracking Sensor

The seam tracking accuracy can be significantly improved by shortening the sensor offset $s_x$. Maximum shortening can be realized with a coaxial sensor setup, where the beam path of the sensor camera is coaxial with the laser (‘coaxial setup’) and observes a tracking line focused only millimeters before the TCP, e.g. /MÜLLER-BORHANIAN2005/, /PERMANOVA2009/, /THYSSEN2007/.

We recently introduced an imaging setup, which enables to observe the joint position close to the TCP, the melt pool and the surrounding work piece surface simultaneously with a high speed, high dynamic CMOS camera /REGAARD2006/. The setup uses a low power diode laser to coaxially illuminate the process area. A narrow-band line filter blocks process radiation and back reflection of the laser.

In this paper we describe a welding head utilizing this sensor setup for robot independent, ‘self guided’ seam tracking and on-line process monitoring.

Opto-Mechanical Setup

The welding head uses an off-axis parabolic mirror (OFP) with 200mm effective focus length to focus the laser beam. A scanner mirror, placed close behind the focusing mirror, provides dynamic positioning capability of the TCP in one axis with a total scan length of 30mm, Fig. 6.

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For coaxial monitoring, a dichroic mirror is placed in the collimated beam path between the collimation optic and the focusing mirror. A second OFP focuses light transmitted through the dichroic mirror onto a high speed camera. An advantage of this setup is that the OFPs are achromatic; therefore the focus position of the camera is constant for any wavelength observed. However, the OFP also induces image distortion for scanner angles $\alpha \neq 0^\circ$, Fig. 8. These distortions have to be corrected in the image processing software.

Illumination of the workpiece surface is conducted by a low power NIR diode laser that is deflected into the collimated beam path, Fig. 6. Using a high intense illumination spot and narrow-band line filters, the thermal radiation of the welding process and back reflection of the laser beam can be suppressed completely; the camera detects only reflected radiation from the illumination laser (Fig. 9).

'Self Guided' Seam Tracking

The coaxial illumination and monitoring is used as a coaxial seam tracking sensor based on gray image recognition. The efficient suppression of process radiation enables to measure the joint position directly in front of the melt pool, 1-4 mm before the TCP. The short forerun significantly reduces tracking errors caused by undetermined robot- or workpiece movement as described above; however, larger tilt angles or transversal movement still cause significant deviations. Furthermore, the seam tracking control has to be adapted to changing contours; and interfacing to the robot has to be implemented to transmit current feed rate and process start signals.

To realize fully robot independent, 'self guided' seam tracking, we implemented image processing algorithms that, supplemental to the joint position, calculate the current displacement of the welding head relative to the work piece in both value and direction. This information is equivalent to the feed rate and feed direction and is used to provide missing information in the 'conventional' seam tracking approach; enabling the welding head to precisely position the TCP independent from the superposed movement of the welding head.
The test welds are performed without seam tracking to simulate alignment errors of joint and weld. The measurements show good correlation to the different defects and it is possible to distinguish defect classes by the melt pool pattern.

Table 1: Effect of welding irregularities on melt pool width and length

<table>
<thead>
<tr>
<th>Type of defect</th>
<th>Effect on melt pool</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offset</td>
<td>Ratio width/length decreases</td>
</tr>
<tr>
<td>Misalignment joint/weld</td>
<td>Width fluctuates</td>
</tr>
<tr>
<td>Joint width too wide</td>
<td>High fluctuation width and length</td>
</tr>
<tr>
<td>No shielding gas</td>
<td>Width, length change randomly</td>
</tr>
<tr>
<td>Damaged part</td>
<td></td>
</tr>
</tbody>
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Fig. 9: User interface for ‘self guided’ seam tracking. The left image shows a life camera image with the detected seam position and the area for displacement measurement. The lower graph shows the measured feed rate and joint position. The upper right graph shows the actual robot movement and seam geometry calculated by the sensor.

Process monitoring

The coaxial images of the process area can also be used for quality monitoring of the weld process. The coaxial illumination allows precise measurement of the melt pool geometry (±40µm). The algorithm compares consecutive camera images and separates stationary and non-stationary patterns. Since the solid surface of the work piece is stationary within consecutive images, the melt pool can be separated with almost pixel-resolution accuracy, Fig. 11.

Fig. 10: Measurement of melt pool geometry (width and height) for process monitoring

Besides other quality parameters, the length and width of the melt pool is a good indicator for several significant process irregularities, as shown in Table 1.

Conclusion

Seam tracking is a well established technique to deliver the high position accuracy needed for laser welding of butt, fillet and flange welds. However, even with seam tracking control, high repeatable robot movement, laborious robot-sensor interfacing
and precise setup and calibrating is needed for correct results. The welding head introduced in this paper allows accurate seam tracking without any robot interfacing and independent of the robot accuracy, enabling high precision welds even with basic pick-and-place robots. The sensor data can be multi-used for additional process monitoring. Image processing techniques calculate welding head movement and the contour of the melt pool in real time, providing robust and easy-to-use quality measurements.

The current setup of the welding head is in prototype status. Current work is focused on improving the stability of the algorithms and increasing the tracking speed. Future work includes a redesign of the welding head from the current modular setup to an integrated design and extension to a 2d-scanner, enabling true 2d-seam tracking without the need of tilting the welding head to follow the weld contour.

References

/BÖGEL1990/

/FALLDORF-SENSOR2009/

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/SERVOROBOT2009/

/STARKE1983/

/THYSSEN2007/

Meet the Author

Boris Regaard is a senior engineer in the diode laser development group of the Fraunhofer CLT. The presented work in the field of seam tracking and process monitoring was started at his former employer, the Fraunhofer ILT in Aachen, Germany, where he worked in the department for system technology. The current development is carried out in close cooperation of both institutes.