Laser Solutions Short Courses

Short Course #2
What Laser Drilling Can Do for Your Business

Mohammed Naeem
Course Instructor

Tuesday, November 3   8:00AM
Room: Narcissus/Orange
What laser drilling can do for your business?

Dr. Mohammed Naeem
GSI Group, Laser Division

Outline

• Introduction
  — Drilling
  — Laser sources
  — Materials

• Applications
  — Aerospace
  — Automotive
  — Others

• Summary

Introduction
Drilling techniques

- Laser
- EDM (Electro Discharge Machining)
- ECM (electro chemical) drilling processes- STEM and Capillary.
  - STEM (Single Tube Electrolytic Machining): The process produces no recast layer or heat affected zone as with EDM or laser machining and can achieve much finer and smoother holes compared to EDM. It uses anodic dissolution using titanium tubular cathodes that have an insulating exterior coating. Very high depth-to-diameter ratio holes can be drilled and many holes (and components) can be drilled simultaneously without slowing of the drilling rate.
  - Capillary drilling produces holes by anodic dissolution using glass tubes with a platinum cathode inserted within. Many holes can be drilled simultaneously without slowing of the drilling rate.

EDM Drilling

- Electro Discharge Machining (EDM) is also used for drilling holes in the aerospace industry. Although EDM is capable of producing good quality holes it is substantially slower than the laser.
- EDM is not suited to the production of holes at high or variable incidence angles where multi-wire heads cannot be used.
- EDM also requires highly complex consumables tooling and electrolyte fluids, both of which contribute adversely to cost of hole production.
- EDM is also not suitable for drilling through ceramic or ceramic coated materials.

Laser Drilling
Advantages of laser drilling

- Non contact process
- Can drill a range of materials
- Fast cycle time
- Can drill a range of hole diameters
- Good repeatability
- Can drill at shallow angles (10-15 degrees from the surface)

Range of laser processes mapped against power density per unit time

Laser Sources

- Excimer
- CO2
- Copper vapour
- Nd: YAG
- Fiber
- Disc
Pulsed Nd: YAG Laser

• Pulsed Nd: YAG lasers are usually chosen for drilling a range of materials for various industry sectors. This choice is driven by the following considerations:
  • Good coupling of 1.06µm radiation into part (both in terms of material absorption and plasma avoidance)
  • High pulse energies and peak powers are well suited for this application
  • High aspect ratio holes in a variety of materials at very high speeds

Laser requirements for drilling

• Good focusability - fine hole size and good access
• Good beam distribution - for round holes and low recast
• High Mean Power - Fast material removal
• High peak power - for high material removal rates, low recast and taper

Laser-Material Interaction
Drilled hole requirements

- Typical requirements for drilled holes are:
  - Angle to surface: 10-30 degrees
  - Diameter: 0.20-1.0mm
  - Configuration: blind hole with passage or shoulder behind hole
  - Metallurgy: minimal recast, minimal HAZ, no micro cracks in parent metal
  - Hole geometry: cylindrical or slightly tapered hole with minimal surface burr
  - Drill through thermal barrier coatings
  - Diameter reproducibility: +/-1% variation

Methods of drilling

- Percussion drilling is a method used to generate holes with stationary laser beam. The beam is focused at a point where a hole is to be produced and shutter opened.
- Trepan drilling is a similar method except it does not rely on laser beam size to give the final dimensions of the finished hole.

Hole Quality

The number denotes the number of pulses used to drill hole. The growth rate is initially linear with number of shots but then it slows down. Hole 13 appears less deep than hole 10 because the molten material has resolidified at the bottom. Recast layer starts from hole 7 onwards.
Some of the common materials which require laser drilling:

- Nickel and cobalt based super-alloys
- Nickel and cobalt based super alloys with thermal barrier coatings
- Alloy steels
- Polymer Composites
- Al based alloys

Applications

Aerospace

Trend in Turbine Engine Components – Increasing Number of Cooling Holes to Improve Efficiency and Reduce Emissions
Typical hole dimensions

