Welcome to TRUMPF’s Design for Laser Welding Seminar

Hosted by: Dave Locke / David Havrilla
Agenda

08:30 – 08:45 Welcome & Introduction

08:45 – 10:00 Fundamentals of Laser Welding
Benefits - Focus fundamentals, power & energy, Wavelength considerations – Laser as a tool

10:00 – 10:15 Break

10:15 – 12:00 Design for Laser Welding
Materials considerations – Weld strength – Joint geometries& design concepts – Keys for success

12:00 – 2:00 Lunch & Tour of TRUMPF facilities
Laser Applications

- Cutting
- Welding
- Metal Deposition
- Drilling
- Brazing
- Marking
- Hardening
- Surface Ablation
A vast array of applications
A vast array of applications
Advantages of laser welding

- **Minimum heat input** and high aspect ratio resulting in …
  - minimal shrinkage & distortion of the workpiece
  - small heat affected zone
  - narrow weld bead with good appearance

- **High strength welds** often resulting in …
  - improved component stiffness / fatigue strength
  - reduction of component size / weight  
    Design Optimization

- **Ability to weld in areas difficult to reach** with other techniques
  - non-contact, narrow access, single sided process

- **Easily automated with accurately located welds**
  - consistent weld penetration / weld geometry / weld quality
  - ability to integrate into existing equipment / production lines
Advantages of laser welding

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

- **Often faster than other techniques …**

  *What is throughput a function of* (besides process engineering & optimization)?
  - high power density weld process
  - high laser uptime (>98%)
  - high beam on-time via remote scanner welding, beam switching, etc.

- **Cost savings …**
  - high productivity >> faster cycle time = *less stations*
  - reduction of scrap and re-work
  - reduction of manual labor
  - reduction of component material and weight
  - can eliminate secondary processes
Laser welding vs. resistance spot welding

- **Reduced flange widths**
  - *reduction of component size / weight*
  - *reduced cost*
  - *greater visibility / accessibility*

- **Increased strength / stiffness**
  - *localized increase of component strength / stiffness / fatigue strength*
  - *weld shape optimization for component loading / stresses*
  - *elimination of lower electrode access holes*

- **Higher throughput**
  - *less stations*
  - *less floor space*

- **High accessibility to weld joints**
  - *narrow access, single sided, line of sight*

- **Low maintenance (non-contact)**
  - *no tip wear, mushrooming, dressing or replacement (esp. hot formed parts!)*
Some challenges

Compared to conventional joining techniques ...

- Relatively high capital investment
- Good part fit-up required
  - part geometry & edge geometry
  - tooling / fixturing
- Good beam to joint alignment for seam welding
  - tooling & motion system
- Welding of Zn coated steels in overlap configuration
- New skill set
  - Laser Safety Officer
  - Laser welding
  - Service & maintenance
Basics of laser welding

10.6 microns versus 1 micron

10.6 micron considerations ...

- Better than 1 micron lasers for spatter critical applications (e.g. power train, stainless steel tube welding)
- Less under bead sagging / dropping compared to 1 micron lasers on full penetration welding of thick materials
- Higher seam quality than 1 micron lasers at high process weld speeds on thin to medium material thicknesses
- Deeper weld penetration on thicker materials (e.g. >8 mm) compared to 1 micron laser with same power & BPP
- Less expensive safety precaution with CO_2 wavelength
Basics of laser welding

10.6 microns versus 1 micron

1 micron considerations ...

- Fiber optic delivery (especially when considering robot applications)
- Materials reflective to 10.6 microns wavelength (e.g. aluminum, copper) can often be welded
- Easy beam alignment, beam switching and beam sharing
- No plasma suppression or shield gas required for welding \(^{[1]}\) (Argon can be used for shielding for oxidation critical welds)
- Floor space flexibility
- High wall plug efficiency (direct diode, disk & fiber lasers)

\(^{[1]}\) Although flame & smoke can reduce weld penetration & weld surface will have oxidation.
### General Guidelines based on wavelength

