Process Monitoring and Control for Laser Welding

Dr. Najah George - Laser Application Engineer
Precitec - USA
Precitec Divisions

**Laser Cutting**
- Processing heads for laser cutting on flatbed, tube and robot machines
- Processing heads for fine, bevel and high speed cutting
- Process monitoring

**Joining Technology**
- Processing heads for laser welding and laser cladding
- Monitoring systems for pre, in and post processing

**Medical Technology**
- Control for corneal and refractive surgery
- Eye tracking systems

**Measurement**
- Chromatical confocal sensors
- Interferometric sensors
- Line and multipoint sensors

**ALL – IN - LIGHT**
- Complete optical solution from one supplier
- Including laser beam source, cutting head and beam guidance
Laser Process Monitoring and Control Means Quality Assurance
Laser Welding Process and Three Zones

WeldMaster Seam Tracking
Laser Welding Monitor IN–Process Depth Meter
WeldMaster Weld Inspect
Welding Failure

Because laser welding is a multi-parameter process, monitoring and laser control systems are ideal to deal with different parameters and provide accuracy in the process (or alarm the operator to check the process).
<table>
<thead>
<tr>
<th>Welding Failure</th>
<th>Some of Possible Reasons</th>
<th>Monitoring and Control (depending on causing root)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Welding off Seam</td>
<td>Fixture/Robot/Part</td>
<td>WeldMaster Seam Tracking</td>
</tr>
<tr>
<td>Cracks on the top of the weld</td>
<td>- Metallurgical problems&lt;br&gt;- Cooling rates&lt;br&gt;- Welding speed changed</td>
<td>WeldMaster Inspect Laser Welding Monitor LWM</td>
</tr>
<tr>
<td>Lack of fusion</td>
<td>- Power density changed&lt;br&gt;- Process gas changed&lt;br&gt;- Weld speed changed&lt;br&gt;- Gap width&lt;br&gt;- Misalignment</td>
<td>Laser Welding Monitor LWM IN–Process Depth Meter IDM WeldMaster Seam Tracking WeldMaster Inspect</td>
</tr>
<tr>
<td>Geometry: - Pinhole&lt;br&gt;- Undercut&lt;br&gt;- Humping</td>
<td>- Gap width&lt;br&gt;- Weld speed changed&lt;br&gt;- Power density changed</td>
<td>WeldMaster Inspect Laser Welding Monitor LWM</td>
</tr>
<tr>
<td>Lack of penetration</td>
<td>- Power density changed&lt;br&gt;-- Process gas changed&lt;br&gt;- Weld speed changed</td>
<td>IN–Process Depth Meter IDM Laser Welding Monitor LWM</td>
</tr>
<tr>
<td>Porosity</td>
<td>- Keyhole collapse/unstable&lt;br&gt;- Oil/Grease pollution</td>
<td>Laser Welding Monitor LWM IN–Process Depth Meter IDM</td>
</tr>
</tbody>
</table>
From the laser material interaction, energy signals are emitted in various forms. Plasma radiation (UV) < 400nm, Temperature radiation (IR) 1100nm – 1800nm, Back Reflection (Laser wavelength).

Each signal emitted from the process might carry information describing the characteristics of laser welding process. The signals are detected by sensors and compared with a pool of reference/good weld data measurements.
Laser Welding Monitor (LWM) – Sensors

- Sensors can be mounted inside laser sources or on any welding head fixed/scanner optics

Sensor-Module:
- Plasma sensor (UV)
- Temperature sensor (IR)
- Back Reflection sensor (BR)
- Laser Power sensor (LP)

4- Sensors build in the head UV, IR, BR and LP
Laser Welding Monitor (LWM) – Advantages and Technical Data

LWM has been an industry-proven solution for 25 years. More than 2,000 different applications are successfully running in the field worldwide.

**Advantage:**
- In-process monitoring system for solid-state, diode and CO₂ lasers.
- Real time measuring system.
- Cost-effective.
- Contact-free signal recording using multiple coaxial sensors.
- Easy retrofit into existing welding systems (fixed/scanner head OR inside the laser resonator).
- The LWM could also be used to support the fine tuning of the welding parameters.
- Suitable for various welding processes (keyhole / conduction welding, pulse / CW laser).
- Full tracking and traceability provides complete part history.
- Suitable for various welding geometry (e.g., butt weld; Lap weld; fillet weld……).