<table>
<thead>
<tr>
<th>Component</th>
<th>Diameter (mm)</th>
<th>Wall Thickness (mm)</th>
<th>Angle to Surface (deg)</th>
<th>Number of Holes</th>
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<tbody>
<tr>
<td>Blade</td>
<td>0.3 – 0.5</td>
<td>1.0 – 3.0</td>
<td>15</td>
<td>25 – 200</td>
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<tr>
<td>Vane</td>
<td>0.3 – 1.0</td>
<td>1.0 – 4.0</td>
<td>15</td>
<td>25 – 200</td>
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<tr>
<td>Afterburner</td>
<td>0.4</td>
<td>2.0 – 2.5</td>
<td>90</td>
<td>40,000</td>
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<tr>
<td>Baseplate</td>
<td>0.5 – 0.7</td>
<td>1.0</td>
<td>30 – 90</td>
<td>10,000</td>
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<td>Seal Ring</td>
<td>0.95 – 1.05</td>
<td>1.5</td>
<td>50</td>
<td>180</td>
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<tr>
<td>Cooling Ring 1</td>
<td>0.78 – 0.84</td>
<td>4.0</td>
<td>79</td>
<td>4,200</td>
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<tr>
<td>Cooling Ring 2</td>
<td>5.0</td>
<td>4.0</td>
<td>90</td>
<td>280</td>
</tr>
</tbody>
</table>

Common IGT and Aero Materials

- Aero Blade (1st stage) - Single Crystal Ni-based super alloy
- Aero Vane (3rd stage) - Duralumin/SiC composite
- IGT Blade (1st stage) - Single Crystal Ni-base super alloy
- IGT Vane (3rd stage) - Single Crystal Ni-base super alloy
- Combustor - Nickel or Cobalt Alloy with TBC
- Transition Duct - Nickel or Cobalt Alloy with TBC

GSI Group Industrial Nd:YAG drilling lasers

- GSI have been producing drilling lasers for the aerospace industry since mid-80s
  - JK894 established benchmark in industrial laser drilling
    * smaller percussion drilled holes 0.25-0.5 mm
  - JK894TR high-speed drilling laser dedicated hole drilling laser
    * higher drilling speeds (30-100%) for percussion and trepan drilling larger percussion drilled holes 0.3 - 1.5 mm
  - First high peak power fiber delivered drilling laser
  - Micro drill (short pulses, high beam quality)
  - New high beam quality/ high peak power directed beam diverged drilled to be launched this year.
**Laser sources**

<table>
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<tr>
<th>Laser type</th>
<th>Pulse width (µs)</th>
<th>Peak power (W)</th>
<th>Pulse energy (J)</th>
<th>Average power (W)</th>
<th>dance quality</th>
<th>Comments</th>
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<td>JK704L</td>
<td>0.3-5</td>
<td>30</td>
<td>50</td>
<td>130</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>JK704LD</td>
<td>0.3-5</td>
<td>30</td>
<td>50</td>
<td>230</td>
<td>50</td>
<td>Used for drill holes up to 7 mm.</td>
</tr>
<tr>
<td>JK704LDL</td>
<td>0.3-5</td>
<td>30</td>
<td>50</td>
<td>230</td>
<td>30</td>
<td>Used for drill holes up to 10 mm.</td>
</tr>
<tr>
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<td>0.2-5</td>
<td>16</td>
<td>35</td>
<td>350</td>
<td>35</td>
<td>Laser beam quality less than above.</td>
</tr>
<tr>
<td>JK100D</td>
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<td>16</td>
<td>35</td>
<td>350</td>
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<tr>
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<td>0.2-5</td>
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**Basic Mirror System vs. FOBD**

- CCTV
- Optical Focus Sensor
- Other Sensor(s)
- Basic Mirror System vs. FOBD

**Typical drilling set-up**

Winbro FHDC800 5-Axis machining centre
2mm thick HastelloyX @ 30 degrees to surface

- Hole dia: 0.63mm
- No. of shots: 10
- Frequency: 12.5Hz
- Recast layer: 30µm-50µm
- Assist gas: oxygen

- Hole dia: 0.54mm
- No. of shots: 10
- Frequency: 12.5Hz
- Recast layer: 10µm-50µm
- Assist gas: Oxygen

2mm thick HastelloyX @ 30 degrees to surface

- Hole dia: 0.32mm
- No. of shots: 25
- Frequency: 61Hz
- Recast layer: 30µm-40µm
- Assist gas: oxygen

- Hole dia: 0.25mm
- No. of shots: 25
- Frequency: 61Hz
- Recast layer: 30µm-50µm
- Assist gas: Oxygen

2mm thick CMSX-4 @ 30 degrees to surface

- Hole dia: 0.44mm
- No. of shots: 15
- Frequency: 19Hz
- Average recast layer: 30µm
- Assist gas: oxygen

- Hole dia: 0.40mm
- No. of shots: 15
- Frequency: 19Hz
- Average recast layer: 35µm
- Assist gas: Oxygen
2mm thick CMSX-4
@ 30 degrees to surface

- Hole dia: 0.33mm
- No. of shots: 15
- Frequency: 29.5Hz
- Average recast layer: 25µm
- Assist gas: oxygen