<table>
<thead>
<tr>
<th></th>
<th>SSL ~ 1 µm</th>
<th>CO₂ ~ 10 µm</th>
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</thead>
<tbody>
<tr>
<td>Low penetration (&lt; ~6 mm)</td>
<td>good performance</td>
<td>good performance</td>
</tr>
<tr>
<td>High penetration (&gt; ~6 mm)</td>
<td>average performance</td>
<td>good performance</td>
</tr>
<tr>
<td></td>
<td>(partial penetration)</td>
<td></td>
</tr>
<tr>
<td>Heat conduction welding</td>
<td>good performance</td>
<td>Poor performance</td>
</tr>
<tr>
<td>Highly reflective materials</td>
<td>good performance</td>
<td>average performance</td>
</tr>
<tr>
<td>Oxide-free seams</td>
<td>good performance</td>
<td>average performance</td>
</tr>
<tr>
<td>Spatters</td>
<td>Poor performance</td>
<td>good performance</td>
</tr>
<tr>
<td></td>
<td>(esp. &gt; 6 (8) m/min)</td>
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</table>

Solid state lasers excel at **heat conduction welding** and on **high reflective materials** (aluminum, copper) whereas CO₂ lasers are first choice in **thick materials** and when **spatters** matter.
**Focused spot size**

- beam fills fiber core
- collimator & lens images fiber spot at focus plane

\[ d = \phi_c \left( \frac{f}{f_c} \right) \]

**Example**

TruDisk 8002: fiber core=200 micron, \( f_c = 200\)mm, \( f = 200\)mm

\[ d = (0.2)(200/200) = 0.2 \text{ mm} \ (0.008 \text{ inch}) \]

*What is the spot size if a 150 mm focusing lens is used? 0.15 mm*
Solid State Beam Delivery

**Depth of focus**

\[ \text{CO}_2: \quad L_{5\%} = \frac{d^2}{(2\lambda M^2)} \]

\[ M^2 \approx 3BQ \]

\[ 1 \ \mu\text{m}: \quad L_{5\%} = \frac{d^2}{(6\lambda BQ_{\text{exit}})} \]

\[ L_{5\%} = 159 \times \frac{d^2}{BQ_{\text{exit}}} \]

**Example**

TruDisk 8002: fiber core=200 micron, \( f_c = 200\text{mm} \), \( f = 200\text{mm} \),

\( BQ_{\text{exit (best)}} \approx 7.5 \text{ mm-mrad} \), \( BQ_{\text{exit (typ)}} \approx 8 \text{ mm-mrad} \)

\[ L_{5\%} = 159 \times \left[ \frac{(0.2)^2}{8} \right] = \underline{0.8} \text{ mm (0.031 inch)} \]

*What else besides the ability to focus to a small spot is required for material processing?*
Power Density

Power density = Laser power / area

\[ \text{area} = \pi r^2 = \pi d^2 / 4 \]

\[ P_d = \frac{4 \ P}{\pi d^2} \]

Examples

TruDisk 8002: \( P=8\text{kW}, d_{\text{raw beam @ collimator}}=1''\), \( d_{f200}=0.008''\)

\( P_d \text{ (raw beam)} = \frac{4 \times 8000}{3.1416 \times (1)^2} = \underline{10,186} \text{ W/in}^2 \)

\( P_d \text{ (f200)} = \frac{4 \times 8000}{3.1416 \times (0.008)^2} = \underline{159,154,571} \text{ W/in}^2 \)

If spot size is doubled, by how much does \( P_d \) change? \( 1/4^{th} \)

What besides \( P_d \) defines weld penetration? Speed (\( \alpha \) energy)
Energy Density

Energy = force * distance (i.e. Newton-meters)

Energy density = Energy per unit area (i.e. Nm/mm²)

Energy density = d * (P_d/V)

\[ E_d = d \times \frac{P_d}{V} \]

Energy density along with coupling efficiency determines …

weld penetration.
Coupling efficiency: The degree to which the energy is transferred to the material being processed.
Coupling efficiency is dependent on …

- Laser type (wavelength)
- Material reflectivity
- Thermal conductivity  
  *also: specific heat, latent heat (phase change)*
- Material quality
- Material cleanliness
- Weld joint geometry
- Plasma suppression
- Power density
- Fit-up
Heat conduction welding

Description
Heating the workpiece above the melting temperature without vaporizing

Characteristics
- Low welding depth (~2mm max)
- Small aspect ratio (i.e. wide weld) Larger HAZ
- 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

Smaller HAZ, plasma supp more critical (CO2 & high P fiber), difficult on thin materials (<0.75mm)
Laser as a tool

