Laser Cutting System
Introduction

- We will be explaining basic CO2 laser concepts
- This presentation’s intention is to give you a general background of the CO2 laser and it’s function in the cutting industry
Overview

• When finished with this presentation you should possess a basic working knowledge of CO2 lasers, how they function, and how they apply to the metal fabricating industry.

• This presentation should also assist you if you ever consider recommending a laser in the future.
Components

- Components of a Fast flow CO2 laser
- A CO2 laser is made from 7 basic components: Optical cavity, Excitation source, vacuum pump, Lasing medium, Reflective optics, Heat Exchanger, and a Turbine or blower
Laser resonator components

- Partially reflective optic
- Lasing medium (CO2, N2, He)
- Optical cavity
- Reflective Optic
- Turbine or Blower
- Vacuum Pump
- Heat Exchanger
- Excitation source

Some lasers require CO as the lasing medium.
LASER

• L  ->  Light
• A  ->  Amplification
• S  ->  Stimulated
• E  ->  Emission
• R  ->  Radiation
How is laser light produced

- All these components working together create an environment that can produce laser light.
- A mixture of CO2, N2 and He are introduced into the optical cavity (a high vacuum environment).
- The gases are circulated in the cavity with the use of a turbine or blower.
- An excitation source is introduced to pump the lasing medium to an E4 energy level.
- This pumping action puts more molecules into an excited state than a normal or ground state. This is called a population inversion.
How is laser light produced

• Once this energy level has been reached, the molecules will want to return to a ground state. While returning, the medium will spontaneously emit a photon (or unit of light). This is called **spontaneous emission**.

• These photons interact with molecules at the E4 energy level stimulating these molecules to release more photons. This is called **stimulated emissions**.

• These photons will be identical in direction, phase, and wavelength which gives laser light it’s unique properties.
How is laser light produced

Population Inversion

Spontaneous Emissions

Stimulated Emissions

Continuous process of above makes the laser beam
How is laser light produced

• The heat exchanger’s (Turbine or Blower) function is to remove excess heat from the excitation process and to keep the resonator at a stable operating temperature.
How is laser light produced

• These photons are aligned using reflective optics that are part of the optical resonator. When enough photons are aligned sufficient power can be generated to output a laser beam.

• One of the optics in the system is partially reflective, and will allow a portion of energy out (about 50%), the rest is reflected back to sustain the reaction.
How is laser light produced

- Gas Flow
- Excitation Source
- Optical Cavity
- Stimulated and Spontaneous Emissions
- Reflective optics
- Partially reflective optic
- Invisible Beam Output
Characteristics of laser light

- **Monochromatic**: CO2 laser light is of a single wavelength (10.6 micro meter), or if it was visible, a single color.
- **Focusability**: laser light’s ability to be concentrated because of it’s short singular wavelength.
- **Coherence**: an orderly train of waves that can travel long distances without significant loss of power.
- **Divergence**: an ability for laser light to travel long distances with a very low degree of deviation, or conversely, a high degree of collimation.
Characteristics of laser light

- Mode: is the distribution of power over a laser beam’s cross-section. For cutting applications a laser’s power is concentrated highest in the center and dissipating equally out to the perimeter. (ex. A bell curve)
Transverse Beam Mode
- Important for Laser cutting -

Energy Distribution Sampling

Distance from center point

Energy Density

Mode shape differs a lot even when there is a little shift of reflection mirror in the resonator. This makes a difference in actual cut result because there is a difference in temperature distribution.

※ Generally, acrylic plate are used to obtain the CO2 laser beam mode.
Specifying Beam Shape from Transverse Beam Mode

TEM (Transverse Electro-Magnetic Wave)

Transverse Mode

TEM

Point

TEM₀₀

TEM₁₀

TEM₁₁

Axis

TEM₀₁

※ #s next to TEM is indicating the number of bottoms in the energy distribution.

1ˢᵗ number is for X direction, and 2ⁿᵈ number is for Y direction.