- Hole dia: 0.25mm
- No. of shots: 10
- Frequency: 19Hz
- Average recast layer: 35µm
- Assist gas: Oxygen

Drilling Time for Trepan Drilling With JK704TR

- 0.75mm dia. hole in 10mm thick 25S alloy %Taper <1.5
- Typical recast layer 20-40um
TBCs are being widely applied in many types of engines and in aircraft’s gas turbines. To increase temperature capability of the engine blades and vanes, a thin coat of a heat-insulating zirconia ceramics is applied on the surface of the blades as a thermal barrier coating. Pulsed laser drilling is well suited to drilling of TBC super alloys since both ceramic and metallic layers can be processed. However, issues on TBC drilling include:

- Localised delamination
- Bond Strength
- Effect on delamination on life
- Drill and coat

In comparison, the competing technology of electrical discharge machining (EDM) is limited to conducting substrates and therefore cannot machine TBC coated components.

Why Ceramics?

Ceramic Materials offer the highest potential for cooling air savings.
Employment of Ceramic coatings in Siemens Gas Turbine Engines

TBC coated blades and vanes

Ceramic heat shield

Future:
Ceramic matrix composites (CMC)

Current practice to drill TBC materials

- Remove coating with a Q-switched pulsed Nd: YAG laser (short pulse widths and high peak powers)
- Followed by drilling with either EDM or laser
- The disadvantage of this technique is cost, i.e. two lasers or laser and EDM machine.

5mm thick In625 alloy
(1mm thick TBC)

Typical drilled hole diameter:
Entry: 0.54mm; Exit: 0.51mm
Percussion drilled holes in 2mm In Haynes 230 alloy with 0.5mm thick TBC, 30 degree to surface

0.40mm dia  0.50mm dia

Turbine engine designers recognized that 'shaped holes' can give improved film cooling by ~2X

EDM wire machines were introduced as the only method to produce this by either oscillating the wire or by moving the part

As this technique is 'slow' and prone to scrap there is a market pull to be able to use a laser and vastly improve the drilling times and yields

Typical holes sizes are:
- 0.6 mm (0.024") - 1.0 mm (0.040") diameter holes
- Entrance fan shapes of 12 - 20 degrees
- 30 - 45 degrees to the surface
- Material 2 mm (0.080") to 6 mm (0.025) thick
- At low angles this can give hole lengths of over 12.5 mm (0.5")

The shapes are quite complex and experience has shown that they have to be programmed off-line using a CAG/CAM & Postprocessor

Each shaped hole is programmed this way and then positioned on the part

The through hole is drilled, the shape is generated using the 5 axes and then the through hole is trepanned to final size

Laser Parameters are changed for different parts of the shaped hole path

1. Pierce undersized thru hole
2. Trepan fan shape- thru hole
3. Finish thru hole to size

Programming methods/ Pierce and Path Sequence

• The shapes are quite complex and experience has shown that they have to be programmed off-line using a CAG/CAM & Postprocessor
• Each shaped hole is programmed this way and then positioned on the part
• The through hole is drilled, the shape is generated using the 5 axes and then the through hole is trepanned to final size
• Laser Parameters are changed for different parts of the shaped hole path
Shaped holes drilled with JK704 and 5-axis CNC machine

Top view  Cross-section

Shaped Hole drilling - summary points

• Requires good laser & machine motion control

• Good beam shape, i.e. roundness and energy distribution

• Can use pulse shaping to tune the process

Compressor liner  Nozzle guide vane  Shaped holes
Laser drilling via a optical fiber offers many advantages over direct beam delivery system:
- An optical fiber laser beam delivery system offers the option of standardising the beam path for all CNC machines.
- Optical fibres homogenise the power distribution across the laser beam giving a top hat profile, which can improve drilled hole roundness.

Fibre delivered percussion drilling offers:
- Trepanned quality holes with significant reduction in production times leading to:
  - Increased throughput
  - Reduced manufacturing costs

Recast layer (20 degrees to surface)

Micrographs showing recast layer in 2mm thick alloy laser drilled at 20 degrees to surface:
- Top to middle, average recast layer thickness 35-45µm
- Middle to bottom, average recast layer thickness 55-65µm
2mm CMSX4 alloy 30 degrees to the surface

Hole diameter: 0.45-0.50mm diameter (pin gauge)

Max Oxide 207µm
Max recast 20µm

Max Oxide 132µm
Max recast 52µm

5mm thick IN 625 alloy 90 degrees to surface

Entry 760µm
Exit 750µm

Average recast layer 25µm

Average recast layer 15µm

TBC material, percussion drilled (Coating Side Entrance)

1.5mm HastelloyX with 1mm thick coating

Recast layer 20-45µm

Note: roundness of the holes
Applications

Automotive

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Automotive Powertrain laser drilling

- Oil & Air Bleed Holes
  - Laser Capable of 0.1 to 1mm dia holes, percussion drilling, larger with trepanned motion
  - Minimal Heat Input
  - Fast, typically less than 1 second for 0.5mm holes in 3mm
  - Drilling at Angles down to 15 degrees to the surface
  - Drilling through Rubber Sealant and Metal together
  - Easy Automation
  - No Consumable Tooling

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Why Laser Drilling?

