Technical information

Laser processing

CO_2 laser

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Before you read on...

This document will provide you with essential technical information about CO_2 lasers.

The beginning of the document described how a CO_2 laser functions and how the laser beam becomes a tool. Further chapters will describe the role played by the laser in material processing and the quality criteria that are applicable for laser cutting.

You will find an index of key words as well as a glossary at the end of the technical information which will help you in locating certain information quickly.

Series: Technical information "Laser processing"

The technical information about "Laser processing" is a part of a series of informational booklets dealing with the topic of lasers and laser processing.

Data collection

A special note on the individual laser cutting machines is given for the data collections which are compiled and published by TRUMPF Werkzeugmaschinen GmbH + Co. KG. Here you can find standard values for laser cutting and piercing of different materials.

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Chapter 1

Basic concepts of laser technology

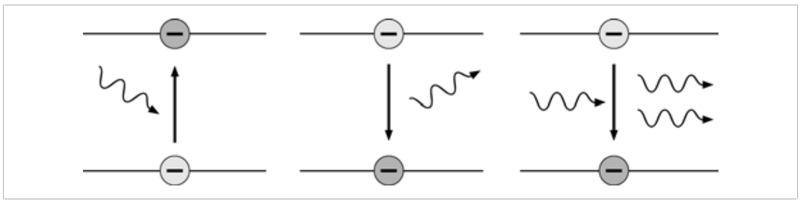
1. Laser principle

Laser is an American term and stands for light amplification by stimulated emission of radiation. It basically means: light amplification by stimulated emission of radiation.

A laser is a source of radiation that emits characteristic electro-magnetic radiation between the ultraviolet and infrared wavelengths. This means that every radiation transmitted by the lasers cannot be seen by human beings (visible range: approximately 400 – 750 nm). Nevertheless, the laser beam is mostly referred to as light.

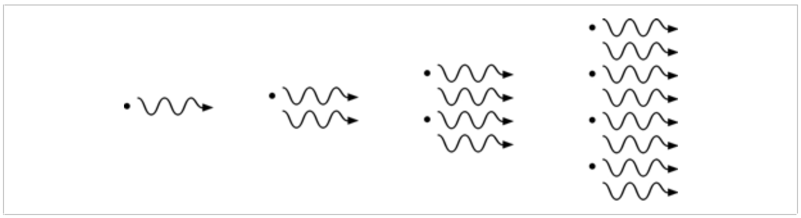
Stimulated emission

During stimulated emission, a photon (the smallest energy part of electromagnetic radiation) meets an excited atom or molecule and stimulates the electron to pass into the low energy level. Here, it transmits another photon. However, the prerequisite is that the incoming photon should have the energy required for this process. It is said to have the required energy when this energy corresponds to the difference in energy between the excited level and the lower level.



Generation (left), spontaneous emission (middle), stimulated emission (right) Fig. 48000

After the stimulated emission, the new photon has exactly the same frequency and the same phase position as the first photon and moves in the same direction.



The laser light increases like an avalanche due to the stimulated emission Fig. 48001

The light beam has increased. Where there was only one photon previously, two of the same kind are en route now. If these photons meet the excited atoms again, they generate more photons and the light beam increases further. Therefore, lasers are also known as light amplifiers.

1.1 Excitation mechanisms in case of CO_2 lasers

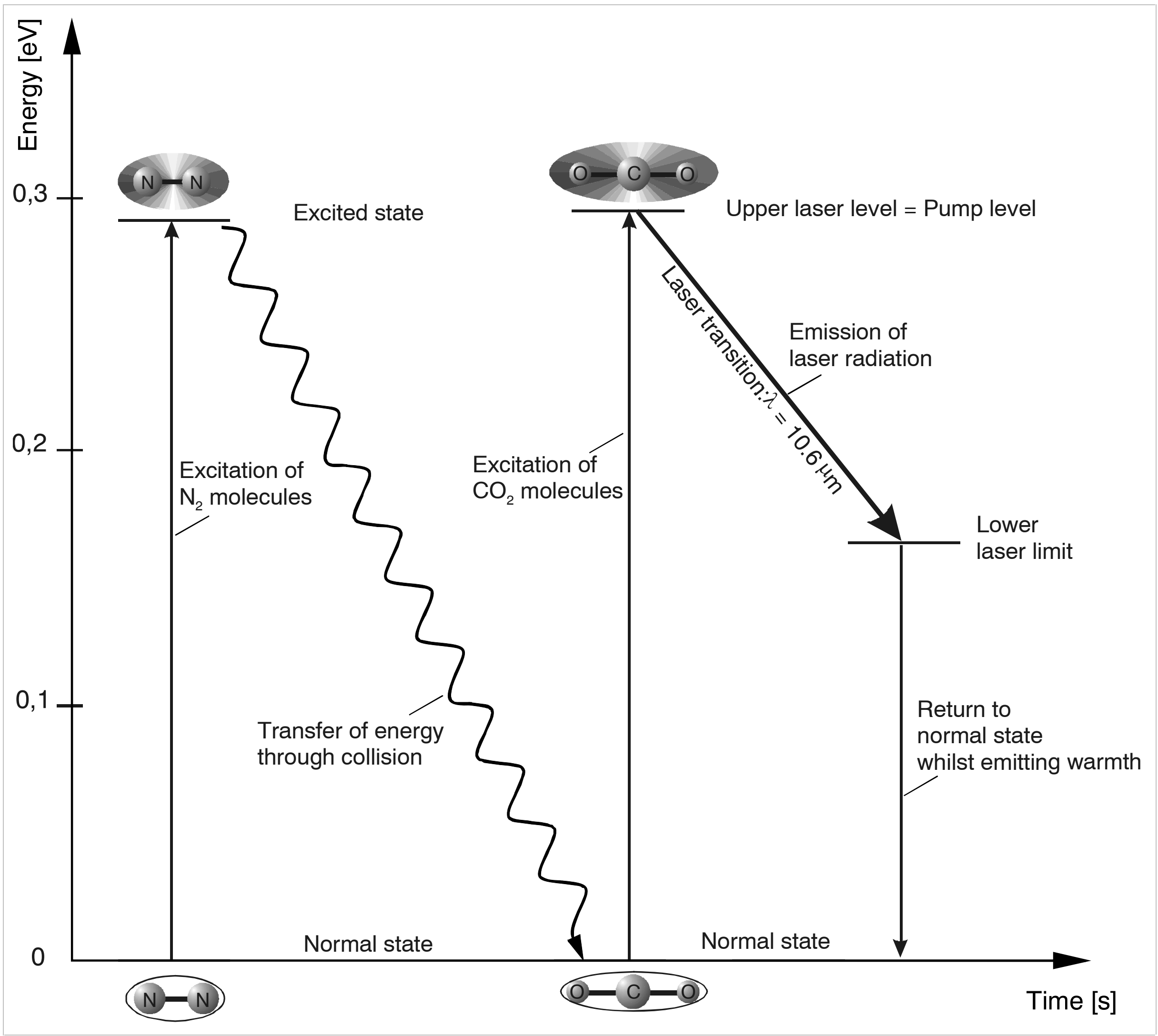
In CO_2 lasers, CO_2-molecules transmit laser light. A CO_2-molecule consists of one carbon atom and two oxygen atoms. They form a chain, wherein the carbon atom lies between the oxygen atoms. If the molecule is excited, it starts vibrating. The various forms of vibration correspond to the differentially high energy levels. The laser process in the CO_2 laser comprises four energy levels. The pump level and the upper laser level are very close to each other.

However, the laser-active medium does not consist of only CO_2. It is a mixture of Helium (He), nitrogen (N_2) and carbon dioxide (CO_2). Helium and nitrogen are assist gasses. They support the actual laser process in the CO_2 molecule.

In detail

Free electrons are generated in the gas mixture through gas discharge at high direct voltage or high-frequency alternating current; these electrons excite the nitrogen molecules by pushing them. The nitrogen molecules start vibrating. By pushing, they pass on their energy to the CO_2 molecule and lift it from the normal state into the upper laser level - a vibration state in which all three atoms of the molecules are moving. During the transition into the lower laser level, the CO_2 molecule emits laser light with a wavelength of 10.6 micrometers.

From there, it emits heat and returns to the normal state. Here, only the atoms of the inert gas helium act: they accelerate the emptying of the lower laser level by pushing with the CO_2 molecules, absorb the heat and dissipate it.

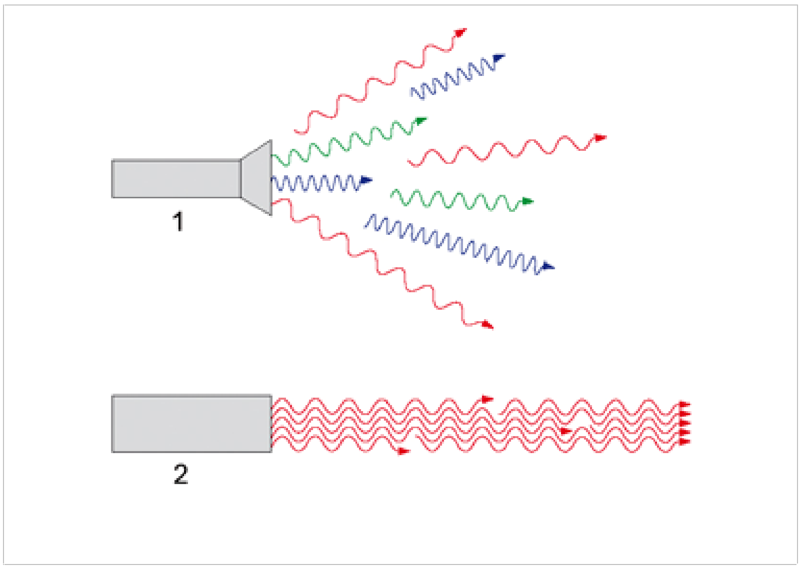


Energy scheme

Fig. 24227EN

2. Properties of the laser light

Thanks to the special properties of laser radiation, lasers have become indispensable today. Whereas the light from natural sources, e.g. a candle or the sun, is made up of various wavelengths, the laser light is monochromatic, coherent and directed. These properties are the reason why the laser can be used for so many applications.



Above: Incoherent radiation of a lamp
Below: monochromatic, coherent laser radiation

Fig. 49057

Monochromatic

All photons have the same wavelength in the laser beam. It is determined by the energy transitions in the substances emitting the laser light. Monochromatic light is primarily in demand for applications which might have interferences when functioning, e.g. when playing a CD or in the measurement technology.

Coherent

All photons vibrate in common mode. The wave trains have the same phase position. This thus gives rise to a coherent laser beam. Similarly, this coherence always plays a role if the interferences are used technically. CD and measurement technology can be named as examples here as well.

Directed

The photons have the same direction. They are almost parallel. Therefore, the laser beam forms a compact light bundle that rarely diverts. Thus, the laser beam can be led particularly well and allows all the energy to be focused on an extremely small burn spot. This is essential for machine processing.

3. Beam quality

Laser beams are directed, but the light waves are not hundred percent parallel. Laser beams have a beam waist and increasingly divert according to it.

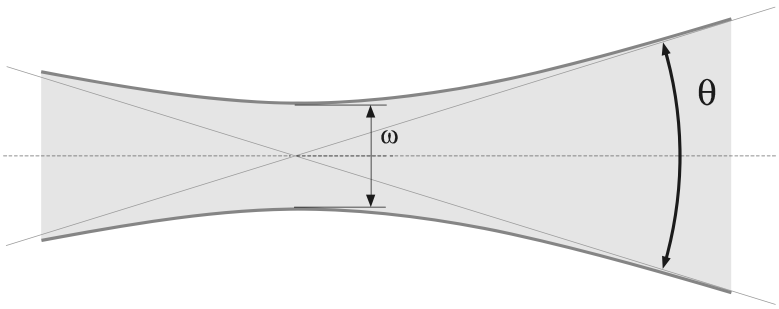
Expansion properties and focusability

The diameter of the beam waist (the narrowest beam cross-section) and the opening angle (divergence) determine the expansion behavior of the laser beam. Beams with a small waist and low divergence can be focused on a relatively small spot and thus have a high sharpness depth. The working distance between the lens and the workpiece can be thus relatively large which is desirable for the laser user and manufacturer.

Smaller opening angles mean more beam quality. The least possible can be achieved only by laser beams with basic mode and depends on the wavelength.

Beam parameter product and M^2 value

The beam parameter product (SPP) or the M^2 value (bending measured value) indicate the beam quality. Both the characteristic figures are determined in the DIN EN ISO 11145.



$$SPP = \tfrac{1}{2}\,\omega \bullet \tfrac{1}{2}\,\theta = (\lambda / \pi) \bullet M^2 \text{ [mm} \bullet \text{mrad]}$$

ω	Diameter of the beam waist	π	Circle constant Pi = 3.141…
θ	Divergence angle in the remote field	M^2	Bending measured value (M^2 = 1/K)
λ	Wavelength	K	Beam propagation factor (K = 1/M^2)

Fig. 48003

In the case of a beam parameter product, the two most important and easily measurable beam parameters are multiplied by each other; these parameters are the radius of the waist and the half opening angle (divergence angle). The following is applicable here: the smaller the beam parameter product, the better is the beam quality. For CO_2 lasers, the attainable minimum is 3.4 millimeter milliradian (1 milliradian corresponds to an angle of 0.057 degrees).

The bending measured value M^2 describes, how great the deviation of the beam parameter product of the observed beam is from the optimum, the laser beam with basic mode. Their values are always greater than or equal to 1. A laser beam with an M^2 value of 1 can be focused optimally. M^2 and beam parameter product can be converted into each other.

What is used and when?

Owing to historical reasons, the beam quality of CO_2 lasers is generally described with K-numbers in Europe and with bending measured values M^2 overseas. The K-number corresponds with the reciprocal of the bending measured value M^2.

To compare the beam quality of lasers with identical wavelengths, both parameters can be used. If lasers with different wavelengths are still compared, the beam parameter quality must be used. The reason for this is that the information of the beam parameter product about the expansion properties and the focusability of laser beams depends on their wavelengths.

3.1 Intensity distribution in beam cross-section

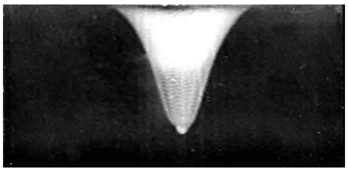
The laser beam has a characteristic intensity distribution in the cross and longitudinal section to the beam axis (energy density per cm^2). This intensity distribution in cross-section is described as a mode.

TLF laser modes

The two most important modes for CO_2 lasers are the basic mode TEM_{00} and the mode shape TEM_{01^*}. TEM stands for transverse electromagnetic mode.

Basic mode TEM_{00}

In the case of basic mode TEM_{00} which is also known as Gaussian mode, the intensity of radiation is the greatest on the beam axis and decreases steadily with the distance of the beam axis. The intensity distribution corresponds to a Gaussian normal distribution. A laser beam with this mode has the least divergence. This mode shape is approximate for CO_2 lasers with laser powers from 700 W to 3 500 W, whose field of application is primarily laser cutting.

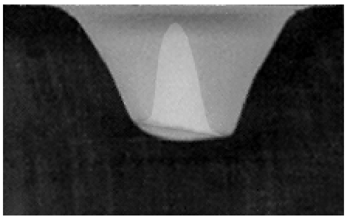


Mode shot in plexiglass cube: example basic mode TEM_{00} ($K \approx 0.9$, $M^2 \approx 1.1$) Fig. 48217

Ring mode TEM_{01*}

In case of mode shape TEM_{01*} which is also known as a ring mode, there is a zero point of intensity on the beam axis, the intensity reaches its maximum on the outside and then decreases. It has been proved practically that the intensity distribution corresponds to a Gaussian normal distribution expanded to its maximum. The expansion is carried out by overlapping the modes TEM_{00} and TEM_{01*}.

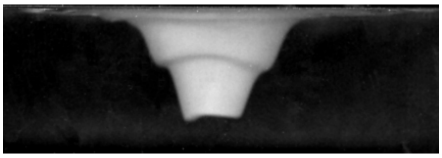
This mode shape is used for cutting or even drilling in cases where lasers with mirror optics and with laser powers between 3,000 W and 7,000 W are used.



Mode shot in plexiglass cube: Example for ring mode TEM_{01*} (Laser: TruFlow 4000, $K \approx 0.6$, $M^2 \approx 1.8$) Fig. 48028

Multi mode

A multi mode is a higher-level mode. It is caused by overlapping several mode shapes, as can occur with lasers that have laser powers from 8,000 W to 20,000 W. CO_2 lasers with this mode shape are predominantly used for welding or surface treatment.



Mode shot in plexiglass cube: example for multi mode (Laser: TruFlow 15000, $K \approx 0.25$, $M^2 \approx 4$) Fig. 48027

Mode shot = making the intensity distribution visible

The distribution of intensity in the cross-section of a laser beam is visible in the so-called mode shot. The unfocused beam is directed onto the surface of a plexiglass cube. Because of this a characteristic depression arises there, which corresponds to the intensity distribution in the cross section of the laser beam.

4. Laser types

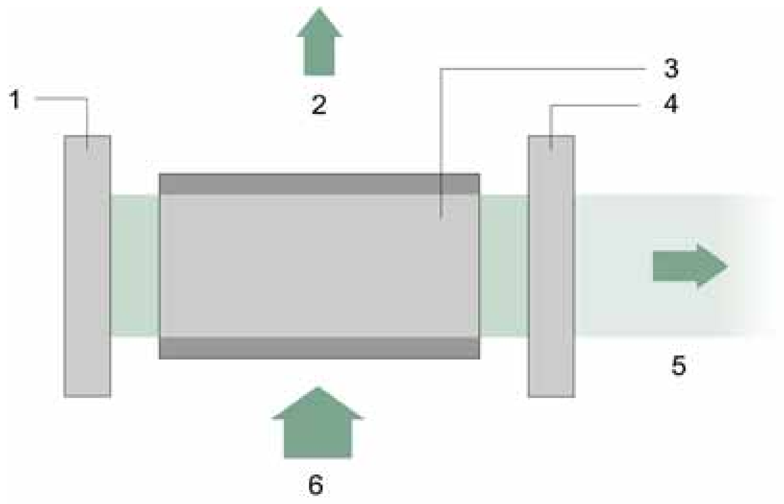
The following table provides an overview of the most important laser types, the wavelengths of their emitted radiation and notes for application.

Laser types	Laser-active material	Wavelength [µm]	Applications / areas of application / notes
Gas laser	Nitrogen	0.3371	Optical pump source for dye laser
	Excimer (inert gas Halogenid laser): ArF KrF XeCl XeF	 0.1931 0.2484 0.308 0.351	• Optical pump source for dye laser. • Materials processing of plastic material, glass, and ceramics. • Spectroscopy • Medicine • Measurement technology.
	Helium-Neon (He:Ne)	0.6328	• Measurement technology. • Holography • Adjustment
	Argon $(Ar)^+$	0.3511-0.5287	• Optical pump source for dye laser. • Measurement technology. • Holography • Spectroscopy • Medicine
	Krypton $(Kr)^+$	0.324-0.858	• Optical pump source for dye laser. • Spectroscopy • Medicine • Photolithography
	Carbon dioxide (CO_2)	10.6	• Materials processing. • Spectroscopy • Medicine
Solid-state laser	Rubin (Cr^{3+}:Al_2O_3)	0.694	• Medicine • Lidar • Materials processing. First technically realized laser (1960)
	Neodymium:Glass (Nd:Glass)	1.062	• Materials processing. • Plasma research. • Photochemistry
	Neodymium:YAG (Nd:YAG)	1.063 1.064	• Materials processing. • Medicine
	Alexandrite	0.755	Medicine
Diode laser	GaAlAs / GaAs	0.635-0.910	• Optical pump source for Nd:YAG laser. • Optical communication engineering. • Audio technology. • Laser printer. • Measurement technology. • Medicine • Also materials processing for higher powers (in the kW range).
	InGaAsP / InP	1.3	
	InGaAlAs	1.5	
Dye laser	Organic dyes in strongly diluted solution	Variable from 0.31-1.28	

Tab. 1-1

5. Construction of a beam source

All the laser beams occur as per the same physical principle. Therefore, the same functional components are located in all the beam sources.



1	Fully reflecting mirror	4	Semi-reflecting mirror
2	Loss energy (heat)	5	Laser beam
3	Active medium	6	Excitation energy

Basic components of a laser　　Fig. 48002

Active medium

Active medium is the substance emitting and amplifying the laser light. Gasses, solids and liquids are suitable. The basic prerequisite is that the materials should transmit light, more specifically electromagnetic radiation with a particular wavelength, if they are stimulated and return from stimulated states to energetically lower states.

Resonator

In the resonator, the light is reflected back to the active medium repeatedly. In the simplest of cases, this can be done using two mirrors. It determines the direction of divergence of the laser light and ensures adequate amplification of the laser beam through stimulated emission.

Excitation

Energy must be supplied to excite the active medium, so that it emits laser light. This procedure is known as pumping. Every beam source requires a pumping source that supplies optical, electrical or chemical energy to the active medium. In case of CO_2 lasers, it is radio frequency alternating current for example.

Cooling The excitation is as important as the cooling of the active medium. A large part of the excitation energy is converted into heat and not into laser light. The heat must be dissipated, as the active medium and the resonator will otherwise heat up excessively.

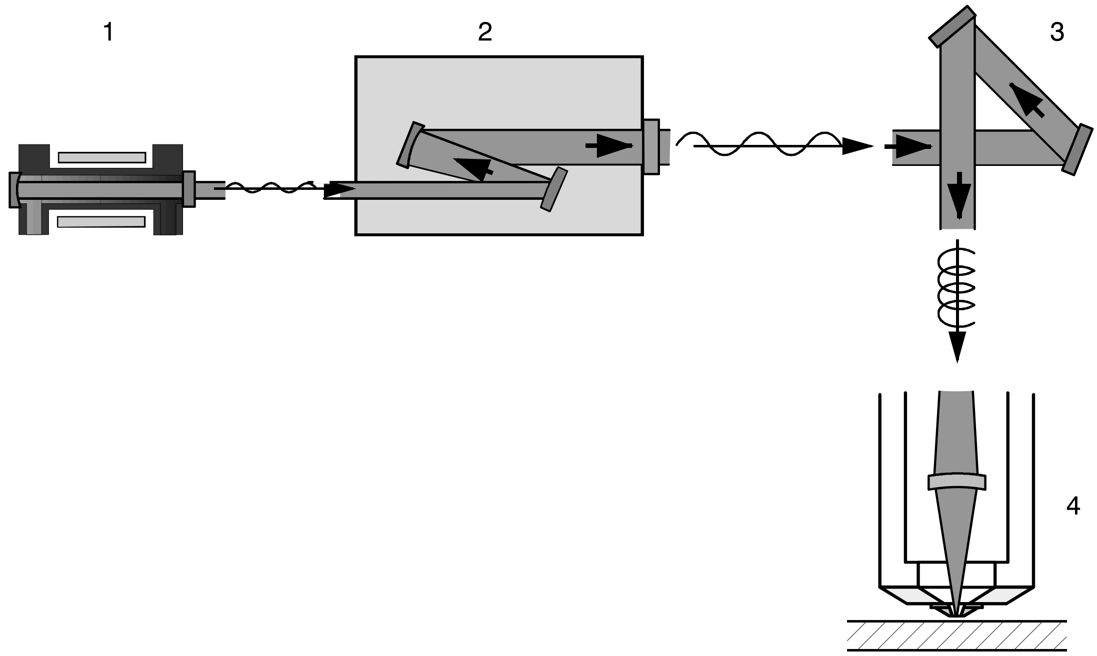
Other components In order to be able to generate a laser beam, the beam source also requires many other elements that will supply it with energy and if required, additional materials such as gas and cooling water.