Good mode for laser cutting
Resonator Types and Mode

Beam Resonator
(CO2 laser)

Stable Type Resonator

Single Mode
- Gauss type energy density
- High energy density

Multi Mode
Lower energy density
Use based on energy density

Trapezoid

Unstable Type Resonator

Ring Mode
- High power
- High energy density
Need to flatten the energy density
**CO2 LASER**

**Features**
- Wave Length $\lambda = 10.6 \, \mu m$
  - Far Infrared Radiation Laser
- High Power
- Resonating Efficiency $\Rightarrow 15\sim30\%$

**Use**
- Thermal process (Piercing・Cutting・Welding)
- Medical (Laser knife)

**CO2 LASER Gas**

Mix gas of CO$_2$, N$_2$ and He

CO$_2$: Resonating Media

N$_2$: Increase energy level of CO$_2$ (Easier to excite)

He: Keep the temperature of CO2 in low level. (Cooling)
  - Put the molecule back to ground state.
CO2 LASER Resonator

Reflective Optic (R ≥ 99.5%)
Anode
Partially Reflective Mirror (T = 35~60%)
Cathode

Laser Gas (Media)
Mix Gas of CO₂+N₂+He

Discharge Tube
LASER Beam

Basic Structure of LASER Resonator

◎Principle of Emission
Excite the electron up to E4 level by N₂ gas

◎CO₂ Gas Vibration Mode
Symmetry Vibration
Winding Vibration

E3
hν = E₂−E₁

E2
hν
E1
Structure of CO2 LASER Resonator

©High Speed Gas Circulation Type CO2 LASER

Side Discharge Type: High Speed Co-Axial

Diagram showing the structure of a CO2 LASER resonator with the following components:
- Electrode
- Reflective Mirror
- Output Mirror
- Gas Turbine or Blower
- Heat Exchanger
- Light Discharge
CO2 LASER

Light

Add Energy

Energy

Level moves up
(Pumping)

Light

Level moves down
(Ground State)

Atomic Nucleus (Positive Ion)

Electron (Negative Ion)
How is a laser put to work

• Once a laser beam is produced you need additional equipment to apply this beam to the work at hand.
• Most CO2 lasers today are coupled with machinery that consists of 4 basic parts:
  • Cutting head
  • beam delivery system
  • CNC or PC control
  • Motion system
How is a laser put to work

Beam delivery

Laser Resonator

Motion System

Cutting Head

CNC/PC Control
How is a laser put to work

- There are 3 basic systems for beam delivery. Fixed beam, Hybrid, and Flying optic.
On board laser

Koike’s onboard laser concept achieves higher efficiency with it’s cutting area.

It actually uses less space, when working with large plates, compared with a stationary laser with a cantilever design.

A long effective cutting length can only be achieved with the onboard oscillator concept.
Effective use of long rail

Multi-machine use of common rail

Large cutting area makes material unloading convenient.
Additions and extensions are easily achieved.
Different cutting methods can be used to efficiently produce parts to the manufacturer’s specifications.
On board laser

Koike unique design, Installing Oscillator on the main beam minimize machine length, and providing balancing machine wait to four whiles.

Both are Conventional Way of delivering the laser beam
Laser interaction with material

- After passing through the focal lens the raw beam is focused to a spot of very intense heat.
- The focused beam passes through a nozzle which is used to direct a cutting gas that will aid in the cutting process. The cutting gas comes out coaxial with the beam.
- When the beam and cutting gas make contact it quickly heats up and begins to oxidize and/or vaporize the material.
Laser interaction with material

- Nozzle
- Lens
- Cutting Gas
- Focused Beam
- Oxidized or Vaporized material
Focus Point

Use the focused light energy (Laser beam) to melt or evaporate the material, and use certain gases to remove the material.

Beam (light) focus point (Focus Position)
Laser cutting can be divided into two processes depending on the materials.

