Technology advantage: Machine dynamics

Evolution of machine dynamics

- **DC motors**
- **Brushless servo motors**
- **Linear drives**

Axis speed $v$ [m/min], Acceleration $a$ [m/s$^2$]

- $a = 2$ m/s$^2$
- $a = 20$ m/s$^2$
- $v = 20$ m/min
- $v = 20$ m/min

Example:

$$R_{\text{min}} = \frac{v^2}{a}$$

- $R_{\text{min}} = 54.4$ mm
- $R_{\text{min}} = 5.5$ mm

Source: TRUMPF
Laser Cutting: Success in parallel technologies

- Today laser cutting has replaced plasma cutting and water jet cutting for flexible sheet metal fabrication because of superior speed and edge quality.
- Punch nibbling is still around (20-30% market share).
- It took 20 years to become the dominant sheet metal fabrication technology.
- It took equal advances in laser physics, rugged industrial source design, machine and drive development, application development, market acceptance to write this success story.
- Reliability and profitability were key to the success – the machine operator doesn’t want to worry about the laser.
- Constant profitability increase allows further market growth (12% CAGR of the last decade for TRUMPF) -> avoid market saturation.
- Today laser cutting has created the third largest single laser source market ($435 Mio.) behind optical storage ($1400 Mio.) and telecom ($670 Mio.), but before medical ($380 Mio.).
Transforming physics into profits

- About TRUMPF

- Case Study 1: Telecommunication Laser Diode
  Understanding volume manufacturing

- Case Study 2: Laser Cutting
  Parallel technologies

- Case Study 3: Laser Welding
  Understanding customer requirements

- Case Study 4: Laser Welding
  Prove your technology
Today’s biggest markets for laser sources

<table>
<thead>
<tr>
<th>Market</th>
<th>Revenues 2002 [TUSD]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical Data Storage</td>
<td>1400</td>
</tr>
<tr>
<td>Telecommunications</td>
<td>700</td>
</tr>
<tr>
<td>Solid-State Laser Pumping</td>
<td>100</td>
</tr>
<tr>
<td>Medical Equipment</td>
<td>50</td>
</tr>
<tr>
<td>Materials Processing</td>
<td>800</td>
</tr>
</tbody>
</table>

- **Diode**: Blue
- **Excimer**: Light Blue
- **Solid State**: Light Yellow
- **CO2**: Dark Red

The TRUMPF Group
Market Drivers for Laser Material Processing in the automotive Industry

- **Trends in Production**
  - Automation
  - Flexibility
  - Quality

- **Laser Technology**
  - Improved Lasers
  - Improved Systems
  - Improved Processes

- **Product Trends**
  - Miniaturization
  - Quality
  - New Features
Market Drivers for Laser Material Processing in the automotive Industry

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  - Miniaturization
  - Quality
  - New Features

- Consumer
Laser welding: Body in White (BIW)

Volkswagen Passat and Golf: Roof seam welding with 4 kW Nd:YAG-Laser

Only laser allows seam welding:
• Sealed roof
  -> no rubber seal
  -> improved painting operation
• Stiffness
  -> improved crash performance
  -> improved handling
Market Drivers for Laser Material Processing in the automotive Industry

Trends in Production
- Automation
- Flexibility
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Laser Technology
- Improved Lasers
- Improved Systems
- Improved Processes

Product Trends
- Miniaturization
- Quality
- New Features

Consumer
Nd:YAG Laser: 3 D Welding applications

Laser Source:
350 - 4500 Watts cw & special pulsed applications

Flexibility:
Fiber Optical Beam Delivery

Especially well suited for 3D welding applications
Market Drivers for Laser Material Processing in the automotive Industry

**Trends in Production**
- Automation
- Flexibility
- Quality

**Laser Technology**
- Improved Lasers
- Improved Systems
- Improved Processes

**Product Trends**
- Miniaturization
- Quality
- New Features

**Consumer**
Trends in Production: Flexibility

Optimized utilization of the laser sources, support of several working stations and redundancy.

Nd:YAG-Laser in Car Body Production: Laser Network
BIW laser welding utilizing TRUMPF Lasers within European Car Companies

It took more than a decade to fully implement laser welding in the European automotive industry

What had to happen:

- At TRUMPF: Development of reliable laser sources and constant improvement
- At Universities, Institutes: Development of applications that add value (e.g. roof seam welding)
- At car manufacturers:
  - Reproduce applications in company lab
  - Educate designers, find value added
  - First timid substitutions of non-critical spot welds with laser welded seams
  - Increase length of laser welded seam on BIW
  - Fully replace spot welding with next model change
In the US market the introduction of laser welding occurred already a decade earlier than in Europe.