6. Components of a laser system

Owing to the compact construction of laser systems, one does not usually notice the numerous components required to process a workpiece optimally using a laser beam depending on the processing task.

The laser beam is formed, guided and then focused on the way to the workpiece. Various components are required for this, depending on the laser type and the processing task:

- Beam protection tube and bellows surrounding and shielding the laser beam.
- Plane mirror to deflect the laser beam or to guide the laser beam to several work stations.
- Semi-reflecting mirror to divide the laser beam.
- Dished mirror for forming and focusing.
- Lens for forming and focusing.
- A phase shifter if the direction of vibration of the CO_2 laser light has to be changed.



1	Resonator	3	Beam-bending mirror and phase shifter	4	Laser cutting head with focusing lens and cutting nozzle
2	Beam telescope				

Beam guideway between resonator and workpiece Fig. 25237

Basic machine

The laser beam intersects the meter-large, flat sheets as well as light and small semiconductor plates or three-dimensional workpieces. However, it can do this only if the optics bundles it appropriately and the machine guiding it allows the required movements. The machine or system version determines the workpiece spectrum that the laser can intersect or even weld.

Different machines are used depending on whether you want to cut or weld. Contours in the plane are cut using 2D laser machines, three-dimensional contours require mobility of a 3D laser machine. Pipes that have to be cut to a certain length are processed on 2D laser machines. However, robots are increasingly being used for cutting, as they are a cost-effective alternative for 3D systems.

Robots are being used for welding in the automobile industry for a long time.

7. Laser safety

But, using a laser involves certain risks as well. The human skin and eyes are particularly endangered. In order to reduce these risks to the minimum, various constructive measures are implemented on the laser machines to attain the laser class 1:

- Integration of the laser in the machine frames and enclosure of beam guideway up to the laser processing head.
- Beam guard on the laser processing head (combination of beam and slag-spray protection).
- Limitation due to light barriers that are coupled with the safety circuit of the machine.
- Encapsulated housing for the laser processing area by means of a closed cabin.

Implementation of all safety measures would be expecting too much here. All the important things regarding "Laser safety" have been compiled in the technical information "Safety guide for laser equipment and laser processing machines".

Chapter 2

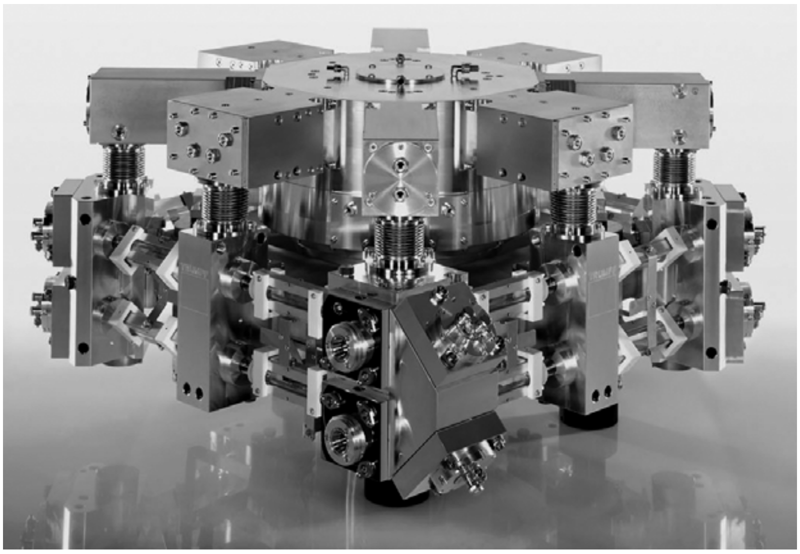
TRUMPF CO_2 laser

1. A tool for the industry

CO_2-lasers have proved to be reliable and loadable beam sources and have thus become a fixed size in material processing. Ten thousands of beam sources are used worldwide. Most of them are used for cutting and welding. The wavelength of a CO_2 laser lies in remote infrared and is 10.6 micrometers.

Attributes

- Large power range, from less than 10 Watt to more than 20 000 Watt.
- High beam qualities, M^2 from 1.1 to 5.0 (K-values from 0.9 to 0.2; beam parameter product from 4 to 17 millimeter milli-radian).
- Selectable operating mode: continuous wave operation or turnable.
- Process reliability through high power constancy.
- Use of CO_2 laser in various fields of activities through adjustable power and power operation (pulsed CW operation).
- Workpiece can be uniformly processed with a uniform intensity distribution, with reference to the beam cross-section and high mode stability, i.e. stable intensity distribution of the laser beam.
- Low power consumption due to high quantal optical degree of effect of approximately 30 %.
- Easy integration of CO_2 laser in the existing machine concepts due to the compact construction.

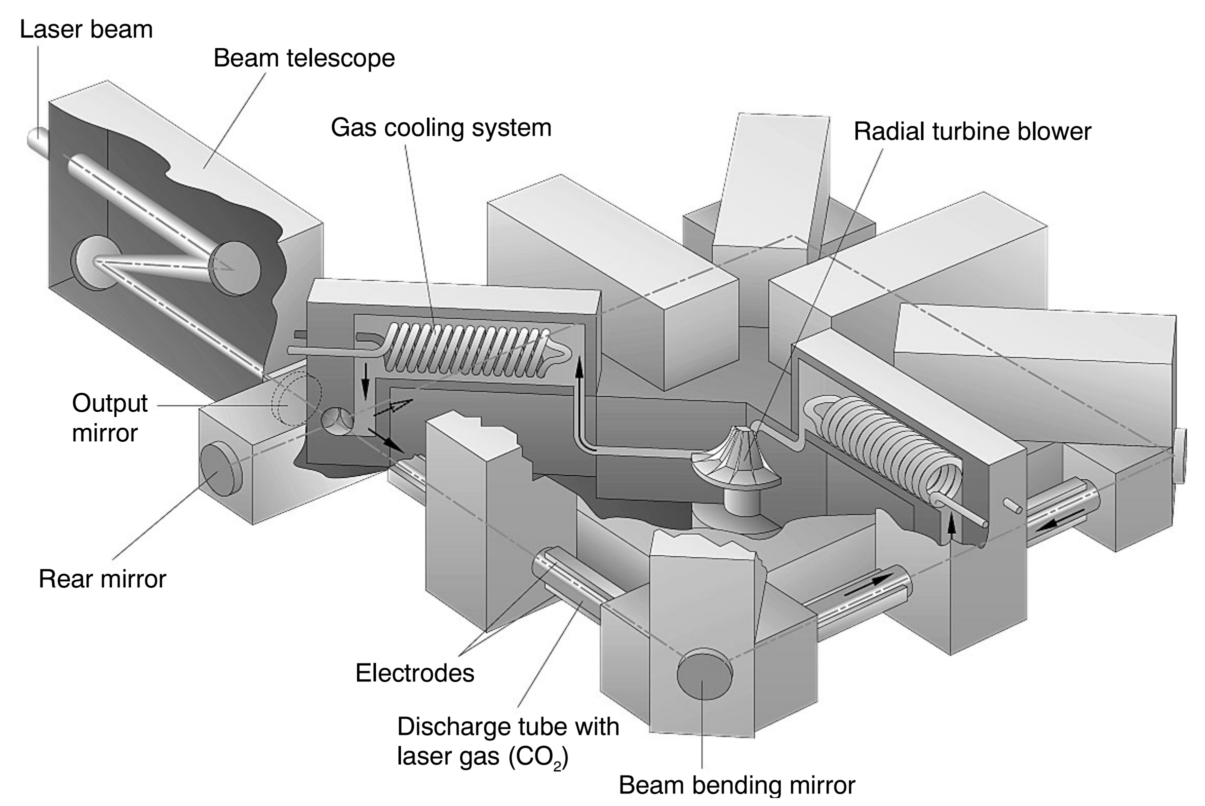


Example of a CO_2 laser Fig. 48029

2. Compact construction of the CO_2 laser

Attributes

- Fold of the resonators.
- Integration of the laser gas circulatory system.
- Integration of the laser gas cooling system.



An overview of the CO_2 laser with a beam telescope — Fig. 24346EN

Advantages

- High mechanical stability.
- Low weight.
- Less space requirements.

3. To concepts for CO_2 laser

Two concepts for CO_2 laser are presented in this section. Both are pumped with radio frequency alternating current. The cooling and the resonator form are however different.

3.1 Surged CO_2 lasers

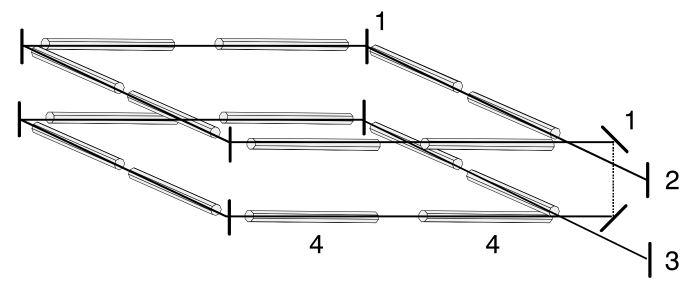
Rectangular construction

Surged CO_2 lasers from TRUMPF have a rectangular construction. They are thus compact, robust and reliable and provide laser beams up to 20,000 W power, depending on the configuration stage.

The discharge path consists of quartz glass tubes which also have the laser gas. There are electrodes on the tubes outside, which inject the excitation energy in the laser gas without contact. The discharge path must be several meters long for laser powers of several kilowatts. In order to attain the compact outside dimensions in spite of this, the discharge paths are folded and arranged for example in a rectangular manner or in case of high laser powers, even in two levels. Deflection mirrors reflect the laser beam at the corners of the squares and connect the discharge paths optically. Rear mirrors and output coupling mirrors complete the resonator.

Folded resonator

The deflection of the beam is also known as "Fold" and the resonator is also known as "folded resonator".



1	Deflection mirror	3	Output coupling mirror
2	Rear mirror	4	Discharge tube

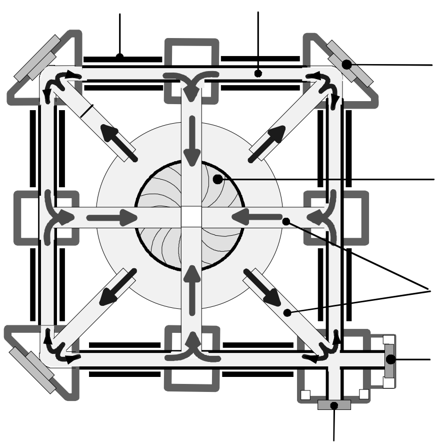
Four-fold folded resonator with two discharge levels — Fig. 24230

Advantages of the symmetric construction:

- Minimum sensitivities against the temperature changes.
- Symmetric gas surging/distribution of the electric energy for maximum laser power and stability.
- Excellent beam quality.

Radial turbine blower

A magnet-stored radial turbine blower is located in the center of the beam source. It rotates the laser gas continuously. The gas surges the corners of the square in the discharge tube and is exhausted again in the center of every side. In the supply and dissipation housings, the gas circulates around the water-cooled heat exchanger and cools. The gas mixer mixes the laser gas made up of carbon dioxide, helium and nitrogen. The vacuum pump ensures the correct pressure. It maintains the gas pressure at around 100 Hectopascal.



1	Electrodes	5	Gas cooler
2	Discharge tube with gas mixture	6	Rear mirror
3	Beam-bending mirror in corner block	7	Output coupling mirror
4	Radial turbine blower	→	Gas flow direction

Gas flow direction in CO_2 laser — Fig. 25238

Advantages of the fast-surged laser

- **Higher laser power:** The higher gas flow per time interval allows a higher laser power in case of the otherwise same output conditions.
- **Less gas cooling:** The higher gas flow rate leads to less dwell time of the gas in the discharge path. The gas heats up less and thus has to cooled less.

Beam characteristics

The coupled laser beam has a circular cross-section and a high beam quality. Which modes vibrate, this depends on the diameter of the quartz tubes in the resonator as well as on the shape of the mirror: basic mode, ring mode or multi-mode can be realized.

3.2 Diffusion-cooled CO_2 lasers

Diffusion-cooled lasers, also known as Coax lasers, have been available in the market in this shape since 2003. They are always used if compactness in the medium power range is demanded in case of high beam quality. This is the case with punching laser combination machines, for example. Here, the Coax laser is placed on the machine frame.

Premix gas cylinder

The gas cylinder with the already premixed laser gas is always connected to the resonator through a valve. The laser gas in the resonator is automatically changed after maximum 72 hours. As the fill volume of the resonator is extremely low, the gas cylinder integrated in the housing is sufficient for around 1.5 to 2 years.

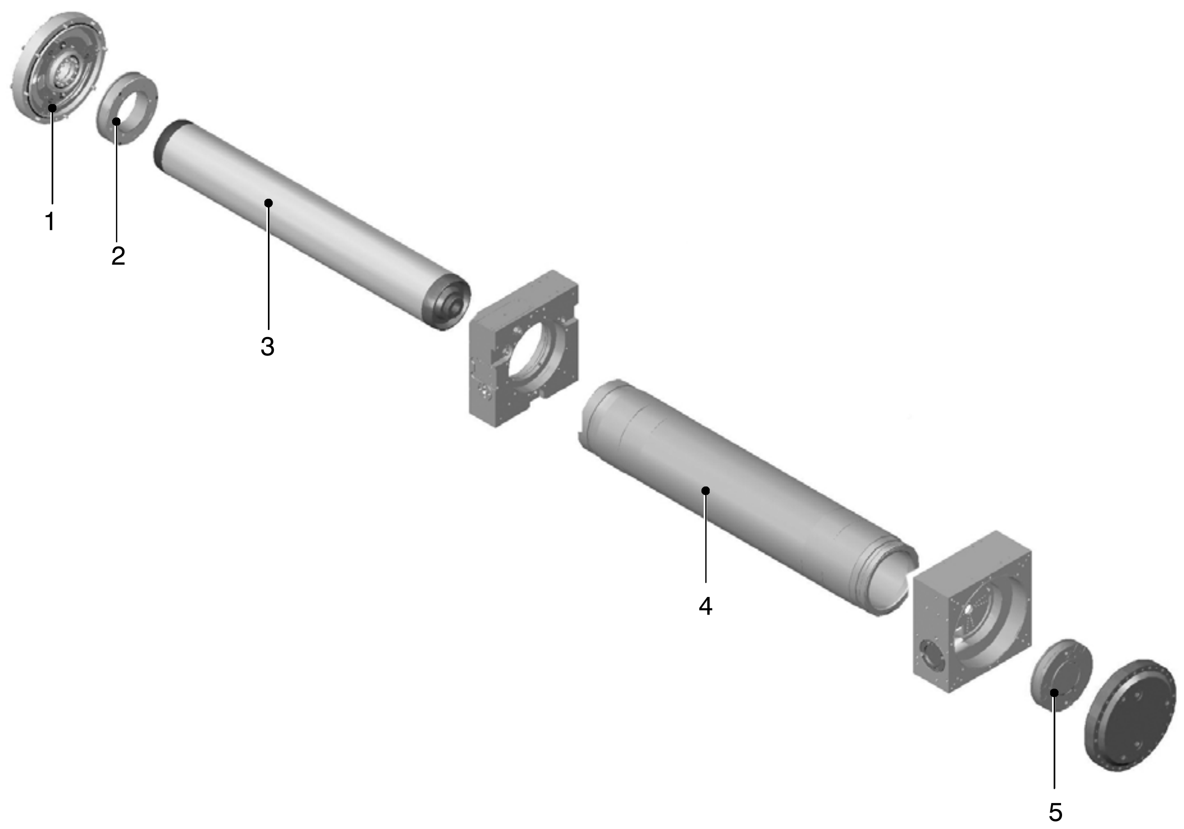
Diffusion cooling

There is no gas circulation in diffusion-cooled CO_2 lasers. In spite of this, the laser gas passes on the heat through the resonator walls (diffusion cooling). The distance between the resonator walls should be as little as possible and the wall surface must be as large as possible so that the heat can be effectively discharged. However, a specific gas volume is still necessary to attain high laser powers.

Compact construction

A compact construction and powers in kilowatt range are attained using the Coax lasers.

The resonator consists of two coaxially arranged metal tubes that are water-cooled. At the same time, they also serve as radio frequency electrodes. The space between the tubes forms the discharge path, wherein the laser gas is located.



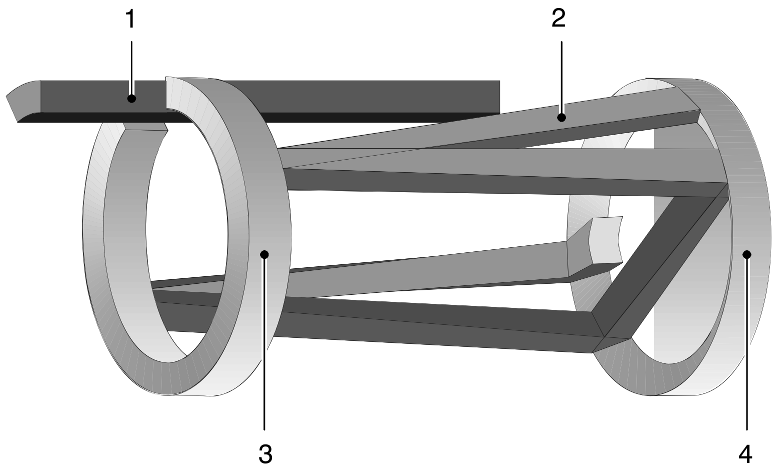
1	Decoupling window	3	Inner electrode	5	Axicon mirror
2	Helix mirror	4	Outer electrode		

Construction of the resonator — Fig. 37388

There is a rear mirror on the rear side, a so-called axicon mirror. Its ring-shaped mirror surface is inclined towards the plane at 45°. The mirror surfaces on the opposite form an angle of 90°. This means that the incoming laser beam reflects on to the opposite side of the ring and returns to the tube intermediate space from there. Incident and reflecting beam are parallel to each other.

The beam falls on a Helix mirror on the other side of the resonator. This is also ring-shaped and its mirror surface has a pitch and an opening from which a part of the radiation field is output as a leaser beam. Through the pitch of the Helix mirror, the beam is reflected at a greater angle and the beam starts moving here and there in zig-zag manner. This leads to a stable radiation field.

Beam guideway for Coax lasers



1	Laser beam going out from the decoupling window	3	Helix mirror
2	Laser beam in the resonator	4	Axicon mirror

Beam guideway in the resonator Fig. 37401

Beam characteristics

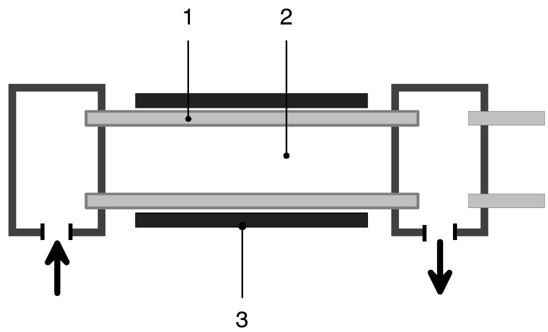
The output beam has the cross-section of a contour segment and cannot be directed and focused as required for material processing. Thus, it is still formed in the beam source with the help of several, cylindrical dished mirrors. When it leaves the beam source, it is symmetrical and has a high beam quality of M^2 equal to 1.1 (K equal to 0.9).

In order to describe the mode of the beam completely, the two directions of the resonator have to be observed: the stable and the unstable. A Gaussian mode is formed between the tube walls in the stable direction. The mode does not have a clear shape around the axis in the unstable direction. There is a non-uniform shape in the mode shot of the unformed beam.

4. Excitation

The laser gas is excited through injection of electrical energy in the CO_2 lasers. This energy is provided by radio frequency generators. They generate radio frequency alternating current.

The advantage of the radio-frequency excitation is that the electrodes with which the energy is injected into the laser gas is outside the resonator and thus do not wear out. Radio frequencies are necessary to ensure that the current flows between the electrodes. The current flow increases with the frequency. 13.56 MHz for surged lasers and 27.12 MHz for diffusion-cooled lasers are commonly used.



1	Discharge tube	3	RF electrodes
2	Discharge path	↑,↓	Gas supply and escape

Radio-frequency excitation — Fig. 25239

Differentiation of the laser generator from other generators

- Quick load changes are possible, as it requires different quantities of energy depending on the operating status.
- It can be pulsed, as the laser power is controlled in this manner.
- It can be activated through the laser control system.

Advantages of the radio frequency excitation

- **Power constancy:** The resulting homogenous gas discharge is a prerequisite for the power constancy of the laser.
- **Lesser gas consumption:** Lower voltage is required for excitation of the gas mixture than that for injection of the energy through a direct voltage source. This results in less decomposition of the CO_2 gas and thus less gas consumption. The risk of accident from electric shock is simultaneously reduced.
- **No electrode wear:** There is no danger of electrode wear as the electrodes do not come in direct contact with the laser medium and are thus not exposed to gas discharge. In addition, electrode material cannot soil the resonator (mirrors, glass tubes) and maintenance work and gas consumption are reduced.

Another option is feeding direct voltage. With DC excitation the electrodes are located inside the resonator. A high direct current is applied to the electrodes. Disadvantage: The electrodes wear out.