**Melting process**

Molten material by laser beam are blew by assist gas, in case of materials with wide range of molten temperature such as metals. **Chemical reaction cut** with Oxygen is using Oxidized heat by blowing oxygen to the molten material. **Non chemical reaction** cut with nitrogen is using laser beam heat to create molten material and blowing the material with Nitrogen gas.

**Evaporating process**

Acrylic plate or ceramic that are with small thermal conduction, or materials with high viscosity are cut by evaporating the material.
Laser Cutting Processes

**Melting Process**

Use assist gas to remove molten material when the range of molten temperature is wide.

- Mild Steel, Stainless Steel, Titanium. (Chemical reaction cut)

**Evaporating Process**

Materials with low molten temperature evaporate when heated by a laser beam, and use assist gas to remove the evaporated material that obstructs the laser beam.

- Acrylic plate, board, ceramic, laser blade for medical, etc.
Introduction of laser cutting

Typical surface of laser oxydation cutting

- Fine layer
  - Fine and smooth plane
- "Drag line" layer
  - Similar to gas cutting

TOP

BOTTOM

Rectangular narrow slit (w=1mm)
Comparison between laser cutting and gas cutting

Gas cutting

- Preheating area
- Cutting oxygen flow
- Wide curf

Laser cutting

- Condensed laser beam <1mm
- Assist gas flow
- Narrow curf
Self Burning of material

A overheated material may burn without laser irradiation

*Sharp corner cutting*
Defects on surface of material

Stable cutting was broken by zink marking line

"Bird's excrement" causes partial bad cutting
KOIKE LASERTEX series

- Power of the SIGMABOX design -
Design Concept

Conventional Design

- Traverse carriage is on the left side
- Traverse carriage moves to the right side
- No Constant Beam Path Device
- No Cover Bellows
- No Movable Reflection Mirrors

SIGMA BOX Design

- SIGMA BOX
- Resonator
- Reflection Mirrors inside SIGMA BOX
- Traverse Carriage
- Controller and Panel

- ✔ No Constant Beam Path Device
- ✔ No Cover Bellows
- ✔ No Movable Reflection Mirrors

*A Constant Beam Path Device has the same laser beam path length even when the Traverse Carriage moves left or right. The Device follows the Traverse Carriage’s movement for half distance.

*SIGMA BOX contains the complete laser beam path inside a sealed unit, the beam path is always same, because the SIGMA BOX always travels with the Traverse Carriage.
*Bellows stretch like an accordion and draw factory air (dust) inside, the dust adheres to the mirror surface and causes power loss this also reduces the lifetime expectancy of the optical equipment.

*It is difficult to maintain a stable quality beam, since external laser beam path moves all the time.

*It is difficult to perform periodic maintenance, since the mirrors are far apart from each other and normally requires two people to perform the maintenance.
Merits & Demerits
SIGMA BOX Design

*Stable & High Quality beam for longer period.
*Longer period of periodical maintenance.
*Longer lifetime of the optical equipments.
*Operator friendly easy maintenance.
*Higher safety.
*Machine balance is the best.

PATENT PENDING DESIGN!!
Effect of Heated Output Mirror

- **Reflection mirror**
- **Output mirror**

Absorption rate of about 0.12%

**ZnSe**

Absorb laser beam and increases temperature of the part of the output mirror where the laser beam penetrates. This will make temperature inclination between $T_0$ and $T_1$.

When the temperature inclination is generated, the penetrating laser beam polarizes with different refractive index $n(r)$ in radial direction ($r$) of the output mirror.

As a result, the character of the transmission beam changes, by output mirror working as long focus distance lens.

**Focus Lens**

Note: Spot diameter $d_0$ and focus length is depending on beam path length.
Effect of Heated Output Mirror

- Focus Point when *heated* output mirror
- Expected Focus Point
- Plate
Thicker plate 25mm 1” – Production cutting system using the Trumpf 6kW Truflow Resonator

Cut 25mm (1”) plate in daytime, using unattended operation cutting 19 mm 3/4” or less plate during the night time.