Promises were made with regards to:

- Reliability
- Process control
- Profitability
- Enhanced functionality

Laser technology, application development, customer requirements were not ready to support these promises.

The generation of plant managers that burned their fingers on the first attempt on laser welding are now finally starting to give lasers another chance.

Listen to your customers needs!
Aluminum Welding in Aerospace

Welding with CO₂- and Nd:YAG-Laser

Advantages laser welding compared to riveting:
- increased speed
- increased stiffness
- less corrosion
BIW Laser welding within the Aerospace Industry

Aerospace is comparable with Automotive in 1994
Transforming physics into profits

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Construction of a lamp pumped cavity

Cavity of a high-power solid-state laser

Principle: Double elliptical reflector

Lamps

Rod

Nd:YAG - rod

Krypton lamps
Efficiency of a Lamp Pumped Nd:YAG Laser

- **Electrical Input**: 100%
- **Power in Pump Bands**: 8% (8 µm), 42% (9,3 µm)
- **Optical Output**: 2%
- **Thermal Loss of Lamps**: 50%
- **Absorption**:
  - Cavity: 30%
  - Water, Flow Tubes: 7%
  - Nd:YAG Rod: 5%
- **Optical Loss**:
  - Reabsorption in the Lamps: 5%
  - Fluorescence: 0.4%
  - Resonator Losses: 0.6%
Absorption of the Nd:YAG / Emission of the lamp

Absorption Spectrum of Nd:YAG

Emission Spectrum of Krypton lamps

Wall plug efficiency:
Lamp pumped Nd:YAG laser: 2%
Diode pumped Nd:YAG laser: 15%
CO₂-laser: 10%
Unmounted Diode Laser Arrays

- P-Side
- Broad Area Emitters
- Mirror / Facet

(References and diagram included)
Thermal Management: Micro Channel Cooler

**Micro Channel Cooler:**
- Brazed water manifold

**Array**

**Graph:**
- *reported records*
- *commercially available*

- SDL
- Opto-Power
- FhG

Micro Channel Cooler: Brazed water manifold
Structure of a pump module

11 Diode lasers per pump module
5 pump modules per cavity

- Cathode of the diode
- Anode of the diode
- Glass plate guides light to the rod
- Reflector
- Integrated “Flight recorder”
Principle of a cavity for a diode pumped Nd:YAG

- Pump module
- Glass tube
- Reflector
- Glass plate
- Diodes
- Glass plate guides the light of the diodes
- Laser rod
- Cooling water
Diode Pumped Solid State Nd:YAG Lasers

Side Pumped All Solid State Rod Laser

- 6 Cavities
- 30 Pump modules
- 330 Diode Lasers

Laser Power: 6 kW
Plug Efficiency: 15%

TRUMPF is one of the first laser manufacturers world-wide to deliver reliable multi-kW diode-pumped Nd:YAG Lasers
Diode pumped cw solid state lasers up to 4500 W

<table>
<thead>
<tr>
<th>Type</th>
<th>Pump chamber [Amount]</th>
<th>Max. power output [W]</th>
<th>Laser power at the workpiece [W]</th>
<th>Beam quality [mm · mrad]</th>
</tr>
</thead>
<tbody>
<tr>
<td>HLD 1003</td>
<td>2</td>
<td>1300</td>
<td>1000</td>
<td>12</td>
</tr>
<tr>
<td>HLD 2304</td>
<td>4</td>
<td>3000</td>
<td>2300</td>
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</tr>
<tr>
<td>HLD 3006</td>
<td>4</td>
<td>4000</td>
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<td>25</td>
</tr>
<tr>
<td>HLD 3504</td>
<td>6</td>
<td>4500</td>
<td>3500</td>
<td>16</td>
</tr>
<tr>
<td>HLD 4506</td>
<td>6</td>
<td>6000</td>
<td>4500</td>
<td>25</td>
</tr>
</tbody>
</table>
Diode pumped high power Solid State lasers

- High power diode lasers promise an order of magnitude less energy consumption.
- They are available from one of the most trusted names in lasers and the currently only supplier of high power solid state lasers into automotive manufacturing: TRUMPF

- Still a large car manufacturer chose to place the largest order in the history of high power solid state lasers on lamp-pumped systems. A power plant for these lasers will be installed

- Reliability outweighs any promised benefit by disruptive technologies

- There are no shortcuts: Prove your technology!
Transforming physics into profits

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TRUMPF Sales in Million Euro

* Forecast

The TRUMPF Group
Market Review: Applications of lasers sources

High-Power Lasers for Industrial Manufacturing
Market Segments and Development

- other applications
- 3D cutting
- welding
- 2D cutting

CO₂

SSL

DL

Million US-$

- 1990
- 1999
- 2004
- 2010
Thank you for your kind attention!