The Basics of Lasers and Laser Welding & Cutting

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Agenda

1. Basics of lasers

2. Basics of laser welding

3. Summary
Advantages of laser welding

- **Flexibility** …
  - beam manipulation (beam switching and sharing)
  - variety of product geometries and materials
  - ease of back-up (especially YAG)

- **Often faster than other techniques** …
  - high power density weld process
  - high laser uptime (>98%)

- **Cost savings** …
  - high productivity
  - reduction of scrap and re-work
  - reduction of manual labor
  - reduction of component material and weight
  - can eliminate secondary processes
Laser basics

- **LASER**
  - Light Amplification by Stimulated Emission of Radiation

- Active Laser Media
  - Nd:YAG (Rod Laser)
    - Neodymium Yttrium Aluminum Garnet
  - Yb:YAG (Disk Laser)
    - Ytterbium Yttrium Aluminum Garnet
  - CO₂ (Gas Laser)
Laser basics

- Nd:YAG (Rod Laser) $\lambda = 1064 \text{ nm}$
- Yb:YAG (Disc Laser) $\lambda = 1030 \text{ nm}$
- CO$_2$ (Gas Laser) $\lambda = 10600 \text{ nm}$
Laser basics

Power supply

Laser pump
(e.g. lamp, diode, RF)

Mirror 1

Mirror 2

Laser active medium
(e.g. Nd:YAG, Yb:YAG, CO₂)

Resonator

Laser beam
Characteristics of laser light

- Many colors
- Many directions
- Many phases

- One color >> select laser for application
- One direction >> can capture all the beam energy
- One phase >> maximum energy at workpiece
Spot size – CO₂

\[ d_f = M^2 \left( \frac{4\lambda f}{\pi D} \right) \]
Spot size - YAG

\[ d_f = M^2 \left( \frac{4 \lambda f}{\pi D} \right) \]

\[ d_f = 3BQ \left( \frac{4 \lambda f}{\pi D} \right) \]

\[ d_w = \phi_c \left( \frac{f}{f_c} \right) \]
Power density

- Power density = power per unit area
- Power density of an unfocused 6 kW CO\textsubscript{2} HQ laser is about 1,000 W/cm\textsuperscript{2}
- Power density of a focused 6 kW CO\textsubscript{2} laser (f200mm) is about 50,000,000 W/cm\textsuperscript{2}
## Effects of Beam Quality

<table>
<thead>
<tr>
<th>Beam-quality</th>
<th>Spot-diameter</th>
<th>Working distance</th>
<th>Depth of focus</th>
<th>Optics</th>
<th>Working area of a scanner optics</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 mm*mrad (LP rod)</td>
<td>![Spot-diameter image]</td>
<td>![Working distance image]</td>
<td>![Depth of focus image]</td>
<td>![Optics image]</td>
<td>![Working area image]</td>
</tr>
<tr>
<td>4-8 mm*mrad (DP disk)</td>
<td>![Spot-diameter image]</td>
<td>![Working distance image]</td>
<td>![Depth of focus image]</td>
<td>![Optics image]</td>
<td>![Working area image]</td>
</tr>
</tbody>
</table>

With same Focussing optics

With same Spot diameter
Focal length

Key advantages of short focal length:

- Faster weld speed
- Less heat input

Key advantages of long focal length:

- Longer depth of focus
- Further from weld spatter & smoke
CO\textsubscript{2} vs. YAG

CO\textsubscript{2} considerations ...

- Higher powers
- Better focusability
- Higher weld speeds on materials non-reflective to CO\textsubscript{2} wavelength
- Deeper weld penetration on materials non-reflective to CO\textsubscript{2} wavelength
- Lower capital and operating costs
- Less expensive safety precautions
CO$_2$ vs. YAG

**YAG considerations ...**

- Fiber optic beam delivery
  (*esp. robotic applications*)

- Materials reflective to CO$_2$ wavelength can often be welded

- Easy beam alignment, beam switching and beam sharing

- Argon can be used for shield gas (plasma suppression not required)

- Long and varied fiber lengths with no effect on process

- High peak powers with high energy per pulse
Heat conduction welding

**Description**
Heating the workpiece above the melting temperature without vaporizing

**Characteristics**
- Low welding depth
- Small aspect ratio
- Low coupling efficiency
- Very smooth, highly aesthetic weld bead

**Applications**
Laser welding of thin workpieces like foils, wires, thin tubes, enclosures, etc.
Keyhole welding

**Description**
Heating of the workpiece above the vaporization temperature and forming of a keyhole

**Characteristics**
- High welding depth
- High aspect ratio
- High coupling efficiency
Description

Heating of the workpiece above the evaporating temperature and creation of a keyhole because of the ablation pressure of the flowing metal vapor, power density of $10^5 - 10^6$ W/cm$^2$

Characteristics

- High cutting depth
- Fine cutting precision
- Very low heat input
# Seam and joint types