The machine is cutting 22 hours a day.
Test Cutting quality with TRUMP 6kW

Sample Laser Quality material 28mm 1.12"

Sample of normal mild steel material 30mm 1-3/16
Laser cutting parameters

• There are 6 basic cutting parameters for a CO2 laser. These parameters determine the time and quality that will result from cutting a part
• Power (CW, Pulsed)
• Feed rate
• Cutting Gas (Type and Pressure)
• Focal Position
• Nozzle type
• Stand off
Laser cutting parameters

Continuous Wave (CW)

Pulsed Power

Frequency

Duty

Time

On

Off

Power

Power

Power

Power

Time

0 500 1000 1500 2000

0 500 1000 1500 2000
Laser cutting parameters

Depth of field

- 7.5 in Focal length
- Depth of field
- Kerf width: 0.6mm

Depth of field

- 10.0 in Focal length
- Depth of field
- Kerf width: 0.7~0.8mm
Laser cutting parameters

- Thin Mild Steel
  - On surface
- Thick Mild Steel
  - Above surface
- Stainless Aluminum
  - Nickel Alloys
  - Below surface
Cut samples using O2, N2

(Oxygen) Mild Steel

(Nitrogen) Stainless Steel
Superior Cutting Accuracy

General cutting accuracy

Oxy-fuel cutting : ± 1mm to 2mm
Plasma cutting : ± 0.5mm to 2mm
Laser cutting : 0.2mm to 0.5mm

Superior cutting accuracy, results in reducing costs not only in the cutting process but also in procedures such as welding.

For example : 100% robot welding is only possible with high quality accurately cut parts.
Process cost reduction is possible

Sample of processing cost per meter of cut

(High speed cutting, unmanned operation at night, and labor rate is included.)

<table>
<thead>
<tr>
<th>Plate Thickness</th>
<th>Oxy-fuel cutting</th>
<th>Plasma cutting</th>
<th>Laser cutting</th>
</tr>
</thead>
<tbody>
<tr>
<td>6mm</td>
<td>$0.41</td>
<td>$0.23</td>
<td>$0.18</td>
</tr>
<tr>
<td>9mm</td>
<td>$0.44</td>
<td>$0.28</td>
<td>$0.24</td>
</tr>
<tr>
<td>12mm</td>
<td>$0.49</td>
<td>$0.34</td>
<td>$0.29</td>
</tr>
</tbody>
</table>

(Oxy-fuel cutting is considered to have 4 torches.)
Decreased manpower possible with unmanned operation

No manual per day consumable changes required. Sensors are used to detect faults, this protection allows for safe unmanned production.

Here is an example of monthly operations:

Company A: 640 hour/month
  (small parts, small hole parts are concentrated in day operations)

Company B steel service center): 560 hour/month
  (using stocker)
Cost Savings

Secondary processes are not necessary

• A steel service center, cutting 80 tons/month with a laser, was able to move 5 workers from hard grinding work to more productive jobs.

• Laser samples:
Productivity is easier to regulate according to work load

Due to unmanned laser cutting, productivity can increase without increasing labor costs.

When production increases or decreases, productivity can be controlled without increasing or decreasing the number of operators or other downstream laborers.

Unmanned cutting is difficult to do with oxy-fuel and plasma, which can cause unnecessary operator intervention or overtime that is sometimes required to meet production requirements.
Safer working environment

Less ultraviolet, noise, and fumes.

Ultraviolet

: Laser cutting --- Flashes only with the start of piercing

: Plasma cutting --- Heavy ultraviolet rays

Noise

: Laser Cutting --- 75 - 80 dB.

: Plasma Cutting --- 90 - 100 dB.

Fumes

: Laser Cutting --- Standard cutting speeds generates a small amount of fumes. Slightly more fumes are generated at high speed cutting, but are easily removed.

: Plasma cutting --- heavy fumes. A fume collector is necessary.