**Technical Data:**

<table>
<thead>
<tr>
<th>Sampling rate of detectors</th>
<th>40 KHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of input/output</td>
<td>16/16</td>
</tr>
<tr>
<td>Number of programs</td>
<td>Up to 256</td>
</tr>
<tr>
<td>Number of sensors</td>
<td>16</td>
</tr>
<tr>
<td>Type of communication</td>
<td>Any Fieldbus</td>
</tr>
<tr>
<td>Fast result transmission</td>
<td>Via TCP/IP interface</td>
</tr>
</tbody>
</table>
Laser Welding Monitor (LWM) – Example Continuous Weld

Good Weld

Material: 1.5mm, stainless steel, butt joined
Laser spot diameter: 500 µm
Processing speed: 4m/min @ 2600W
Laser Welding Monitor (LWM) – Example Continuous Weld

Seam – One Spot Miss Match
Laser Welding Monitor (LWM) – Example Continuous Weld

Seam – Lowered Laser Power
Laser Welding Monitor (LWM) – Example Continuous Weld

Seam – Two Spots Oil/Grease
Laser Welding Monitor (LWM) – Example Continuous Weld

Seam – Focus Position Change +5mm
Laser Welding Monitor (LWM) – Example Continuous Weld Seam – Lowered Ar. Gas Flow
Laser Welding Monitor (LWM) – Example Spots Weld
Laser Welding Monitor (LWM) – Example Spots Weld
IN–Process Depth Meter (IDM) – Principle

The IDM is an optical coherence tomography system, which is capable of measuring optical path lengths.

The light of a low coherent emitter (super-luminescent diode, SLD) is split into two beam paths. One part of the radiation propagates into the reference path. The other part, the measuring light, propagates through the processing head into the keyhole. The path length difference between the two light paths leads to an interference on the sensor. The distance information is contained in the frequency of the occurring interference, not in the intensity of the detected signal.
IN–Process Depth Meter (IDM) – Advantages

In-process measurement system
✓ The accuracy of micrometers and a time resolution less than a millisecond
✓ Industrial system
✓ Cost-effective: Reduces destructive component testing
✓ Works coaxially
✓ Not limited to one application
✓ Non-contact measurement
✓ Compact design
✓ Process emissions do not interfere with the measurement
✓ The IDM could also be used to support the fine tuning of the welding parameters
✓ Full tracking and traceability provides complete part history

Technical Data:

<table>
<thead>
<tr>
<th>Sampling rate</th>
<th>Up to 70 KHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement range</td>
<td>up to 10 mm</td>
</tr>
<tr>
<td>Interfaces</td>
<td>Network, RS-422, 2x analogue (-10V ... +10V)</td>
</tr>
<tr>
<td>Synchronization with external devices</td>
<td>Trigger input Synchronization output Encoder</td>
</tr>
</tbody>
</table>
IN–Process Depth Meter (IDM)
TwinTec module
Welding Depth Measurement

The module splits the collimated IDM measurement beam into two beams. One beam is directed into the keyhole and the other is directed onto the surface. The keyhole measurement beam runs in an axial direction to the welding beam. The surface measurement beam is laterally offset at the processing level.
IDM and LWM in One System

By using the combination of IDM and LWM, we can record all welding data for each part for future reference.
IN–Process Depth Meter (IDM) - PowerTec
Adjusting the welding depth (Closed loop laser power control)

The IDM is fitted with an integrated controller. Different signals measured by the IDM can be used as control values. The correcting variable is affected by the analogue outputs (0-10 V) available. For example, the required welding depth is specified and maintained at a constant value by adjusting the laser power. The controller update rate is the same as the sensor sampling rate, and is no more than 70 kHz.
IN–Process Depth Meter (IDM)
Example - Adjusting the welding depth (Closed loop laser power control)

IN–Process Depth Meter (IDM)- Example
- Changing laser power

- Bead-on-plate welds of mild steel
- Laser power was varied,
- 5 m/min feed rate, 200 μm spot
- -2 mm defocus position kept constant

The Yellow line is the IDM data

From Dorsch, Harrer, Haug, et al. (TRUMPF) / ICALEO 2016
IN–Process Depth Meter (IDM) - Example Pulsing with Laser

Compared depths on Titanium alloy TA6V, Laser source TRUMPF HL506P (600 μm spot size diameter)

Compared depths on stainless steel 316L, Laser source TRUMPF TruPulse62 (200 μm spot size diameter)

From Authier, Baptiste, Bruyere, et al. (CEA) /ICALEO 2016