- relatively wide / narrow
- deep / shallow
- continuous / stitch / spot
- smooth & oxide free / non-aesthetic joining
- 1D / 2D / 3D
- through / partial
- line / optimized shape
- conventional / remote
- multiple layers

*When would you want wide? When narrow?*

*What benefits does partial penetration have? Why would you want a shape that is not a straight line?*
Laser – The Universal Tool for Welding

HF
MIG
TIG
EB
Plasma

MIG
EB

Seam welding
Spot welding

Laser welding

Narrow weld seam
Min. heat affected zone
Little metallurgic effects on the material

Little distortion
No filler material required
High process speed
Non-contact
No wear

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Material Selection

1. Causes of porosity, underfill, undercut:
   - Volatile constituents (e.g. S, P)
   - Coatings/surface contaminants (e.g. Zn, oil based lubricants)

Notes for welding of Zn coated steels in overlap configuration

a. If weld is non-aesthetic and has limited load functionality, perhaps no special action required
b. Increased weld length may compensate for porosity in non-critical components
c. Electro-galvanized & electro-galvaneal are better than hot dipped galvanized
d. Bare to Zn is often okay (especially electro plated)
e. Zn to Zn configurations usually require a gap and/or Zn exhaust path for reasonable results (e.g. dimples, shims, knurling, fixture/tooling, leading pressure finger, part design, joint design)
f. Other methods such as Zn removal (mech. or laser) and chemical pastes (interfacial alloying) also possible
g. Spatter protection critical
h. Watch out for patent infringements!
2. **Brittleness & cracking**
   - Can occur in steels when
     >0.3%C (>0.4%C equivalent)
     S+P+Se+Cd > 0.05%
   - 6000 series aluminum

3. **Reflectivity**
   - With high reflective materials
     (e.g. Al, Cu) – 1 micron
     wavelength has greater absorption than 10.6 microns
Material Selection

Notes for welding steel

- Use killed not rimmed steels to minimize oxygen levels & resultant weld porosity
- C < 0.25-0.30% (CE < 0.35-0.4%) to avoid brittleness and cracking
- Sulfur (S) and Phosphorous (P) < 0.04% each to avoid solidification cracking
- Sulfur (S) + Phosphorous (P) + Selenium (Se) + Cadmium (Cd) < 0.05 % total to avoid weld porosity & solidification cracking
- Molybdenum (Mo) < 2.5 %
- Manganese (Mn) < 2 %
- Lead (Pb) = 0%
- Nickel plated: chemical = prone to solidification cracking, electrolytic = less prone
- Carburized: surface C>0.6% can be prone to solidification cracking & shrinkage cracking in HAZ
- Nitrided: welding reduces surface hardness & is prone to porosity/cracking
- Aluminized: poor weld strength, but appearance okay for most appliance applications
Notes for welding stainless steel & titanium

- Laser welding - low heat input / high weld speeds keep corrosion resistance intact (chromium rich carbides don’t have time to precipitate at grain boundaries)
- Austenitic (200/300 series): good except free machining 303/303Se which contain sulfur & selenium (hot cracking). 304/304L = excellent. 316/316L = good (providing Cr/Ni ratio > 1.7)
- Ferritic (400 series – building block is 430): grades with low C & chromium levels weld best (e.g. 409, 430 & 434), weld toughness can be affected by grain coarsening
- Martensitic (400 series – building block is 410): welds & HAZ's are hard & brittle due to high C. For >0.1%C, austenitic filler wire can be used to avoid cracking & increase toughness. Preheating & tempering can be used to reduce cracking/brittleness.
- Titanium: good quality, but material cleanliness & high quality inert weld pool helium shielding (10.6 micron) or argon shielding (1 micron) are critical
Material Selection

Notes for welding aluminum

- Critical issues – HAZ softening, blow holes, porosity, solidification cracking & in some alloys - loss of volatile elements (e.g. Mg, Zn) due to vaporization
- Natural oxides on surface + moisture from atmosphere produce hydrogen which is highly soluble in Al & causes porosity
- Anodized aluminum prone to cracking & foams up
- Remove Al oxide (AlO₂ @ T_melt=1800°C compared to 700 °C for Al) for overlap joints to increase weld width at interface
- 1000 series: (e.g. 1050=Al 99.5) welds good. Also 3003, 4032, 4047 okay.
- 5000 series: (e.g. 5005, AlMg5) most weld good. Filler wire if needed: AlMg5 or AlMg4.5Mn (e.g. AlMg3 + AlMg5 wire = poor appearance w/ good strength)
- 6000 series: (e.g. AlMgSi1 – silicon added for machinability) – not ductile enough to handle shrinkage stresses & is prone to cracking. Weldable when Si>3% & Mg>4.5% (e.g. 6061). Filler wire used to increase weldability (e.g. AlMgSi1 + AlSi12 wire = good appearance w/ average strength)
- Shield gas = generally Argon, Helium to avoid inclusions and sink holes
Material Selection