In case of Mild Steel cutting
Less effected by heat

The heat input of the laser into the material is less than that of any other thermal cutting method. This minimizes the camber or distortion of the cut part in long length cutting.

Heat warping can be held to under 1mm or less, when the plate thickness is 4.5mm – 6mm, cutting length is 6M – 8M, and the cutting width is 150mm – 500mm. These tolerances however, depend on the sequence of the cutting process.
HSQ Piercing

- HSQ was developed to address the problem with piercing thick plate steel in a fast yet effective way
- The **pierce results** are quick with a very clean and controllable spatter region
- The **cut results** are cleaner more consistent lead-ins with higher process reliability
- HSQ also increases the reliability of unmanned operation
HSQ Piercing

Stand off during cut

2.5 mm

Stand off during piercing

X mm

Down lens

Raise torch
**AFT nozzle**

- A new nozzle design called AFT (Active Flow Technology).
- The AFT nozzle creates a stable environment for optimizing pierce times and cutting results by helping.
- The AFT nozzle produces higher cutting reliability, better cut quality, and improved lens and nozzle protection.
Laser bevel cutting system and cutting technology
LASER Bevel Cutting application in Shipyard
Beveling torch head

Beam path to the nozzle through 2 copper mirrors and focusing lens.

Copper mirror
Automatic focus lens
Copper mirror
Angle axis (A)
Rotation Axis (C)
This mirror requires daily cleaning.

Rotational device
Beveling torch (side view)
Movement of beveling torch

Stabilized the end point of nozzle by positioning control feature

Nozzle is always pointing to the same point of contact on the steel by NC control.

Rotational axis (C) ± ∞ contours to the cutting direction.

Angle axis (A) ± 45° controls the bevel angle.

Machine motion moves along with revolution (C) • angle (A) action, therefore, the focal point is maintained.
Movement of beveling torch -2

Bevel cutting of curved line becomes available with curve following function

Rotation unit

Wiring and Piping are not cut when the unit is rotating.

Rotation Axis \( \pm \infty \)
Follows the cutting direction

Following function OFF
Can not achieve same bevel angle on a curved line

Following function ON
Same bevel angle can be achieved
Angle fixed bevel cutting  \( V \) beveling • \( Y \) beveling

- \( V \) (top) beveling / \( \Lambda \) (bottom) beveling

- \( Y \) beveling
  - I-cut together with \( V \) bevel cut (cut twice)

- Negative bevel / Positive bevel

- LS/ 16mm/ \( V30^\circ \)

- LS/ 16mm/ \( Y45^\circ \) / Land 3mm

SAIL 2008
Multi bevel cutting and CVBA cutting

**Multi bevel cutting**

It is called “Multi bevel cutting (Dogae)” when the bevel angle is changed on the cutting path.

**CVBA cutting**

(Continuously Varying Bevel Angle)

Beveling angle is gradually and continuously changed on the cutting path. This cutting method is required for shipbuilding.

- **LS/ 16mm/ 0° → V30° → 0°**
- **Mild steel/ 12mm/ V45° → V30°**
Special form / drain

Multi-bevel cut

This drain part with the bevel cut will be welded afterwards. This is an essential technique for shipbuilding.

V30° drain water was performed after 16mm/ I-cutting

For this cut drain part, second piercing is needed after I-cut.
ZRP mild steel cutting sample

LT-3560TRV (TLF6000 bevel)
- Bevel cutting for 16mm 5/8”
- Y bevel cutting & loose curve (R500mm) of 45° Land: 2.0mm
- 15° → 30° CVBA cut
- 30° V Oval
Several cutting surface views