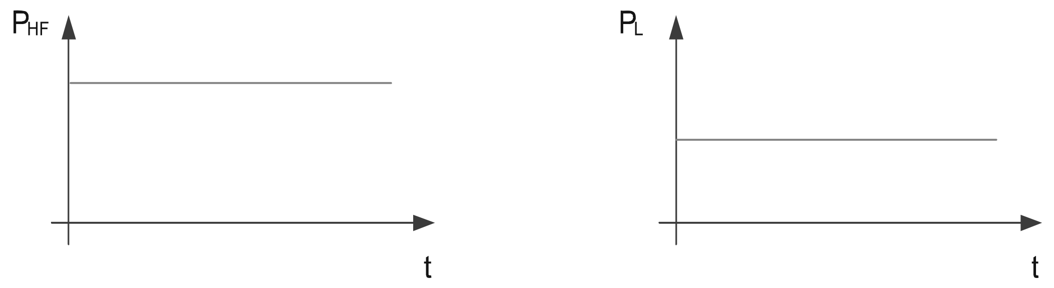
5. Operating modes

The operating mode depends on the application. For example, continuous laser beam is required for deep welding of long seams. Short pulses are suitable for point welding. The following operating modes are used:

- Continuous wave operation (cw mode, cw = continuous wave).
- Pulsed CW operation.
- Ramp mode.

Continuous wave operation

In the continuous wave operation, the laser beam is continuously generated with constant energy supply. The laser transmits laser light of constant power.



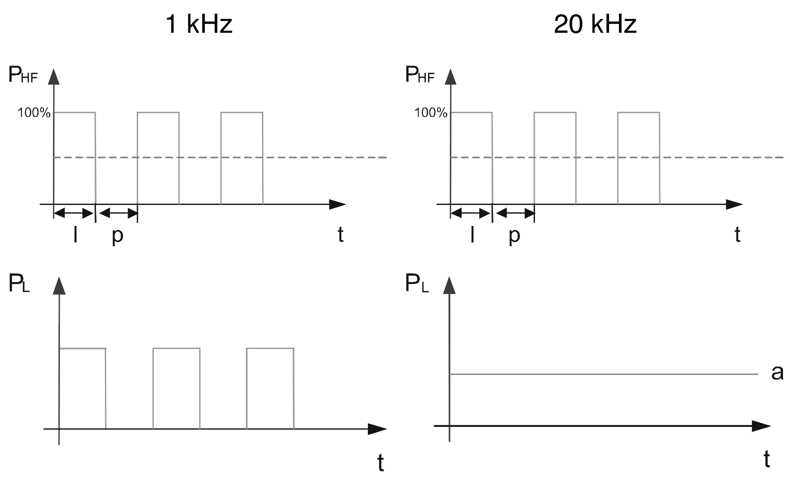
P_{HF} RF power P_L Laser power output   t Time

Continuous wave operation: Time response of excitation and laser power output   Fig. 25240

Pulsed CW operation

In the pulsed CW operation, the active medium is excited in pulses and generates short laser pulses. Excitation (pulse duration) and excitation pauses (pause duration) alternate at short intervals. Pulses with the maximum output are generated. The mean power output of the laser is regulated by the relation of pulse duration to pause duration.

Example:
The power output is 3000 W. The laser generates 1000 pulses of 0.0005 seconds each in one second. Between two pulses lies a pause of 0.0005 seconds in which no laser light is transmitted. The average power output is then 1500 W.



P_{HF}	Excitation power	t	Time
P_L	Laser power output	l	Pulse duration
a	Average power output	p	Pulse pause

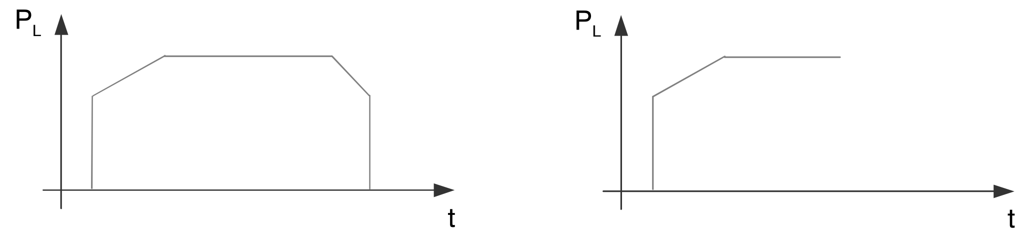
Pulsed CW operation: Time course of excitation and laser power output — Fig. 48254-48256

Laser gas has the property to store excitation energy for a short time. If the excitation frequency is high (around 20 kHz), the energy is sufficient to gap the pauses and a laser beam with constant power is generated. If the excitation frequency is low (1 kHz), the energy is not sufficient for this and individual pulses are generated.

In this way, the laser power outputs and the power course can be controlled well and the pulses are precisely adapted to the processing. This advantage is mainly used in case of extremely low laser powers. For example, extremely small contours or filigree slats can be cut in sheets, the diameter or width of which is less than the sheet thickness.

Ramp mode

In ramp mode, the laser power is continuously increased through a programmable time interval and is reduced again later. The excitation amplitude is always 100 %. The laser power output is changed by changing the ratio of the pulse duration to the pause length.



P_L Laser power output t Time

Left: Ramp mode during laser welding
Right: Ramp mode during piercing

Fig. 25242

The so-called ramp cycles are used to program the speed of increase of the power output and the duration over which it will be reduced again.

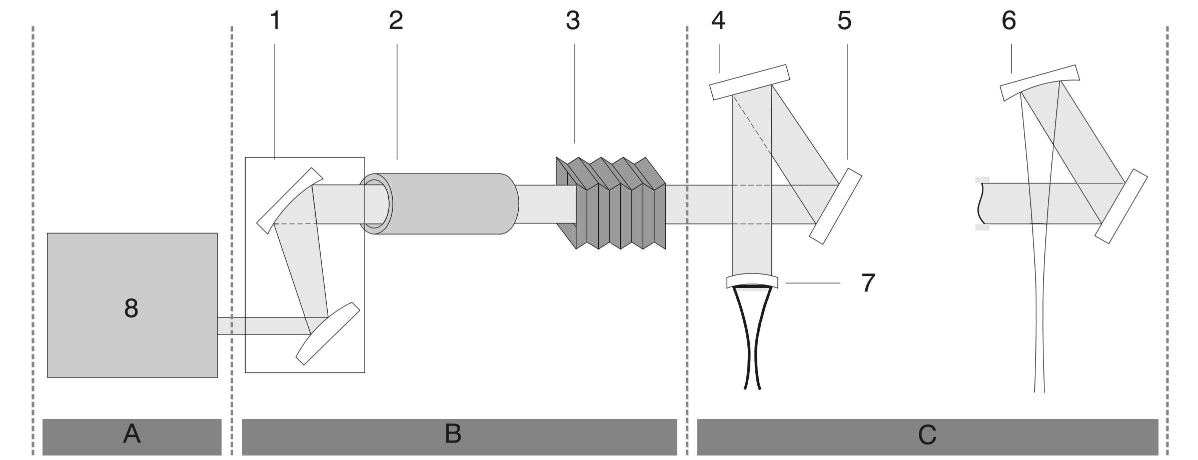
The ramp mode is an important function of the TASC 3 laser control system and mainly used for the piercing cycle during welding and cutting. At the beginning of the process, the laser power is increased slowly. If a start hole is created, the ramp cycle is ended.

Chapter 3

Forming and guiding the beam

1. Components

The laser beam of the CO_2 laser is mostly diverted between the beam source and the workpiece, it then runs as a free beam in the tubes or bellows and is finally focused using mirrors or lenses.



1	Telescope	5	Phase shifter	A	Beam source
2	Beam protection tube	6	Focusing mirror	B	Forming and guiding
3	Bellows	7	Focusing lens	C	Focusing
4	Deflection mirror	8	CO_2 laser		

Path of the laser beam from the beam source to the workpiece

Fig. 48004

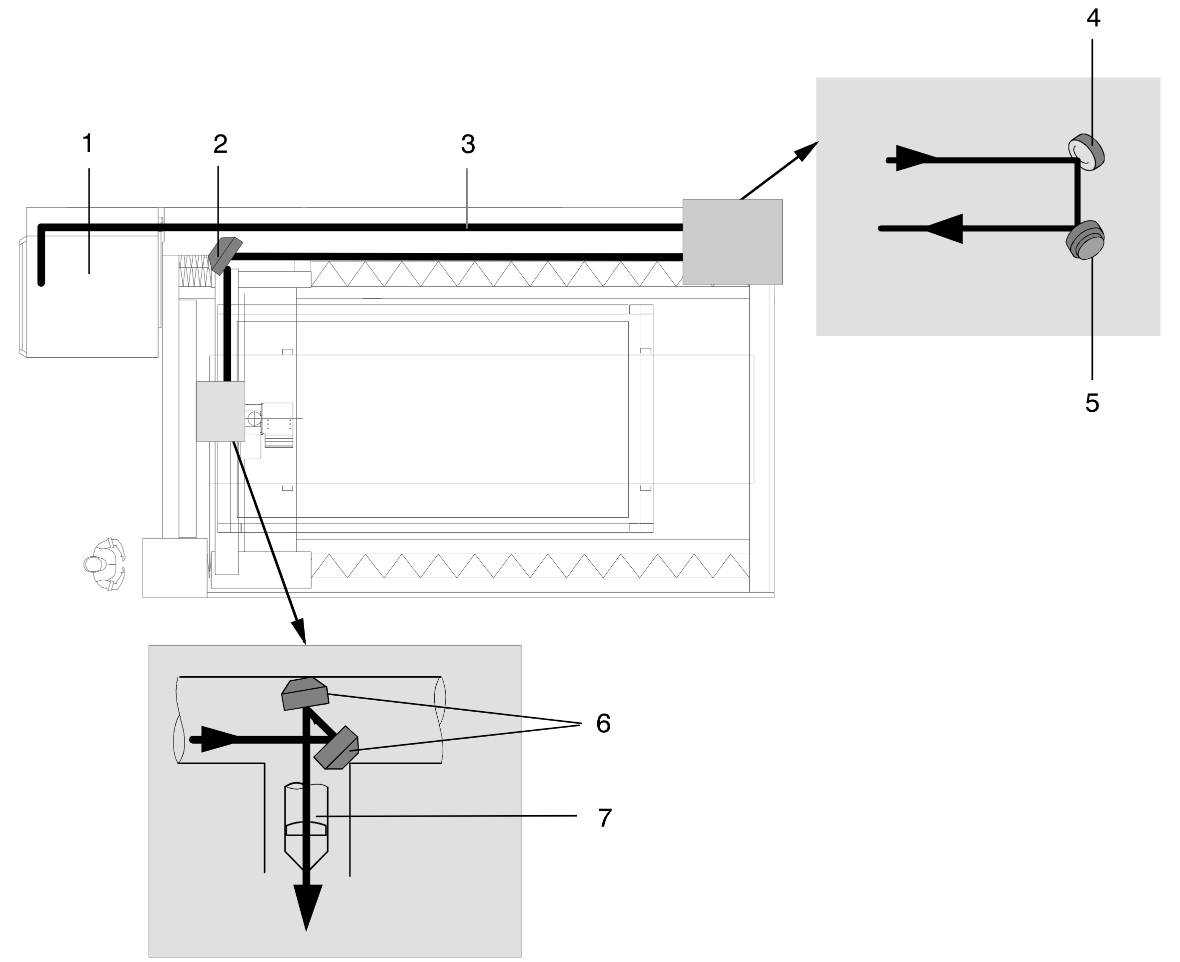
The wavelength of the laser beam determines the components and materials to be used. Quartz glass cannot be used, as it absorbs the CO_2 laser light completely. The light of the solid-state laser can be thus guided in glass fibers, whereas that of the CO_2 laser cannot be.

2. Mirror

The laser beam is taken to the processing station in fixed beam protection tubes through the mirror.

Thermal Blooming

The tubes and bellows contain a medium that does not absorb, scatter or deform the laser beam. Nitrogen or purified air is normally used. Impurities in the gas absorb the laser light and lead to the so-called thermal blooming. The gas is heated and a thermal gas lens is formed in the beam path. This results in expansion of the laser beam and thus in divergence and focus position change.



1	TLF laser with beam telescope	4	Deflection mirror	6	Deflection mirror
2	Deflection mirror on the motion unit	5	Deflection mirror and phase shifter in the circular polarizer	7	Focusing lens in the laser cutting head
3	Laser beam				

Beam guideway as an example of TruLaser 3030 Fig. 25236

Copper mirror

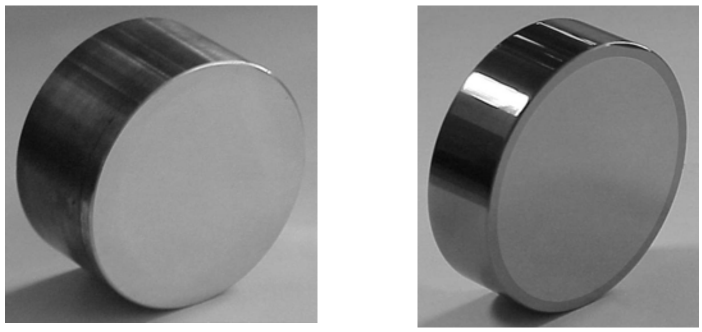
Copper mirrors have high reflection property and high heat conductivity. A disadvantage is intense thermal expansion.

Silicon mirror

When compared to copper mirrors, silicon mirrors have low reflection property and low heat conductivity. However, they are characterized by a considerably lower thermal expansion which again results in the low thermal deformation of the mirror.

In order to prevent heating and thus the destruction of mirrors, the mirrors should absorb the least possible radiation. Uncoated Cu mirrors absorb 0.6-1.1% of the radiation. Application of dielectric layers on Cu mirrors enables minimization of absorptions to up to 0.1% (MMR deflector). Here, a high-reflecting layer is first applied on the mirror and then an anti-reflecting layer is applied.

Even contaminated mirror surfaces absorb laser light. The mirror thus heats up and is deformed. It results in a change in direction of beam expansion and thus a shifting of the focus position.



External deflection mirrors: left made of copper, right made of silicon — Fig. 25244, 25245

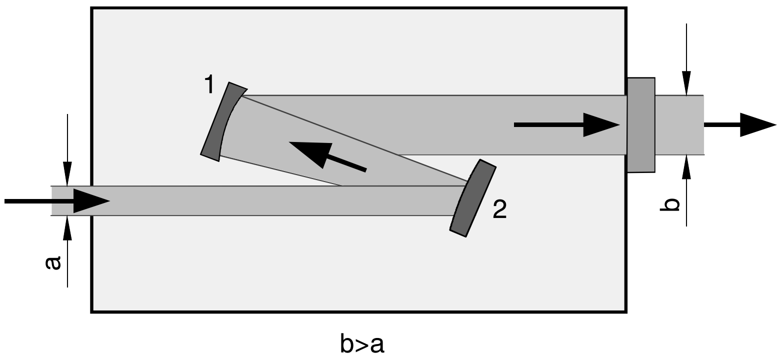
Multilayer

The so-called multilayers consist of several layers and act as phase shifters. They have a degree of absorption of 2 % and are extremely sensitive.

3. Beam telescope

Beam telescopes are used in machines with mobile optics in order to transport the laser beam over great distances in a near parallel manner. Besides, the peak intensity of the laser beam on the beam guideway components is reduced; as a result, it does not heat up as much and the focus position does not shift so much.

The laser beam passes through the beam telescope directly to the exit point of the beam source. Two mirrors are installed in the telescope, one convex and one concave (fig. 24223). The convex mirror diverts the laser beam to a defined measure. The concave mirror makes it parallel again. Telescopes increasing the beam diameter by the 1.5 to 2.0 factor can be used.



1	Concave mirror	a	Beam diameter before entering the telescope
2	Convex mirror	b	Beam diameter after leaving the telescope

Schematic: Beam widening in the beam telescope Fig. 24223

The beam telescope is used in case of laser powers up to 3.2 kW.

External beam telescope

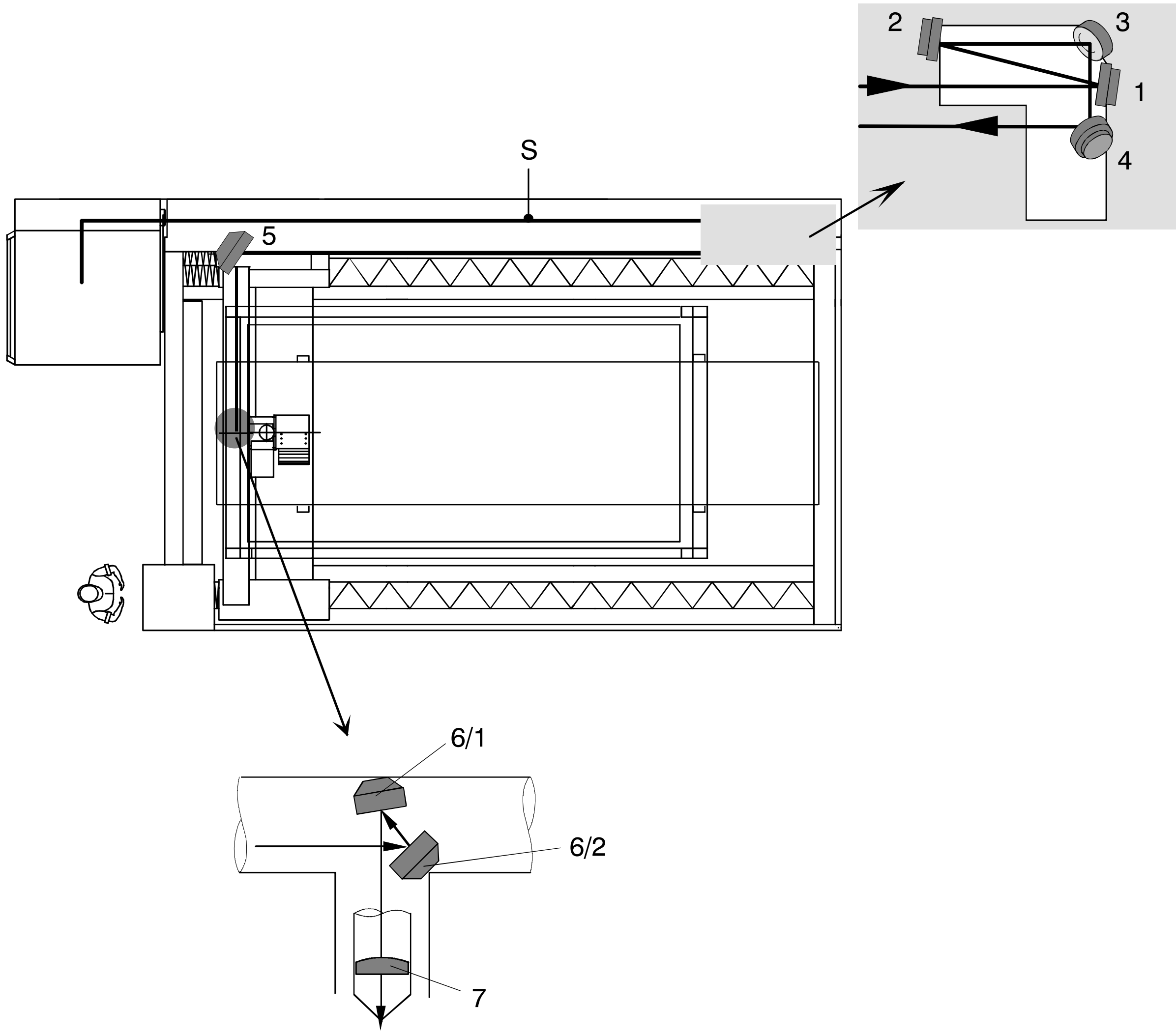
The external beam telescope is mainly used in case of 4 kW lasers. Higher power leads to more requirements for the construction of the telescope to ensure high beam quality.

The laser beam leaves the laser and enters the telescope only at the machine. It first passes an adaptive signal that diverts the beam. It is then deflected to the auto focus mirror of the motion unit through a deflection mirror.

The divergence angle of the laser beam is changed using the auto focus mirror in such a manner that the focus can be systematically shifted upwards or downwards.

Functions of the mirror:

- Automatic adjustment of the focus position as per the type and thickness of material.
- Compensating for the changes in the focus position through differential beam lengths over the working area.

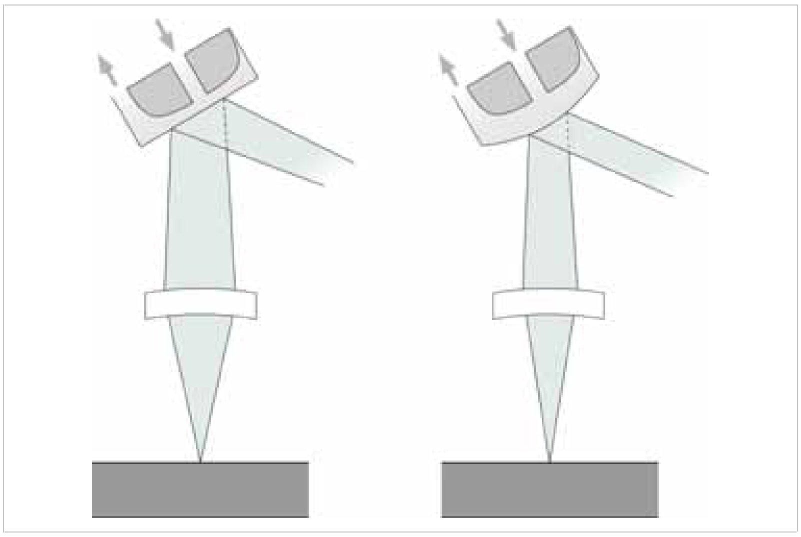


1	Deflection mirror	4	Deflection mirror	6/1+	Auto focus mirror and deflection
2	Adaptive telescope mirror (copper)	5	Deflection mirror on the motion unit	6/2	Mirror (FocusLine)
3	Phase shifter			7	Cutting head lens optics
				S	Beam

Beam guideway on TruLaser 3030/3040/3060 with TruFlow 4000 Fig. 19061

3.1 Adaptive mirror

Adaptive mirrors are used to change the divergence of the laser beam specifically and thus to control the focus position. Their curvature can be changed using the pressure of the cooling water behind the mirror surface.



Water pressure curves the adaptive mirror outwards Fig. 48007

If the pressure of the cooling water increases, the adaptive mirror curves upwards. The differences lies in the micrometer range. This is however sufficient to change the divergence of the laser beam in such a manner that the focus position on the workpiece shifts up to 12 mm. Thus, the shifting of the focus position can be balanced and the focus position can be also adjusted as per the various material thicknesses.