Notes for welding aluminum (con’t)

• Filler wire selection considerations:
  • Weldability / freedom from cracking
  • Strength of weld (tensile / shear / fatigue / impact)
  • Ductility of weld
  • Corrosion resistance
  • Temperature of service (e.g. stress corrosion cracking)
  • Color match after anodizing
  • Post-weld heat treatment
Aluminum on the rise in automotive

Drivers for the use of aluminum in automotive …

- Weight reduction ⇒ increased fuel economy (54.5/’25) ⇒ reduced CO₂ emissions

  - On meeting upcoming fuel-economy regulations …

    “In the long run, dual-phase and boron steels will contribute to that weight savings, but most of the reduction will come from aluminum.”

    *Richard Schultz, Managing Director - Automotive Materials Practice, Ducker Worldwide.*

- Corrosion resistance

- Structural performance

- Manufacturability
Myriad of proven applications

1. VW Phaeton door welding, hybrid welding, 6xxx
2. Shanghai Transrapid roof panels, 6xxx/5xxx
3. Audi A8 frame rail, hybrid welding, 4xxx
4. Daimler suspension link, hybrid welding, 6xxx
5. BMW steering column, 6 kW CO$_2$, bi-focal, 6xxx
6. Euro Fighter turbine air inlet vane welding, 6xxx
7. Fuel filter, 1xxx
8. Audi A2 30 m laser welding, 3 kW 1 µm, sheet to profiles, 6xxx
9. BMW 7 aluminum door welding & deck lid, 6xxx
10. Automotive wheel assembly, 6 kW CO$_2$, bi-focal, 4xxx
Production experience …

… at TRUMPF

- Part: TruFlow resonator cover
- Material: 2 mm Al 5052
- Power: 3.4 kW (disk laser)
- Speed: 1.5 m/min
- Shield gas: 50/50 He/Ar
Weld Strength

For autogenous laser welding, weld strength is a function of weld joint fit-up.

A gap (or mismatch) reduces weld strength because it can yield an underfill and/or undercut which …

a. Reduces weld area \( (S = \frac{F}{A}) \)

b. Creates a stress riser

![Diagram of stress concentration and lines of force](image)
Rate the weld shapes from best to worst (1=best) and explain why?
How can we estimate the weld length of a laser “stitch” to give the same strength as a resistance spot weld?

1. Determine average RSW nugget diameter
2. Calculate nugget area
3. Determine the average weld width at interface of the laser welded component
4. Set nugget area \( A \) equal to the weld length \( L \) x the weld width at interface \( w \)

\[
A = L \times w
\]

\[
L = \frac{A}{w}
\]

Typical values of \( w \) are 0.8-1.0 mm
Typical values of \( L \) are 18-25 mm
Weld strength

Function of:

- Base material \((ductile \ vs. \ brittle)\)
- Fit-up \((intimate \ vs. \ gap, \ reduction \ of \ fusion \ zone \ + \ crack \ propagation)\)
- Fusion area \((load \ bearing \ width \times \ length, \ porosity, \ underfill, \ cracks, \ etc.)\)
- Load type \((shear \ vs. \ tensile, \ axial \ vs. \ peel, \ static \ vs. \ fatigue, \ single \ vs. \ multi \ axis)\)
- Shape factor \((linear \ stitch, \ C, \ S, \ etc.)\)
Seam and joint types