- Small Holes 0.1-0.8mm dia.- twist drills break or are too slow, EDM is too costly if the accuracy isn’t needed
- Angled Holes- no need to machine a start flat
- Coated Parts- drill thru polymer, rubber
- Difficult Access- in grooves, shoulders deep recesses in castings, etc.
- Hard Materials- through hard coatings, carburized parts, or hardened base alloys
Drilling head and drilling techniques

- Percussion Drilling: Setting laser focus for the correct hole diameter, laser fires pulses with no relative motion to drill the correct hole size.

- Trepan Drilling: Cutting out a hole using a motion system or optical trepanner.

Laser Drilling Seal Rings

- 0.5mm dia. hole in 1.8mm steel with polymer coating, drilling time 0.17 sec/hole

Drilling Gears

- 0.57mm dia. hole in 3.7mm steel, 0.5 sec
Drilling Gears

- 0.8mm dia. hole at 45 degrees, approx. 9.5mm depth, 6.9 sec/hole
- 0.6mm dia. hole, 2.0 sec/hole

Con-Rod Oil Hole drilling

- ~1mm diameter holes in con-rod
- Mirror delivered YAG beam
- ~20 sec/hole in 10mm thick wall

Transmission casting drilling

- Air Bleed Hole in overdrive servo pocket
- 0.45mm diameter hole, ~1 sec, thru 3mm aluminum casting alloy
Rocker Arm Drilling

- Oil hole to lubricate valve actuators
- As low as 15 degrees
- ~0.4mm dia hole, JK450HP, JK300HP, JK300D

Other applications

Micro-drilling

- The main requirements for laser micro drilling are:
  - Minimum HAZ
  - Minimum recast layer
  - Parallel holes
  - Hole diameter 40-150µm
  - Diameter reproducibility: +/-0.5% variation
Microdrilling

Nickel based alloy (150µm dia)
Carbon composite (150µm dia)
304SS (70µm dia)

Microdrilling

500µm thick 304SS
pulsed laser, 60µm dia hole

Microdrilling

0.6mm thick Alumina (99.6%)
Percussion drilled (50µm dia. hole)
Ceramic Sample Cutting

- 0.6 to 1mm thick, 200W peak, 20% duty.
- Cut quality is very good, very small taper and almost a micro-dross is produced leaving no visible cracking.
- Multipassing needed in thicker material for part to drop out.

Al-Alloy

- Hole dia. Approx 30µm

Summary

- Laser is a very versatile tool for a range of drilling applications i.e. aerospace, automotive, microdrilling etc.
- It can drill a range of materials including TBC coated materials.
- It can drill at very shallow angles (10 degrees from the surface).
- No tool wear.
- Produces consistent quality holes.
- Scrap rate is minimum.
- Some the materials can only be drilled with laser.
- It offers easy of integration.
Course #2:
What Laser Drilling Can Do for Your Business

Course Instructor: Mohammed Naeem

Please rate the following:  (circle)

<table>
<thead>
<tr>
<th>Course</th>
<th>Excellent</th>
<th>Very Good</th>
<th>Good</th>
<th>Fair</th>
<th>Poor</th>
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<tr>
<td>Overall Course</td>
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Would you recommend this course to others in your profession?  yes  no

What was the strongest feature of the course?

________________________________________________________________________

________________________________________________________________________

What was not covered that you felt should have been covered (if anything)?

________________________________________________________________________

________________________________________________________________________

What would you like to hear more about next time?

________________________________________________________________________

________________________________________________________________________

What was covered that left an impression/impact on you?

________________________________________________________________________

________________________________________________________________________

Suggestions & Comments (for this course or courses you would like in the future):

________________________________________________________________________

________________________________________________________________________

Name: (optional)  __________________________________________________________

Please Use Reverse Side for Additional Comments.

Please return evaluation form to the Registration Desk by Thursday afternoon
or fax 407.380.5588 to LIA upon your return home.

THANK YOU!