<table>
<thead>
<tr>
<th>Name</th>
<th>Example</th>
<th>Characteristics</th>
</tr>
</thead>
</table>
| Seam weld on butt joint       | ![Example](image1.png) | + weld fusion area  
- positioning tolerance |
| Lap weld on lap joint         | ![Example](image2.png) | + positioning tolerance  
- weld fusion area |
| Fillet weld on lap joint      | ![Example](image3.png) | + weld fusion area  
- positioning tolerance |
| Fillet weld on T-joint        | ![Example](image4.png) | + weld fusion area  
- positioning tolerance |
<table>
<thead>
<tr>
<th>Name</th>
<th>Example</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lap weld on T / border joint</td>
<td><img src="example1.png" alt="Example" /></td>
<td>+ positioning tolerance - weld fusion area</td>
</tr>
<tr>
<td>Seam weld on flange</td>
<td><img src="example2.png" alt="Example" /></td>
<td>+ weld fusion area - positioning tolerance</td>
</tr>
<tr>
<td>Lap weld on formed seam</td>
<td><img src="example3.png" alt="Example" /></td>
<td>+ positioning tolerance - weld fusion area</td>
</tr>
</tbody>
</table>
Seam and joint tolerances

Butt joint configuration:

- Gap: 3-5% thickness of thinnest sheet
- Offset: 5-12% thickness of thinnest sheet

Overlap joint configuration:

- Gap: 5-10% thickness of thinnest sheet

Why is this general guideline not absolute?

(What influences the amount of gap that can be bridged?)
Laser Welding & Cutting

Examples
Remote welding with Disk Laser
Register Enclosure

- **Material**
  - Stainless Steel
  - Thickness 0.040”

- **Laser Welding Strategy**
  - Heat Conduction Welding
  - Shield Gas He
Register Enclosure

Example: Housing 16”x24”x10”

Production time in [min.]

- Laser welding
  - 4 min
  - 3 min
  - 2 min

- MIG welding
  - 24 min
  - 10 min
  - 3 min
  - 2 min

ca. 30 min.

1) Cutting out the blank
2) Bending
3) Welding (with fixture)
4) Grinding and cleaning
## 2. Elimination of Post Processing: OLYMPUS – Display Enclosure

<table>
<thead>
<tr>
<th></th>
<th>Manual welding</th>
<th>Laser welding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Welding time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(manual 56 €/hour)</td>
<td>10 Min</td>
<td>4 Min</td>
</tr>
<tr>
<td></td>
<td>9.33 €</td>
<td>9.33 €</td>
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<tr>
<td>Grinding</td>
<td></td>
<td></td>
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<tr>
<td>(manual 48 €/hour)</td>
<td>24 Min</td>
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<tr>
<td></td>
<td>19.20 €</td>
<td></td>
</tr>
<tr>
<td>Sum</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>28.53 €</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Savings</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>19.20 €</td>
</tr>
<tr>
<td><strong>in %</strong></td>
<td></td>
<td>67%</td>
</tr>
</tbody>
</table>
Laser Welding in Sheet Metal Manufacturing
3-D Laser Cutting
Laser Welding

Keys to Success
Outline

• Early involvement from production personnel
• Creating a laser champion
• Selecting partners for success
• Considering the ambient environment
• Design for maintenance and service
• The making of exceptional operators and maintenance personnel
• Commitment to training
• Not sparing the spares
• Conclusion
Early involvement from production personnel

Include plant personnel early in the process
> relational and philosophical disconnect between engineering and plant personnel can result in implementation delays and reduced system operational efficiency

> Early involvement is the key to ...
  • ownership
  • technology transfer
  • acceptance
  • integrating suggestions based on plant experience

> In summary ...
  • involve
  • lead
  • listen
  • expect great things
Creating a laser champion

Appoint plant laser champion
> not having a laser champion at the using plant can increase system downtime and reduce system operational efficiency

• appointing a champion

• characteristics of a champion
  > ideally a welding or mechanical engineer
  > has an interest in laser technology
  > will be around for awhile
  > is teachable/trainable
  > can teach others

• shepherding the champion
  > instilling the vision
  > provide and support key training
  > enablement - authority and focus
Selecting and mentoring operators and maintenance personnel
> inappropriate selection of operators and maintenance personnel can increase system downtime and reduce system operational efficiency

- **selecting** (when allowed)
  > attitude
  > aptitude

- **training**
  > need to know how to safely operate and maintain the system in all “modes”
  > need to know how components function
  > need to know when the system is not operating at optimal performance
  > laser training at using site vs. TRUMPF
  > supplemented by laser champion and LSO (on-going)

- **empowering**
  > proportional to mentoring and training
  > proportional to attitude and aptitude
Commitment to training

Training of laser personnel
> inadequate and improper training of key laser personnel can increase system downtime and reduce system operational efficiency

• commitment to training = commitment to quality

• training requires investment (time and money)

• it’s more than just cranking out parts (safety, operator, maintenance, application, LSO, technology transfer, etc.)
Not sparing the spares

In-house spares
> inadequate appropriation of spare parts can increase system downtime and reduce system operational efficiency

• “We’ll take care of that later.”

• the role of tele-diagnostics
Advantages of laser welding

- **Flexibility …**
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  - variety of product geometries and materials
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- **Often faster than other techniques …**
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- **Cost savings …**
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Conclusion

What I am NOT saying ...

• ignore economics and cost justification
• forget about the details of laser physics
• don’t bother with prototype parts and DOE’s
• underestimate the mechanical & electrical engineering considerations
• tooling and part fit-up are no big deal
• part cleanliness doesn’t matter
Conclusion

What I am saying ...

- continue to do all these things better than ever before

- re-emphasize and strongly consider these items ...
  > involve key people from production personnel early in the process
  > create a laser champion at the using plant
  > select partners that have proved themselves – over and over again
  > consider the ambient environment
  > insure the issues of maintenance and service are not overlooked in the system design
  > be truly committed to training and mentoring operators and maintenance personnel
  > procure key spare parts before you need them
Thank you

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