Lap weld on lap joint

Seam weld on butt joint
# Seam and joint types

<table>
<thead>
<tr>
<th>Name</th>
<th>Example</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seam weld on butt joint</td>
<td><img src="image" alt="Example" /></td>
<td>+ <strong>Weld Fusion Area</strong>&lt;br&gt;• less material = weight &amp; cost savings&lt;br&gt;• <em>faster or less power</em>&lt;br&gt;• less HAZ / distortion&lt;br&gt;• no issues w/ Zn&lt;br&gt;• no step&lt;br&gt;&lt;br&gt;- <strong>Positioning Tolerance</strong>&lt;br&gt;• edge requirements&lt;br&gt;• fit up can be more difficult to obtain&lt;br&gt;</td>
</tr>
<tr>
<td>Lap weld on lap joint</td>
<td><img src="image" alt="Example" /></td>
<td>+ <strong>Positioning Tolerance</strong>&lt;br&gt;• larger process window&lt;br&gt;• can have aesthetic underside&lt;br&gt;• <strong>Weld Fusion Area</strong>&lt;br&gt;• more energy required = slower or higher power &amp; more distortion / HAZ&lt;br&gt;• inefficient process&lt;br&gt;</td>
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*Think about a positive & negative characteristic of both the butt & lap weld configurations.*
### Seam and joint types

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<tbody>
<tr>
<td>Seam weld on stepped lap joint</td>
<td><img src="image1.png" alt="Example" /></td>
<td>+ weld fusion area&lt;br&gt;- positioning tolerance</td>
</tr>
<tr>
<td>Seam weld on T-joint</td>
<td><img src="image2.png" alt="Example" /></td>
<td>+ weld fusion area&lt;br&gt;- positioning tolerance</td>
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</tbody>
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Seam and joint types

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<tbody>
<tr>
<td>Lap weld on T / border joint</td>
<td><img src="image1" alt="Example" /></td>
<td>+ positioning tolerance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- weld fusion area</td>
</tr>
<tr>
<td>Seam weld on flange</td>
<td><img src="image2" alt="Example" /></td>
<td>+ weld fusion area</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- positioning tolerance</td>
</tr>
<tr>
<td>Lap weld on formed seam</td>
<td><img src="image3" alt="Example" /></td>
<td>+ positioning tolerance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- weld fusion area</td>
</tr>
</tbody>
</table>
Seam and joint tolerances

**Butt joint configuration:**
- Gap: 3-10% thickness of thinnest sheet
- Offset: 5-12% thickness of thinnest sheet

**Overlap joint configuration:**
- Gap: 5-10% thickness of top sheet

*Why is this general guideline not absolute?*  
*(What influences the amount of gap that can be bridged?)*

- Focus spot size
- Edge geometry for butt weld
- Strength requirements
Tolerance Compensation
Tolerance Compensation

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Joint bridging techniques

**Autogenous**
- Larger focus spot
- Twin spot
- Wobble

- Slower, more heat input
- 2x higher power density
- Less wasted energy
  - Faster!!
- Directionality

**Non-autogenous**
- Hybrid (laser + MIG + wire feed)
- Wire feed
- LMD

- Cost, complexity, may require vision system
- Gap & metallurgical bridging
General Guidelines

- Butt joint provides higher strength, higher welding efficiency and reduced material usage, but requires greater positioning tolerances and better edge geometry and fit-up

- Overlap joint provides greater process window regarding positioning, but generally yields lower strength, lower welding efficiency, and increased material usage

- Weld in the thin to thick configuration whenever possible

- Weld perpendicular to surface whenever possible

- Use 50% minimum penetration (relative to top layer) into lower component when partial penetration welding is required

- Don’t weld with focus optic facing upwards

- Distortion can be minimized by: 1) smaller focused spot, 2) beam splitting, 3) high speed tack weld, 4) remote scanner welding w/ large field
Design of a K-Joint

Patent pending
Design features

Material fit of a K-Joint

Patent pending
Design features

Weld Seam on a K-Joint

Patent pending
Design features

Different Applications of a K-Joint

Patent pending
Design features

K- Joint in Application / Flange-reduced Design
Design features

Specialized cutting & bending of tubes

Multiple bend tubes:
Allows 3 dimensional structures.

Bend tubes:
Allows high quality on corners.
Design features

Specialized cutting & bending of tubes w/ positioning aids

Special bent tubes techniques create connections with the need of only a few welds.