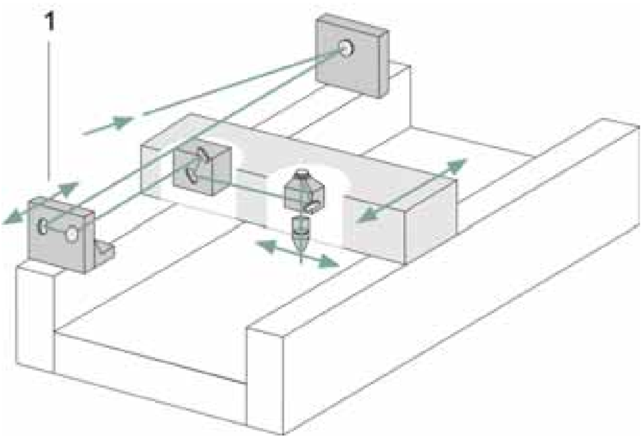
Adaptive mirrors are used at various points of beam guideway:

- In the beam telescope to keep the focal diameter constant.
- As the first mirror to set the beam diameter.
- As the last deflection mirror in front of the processing optics to adjust the focus position.

3.2 Movable mirror carrier

The movable mirror carrier ensures uniform beam properties over the entire working area of the machine.

Two deflection mirrors that can be moved as per the position of the laser cutting head in the working area ensure that the beam path is always approximately equally long.



1 Beam trombone

Beam path in a flat bed laser cutting machine Fig. 48008

The movable mirror carrier is normally used in case of 5 and 6 kW lasers.

3.3 Focus position shifting

Divergence change

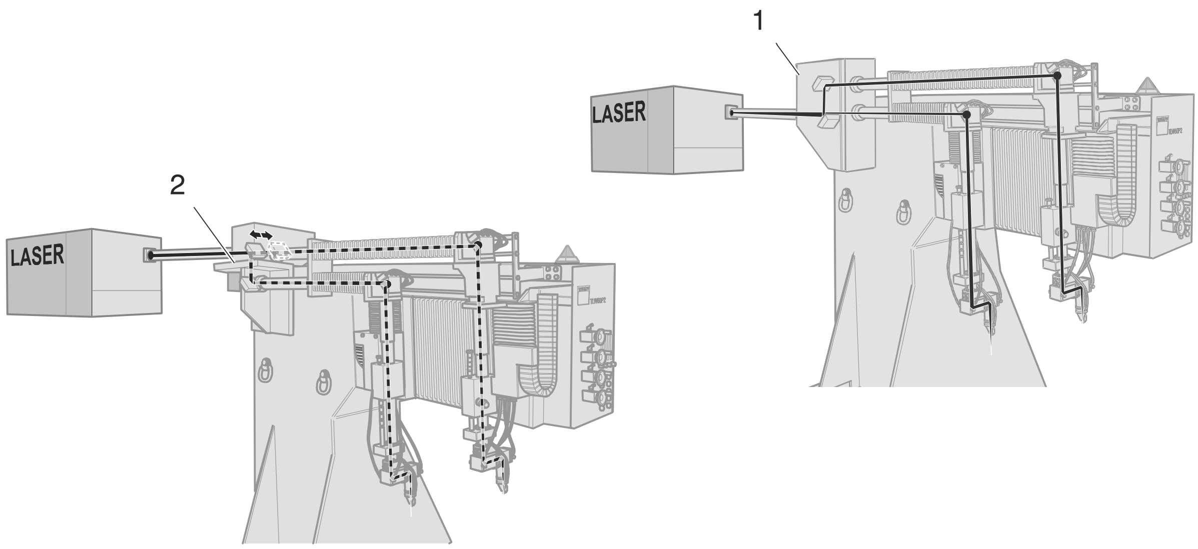
A divergence change is responsible for the shifting of the focus position. Again, there are two reasons for this:

- The distance between the beam waist and the optics changes. This is the case with laser cutting machines with flying optics.
- Optical components such as coupling or deflection mirrors heat up, thus additionally diverting the laser beam.

Adaptive mirrors and movable mirror carriers are the remedies for this.

4. Multistation operation

The laser beam can be divided with the help of beam splitters and can be thus supplied to two or more working stations simultaneously.

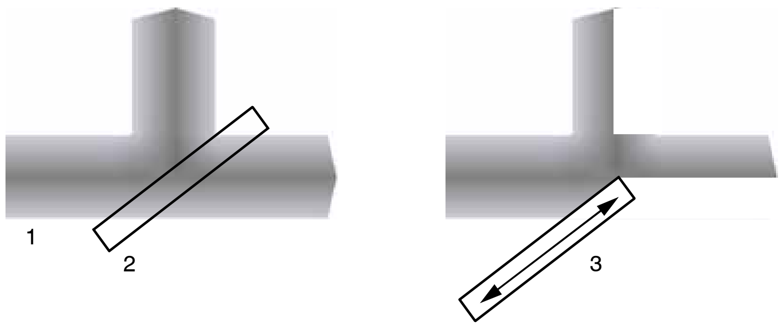


1 Beam splitter 2 Beam deflector

Beam guideway TruLaser Cell 1100 in P2 version Fig. 47182

4.1 Beam splitter

Beam splitters are deflection mirrors that are either retracted into the beam through a linear guide and the beam reflects completely or partially (depending on the position) in a 90-degree angle (reflection). Or they have a reflecting coating that divides the beam. In these semi-reflecting mirrors, a part of the laser light passes through the mirror in a straight line (transmission), and the other part is again reflected in a 90-degree angle. The beam distribution is defined through the transmission degree of the mirror here.



1	Laser beam	3	100% reflecting mirror, adjustable Power distribution is defined through the position of the mirror edge as compared to the center of the beam.
2	Semi-reflecting mirror Power distribution is defined through the transmission degree of the mirror		

Fig. 47282

The Gaussian intensity distribution with the maximum intensity at the center of the beam is maintained after beam division. However, during the transmissive beam division, the intensity as well as the power of the laser beam is reduced per cm^2 as per the division ratio.

4.2 Beam deflector

Beam deflectors have a movable mirror that deflects the laser beam completely. Depending on the position of the deflection mirror, the laser beam is directed towards the various stations.

If the beam deflector is inactive, the mirror is located outside the beam path. If the deflector is activated, the mirror swings in the beam path and directs the laser beam completely into the corresponding beam guideway completely.

Chapter 4

Components for focusing

1. Basics

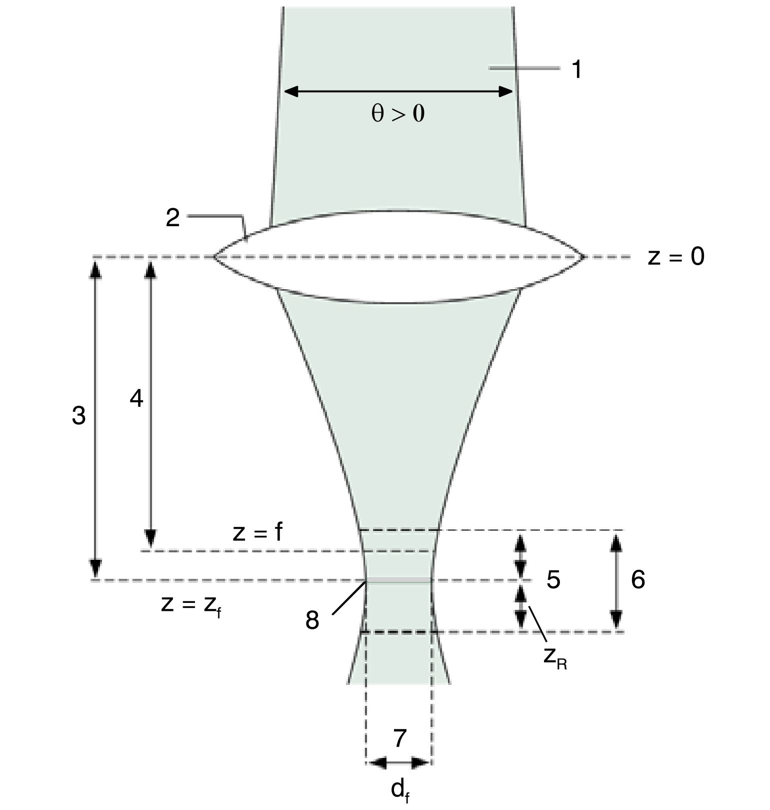
The laser beam enters the processing optics at the end of the beam path. There, the properties of the laser beam such as the focal diameter, the sharpness depth, the image distance and the power density are adapted to the various machining processes. The material can be processed now.

Since there are many material machining procedures, various processing optics is used. All of them use mirrors or lenses to focus the laser beam. Their detailed construction depends on the procedure for which and the machine on which they are used.

Physical basics

The laser beam is bundled during focusing. The point with the smallest beam diameter is the focus; it is often known as burn spot as well. Here, the power density increases by a few decimal powers; it is now sufficient to process material.

Mirrors or lenses focus the laser beam by deflecting and bundling it through reflection or refraction.



1	Laser beam	6	Sharpness depth
2	Focusing lens	7	Focal diameter
3	Focus position	8	Focus
4	Focal length	θ	>0: divergent
5	Rayleigh length	θ	<0: convergent

Focusing principle Fig. 47279

Parameters

Focal diameter

The smaller the focal diameter, stronger is the focusing of the beam - higher the power density in the focus, finer is the material processing. A high process speed is also achieved.

Rayleigh length

The beam diverts as per the focus. The Rayleigh length specifies the distance to the focus at which the peak intensity in the beam becomes half or the beam cross-section surface becomes double.

$$I_{ZR} = I_{zf}/2 \rightarrow r_{ZR} = \sqrt{2} \bullet r_F$$

r_{ZR}	Beam radius at a Rayleigh length distance from the focus	r_F	Beam radius in focus

Greater the Rayleigh length, lesser is the expansion. The double Rayleigh length is often called sharpness depth. Greater Rayleigh lengths are required for cutting thick sheets, for example.

Image distance

The image distance indicates the distance between the center of the lens and the focus. It approximately corresponds to the focal length. Greater the image distance, greater is the distance between the lens and the workpiece, the so-called working distance.

Large working distances are mainly required for welding with scanner optics.

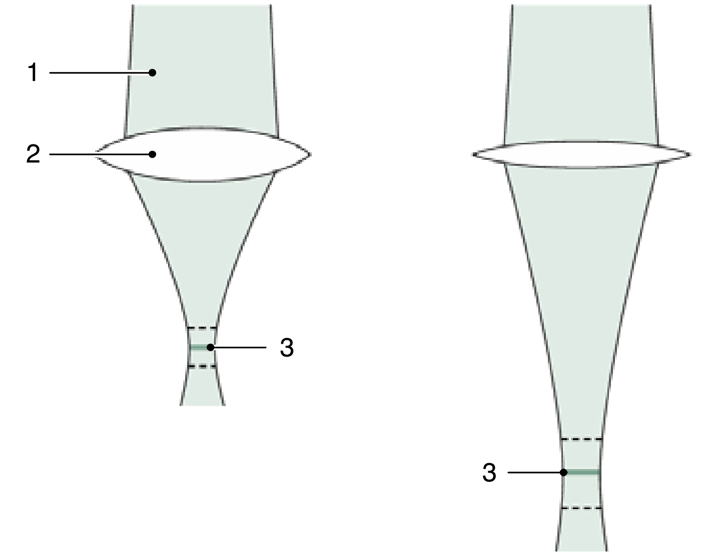
Advantages of larger working distances:

- Minimum contamination of the optics.
- Improved sharpness depth.
- Better accessibility.

Various influencing variables determine the values that the parameters will adopt:

Focal length

The focal length of the lens or the focusing mirror indicates the distance between the center of the lens or the mirror and the focus of an ideal parallel beam. The smaller the focal length, the stronger is the focusing of the beam and the smaller is the focal diameter, Rayleigh length and the image distance.

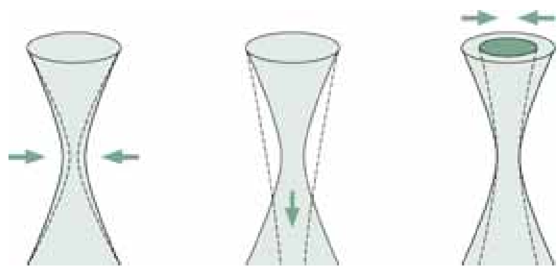


1 Laser beam
2 Focusing lens
3 Focus

Smaller focal length (left) Fig. 47280

Beam quality

The beam quality affects the smallest possible focal diameter and the Rayleigh length. The better the beam quality, the smaller is the focal diameter that can be generated. Besides, in case of same focal diameter, the Rayleigh length is greater.



Greater working distances and smaller beam diameter on the lens due to higher beam quality Fig. 47281

Divergence

The divergence (opening angle) of the laser beam has an effect on the image distance. In case of a positive opening angle, the image distance increases against the focal length. In case of a negative opening angle (convergence), the image distance is less than the focal length.

Beam diameter

The diameter of the beam on the lens has an effect on the focal diameter. The greater it is, smaller is the focal diameter.

2. Processing optics

In processing optics, the laser beam is focused using lenses or mirrors. It also has other tasks:

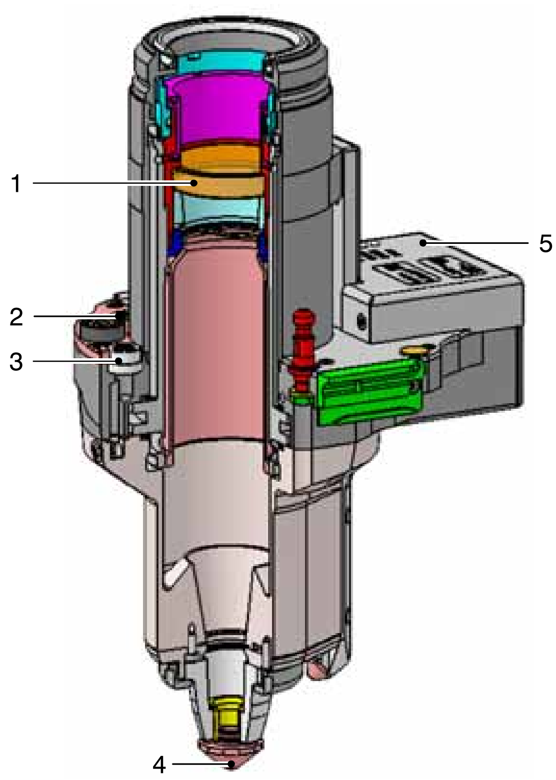
- Additional materials required for the procedure are provided, e.g. gas for cutting or welding, or fillers for welding.
- Sensors are installed for process control, e.g. distance regulation during laser cutting or process monitoring during laser welding.
- There are interfaces to the machine and the machine control system, e.g. energy and cooling water connections as well as data interfaces.
- Guards that keep dirt and dust away from the sensitive lenses or mirrors, e.g. protective glasses or crossjets - air currents deflecting the spatters.
- Help to set up the machining process how power meter and a pilot lamp can be comprised.

2.1 Lens optics

Lenses must be transparent for the wavelength of the respective laser beam. Otherwise, the lenses will absorb and heat up. The lenses get stretched, thus leading to aberrations. In the worst of cases, the thermal voltage is so strong that the lenses are destroyed.

Glass lenses cannot be used in CO_2 lasers, as they absorb the laser light of the CO_2 laser beam almost completely. However, Zink selenid or gallium arsenide lenses focus the CO_2 laser light well. But they are used for a laser power of up to a maximum of 6 kW. If they heat up excessively, they might burn and release decomposition products that are harmful to health.

Cutting nozzle is used to bring the laser beam and the cutting gas on the workpiece for processing. Cooling is done either directly using the process gas or using a water circuit.



1	Zink selenid lens	4	Cutting nozzle
2	Blow air	5	Laser cutting head electronics
3	Cutting gas supply (oxygen, nitrogen)		

Example of a laser cutting head of a laser cutting machine — Fig. 48908

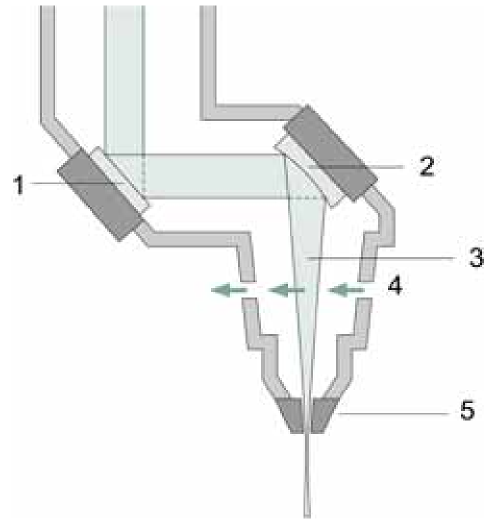
2.2 Mirror optics

Mirror optics are used for higher laser powers. They can be directly cooled under the mirror surface and have a higher destruction threshold and a lower deformation. Even the Zink selenid lenses are on their load limit here. Therefore, metal mirrors are used in mirror optics. They cannot be destroyed thermally and are thus more insensitive to contaminations that absorb laser light.

The mirrors can focus or divert the laser light through concave or convex mirror surfaces. Mirrors that are dished outwards (convex) divert the beam and mirrors that are crooked inwards (concave) focus the beam. At the same time, the mirror deflects the laser beam.

Parabolic mirrors are used in welding and cutting optics. They are cooled directly using a water circuit.

Welding optics



1	Deflection mirror	4	Crossjet
2	Focusing mirror	5	Nozzle
3	Laser beam		

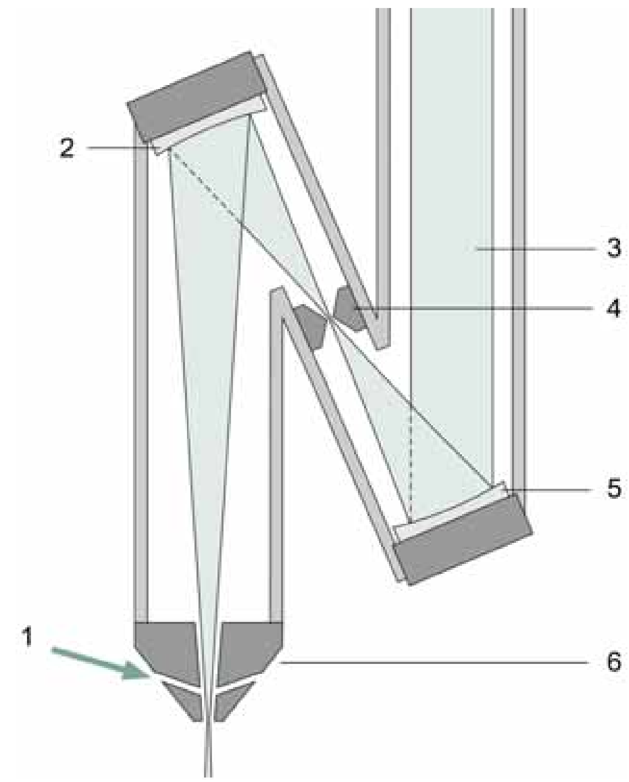
CO_2 mirror welding optics. The focusing mirror deflects the laser beam by 90 degrees at the same time — Fig. 48009

Two mirrors are arranged in a staggered manner against each other in this optics. The first mirror is mostly plane and deflects the laser beam in such a manner that it meets the dished focusing mirror at right angle. The focusing mirror bundles the laser beam and directs it to the workpiece.

The mirrors consist of copper and are cooled using water, as they absorb 0.5 - 2 percent of the laser power and can thus become so hot that they get deformed. The crossjet, a gas current that is blown in perpendicular to the laser beam ensures that there are no spatters on the mirror during processing.

If three-dimensional workpieces have to be processed, the optics must be mobile, so that the laser beam is always perpendicular to the workpiece. This is possible if the optics has two rotary axes: one in front of the deflection mirror and the other between the deflection and the focusing mirror.

Cutting optics



1	Cutting gas	4	Pressure seal
2	Focusing mirror	5	Focusing mirror
3	Laser beam	6	Nozzle

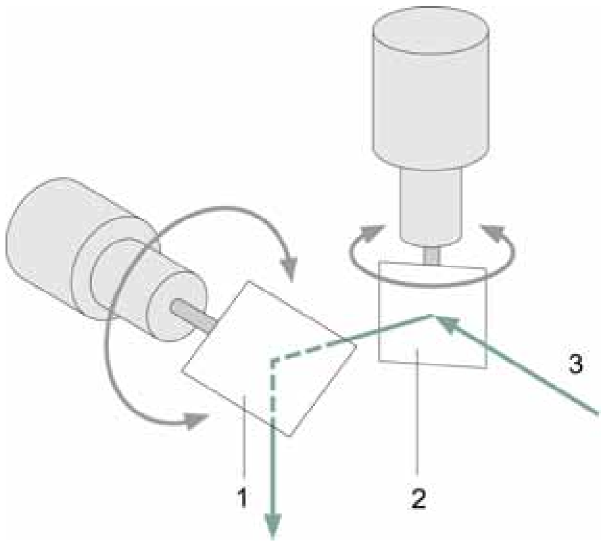
Construction of a CO_2 mirror cutting optics for high performances Fig. 48010

Mirror optics is used even in flat bed laser cutting machines in case of high cutting performances of more than 8 kW laser power. However, this has become possible only after a pressure seal was realized between both the focusing mirrors. It separates the beam guideway from the nozzle room. Previously, the pressure gradient between the cutting gas pressure in the nozzle chamber of the optics and the gas pressure in the beam guideway was too great.

2.3 Scanner optics

Principle

In case of scanner optics, the laser beam is directed through two rotating mirrors and then focused using a lens. The axes of rotation of both the mirrors are at a right angle to each other. The focus can be directed to every point in the working field by turning the mirror.



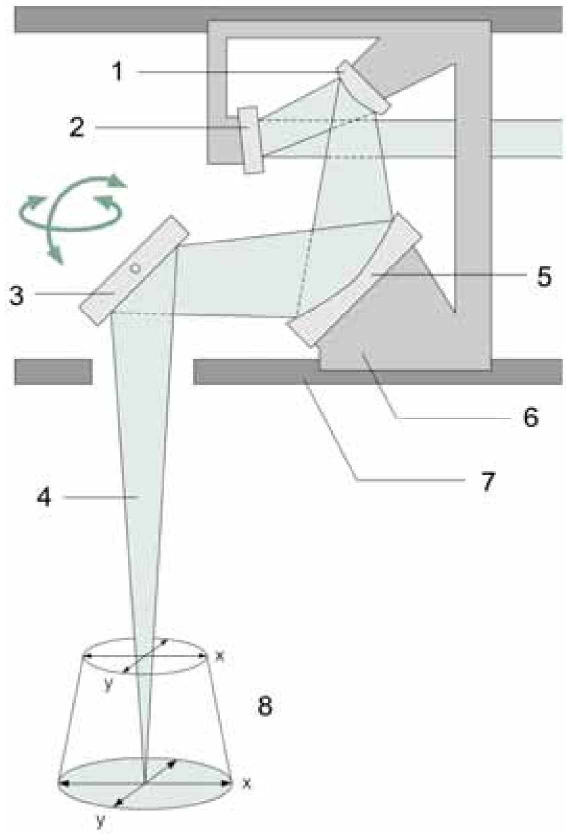
1 Scanner mirror Y-axis
2 Scanner mirror X-axis
3 Laser beam

Scanner construction Fig. 48011

The scanner construction has one disadvantage: With reference to the focus, the working field is dished. The focus position in the working field changes; good result cannot be obtained at all points in case of large workpieces. The scanner construction must be changed to keep the focus position constant.