V30° Oval

Y45° land 2mm

Angle cut

Zinc Coated mild steel; 16mm

Vertical cut
<table>
<thead>
<tr>
<th></th>
<th>I-cut</th>
<th>V bevel</th>
<th>Λ bevel</th>
<th>Y bevel</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mild steel</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>black scale</td>
<td>22.0mm, F800</td>
<td>19.0mm / 30°, F800</td>
<td>16.0mm / 45°, F900</td>
<td>Plate thickness:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>16.0mm / 45°, F900</td>
<td></td>
<td>according to V</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>root face: &gt; 3 mm</td>
</tr>
<tr>
<td><strong>Mild steel</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ZRP</td>
<td>22.0mm, F700</td>
<td>19.0mm / 30°, F700</td>
<td>16.0mm / 30°, F800</td>
<td>As above</td>
</tr>
<tr>
<td></td>
<td></td>
<td>16.0 mm / 45°, F800</td>
<td>12.0 mm / 45°, F1200</td>
<td></td>
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</tbody>
</table>
Cutting surface of ZRP/16mm

From the left side, I-cut V20° ∧ 20° ∧ 45°

Top and bottom bevel cutting surface view
Corner pass on bevel cut

※Melt at the direction change at a corner.

Corner R processing

Piercing twice
(In case of changing bevel angle)
How to offset of V,Y bevel

**EX: all round V bevel cutting of \( \phi 100 \)**

Normally, the cutting machine moves on the surface with a criteria by positioning control commands. Therefore, the diameter size on the top surface becomes \( \phi 100 \), the diameter size of bottom side becomes larger.

To compensate for the part diameter an offset function is required. The amount of offset is dependant on plate thickness and beam diameter.

**There are two methods on how to offset**

1. **Modify the cutting path with programming software**
2. **Compensate the cutting path using KERF width compensation**

Using path modification in the software, the lead-in length after piercing becomes shorter.

Using kerf width compensation, lead-in distance will become longer because the machine is moving from original path to the offset path.

This type of lead in could cause an alarm depending on the NC program.
Improvement of Bevel Cutting Torch Block

- Improve design to achieve stable daily production without down time.
  - Refine location of piping and parts.
  - Easier adjustment and maintenance.
  - Compact / Light design

- Improve parts and design for finer cutting.
  - Nozzle development
  - Supporting fluid spray unit.
  - Prevent accident

*Introduced at JIWS 2008*
LASER Bevel is now getting popular in industries

Shipbuilding, Crane manufacturer, Defense industry, Nuclear energy
LASER Safety

- **Class 1**: Safe.
- **Class 1M**: Safe provided optical instruments are not used.
- **Class 2**: Visible lasers. Safe for accidental exposure (< 0.25 s).
- **Class 2M**: Visible lasers. Safe for accidental exposure (< 0.25 s) providing optical instruments are not used.
- **Class 3R**: Not safe. Low risk.
- **Class 3B**: Hazardous. Viewing of diffuse reflection is safe.
- **Class 4**: Hazardous.
  Viewing of diffuse reflection is also hazardous. Fire risk.
# LASER Safety

<table>
<thead>
<tr>
<th>眼球における吸収概要</th>
<th>CIE の波長領域 (nm)</th>
<th>眼に対する作用、障害</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>UV-C 200</td>
<td>光化学作用、熱作用による角膜、結膜の激痛を伴う炎症</td>
</tr>
<tr>
<td></td>
<td>UV-B 280</td>
<td>熱作用による水晶体渦渦（白内障）</td>
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<td>UV-A 315</td>
<td>可視光の光化学作用による網膜障害、光化学作用、熱作用、衝撃波による網膜損傷</td>
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<td>IR-A 400</td>
<td>熱作用による角膜火傷、口内障</td>
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<tr>
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<td>IR-B 780</td>
<td>可視光の光化学作用による網膜障害、光化学作用、熱作用、衝撃波による網膜損傷</td>
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<tr>
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<td>IR-C 1,400</td>
<td>熱作用による角膜火傷、口内障</td>
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<tr>
<td></td>
<td>3,000</td>
<td>熱作用による角膜火傷、口内障</td>
</tr>
</tbody>
</table>

*YAG/FIBER lasers (Retina)*

*CO2 laser (Cornea)*

※CIE は Commission Internationale de l'Éclairage (国際照明委員会) の略