Positioning aids
Design features

Positioning tabs & bayonets for tubes

Perfect interface for welding operations

Precision location

Bayonet coupling ensures orientation and reduces need for precision fixturing.
Design features

More Tube Interfaces

- Coding system to avoid possible assembly mistakes, accurate position.
Design features

Positioning tabs for tubes & plates

Mounting plate to tube:
Well suited for welding
High positioning accuracy

Accurate sheet flange to tube design
Design features

Interlocking tabs for tubes
Design features

Box corners and flanges
Integrating locating & interlocking features
Design features

Concept for an Underbody design with K-Joint & Interlocked Joints

Cross Member (Seat)

Tunnel

K-Joint

Integrated Longitudinal Enforcement

Interlocked Joints
Tolerance Compensation

K-Joint & Interlocked Design for Underbody
1. Direct
   a) Non-destructive (e.g. visual, eddy current, ultrasonic, X-ray, leak test)
   b) Destructive (e.g. tensile, peel, push-out, shear, chisel, macro-section)

2. Indirect
   a) Coupon / dummy part test welds
   b) Process monitoring (e.g. infrared, UV, acoustic) – Precitec, 4D, Plasmo
   c) Equipment performance monitoring (e.g. cover slide monitor, routine monitoring of power delivered to workpiece, weld parameter monitoring such as speed, power, shield gas type & flow, focus position – Z & beam to joint, BPP – Primes, Spiricon, Coherent, Promotec)
   d) Monitoring of material cleanliness & chemistry
Part Fixturing

**General**

1. Beam to seam weld joint location is critical because the spot size & depth of focus are relatively small

**Weld Joint Position**

1. Weld joint location is dependent on both part tolerances, tooling tolerances and motion system repeatability
2. Influencing factors: focused spot size, depth of focus, power, speed, and weld joint geometry.

**Note**

The cross seam tolerance on a butt joint is directly related to spot size, while the “in & out” tolerance on a butt and overlap joint is directly related to the depth of focus.
Part Fixturing Example
How can the tooling be modified to eliminate as many tolerances as possible?
How can the laser welding process be modified to eliminate as many tolerances as possible?
Part Fixturing Example

Redesign 2 ...

What is the disadvantage of this change in process?
Weld strength

What can be done to minimize this disadvantage?

* Larger spot (slower)
* Double pass (slower & index req’d)
* Twin spot (slower)
Part Fixturing Considerations

Requirements / Performance of the clamping fixture

- Investment cost in relation to the production costs
- Easy-to-operate design (→ simple to load/unload)
- Exact positioning of the subassemblies / joints / part fit-up
- Damage-free clamping
- No interfering contour / accessibility to the part, joints
- Hard-wearing in regards to mechanical cycling, thermal radiation, reflections & fumes
- Ensure repeatability (→ low heating influence) / cooling requirements?
- Linear application of force along the welding joints
- Clamping in close proximity to the welding joints
- Consideration of part shrinkage
- Accommodation for through penetration welding
- Accessibility for or integration of shielding gas
Production fixtures

Automatic Clamping Devices - Hat Rack
Production fixtures

Automatic Clamping Devices – Seat Products
Modular clamping

TRUMPF Modular Clamping Device

- Easy clamping and positioning
- Deep penetration- and heat conduction welding
- Longitudinal and corner seams
- Automatic welding w/ quantity 1
- Different part dimensions:
  - Max. part length: 600 mm
Robotic clamping

Clamping Devices – Robotic
Shield Gas Overview

Considerations

1. In laser welding, inert shielding protects the molten weld from oxidation, suppresses plasma formation (which can absorb laser power) and stabilizes the process. Note CO₂ vs. SSL!

2. The most commonly used shield gases are helium & argon, with typical rate of 40-60 scfh and 60-80 scfh respectively most common

3. Both co-axial & auxiliary tubes

Types of Nozzles:

- Coaxial
- Lateral
Helium

- Very good protection against oxidation
- Less critical application, typical 6mm nozzle with relatively easy adjustment
- High ionization energy means minimal flow required for plasma control
- Good plasma control results in regular and smooth weld seam in areas of high energy input
- Drawback - high gas cost (about 3X Argon)
Argon

- Excellent protection against oxidation
- Average gas costs
- Can be used for 1 µm welding with no limitations
- Drawback – Higher gas flow required (about 2x) compared to Helium
- Drawback - Poor nozzle adjustment can result in unsteady weld seam and increased plasma (for CO₂ and high P_d 1 µm)
- Drawback - Increased plasma will absorb laser energy reducing penetration - weld may ‘breath’ (can only be used up to critical power density with CO₂ laser)

Underbead shielding (deep penetration welding)

- Reduces sharp angles
- Reduces underfill
- Reduces sagging
Principles of Programmable Focusing Optics