Mirror scanner optics

In case of mirror scanner optics, the laser beam is focused using a mirror telescope. Here, it is first deflected to a dished mirror using a deflection mirror. This diverts the beam and then falls on a focusing mirror. All three mirrors are on a mobile carriage which ensures that the beam path between the focusing mirror and the workpiece remains constant.



1	Diversion mirror	5	Focusing mirror
2	Deflection mirror	6	Mobile carriage
3	Cardan mirror	7	Guide rail
4	Laser beam	8	Working area

Mirror scanner optics with a cardan mirror and a mobile carriage — Fig. 48012

The focused laser beam finally falls on a plane mirror. This mirror, a so-called cardan mirror, has two motion axes. It directs the laser beam accurately on the workpiece by turning and tilting. As it can move the beam further, larger working areas are attained.

In case of the TrumaScan L 4000 laser cutting machine, even the cardan mirror can be moved on a guide rail. The working area is thus expanded in X direction to 3900 mm.

2.4 Monitoring sensor system

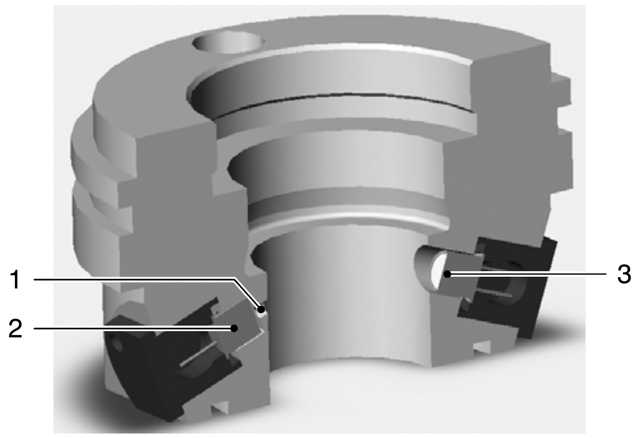
Lens monitoring sensor system

High power density puts forth extremely high requirements for the components of machines, especially on the focusing lens. Any contamination on the lens leads to increased absorption of the laser radiation. It can also lead to heating and in the worst of cases, to thermal decomposition of the lens.

The lens monitoring sensor system prevents complete evaporation of the focusing lens, by switching off the laser within milliseconds if thermal decomposition of the lens begins. The flashing of the lens, which precedes the beginning of thermal decomposition, is identified via a photodiode, while an integrated light barrier detects any development of fumes in the area above the lens.

Monitoring sensor systemof the output coupling mirror (OMS)

Output coupling mirrors help in monitoring damage and contamination. An infrared light diode and a photo diode are usually accommodated for this. Both the diodes are arranged opposite each other and form an angle of 20° to the mirror surface.



1	Diaphragm (prevents entry of process light)	3	Infrared LED
2	Photodiode		

Configuration of the diodes in the output coupling mirror — Fig. 40159

Function

The radiation coming from the infrared light diode is reflected on the output coupling mirror and then meets the photo diode. This generates a current that is proportional to the radiation intensity, which is evaluated by the electronics and converted into signal voltage.

Increase in the signal voltage

Particles or surface defects in the coating of the output coupling mirror lead to an increased absorption of laser radiation and thus to light occurrences and an increase in the signal voltage. If the long-term average of 2 V is exceeded by 0.5 V, the sensor system triggers off and the laser beam is switched off.

Decrease in the signal voltage

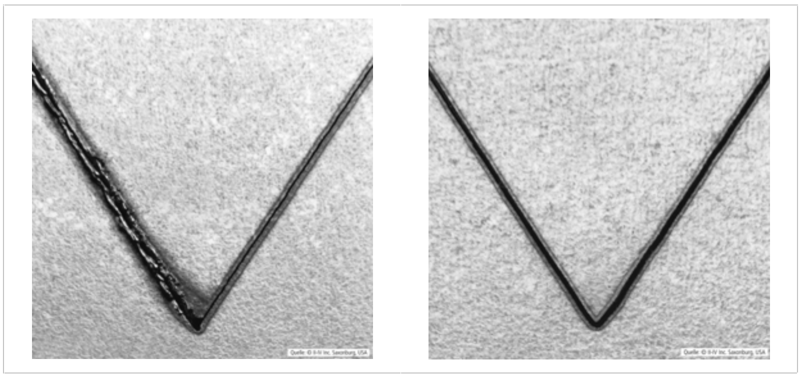
If the output coupling mirror is badly damaged, then it leads to reduced reflection of the light diode radiation and the signal voltage decreases. If the voltage falls below 1 V, the laser beam is switched off and cannot be switched on again.

2.5 Polarization

Though the laser process does not have an effect on the polarization direction of the laser beam, the light of an individual polarization direction is amplified in the four-fold resonator of the CO_2 laser, so that the escaping laser beam is linear polarized.

Linear polarized light

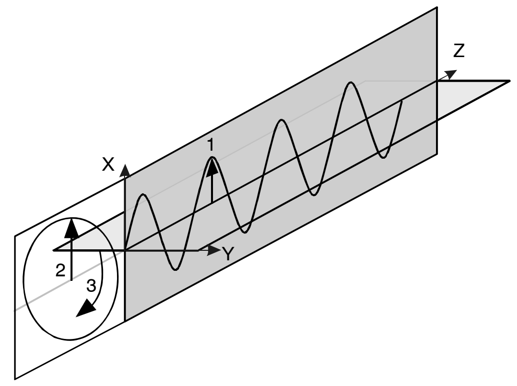
If cutting is done with a linear polarized laser beam, then the cutting results depend on the direction. If the direction of movement corresponds to the direction of swinging, then the cut is even and free of burrs. The cutting speed can be extremely high. However, if the light swings at right angle to the direction of processing, his leads to burr. There are similar effects during laser welding, but they are less obvious. Linear polarized laser light is thus suitable only for applications with a direction of movement, e.g. to cut tubes into sections.



Laser-cut edge with polarization plane perpendicular (left) and parallel (right) to the direction of processing

Fig. 061_011, 061_012

All the light waves swing in one direction. The direction of swinging is on one level, perpendicular to the direction of divergence.



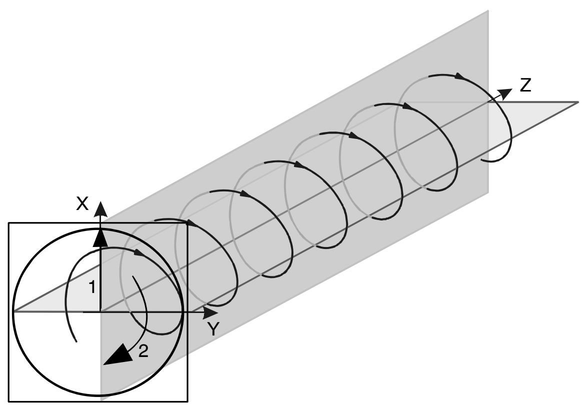
1 Field vector
2 Time
3 Rotary frequency ω

Linear polarized light Fig. 48206

However, in reality, good cutting result that remains the same in all directions is desired. This is achieved using laser light, where the direction of swinging turns. This is called circular polarized light.

Circular polarized light

In case of circular polarized light, the field vector (refer to Fig. 48206) rotates around the axis of divergence.

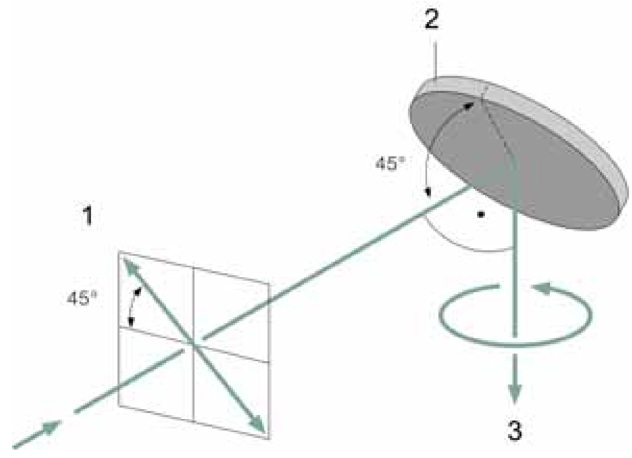


1 Time
2 Rotary frequencyω

Circular polarized light (electrical field) Fig. 48204

λ/4 Mirror for phase shift

Circular polarized light can be generated from linear polarized light with the help of a multiply coated mirror, the so-called λ/4 mirror.



1	Laser beam, linear polarized	3	reflected laser beam, circular polarized
2	Phase shifter mirror		

Arrangement for polarization change Fig. 48013

The λ/4 mirror has several reflection properties for the swinging parts that are perpendicular or horizontal to its surface. One part reflects normally and the other part penetrates deep into the coating. It is thus reflected with a delay and the waves are phase-shifted by 90°. At the same time, the waves are at a right angle to each other. If the reflecting waves overlap, the resulting wave is circular polarized. The change in polarization can be brought about only if the direction of swinging of the incident laser beam is set to less than 45° to the λ/4 mirror

As per the λ/4 mirror, the polarization should be maintained. However, effects that are similar to those at the λ/4 mirror may be seen at the deflection mirrors in the beam guideway; the polarization may change a little. But the change is so small that it does not affect the processing result.

Chapter 5

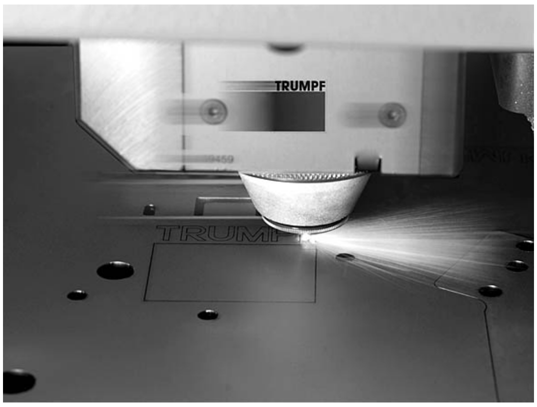
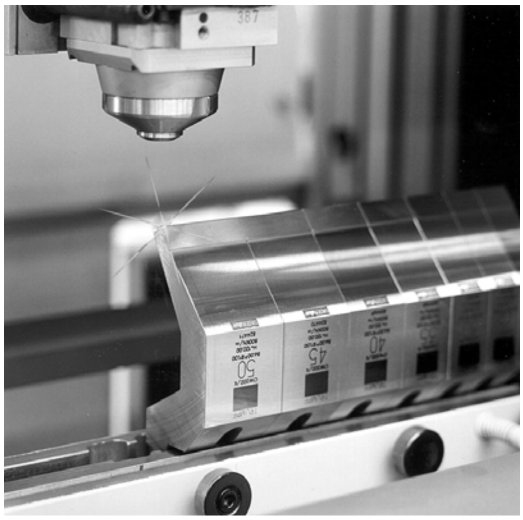
Procedure

1. Areas of application for the CO_2 lasers

The laser has taken a permanent place in the industry. Being a thermal material, the laser beam can execute the following activities as regards a material

- Heating (hardening or soldering).
- Melting (cutting or welding).
- Evaporating or decomposing (drilling or structuring).

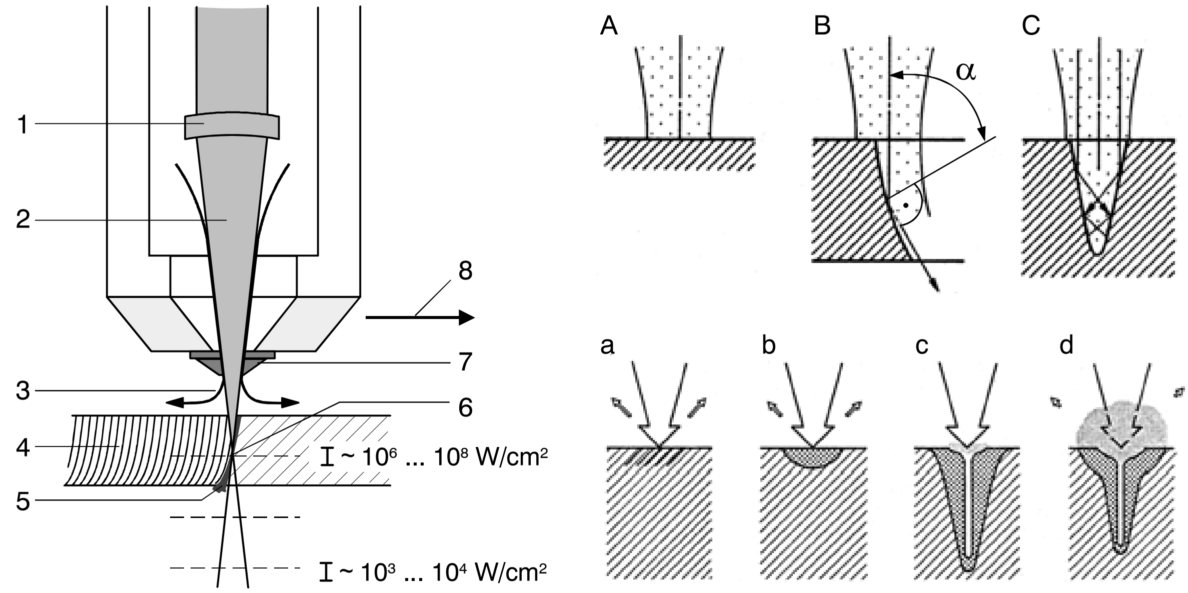
Laser welding	Laser cutting
	

Labeling and point marking using the laser	Surface treatment using the laser
	

Areas of application of the TruFlow laser

Fig. 129_034, 069_001, 24626, 24337

Power density The laser beam, the beam divergence and the focusing must be adapted to each other in such a manner that the power density is optimally suitable for the relevant process.

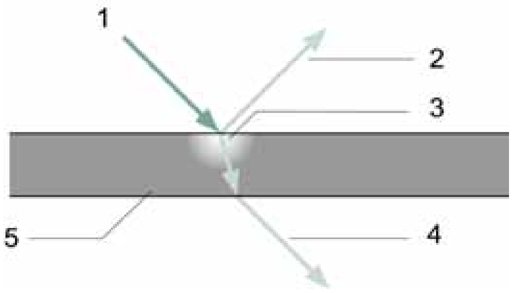


1	Focusing optics	7	Nozzle	a	Heating
2	Laser beam	8	Cutting direction	b	Melting
3	Gas jet work gas	A	Hardening (perpendicular incidence)	c	Evaporation
4	Drag lines			d	Plasma shielding
5	Melt or slag	B	Cutting (slanting incidence)	α	Deviation from the perpendicular incidence (degree)
6	Cutting edge on the workpiece	C	Welding (multiple reflection)		

Power densities depending on the distance from the focus of the laser beam and its applications Fig. 48221

The power density in the focus is between 10^6 - 10^8 W/cm^2. This power density enables cutting, welding as well as evaporation of the material (c). Even the plasma shielding exists here (d). The material (b) melts at an average power density of around 10^5 W/cm^2. Power densities of around 10^3 - 10^4 W/cm^2 are still sufficient to harden and heat the material.

In all the procedures, the workpiece absorbs a part of the laser beam, a second part is reflected and a third part penetrates the workpiece without interaction (transmission). The ratio of absorption, reflection and transmission depends on the material. For example, there is no transmission in case of metals.



1	Incident laser beam	4	Transmission
2	Reflection	5	Workpiece
3	Absorption		

The laser beam falls on the workpiece   Fig. 48014

Degree of absorption

The degree of absorption is decisive. It depends on the following:

- Wavelength
- Polarization
- Angle of incidence of the laser beam.
- Material
- Temperature
- State of matter.
- Geometry of the workpiece.
- Surface of the workpiece.

The greater the degree of absorption, more is the energy that is brought into the workpiece and that is present for processing.

2. Laser welding

Besides gas welding and arc welding, many other welding procedures are currently present for special areas of activities. Because different materials call for different techniques. Innumerous technologies are present only for welding metals, where use of lasers in continuously increasing.

Other conventional welding procedures such as WIG (Wolfram inert gas welding), MAG (metal active gas welding) or plasma welding do not attain the energy densities required for a deep welding effects.

2.1 Principle of laser welding

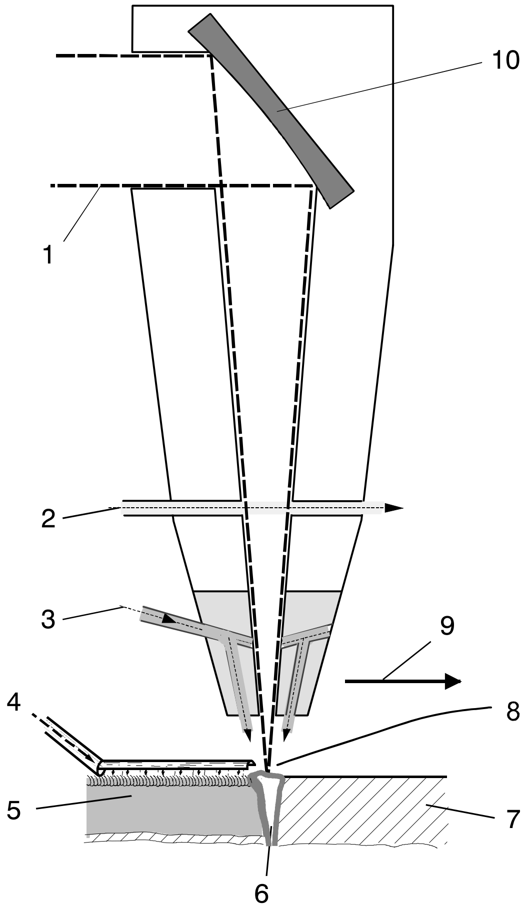
The energy required for the welding process enters the workpiece through the laser beam. Deflection mirror and focusing equipment, e.g. focusing mirror is used to bring this energy to the spot where it should have an effect, on the seam point of the workpiece

Welding process

The workpiece is accurately positioned and fastened in a clamping fixture, so that the laser beam is directed exactly to the joint gap. The laser welding head moves along the joint over the workpiece. The enormous energy density of the laser beam in the focus – around 10^6 W/cm² – brings the material for melting and partially for evaporation.

The pressure of the dispersing metal vapor can become so high that it leads to creation of a vapor channel in the material – the so-called "keyhole"T. his keyhole penetrates a few meters into the material only if the power densities are high.

When the laser welding head moves over the workpiece, the keyhole moves with it under the laser welding head. The melt flows in behind it. The joined and mixed material cools off and the cast solidifies to a narrow welding seam.



1	Laser beam	6	Melt with vapor channel
2	Crossjet	7	Workpiece
3	Coaxial work gas	8	Wire
4	Inert gas	9	Welding direction
5	Welding seam	10	Focusing mirror

Principle of laser welding Fig. 24697

Inert and active gas

During processing, the welding seam is protected against reactions with air by an inert gas. This prevents the cooling metal melt in the seam from reacting with oxygen, humidity or carbon dioxide and thus oxidizing.

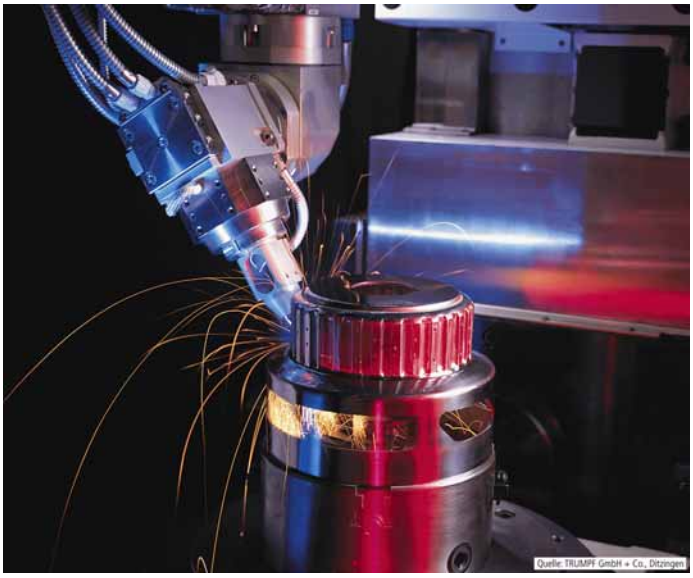
The active gas prevents formation of a plasma cloud that would bring about beam widening through thermal blooming (refer to chapter 3, section 2). The current direction and the gas quantity must be adjusted such that they do not have an effect on the weld pool.

Depending on the material, helium (He), argon (Ar), nitrogen (N_2) or gas mixtures are used as inert or active gasses. If the gas comes out of the same nozzle as the laser beam, then this is a coaxial supply. In case of lateral supply, the gas is directed to the processing point through another nozzle. A gas nozzle can be accommodated in the clamping fixture as well.

2.2 Welding procedure

Two welding procedures can be differentiated during welding using lasers: heat conduction welding and deep welding.

During heat conduction welding, the material is melted only on the surface. In this way, welding seams a few tenths of a millimeter deep are formed. This welding procedure are common for pulsed solid-state lasers that are used to weld components for the electronic industry or small parts of medicine.



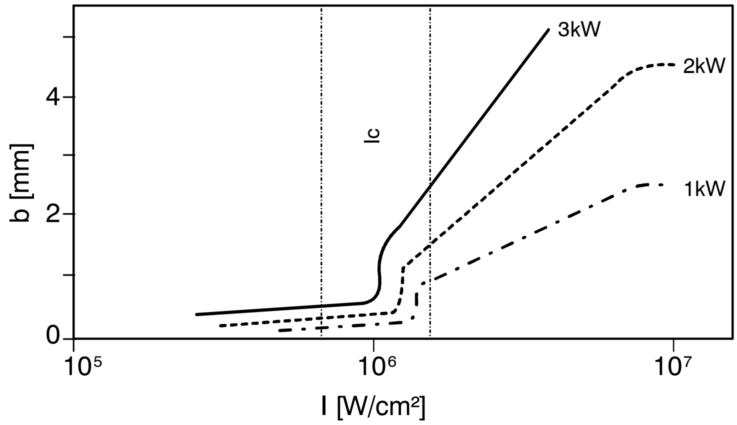
Welding a pacemaker with solid-state laser
Welding a gearbox part with CO_2 laser welding head
Fig. 123_009, 123_010

When manufacturing gearbox parts, profiles and thick-walled tubes, extremely deep and narrow welding seams are required. In such cases, deep welding is done using the CO_2 laser in the cw mode.