2D Scanner
- PFO 20
- PFO 33

3D Scanner
- PFO 3D
Advantage: Reduced cycle time

Conventional Laser Welding

Unproductive travel times

Laser Scanner Welding

Significant cycle time reduction
Advantage: Programmable Weld Shapes

Customized weld patterns for optimal joint strength:

- Distribution
- Orientation
- Shape
Scanner vs. conventional techniques

Past

9 RSW-Robots
100% Invest
$2M

2003

3 Laser-Robots
100% Invest
$2M
LP-Nd:YAG

Now

1 Laser-Robot
50% Invest
$1M
Disk-Laser
Scanner welding: VW Passat hat rack

**Spot weld - production**

34 ° + mech. shift code
4 robots, 5 welding guns
Welding time: 34.7s

**Laser remote weld - production**

34 ° + shift code
1 robot, 1 scanner optic
Welding time: 13s (4kW), <10s (6kW)

Source: Volkswagen AG
Remote cutting

- Molten material ejection by melt pressure
- Remote cutting on the fly with PFO (no cutting nozzle!)
- Good (burr free) cut quality, but oxidation layer
- Up to 4 mm sheet thickness
- Cutting speed < welding speed (approx. 50%)
- One tool for remote welding & cutting
- Remote welding is the driver

`t = 1 mm, v = 8 m/min, P = 6 kW`
`t = 3 mm, v = 3.5 m/min, P = 6 kW`
`t = 2x 1 mm, v = ca. 3 m/min, P = 4 kW, kerf welded together`

Top side

Bottom side
Design & re-design components for laser welding

- Reduce component weight & cost by reducing or eliminating flange widths (*enabled by single sided, narrow beam access*).

- Increase vehicle accessibility & driver visibility by reducing or eliminating flange widths (*enabled by single sided, narrow beam access*).

- Reduce component weight and cost by reducing gage thickness (*enabled by increasing strength through optimized weld shapes and/or continuous weld seams in high stress locations*).

- Reduce component weight and cost, and increase strength (*enabled by elimination of RSW lower electrode access holes in structural reinforcements*).
- Know & employ the strengths of the full variety of weld joint styles

- Realize there are several ways to bridge the gap, … but don’t start there

- Consider the variety of design features when designing for laser welding (e.g. K-Joint, positioning aids, tabs, bayonets, interlocking joints, tolerance compensation planes, etc.)
Keys to success

- **Design components for laser welding**
  (reduced flange widths/gauge thicknesses, lower distortion, single sided access, elimination of RSW access holes, elimination of secondary processes)

- **Maximize laser “beam on” time**
  (i.e. time sharing of beam to multiple stations, remote scanner welding)

- **Good part fit-up req’d via part tolerances & fixturing**
  Butt weld: edge preparation, gap <10% of \( t_{\text{min}} \), seam location
  Overlap weld: gap < 10% of \( t_{\text{min}} \)

- **Parts must be clean & dry for optimum results**
  (no dirt, rust, rust inhibitor, coolant, grease, heavy oils, sand residue, paint/primer, adhesives, sealers, water, solvent)

- **Zn coated steels in overlap configuration requires special considerations**

- **Assign laser welding champion at using plant**
  (engineer, attitude/aptitude, teachable, can teach others)

- **Early involvement of production personnel**
  (ownership, design for service & maintenance, safety)

- **Commitment to training & spare parts**

- **Partner with suppliers that have proven expertise, longevity & reputation**
Continuous Education / Improvement

**Laser Welding**
Christopher Dawes  
*Abington Publishing* (1992)

**Laser Welding**
Walter W. Duley  
*John Wiley & Sons* (1999)

**Laser Material Processing – Fourth Edition**
William M. Steen / Jyoti Mazumder  
*Springer* (2010)

**AWS Welding Handbook**
Welding Processes, Part 2  
Ninth Edition, Volume 3  

**LIA Handbook of Laser Material Processing**
John F. Ready – Editor in Chief  
*Laser Institute of America* (2001)
Thank you

TRUMPF Laser Technology Center
Plymouth, MI
(734) 454-7200
Energy Input

The less the energy input is, the less is the distortion!

![Graph showing energy input vs. J/mm for Laser, Plasma, TIG, and MIG processes.](chart.png)
Design Optimization

Laser welding  Resistance spot welding  Laser welding

Flange Reduction or Elimination (flangeless design)
Better Accessibility
Less Interference
Principle of time sharing

Throughput maximization & manufacturing flexibility
Principle of energy sharing

➤ Reduced distortion
PFO’s in a TRUMPF LASER NETWORK

Backup- and Redundancy Concepts
Reduction of flange width

Resistant Spot Welding

Laser welding

Weight Saving
Continuous weld & strength optimization
### Stiffness: Golf IV / Golf V

<table>
<thead>
<tr>
<th></th>
<th>Static Torsion Stiffness</th>
<th>Dynamical Torsion Stiffness</th>
<th>Dynamical Bending Stiffness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Golf IV</td>
<td>100%</td>
<td>+15%</td>
<td></td>
</tr>
<tr>
<td>Golf V</td>
<td>100%</td>
<td>+35%</td>
<td></td>
</tr>
<tr>
<td>+80%</td>
<td></td>
<td></td>
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</tbody>
</table>
Summary: Golf IV / Golf V

- Conclusions based on ½ year production

**Goals reached:**

- Increased process speed (joining).
- Increased productivity
- Short cycle times (30 Seconds)
- Increased strength of the modules compared to most alternative joining methods
- Reduced heat distortion
- Narrow or no flange => Weight reduction
- High flexibility due to the possibility to direct the laser beam by the means of Laser Light Cables into different work cells.
- Reduced floor space

<table>
<thead>
<tr>
<th></th>
<th>Golf IV</th>
<th>Golf V</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor space Side panel</td>
<td>2816 m²</td>
<td>1472 m²</td>
<td>(-50%)</td>
</tr>
<tr>
<td>Floor space Underbody</td>
<td>480 m²</td>
<td>320 m²</td>
<td>(-33%)</td>
</tr>
<tr>
<td># of Weld spots</td>
<td>4608</td>
<td>1400</td>
<td></td>
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<tr>
<td>Length of laser weld</td>
<td>1.400</td>
<td>70 m</td>
<td></td>
</tr>
</tbody>
</table>
Wide vs. narrow

Wide

Overlap welding

Poor edges

Poor fit-up

Poor beam to seam location tolerance

Narrow

Low distortion, high speed welding w/ minimum power for butt welding configurations

... but, good edges, excellent fit-up, & good beam to seam location tolerance required
Partial penetration vs. full penetration

**Partial**

Compared to through penetration weld ...  
- Aesthetics on back side of component  
- Mating part considerations (fit-up & friction)  
- Thickness of lower part (through penetration may be impractical or impossible)  
- Protection of heat or spatter sensitive components  
- Higher speeds (or lower laser power) w/ less HAZ & distortion  
- No possibility for underbead dropping (issue for penetrations > 8 mm)

**Full**

Compared to partial penetration weld ...  
- Visual weld verification possible  
- Larger fusion area for butt weld configuration
Advantage: Programmable Weld Shapes

Stress = \( \frac{F}{A} \)
Advantage: Programmable Weld Shapes

Peel

Peel
Zn coated material: Gap for out gassing

- Evaporating temperature of zinc < melting temperature of steel
- Vapor pressure causes expulsion of molten steel in upper sheet
- Result: Welding seam becomes highly porous and weak
Gap for out gassing: Laser dimpling

- Pre-treatment of one sheet to generate 0.1-0.2mm standoff between sheets
- Use of same laser equipment and optics
Gap for out gassing: Laser dimpling

- Constant dimple height (depending on zinc layer approximately 0.15 - 0.2 mm)
- Dimple height adjustable via laser parameter
Gap for out gassing: Laser dimpling

- **Step 1:** Laser Dimpling
- **Step 2:** Placement of upper sheet
- **Step 3:** Scanner Welding
Speed & power benefits of a butt joint

- Material: Mild Steel
- Focusing Optics: PFO33

Graph showing welding speed in m/min vs. welding depth in mm.

- Blue squares: \( d_{of} = 0.6 \text{ mm}; P = 8 \text{ kW} \)
- Red diamonds: \( d_{of} = 0.6 \text{ mm}; P = 6 \text{ kW} \)
- Black triangles: \( d_{of} = 0.6 \text{ mm}; P = 4 \text{ kW} \)

Graph annotations:

- 4 kW, 9 m/min, 4 m/min → half the power or twice the speed
- 8 kW, 17 m/min, 9 m/min