A special form of deep welding is deep welding with fillers, which is always used when large widths of gap and sheet thicknesses are processed.

Deep welding

In case of extremely high power densities (around 1 megawatt per square centimeter), the laser beam heats the material as far as it not only melts but also evaporates on the surface.



b [mm] Welding depth
Ic Critical intensity
I [W/cm$_2$] Laser intensity
Additional data:
Steel, v = 10mm/s, Gas:He

Laser intensity and welding depths Fig. 25389

Vapor channel = keyhole

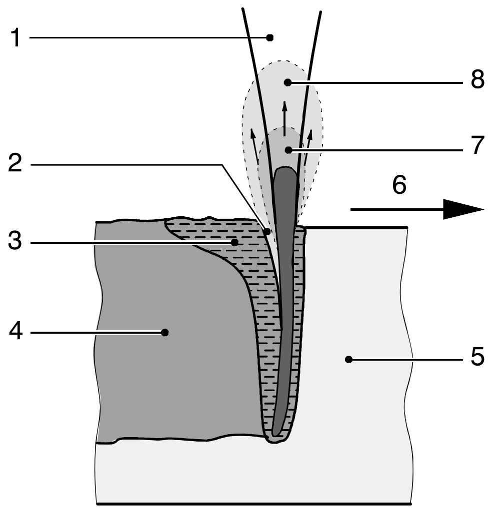
Evaporation of the material and the pressure of the dispersing metal vapor leads to a vapor channel in the workpiece, the "keyhole". The laser beam is multiply reflected on its fused walls. Here, the melt absorbs the laser beam almost completely and the efficiency of the welding process increases. The evaporated material also absorbs laser energy and is ionized: a laser-induced plasma occurs. This should be possibly avoided, as the plasma "blocks" the vapor channel.

One can see another effect in case of CO_2 laser: the degree of absorption of the plasma for the wavelength of the CO_2 laser is greater than the degree of absorption for the melt. This leads to the energy being almost completely fed into the workpiece after the plasma is formed.

The vapor channel is surrounded by a liquid phase, in which the melt circulates intensely due to the enormous temperature and pressure fall. It follows the movement of the laser welding head - it is "pulled" from the laser welding head along the seam. The melt continuously streams around the vapor channel and solidifies on its back side. This leads to formation of a narrow and deep welding seam with uniform structure.

The high welding speeds during deep welding lead to a small heat-affected cone and thus to slight distortion.

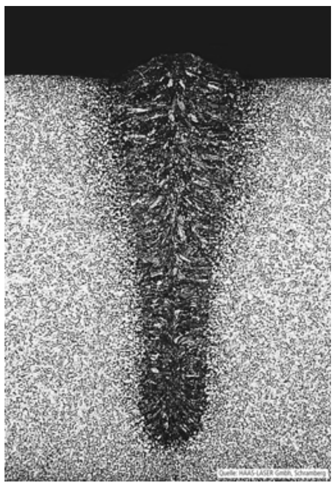
The development of the vapor channel is known as "deep welding effect", as this effect leads to the reachable welding seam depth becoming much more than that during heat conduction welding. An example: with a 12 kW-CO_2 laser and a feed of 0.5 m/min, deep welding seams are created in mild steel 19.



1	Laser beam	5	Workpiece
2	Vapor channel (keyhole)	6	Welding direction
3	Zone of fusion (liquid)	7	Dispersing metal vapor
4	Solid melt	8	Plasma cloud

Principle of deep welding Fig. 48225

Example



Example of a deep-welded welding seam Fig. 125_18

Deep welding with fillers

This procedure is another version of the deep welding described above.If the width of gap is more than 5 % of the welding depth, then the melt can no longer bridge the distance between the workpieces completely. The welding seam collapses or - at worst - the workpieces will no longer be connected to each other.

Fillers are required in such cases, which are supplied as wire or powder during the welding process. The required quantity of wire or powder depends on the welding speed, the width of gap and the welding depth. Besides apportionment, exact positioning of the extremely thin wire (diameter around 0.8 to 1.2 mm) is also very important.

Fillers also have another significance. By penetrating the materials in the melt, the metallurgical properties of the melt or the welding seam are specifically changed. This helps in improving the welding suitability, tensile strength, viscocity, corrosion resistance etc.

Hybrid procedure

Hybrid procedure means a combination of laser welding with other welding procedures, for example MIG or MAG welding (metal insert gas and metal active gas welding)This procedure is used only for special applications, in shipbuilding industry for example. Large sheet metal plates of up to 20 m length and 15 mm thick are welded here. The gap distance are so large that the laser beam cannot gap them by itself.

Therefore, MIG welding is combined with laser welding. The laser provides high power density for large seam depths, allows high welding speeds and thus reduces heat input and distortion. Using the MIG torch, the gap is bridged and the joint is closed with the help of an extra wire: Advantages of the hybrid procedure: It is faster than MIG welding and the distortion of parts is less.

Scanner welding

During scanner welding, the laser beam is directed to the workpiece using scanner optics at a large distance. One or two mobile mirrors position the workpiece quickly on the workpiece. The beam source can be thus used more optimally, as positioning times between two seams in which the laser beam is switched off reduces to almost zero. Thus, scanner welding is used for many short seams. An optimum welding sequence enables a minimum heat input and thus reduced distortion. Lap seams and butt joints are welded with the help of scanner welding. The inert gas is supplied through clamping fixture.

2.3 Features of the procedure

In order to connect two workpieces with the laser beam optimally, the requirements for the connection must be first determined and then taken into consideration:

- Which seam geometry is best suitable for the workpiece or which requirements should it fulfill?
- Which preparations must be made for an optimum seam?
- Should the connection be gas and liquid-proof?
- How much heat should be allowed to enter the workpiece?

Seam geometry and type

The seam geometry describes how the corners of the joint partners meet each other. For example, they can overlap or can push one another bluntly.

There are various types of seam geometries (refer to the following table). In brief, their properties and especially stable geometries are described.

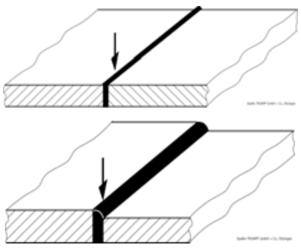
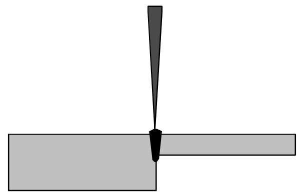
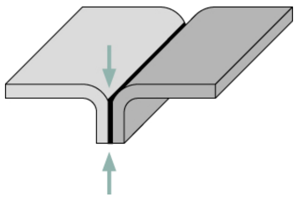
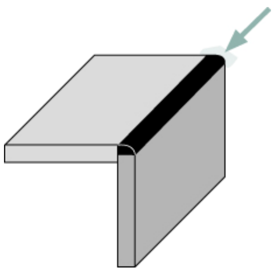
Seam geometry	**Description**	**The most favorable seam geometry**
Butt joint 	• Various sheet thicknesses possible. • The most favorable force flow. • Good accessibility. • Expensive preparation. • Characteristic features: The joint gap must be very small.	
Double flanged joint 	• Extremely low preparation costs. • High rigidity. • Unfavorable force flow. • Very good accessibility. • Characteristic features: Higher material cost.	
Corner seam 	• Low plaster cost. • Only 90° angle weldable. • Characteristic features: Solid-state laser in case of this seam geometry advantageous.	

Fig. 128_27G, 128_28G, 48035, 48037 Tab. 5-1

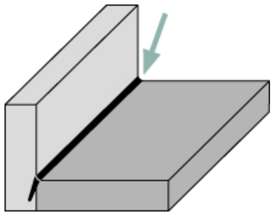
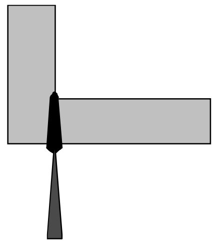
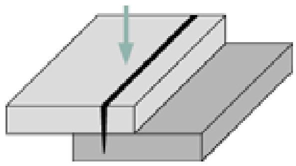
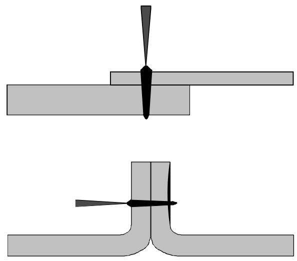
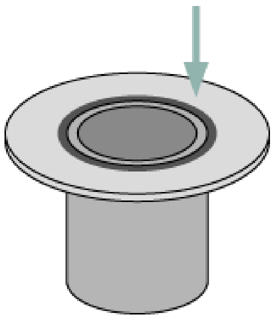
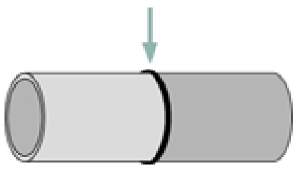
Welding seam	Description	The most favorable seam geometry
Fillet seam 	• Expensive preparation. • Favorable force flow. • Unfavorable accessibility. • Characteristic features: Bends due to the bad accessibility to the lack of fusion.	
Lap seam 	• Low preparation cost. • Good accessibility. • Power transmission over the seam cross-section. • Unfavorable force flow.	
Axial circular weld 	• Corresponds to a butt joint. • Preparation: Tacking or force fit. Reason: The gap on the opposite side is expanded due to diagonal shrinking at the beginning of the seam. • Favorable force flow. • accessibility depends on the geometry of the workpiece.	
Radial circular weld 	• Corresponds to a butt joint. • Easy preparation. • Favorable force flow. • Good accessibility. • No shrinking. • Characteristic features: The radial seam should be preferred to the axial seam (better and easier fixing possible).	

Fig. 48036, 48038, 48039, 48040 Tab. 5-2

Seam type The seam type is determined as per the seam geometry. Is the seam pulled through or are individual welding points set? Does the seam consist of several short lines or several small circles? Important: The seam must attain the required tensile strength and should not bring too much heat into the component.

Form	Graphics	Evaluation
Pull-through line		• Quick and easy to manufacture. • The mechanical voltage for load is the highest at the beginning and the end of the seam (voltage peak). • Less welding depth at the beginning and end.
Line made up of single points		• Less heating due to pulsing. • The workpiece cools in the breaks between the pulses.
Stepped line		• Heat input less than that in case of pull-through line. • Less welding depth at the beginning and end of every seam section.
Oval		• High tensile strength during shell loading. • Double welding length. • Higher heat input.
Round-stepped		• Tensile strength during shell loading higher than stepped line. • Higher heat input as well.
Free shapes		• Shape is optimized for loading. • Heat input is optimized.

Tab. 5-3

Seam preparation

Especially the butting edges and the workpiece surfaces require a more careful preparation when welding with a laser than when welding with conventional welding procedures.

The width of the joint gap plays an important role in the selection of the procedure: deep welding with or without filler.

Abutting edge When deep welding, only a small zone of fusion is formed, which requires a very exact machining of the seam parts. The abutting edge should lie flush next to each other. The roughness may not be greater than the width of gap. For this reason, it is very decisive which technique is used for machining the seam parts.

Metal-cutting produced parts can be welded with the laser very well. Parts, that were machined with laser or water jet, are usually suitable. Seam parts with nibbled edges are unsuitable, since they exhibit excessive roughness.

Surfaces

The cleaner the surface, better is the welding seam. High welding speeds and small melting volumes prevent the arising gasses from escaping from the melt.

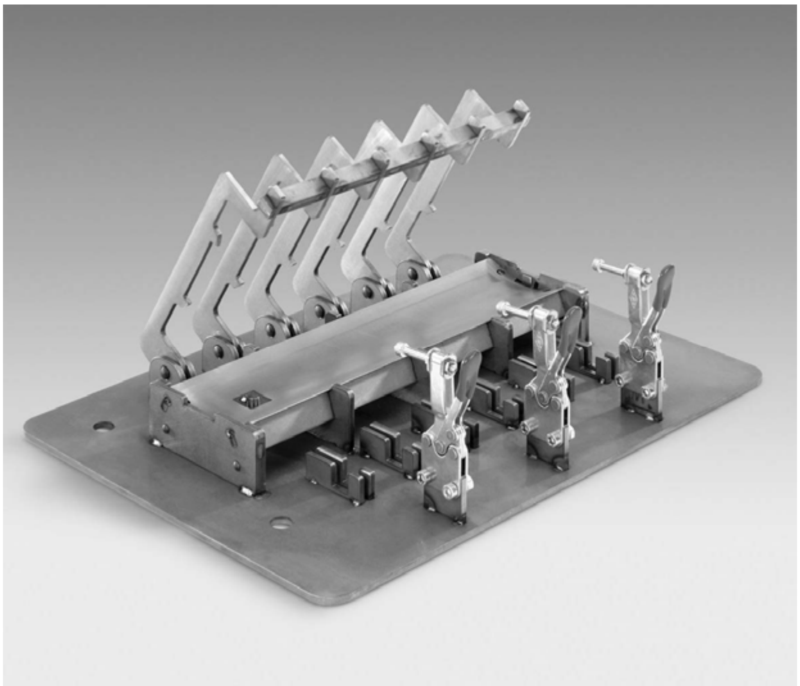
In this way joint parts can be welded well with a lightly oiled surface using suitable welding parameters. Heavily greased or dirtied surfaces must be carefully cleaned before welding. Sheets having a scale, lacquer, grate or eloxal layer often show strong pore formation, melt ejections and surface defects after welding.

Seam gap

The maximum width of the joint gap depends on the welding speed and the welding depth. Thus, the width of the joint gap can be greater by around 1.5 factor in an overlap seam than in a butt joint. Fill material is required if the gap between the parts to be welded is more than 5 % of their thickness. The fill material is usually fed as wire.

Clamping fixtures

In order to obtain good results when welding, all parts of an assembly are put in a suitable clamping fixture. These must be previously designed by the constructor.



Clamping fixture Fig. 48226

Tasks

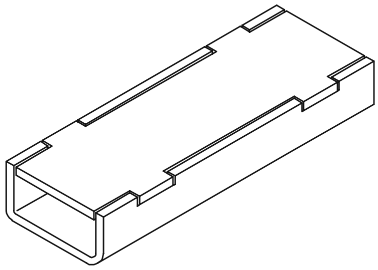
- The clamping fixture makes it possible to always position and fasten the components of the assembly accurately in the same manner.
- It ensures a narrow joint gap of less than 0.1 mm.
- It can balance process tolerances, e.g. dimensional deviations, in the preceding process steps.
- In certain applications, e.g. welding with scanner optics, it can also supply inert and active gas.

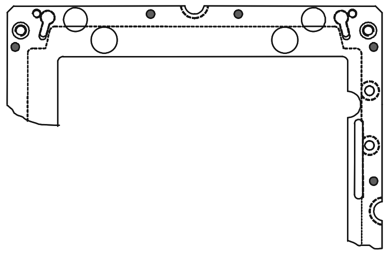
Clamping fixtures have bearing areas and back stops that carry and adjust the workpiece. They have a partially complex structure. Clamping elements on the fixture fasten the workpiece.

Joining techniques

The fixture costs can be reduced considerably if joining techniques are used on the workpiece. The workpieces are then positioned to each other and the clamping fixture is used to clamp the workpieces. Some of the joining techniques are:

- Staking
- Mortising
- Butting
- Centering

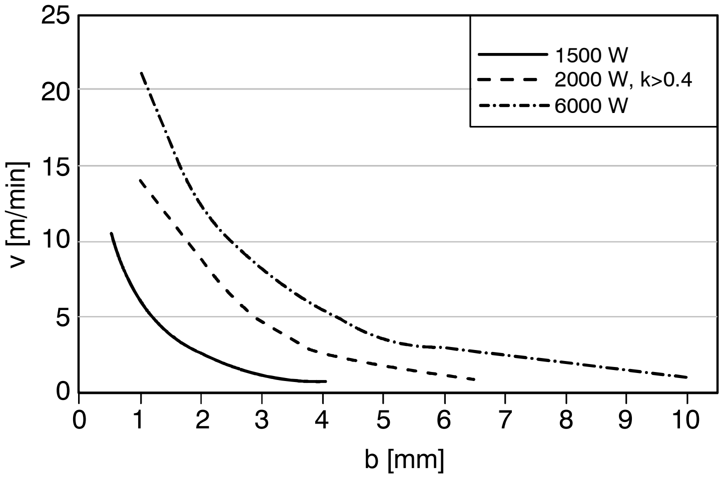




Mortising Staking

Fig. 48227, 48228

Laser power and welding speed



v [m/min] Welding speed b [mm] Welding depth

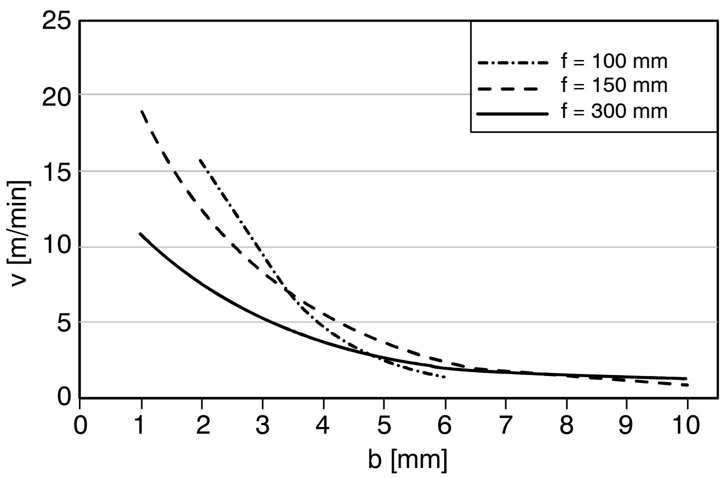
Welding speeds and welding depth depending on the laser power Fig. 25390

The laser power must be adapted to the thickness of the workpiece: greater the material thickness, greater are the laser powers required for welding.

With higher laser output, higher welding speeds and deeper welding seams can also be attained.

Welding seam depth and geometry can be influenced with the welding speed. High welding speed leads to thin, but less deep welding seams. Additionally, the seam can be positively influenced with the welding speed. This is important when materials are welded, whose melt tends to solidify to hardness or reinforces to cracks.

Beam quality and focal length



v [m/min] Welding speed b [mm] Welding depth

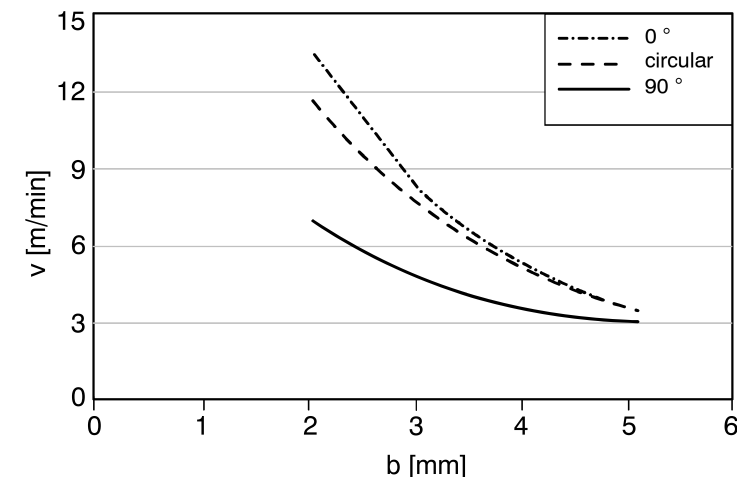
Welding speeds depending on the focal length Fig. 25391

The beam quality describes the focusability of a laser beam. A laser has a laser beam with good beam quality, when the beam can be focused on a small burn spot with great sharpness depth.

During laser welding, a laser beam with a small focal diameter is advantageous on one hand, in order to attain high energy density on the smallest surface and thus high welding speeds. On the other hand the sharpness depth must correspond to the welding depth. When the focal length is short and the focus diameter small, then the highest welding speed is achieved with low welding depth.

High welding speed is achieved with deep welding seams only with long focal lengths.

Polarization



v [m/min] Welding speed b [mm] Welding depth

Welding speed depending on the polarization Fig. 25392EN

The polarization of the laser light has an effect o the cross-section of the deep seams. The linear polarized laser light helps in attaining the greatest welding depth, if the laser light parallel to the direction of feed swings and meets the welding front at a flat angle. The least depth is attained if polarization and direction of feed are perpendicular to each other. This effect increases with increasing welding speed.

In case of continuous welding with the same direction, e.g. when welding tubes together, this effect is used positively. If, however, you are welding in different directions, then it has a disturbing effect. In such cases, CO_2 lasers with circular polarized laser light is used to operate. In this way the welding result does not depend on the direction of the seam.

2.4 Advantages and applications

On comparing the laser welding with the conventional welding procedure operating with the arc, possibility of deep welding is a large advantage. In case of other procedure, it is not possible to attain the required energy densities for a deep welding effect.

Other advantages

- Besides the electron beam welding technique, only the laser reaches such high energy densities, that are necessary for welding.
- The workpieces are welded contact-less and with high speed. This leads to short processing times.
- Very thin seam geometries are formed with a large depth-width ratio. The distortion is minimum and the tensile strength is high.
- Specific energy effect is possible in a small area. A very small hear-affected zone is attained through this, thermal loading of the workpiece as well as distortion is low.
- Areas inside the workpiece that are difficult to access can be also easily reached using the laser welding procedure.
- The narrow, uniform weld surface and the low spatter formation require only a little or no refinishing operation.
- Because the laser beam can be very precisely controlled, the welding process offers a high degree of automation. Besides, laser welding can be combined well with other process steps as well.
- Good process control through monitoring the parameters using the machine control system and the sensors.

Applications

In industrial practice, laser welding is used mainly for joining coated materials, sheet stacks and components of different sizes where distortion is a risk.

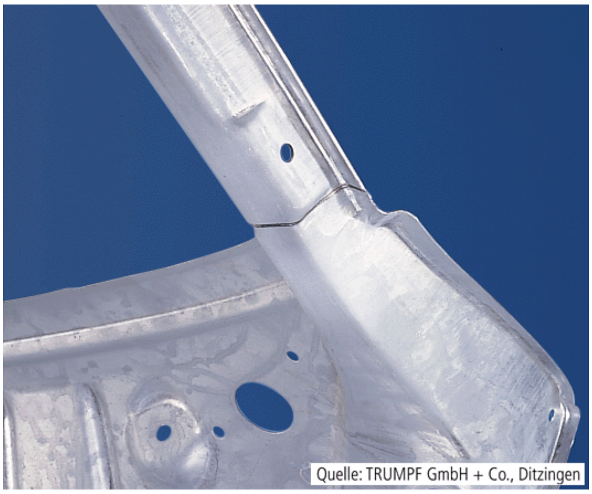
The alloying elements determine the weldability of the materials and thus the fields in which the CO_2 laser is used.

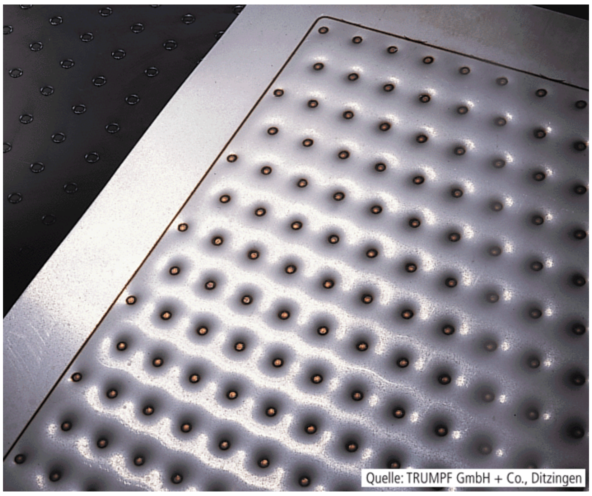
Steels

In case of steels, the weldability of the workpieces mainly depends on the percentage of carbon. Constructional steel made with less than 25% carbon is well suited for welding. Its weldability decreases as the percentage of carbon increases up to 35 %. Reason: Carbon leads to hardening of the welding seam. Stress occurs within the welding seam, which can then lead to cracks when cooling down. In such cases, preheating the workpieces before the welding process and cooling the welding seam slowly when solidifying the melt has proved to be advantageous. Steels having more than 35 % of carbon are extremely unsuitable for welding.

Chrome nickel steels are generally easy to weld and permit high welding speeds because of their low heat conductivity. If an inert gas is introduced when welding, then an oxide free welding bead can be formed.

Examples:





Left: CO_2 laser-welded Tailored Blanks
Right: CO_2 laser-welded plate heat exchangers

Fig. 126_020, 126_022

Non-ferrous metals

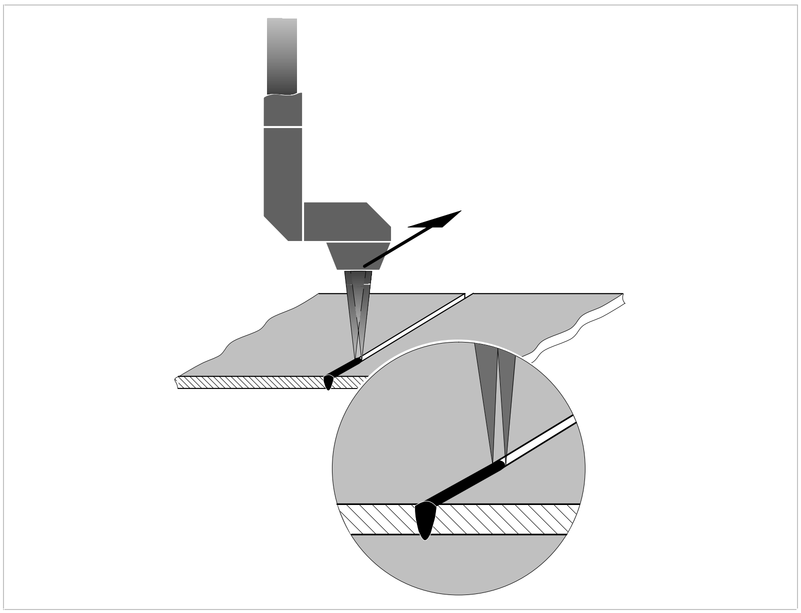
Non-ferrous metals are not as good as steels for welding. This is because these alloys have a low degree of absorption for laser radiation than steels.

Here, the Nd:YAG laser has a huge advantage over the CO_2 laser: Non-ferrous metals absorb the wavelength of the Nd:YAG laser better than that of the CO_2 laser. In spite of this, many non-ferrous metals are welded nowadays with good results.

Some examples:

With **aluminum** and **aluminum alloys** one must work with great care concerning work and protective gas because of the thin-bodied melt. An exact balancing of the composition of gases and their flow rates when melding guarantees a very good welding seam.

The two-beam technology TwistLas helps in better jumpering of gap tolerances and in avoiding seam spatter. Two separate focus points at an adjustable distance from each other are created on the workpiece through a suitable beam formation in the focusing optics. With this "double focus", the key hole is expanded in such a manner that there can be no seam spatter. TwistLas is mainly used when processing aluminum and aluminum alloys. The outermost thin melt easily leads to an uneven welding seam.



Welding with double focus Fig. 17271

Titanium and **titanium alloys** can be welded well with the laser. However, one property makes the welding process difficult - they react very strongly with the main components of air: oxygen and nitrogen. Here both by welding and by cooling down, the welding seam must be selectively work on with shield gas or even in a shield gas atmosphere.

Non-ferrous and **precious metals** cannot be welded using the CO_2 laser practically. The Nd:YAG laser is used here, as these metals have a greater absorption property as compared to the Nd:YAG laser. This is mainly applicable to the cosmetics industry.

2.5 Identify high-quality seams

High requirements are put forth for the welding seams.

Width and depth

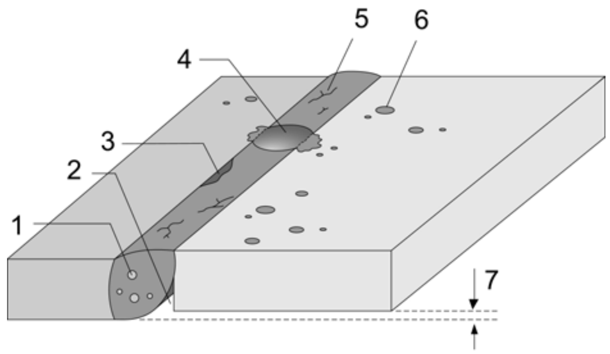
Width and depth of the seam must attain the defined values, since they determine the tensile strength of the seam. Width and depth should be usually constant over the entire seam.

Metallurgical properties

The following is applicable to all metallic welding seams: The structure of the seam must be as uniform and fine-grained as possible. Other properties of the seam depend on the alloy components.

The melts of the joint partners merge in the welding seam. If joint partners of a material are merged, their properties can correspond to those of the basic material. If the joint partners consist of various materials or if fillers are used, an alloy is formed. Certain properties can be achieved depending on the material used: chromium or nickel make the seam more resistant to corrosion. Silicon helps in avoiding strong cracks when welding the aluminum alloys.

Seam errors



1	Pores	5	Cracks
2	Root notch	6	Welding spatter
3	Connection errors	7	Offset of the edges
4	Melt rejects, hole		

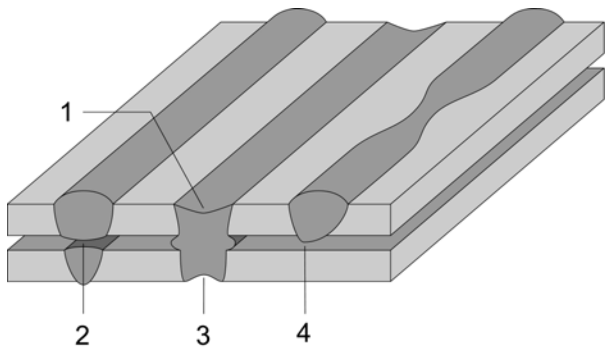
Outer and inner seam errors that can occur during laser welding, for example, a butt joint connection

Fig. 48047

Technical standards differentiate outer and inner seam errors.

Outer seam errors	Effect
Scorching or root error	Seam can crack at these points.
Melt ejection	Melt ejection from the holes leads to formation of holes that reduce the tensile strength. The seam also becomes unsealed.
Seam collapse and root relapse	Reduces the seam cross-section and thus the tensile strength.
Offset of the edges in case of butt joint on the butt joint	Reduces the seam cross-section.
Depressions at the end of the seam (end crater)	Reduces the seam cross-section; Occurs if the laser beam is switched off too quickly.
Oxidation of the upper and lower grub	Reduces the resistance to corrosion of rustproof steels.
Spatter in the workpiece or seam	Interrupt and require refinishing operation.

Tab. 5-4



1	Seam collapse	3	Root relapse
2	No connection due to an excessively gap	4	No connection due to non-uniform seam depth

Errors that can occur at the overlapping joint during deep welding — Fig. 48048

Errors in the seam due to quality defects in the material or incorrectly set process parameters:

Inner seam errors	Effect
Connection errors	The joint gap is not completely filled.
Pores	The seam does not have air or gas bubbles.
Cracks in the seam surface or in the workpiece	They occur due to loads or material shrinking during cooling.

Tab. 5-5

Heat input and distortion

The melt gives the heat to the surrounding material. Even in case of low heat quantities, the workpiece can get distorted or sensitive parts can get damaged.

In order to attain high quality, the workpiece should be heated as little as possible and the heat must get discharged. Stepped seams heat the workpiece less than the pull-through welding lines. The distortion is correspondingly less. If the laser beam operates in pulsed CW mode, the material can cool in the breaks between the pulses. The cooling can be accelerated with the help of cooled fixtures that dissipate the heat properly.

Many welding points and seams bring a lot of heat into the workpiece. In order to avoid distortion, the welding sequence is adjusted in such a manner that heating takes place simultaneously.

2.6 Machines and systems

The construction of a laser welding system depends on several factors:

- Shape of the workpiece.
- Seam geometry.
- Seam type.
- Quantity
- Degree of automation of production.
- Procedure and material.

1D-systems

Systems with only one motion axis, such as the seam welding machine or the tube welding system, is sufficient to weld tubes and edges. Either the workpiece or the processing optics is moved here.

3D-systems

The laser beam mostly connects three-dimensional components with such seam geometries. Coordinate laser systems with 5 motion axes and one mobile optics are then used. Robots along with solid-state lasers are commonly used in the automobile industry.

Systems for scanner welding

Two machine concepts are available 2 scanner welding: the scanner welding system and the robot carrying the scanner optics.

In the scanner welding system, the workpiece is positioned in the working field under scanner optics and then welded. If several parts with short processing times are welded, they can be continuously moved under the optics. This is floating processing.

If the robot is used for welding, then its leaves out the spacious contours such as the contour of an auto door. The scanner optics is appropriate for accurate positioning of the laser beam and moves it over the workpiece. This welding procedure is extremely critical as regards the control technology, as the machine control system has to coordinate the overlapping movement of the robot and the scanner optics. The control unit measures the exact spatial position of the robot in a millisecond cycle and compares the position with the programmed path. If the position deviates, the control unit balances it using the scanner optics.

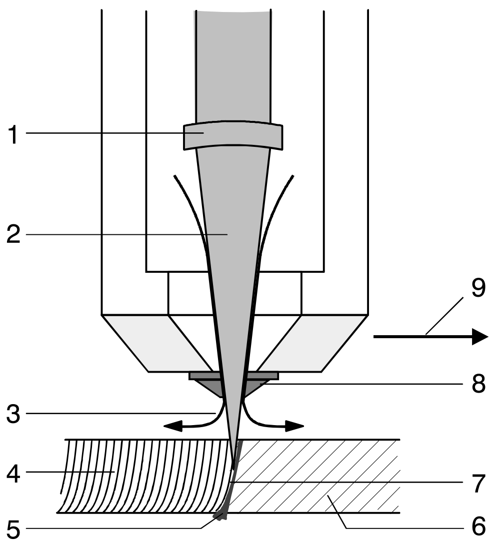
3. Laser cutting

Lasers were used for cutting in the 1970s, at that time, CO_2 lasers with 200 to 500 watt power. The big breakthrough happened with the development of the cutting system. This because the laser requires a system that directs the laser beam and guides it to the processing place accurately.

3.1 Principle of laser cutting

What happens when a laser beam is used on material?

If a laser beam is used on a workpiece, the material heats up so much that it melts or evaporates. The cutting process begins if it has penetrated the workpiece completely. The laser beam moves along the part contour and melts the material continuously. It is blown from the kerf with the help of a gas current. A narrow kerf between the part and the waste grid occurs. The cutting gas current exits the nozzle with the laser beam.



1	Focusing optics	6	Workpiece
2	Laser beam	7	Cutting edge on the workpiece
3	Gas jet work gas	8	Nozzle
4	Drag lines	9	Cutting direction
5	Melt or slag		

Principle of laser cutting Fig. 24695

Piercing

The laser beam must first penetrate the material at a certain point, before a contour can be cut. The piercing can be done quickly using complete laser power or slowly using a so-called power ramp. When creating a start hole in the ramp mode, the laser output is gradually increased, then it is held constant until the start hole has been formed and finally the output is again slowly reduced.

Even when piercing, the process can be supported by adding a gas and the cutting process can be influenced.

The choice of piercing gas or cutting gas depends on which material is being machined and level of quality needed for the workpiece.

Usually either oxygen, nitrogen, argon or simply air is used as a cutting gas.

3.2 Cutting procedure

Whether it is micrometer kerfs in thin semiconductor chip or quality cuts in the 30 mm thick sheet metal, the laser is presently capable of executing a wide range of tasks. Various cutting procedures are used for this.

Cutting using oxygen: flame cutting

In flame cutting, oxygen (gas purity 99.95 volume percent, 3.5) and a pressure of maximum 6 bar is mainly used to cut mild steel. The heated metal reacts with the oxygen in the kerf, it burns and oxidizes. The melting created is blown out together with the iron oxides out of the kerf.

The oxidation process provides additional energy (exothermal reaction) that affects the cutting process to the effect that higher cutting speeds are possible and greater material thicknesses can be processed as compared to cutting using nitrogen.

A disadvantage of the process is the oxide film that gets formed on the cutting surfaces. If the parts are painted later, the oxide film has to be previously removed. If the film breaks, the part is no longer protected against corrosion.

Cutting using oxygen: area of a cutting edge Fig. 24694

Cutting using nitrogen: fusion cutting

In fusion cutting, nitrogen or argon is used as the cutting gas. Even in this procedure, the material is first melted and blown away from the kerf with the help of the cutting gas, usually nitrogen. There is no reaction with the molten metal. Exception is titanium: If titanium is cut, argon must be used as cutting gas, as titanium reacts strongly (gas purity of argon: 99.996 volume percent, 4.6). A gas pressure between 2 ad 20 bar (so-called high-pressure cutting) is normally used to operate (with a gas purity of nitrogen of 99.999 volume percent, 5.0).

High-pressure cutting

	O_2	N_2
	1.2 mm nozzle	2.3 mm nozzle
1 - 3 mm	4 bar	20 bar
5 - 30 mm	0.3 bar	20 bar

Comparing the pressures during flame and high-pressure cutting using nitrogen — Tab. 5-6

By using the high gas pressure, we can be assured that the cutting edges remain free of burr formation to a great extent and that no slag settles. Refinishing is not required.

Besides, use of inert gasses leads to oxide-free cutting edges; however, it makes the piercing in the beginning difficult. As a result, several cutting systems have the option to pierce using oxygen and then cut further using nitrogen.

Cutting using nitrogen: part with oxide-free cutting edge — Fig. 078_021

Compressed-air cutting

Even compressed air can be used to cut thin sheet metals. Compressed air with 5 to 6 bar is sufficient to blow the melt from the kerf. As air consists of 80 % nitrogen, the compressed air cutting is mainly a fusion cutting procedure. However, the compressed air must be compressed, dried and deoiled, as a result of which it is not really a favorable procedure. Which sheet thickness should be cut, depends on the pressure of the compressed air and the laser power. With a laser power of 5 kW and a pressure of 6 bar, a 2 mm thick sheet metal can be cut free of burr. The best cutting results are obtained with aluminum.

Plasma-supported laser cutting

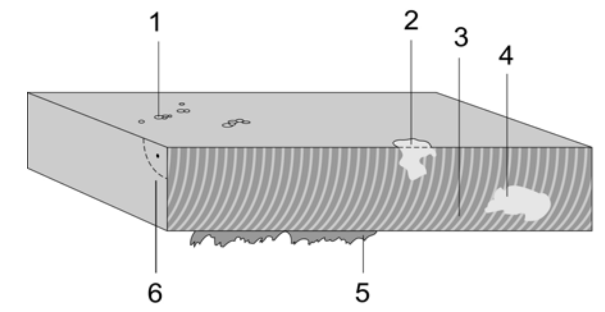
In plasma-supported laser cutting, a plasma cloud is generated in the kerf. It consists of ionized metal vapor and ionized cutting gas. It absorbs the part of CO_2 laser beam, which would have been radiated through the cutting gap unused without plasma cloud and passes on the energy laterally to the cutting edge. Thus, the material melts faster, higher cutting speeds are attained.

However, the plasma cloud is advantageous only in the thin sheet metal range of up to 3 mm sheet thickness. In case of larger sheet thicknesses, a plasma cloud in the kerf prevents the laser beam from radiating the workpiece completely. The cutting process "breaks off". In order to avoid this, sensors are used for monitoring and control in case of greater sheet thicknesses, so that there is no longer a plasma cloud in the kerf (plasma line).

In thin sheet metals, extremely high cutting speeds can be used. 40 meters and more per minute are possible in case of sheet thickness of more than 1 mm. The cutting edge is always more rough than during fusion cutting using nitrogen. The maximum sheet thickness again depends on the laser power. With 6 kW laser power, up to 4 mm thick aluminum plates can be processed especially quickly using this procedure.

3.3 Cutting criteria

Cutting criteria such as pittings, burr or groove coasting can be analyzed with the naked eye. Additional equipment is used for the roughness, the perpendicularity and the width of gap. Which criteria are important and when, must be practically determined. The function of the part is decisive here.



1	Material storage	4	Erosion
2	Pitting	5	Burr
3	Groove coasting	6	Perpendicularity

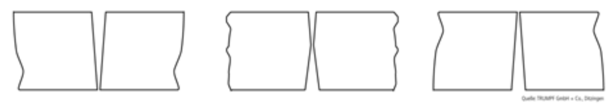
Criteria for the quality of the cutting edge Fig. 48022

Roughness

When cutting the contours using the laser beam, perpendicular drag lines are formed on the cutting surfaces. Its depth determines the roughness. The lesser the roughness, more even is the cutting surface. During laser cutting using CO_2 lasers, the roughness increases with the material thickness.

Kerf shape and width

A kerf occurs during laser cutting, which is usually not parallel from the upper cutting edge to the lower cutting edge.



Kerf shapes during laser cutting Fig. 079_024G

The kerf width increases with the material thickness. It depends on the following factors:

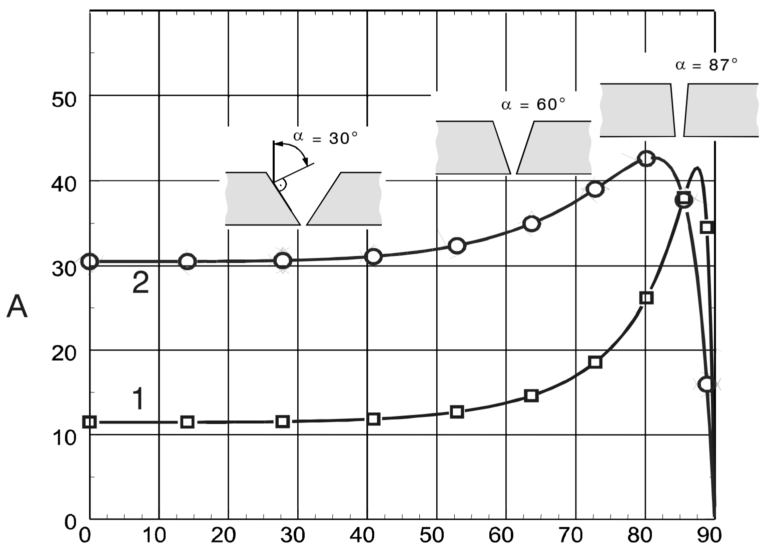
- Focal diameter.
- Material
- Wavelength
- Cutting procedure.

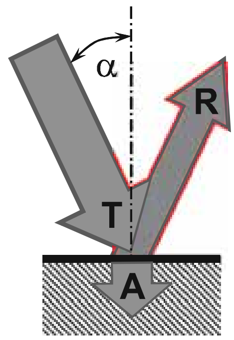
It varies between 0.15 mm (material thicknesses of 1 - 6 mm) and up to 0.5 mm (material thicknesses of 20 - 30 mm). The width must be constant over the entire work area; otherwise, the dimensions of the parts and contours become inaccurate.

The kerfs attained with CO_2 lasers are narrower than those attained with solid-state lasers. The reasons are:

- The maximum absorption of the laser power is at an angle of 87° for CO_2 lasers, as compared to 82° for YAG lasers.
- The absorption at an angle α = 0° is 12 % for CO_2 lasers, at an angle of α = 87°, 42 %. As against that, the YAG lasers absorb 32 % of the laser radiation at 0° and 43 % at 82° (compare to page 5-4).

Areas of application of the CO_2 laser are thus welding and cutting thin and thick sheets, whereas the YAG laser is used only for thick sheets.





A	Absorbed laser power [%] per reflection of the cutting edge	1	CO_2 (circular, phase shifter)	T	Laser beam
α	Deviation from the perpendicular incidence [degree]	2	YAG (circular, fiber-coupled)	R	Part reflected
				A	Part absorbed

Absorbed laser power depending on the angle of incidence

Fig. 48223, 48222

Burr-freeness

Burr-freeness is one of the most important criteria for laser cuts. This is so because burr must be always removed, i.e. an additional work cycle is required. Several different burrs can be formed: right from crumbly slag residue that can be easily removed up to sharp metallic burr that is firmly stuck to the lower side of the edge.

Material and laser power

The laser power must be adapted to the procedure, the type of material and the material thickness. The maximum material thickness, that can be cut, depends on the type of material and the laser power. Generally: The material thickness increases with the laser power, which can be still processed.

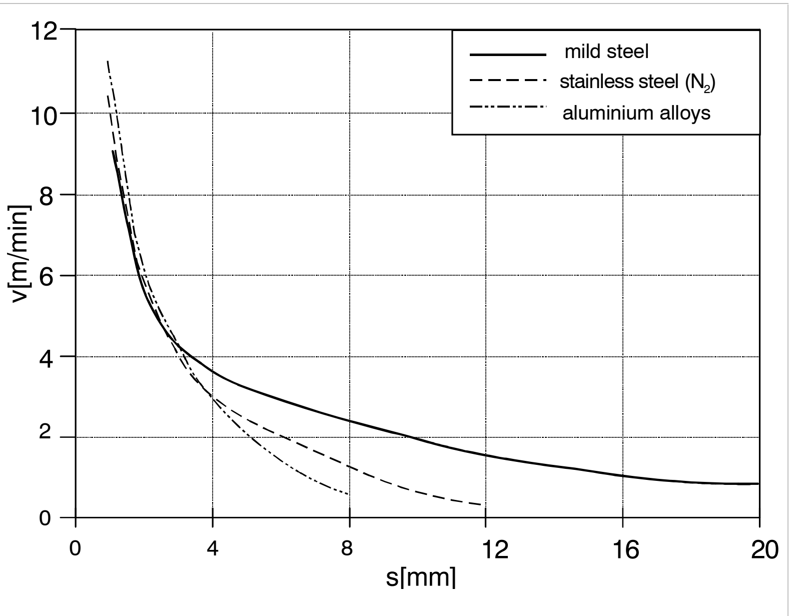
Operating mode

With the continuous wave or pulse operating mode, one can control the amount of energy and the duration for which it has to be brought into the workpiece, that is, continuously or at short intervals. Standard contours in the millimeter and centimeter range is cut in the continuous wave operation. as against that, filigree contours are pulsed with low frequencies; otherwise, it might lead to distortions. Heat can get discharged in the intervals and the workpiece cools.

Cutting speed

Like the laser power, even the cutting speed must be adapted to the type of material and the material thickness. An erroneous cutting speed can lead to roughness, burr formation or pits in the cut contour. If the contour is cut too quickly, then it might result in the material not slitting any longer.

Basically: The more the laser power available, faster is the cutting. In case of equal laser power, the cutting speed decreases with increasing material thickness.



v [m/min] Cutting speed s [mm] Material thickness

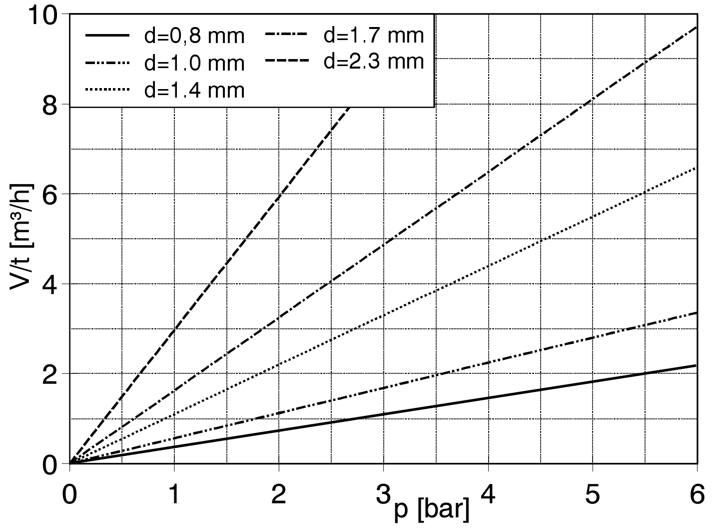
Maximum cutting speed with 4000 W laser power depending on the material thickness Fig. 18730EN

Gas consumption during flame cutting and fusion cutting

The gas consumption depends on the cutting gas pressure and the size of the nozzle orifice.

Basically: the greater the gas pressure and the bigger the nozzle orifice, greater if the cutting gas consumption.

Example: Cutting using oxygen at cutting gas pressures up to 6 bar.



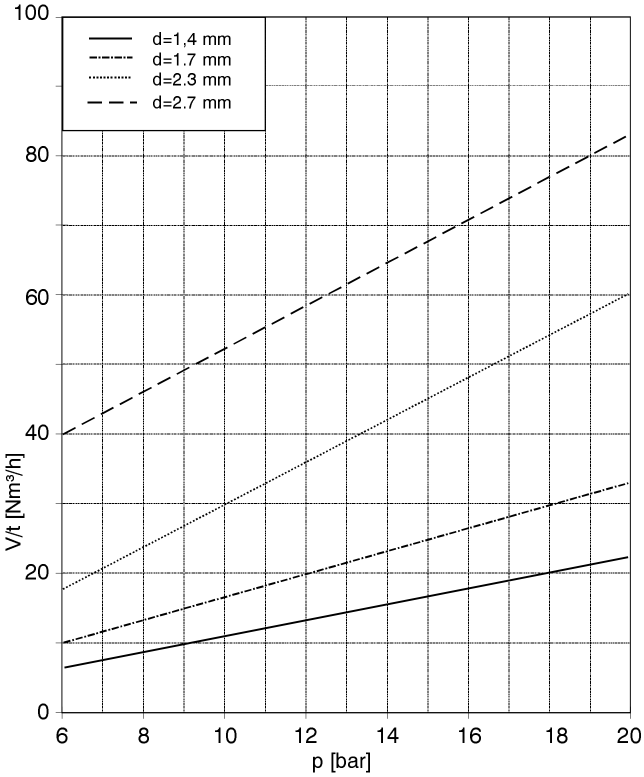
V/t [Nm³/h] Gas volume per time

p [bar] Pressure (compared to the outer pressure)

Maximum cutting gas consumption per hour in continuous cutting

Fig. 8809

Example: Cutting using nitrogen at cutting gas pressures up to 20 bar.



V/t [Nm³/h] Gas volume per time p [bar] Pressure (compared to the outer pressure)

Maximum cutting gas consumption per hour in continuous cutting Fig. 23507

3.4 Advantages and applications

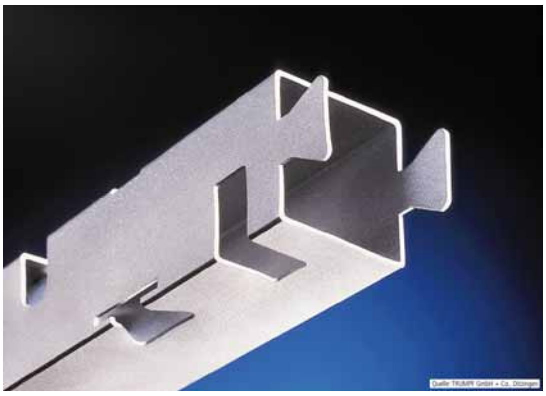
Advantages

The laser cutting offers several advantages as compared to other slitting processes such as plasma cutting, punching and nibbling or wire erosion:

- Processing the workpiece is possible without contact or force.
- As opposed to punching and nibbling, almost every contour shape can be made, without requiring a single tool change.
- With the laser beam, both large cuts in any shape can be cut as well as small, filigree and complicated contours. Geometric shapes can be processed especially quickly with only a few piercings.
- Separation is precise. The extremely narrow kerf remains virtually constant. Tolerances up to 0.05 mm can be maintained in the series production.
- The cutting speed is high. Therefore, the course of production can be considerably accelerated as compared to wire erosion.
- Due to the high energy density, the heat-affected zone can be kept very small: hardening depths from 0.1 to 0.2 mm are possible. An oxide film forms when cutting with oxygen.
- Less heating of materials ensures less distortion of the material at all events.
- The roughness of the cutting surfaces is low: less then 100 μm. The workpiece does not require refinishing.
- The most commonly used steels can be cut without any burr formation, eliminating the need for subsequent burr removal.

Applications

Flat workpieces as well as round or rectangular tubes and profiles with different cross-sections and made of different materials are processed in industrial application using the laser beam.



Square tubes and centering stars cut using laser — Fig. 078_20, 081_029

Mainly metallic materials like mild steel, tool steel, rust-free steels (CrNi steels) and aluminum and aluminum alloys are cut.

Left: Laser-cut parts in case of an auto door made of mild steel — Fig. 076_017, 083_034
Right: Laser-cut stainless steel can

In case of non-metallic workpieces such as cardboard, wood, leather, glass, ceramic, plastic (e.g. plexiglass, polyethylene, polyamide, polyurethane etc.), the laser beam can be used only as a slitting tool.

Note
Toxic substances may be released, particularly when cutting plastics with a laser. Cutting plastics using laser cutting machines of TRUMPF is not allowed.

3.5 Machines and systems

In order to be able to cut meter-long, flat sheets as well as three-dimensional workpieces, the laser beam requires an optics that bundles it and a machine that directs it and allows all the required movements. Which spectrum can be cut on workpieces, this is determined by the machine or system version.

Motion axes

In order to cut contours, the laser beam and the workpiece should move relatively to each other. During processing, either the laser cutting head or the workpiece or both are moved. One or more axes are required depending on whether the workpiece is flat or three-dimensioned. Use of robots is on an increase.

1D laser machines

1D laser machines are required only for straight cuts, such as cutting tubes into sections.

2D laser machines (flat sheet laser cutting machines and tube processing machines)

2D laser machines are used to cut even sheets and tubes. Machines where the laser cutting head moves over the workpiece are most frequently used.

3D-systems

3D systems cuts contours in three-dimensional workpieces. For this, the optics must have at least five motion axes, the three room axes as well as a rotary and swinging axis. In special cases, even the workpiece can be moved.

Tube cutting systems

In tube cutting systems, contours of tubes and profiles are cut. The processing optics have two to five motion axes. In addition, the workpiece is always moved here.

Robot

Robots as a cost-effective alternative to 3D systems are becoming increasingly common. However, they can also process flat workpieces. The combination with CO_2 lasers was difficult for a long time, as the laser beam cannot be directed to the robot through a laser light cable. However, the diffusion-cooled solve this problem. They are compact and light and are placed directly on the robot arm. One disadvantage of the robots is that they are less accurate than the cartesian machines.

4. Labeling and point marking using the laser

Labeling

When labeling with the laser beam, the material surface is moved slightly and discolored. This slight moving of the surface is no longer visible after the workpiece is lacquered.

Mild steel, rustproof steel and aluminum or aluminum alloys are labeled with the laser as per the following factors:

- Processing all sheet thicknesses.
- Sheets with oil-free surface.
- Low laser power.
- Focus position over the material surface.
- Oxygen as cutting gas results in a discoloration of the material surface.
- Nitrogen as cutting gas is possible with mild and stainless steel, unsuitable with aluminum and aluminum alloys, since the laser beam will be reflect very strongly.

Dot point marking

During dot point marking, a point depression is made into the material surface. This can be done in two ways:

- **Circular point marking** – here, two circles using the laser beam are described. With mild steel, the circles have same diameter of 0.6 mm, with rust-free steel two concentric circle with a diameter of 0.3 mm and 0.6 mm.
- **Dot point marking** means that a start hole is created with the help of a ramp cycle, i.e. with reduced laser power.

Point marking is possible preferably with mild and rust-free steel. In case of mild steel, oxygen and in case of rust-free steel, nitrogen are used as cutting gasses.

5. Surface treatment using the laser

"Treatment" of a surface of a material means to change the structure or the composition of the metallic material in the edge layer of the workpiece.

The martensitic conversion hardening, melting, glazing and shock hardening belong to the techniques where the structure is changed.

The composition of the material can be changed by adding filler metals. This is done with techniques like alloying, coating and dispersing.

Laser hardening = martensitic conversion hardening

Laser hardening is based on a pure phase conversion and is the most important procedure in material processing. This technique corresponds to the classic martensitic conversion hardening. Doing this, the carbon is released by warming the material to just under the melting temperature, which can then diffuse in the available iron structure. With a very quick cooling down of the material, carbon forms a new structure with the iron, that is called martensite. This hardening technique is used, for example, with bending tools.

Material

Cast irons and steels, whose percentage of carbon lies between 0.3 % and 6.67 % are well-suited for hardening. The texture of the material also plays a special role. A fine-grained structure aids the process, since the carbon in the texture can diffuse faster. Steels having a larger part of iron and a rough-grained joint are less suitable for laser hardening.

Workpiece geometry and material thickness

Depending on the workpiece and material thickness, some points have to be taken into consideration:

- Adequate material must be available as regards the side and the depth so that heat dissipation is ensured in the remaining material.
- The hardening, tempering of sharp corners or hardening, tempering near contour areas, that cause heat accumulation, is very demanding.
- The laser hardening is almost non-warping and requires no dimensions for additional finishing.

Hardness depths

As only the structure of the edge layer is changed during laser hardening, the possible hardness depths lie between 0.4 mm and 1.0 mm. A greater hardness depth is attained through specific heat buildups.

5.1 Laser hardening using CO_2 lasers

During hardening using the CO_2 laser, injecting the laser beam in the material through a uniformly thick graphite coating is ensured. The layer partially burns into the surface and must possibly be removed after the process. An oxide-free hardening is possible, though difficult and commercially disadvantageous because of the strong reflections of the laser beam.

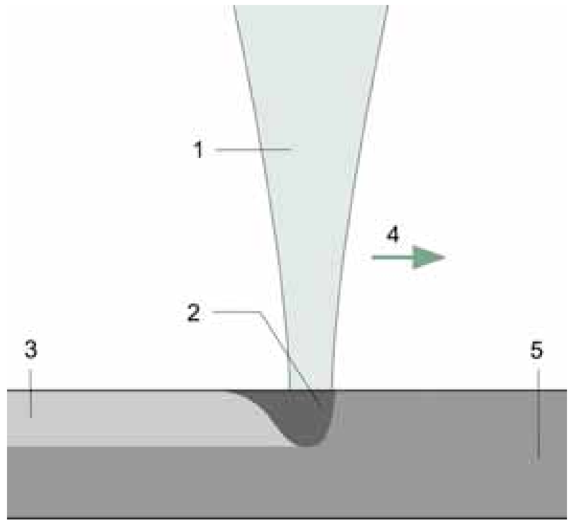
Hardening using CO_2 laser is done either by using facet optics or using scanner optics.

Facet optics In facet optics, the path width is determined using the optics. This option is especially suitable for hardening flat workpieces.

Scanner optics The scanner optics enables programming of the width of the path: The scanner mirror is set vibrating and the vibration amplitude determines the width of the path. Additionally, the temperature can be optimally set using a pyrometer (radiation thermometer), because it is important that a constant temperature is kept in every section.

5.2 Remelting

During remelting, the surface is not only heated but also melted continuously. If the melt solidifies, the metal crystallizes and forms a new joint. This is more uniform and fine than before the processing. Its properties are changed. The degree of hardness or the resistance to corrosion can be improved with this procedure depending on the material.



1	Laser beam	4	Processing direction
2	Melt	5	Workpiece
3	Molten layer		

Remelting Fig. 48051

Remelting is done mainly for cast irons. An example is the camshafts that control the engine valves in the vehicle.

Remelting with additional material

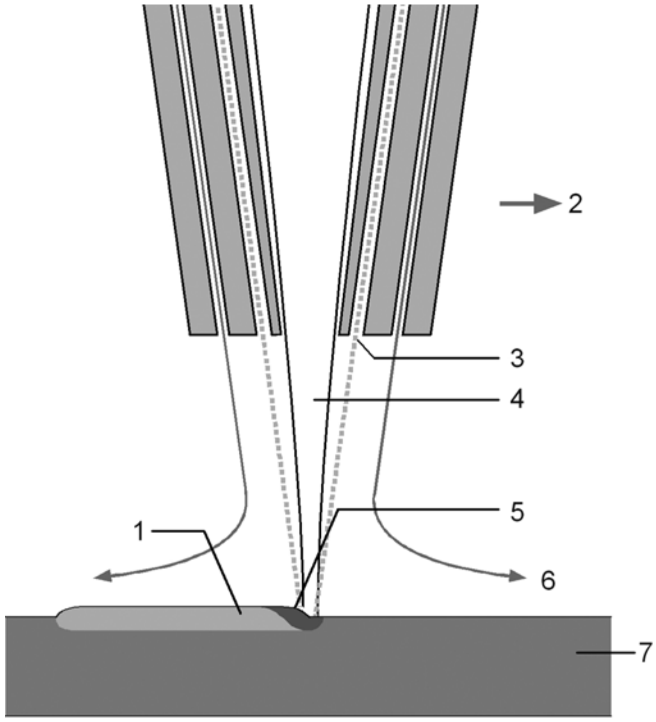
Additional materials are added to the melt and they change the properties of the edge layer. In this manner, reasonable basic workpieces can be equipped with high-quality edge layers. Chromium, nickel and titanium make the remolten layer resistant to corrosion. Carbides improve the wear resistance.

If the melt and the fillers mix completely, it is called alloying. However, if the fillers are stored only in the material, it is called dispersing.

Laser hardening and remelting are mainly used in special cases, for example, for three-dimensional tools and parts, that cannot be hardened with other procedures.

5.3 Alloying and dispersing

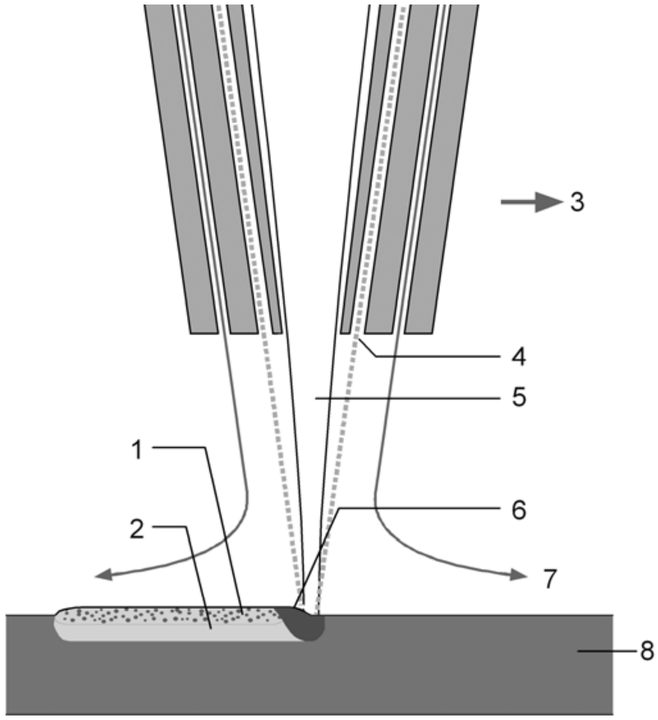
Alloying During alloying, the surface is melted with a little energy and an additional material is directed into the melt through a nozzle. The additional material gets dissolved in the melt and a thin layers is formed.



1	Connection zone	5	Molten powder
2	Processing direction	6	Inert gas
3	Powder beam	7	Workpiece
4	Laser beam		

Alloying Fig. 48509

Dispersing Unlike alloying, more energy is brought in to the workpiece surface during dispersing. More material is melted and an additional material is again directed into the melt through a nozzle. However, the additional material does not dissolve in the melt; a separate, thin layer is formed on the surface.



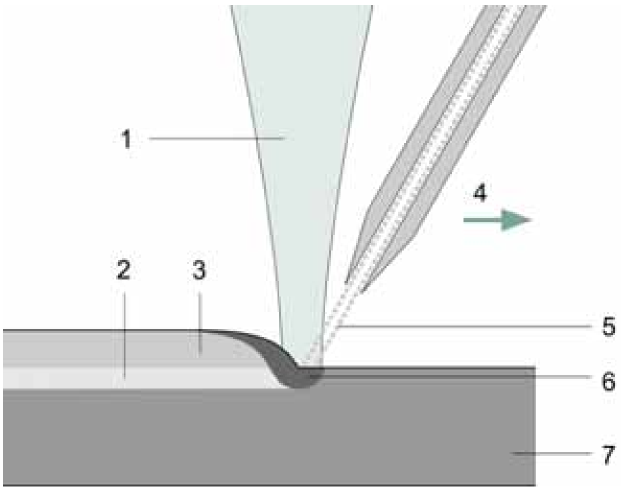
1	Dispersed layer (low degree of mixing)	5	Laser beam
2	Connection zone	6	Molten powder
3	Processing direction	7	Inert gas
4	Powder feed	8	Workpiece

Dispersing Fig. 48510

5.4 Coating

During coating, a filler is melted by the laser beam, which gets connected with the material surface. A separate layer is formed, which is between 0.5 and a few millimeters.

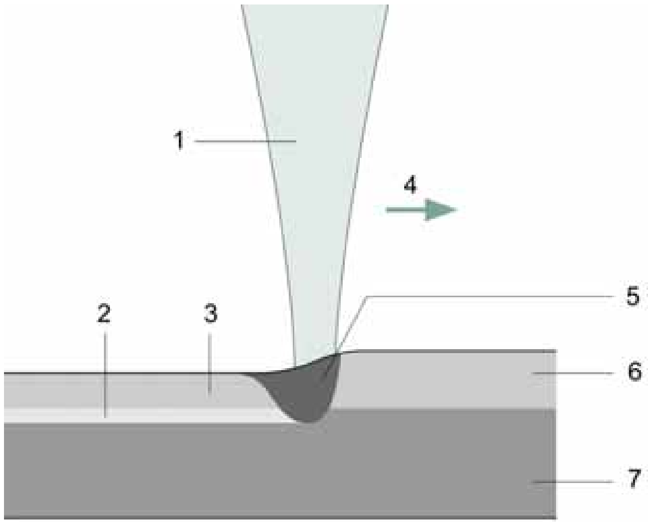
The additional material is supplied in 2 ways. The first: The additional material is provided in powder form through a nozzle directly to the melt - analog to the Direct Metal Deposition (DMD, refer to the next section).



1	Laser beam	5	Powder feed
2	Connection zone	6	Melt
3	Coating	7	Workpiece
4	Processing direction		

Single-layer laser coating   Fig. 48052

The second: In the first step, the filler is applied on to the workpiece surface. In the second step, the laser beam melts the applied layer with the basic material.



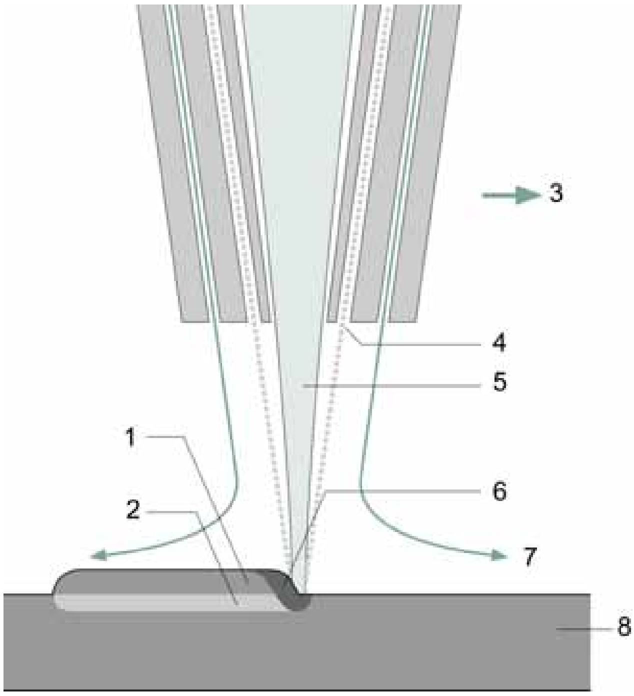
1	Laser beam	5	Melt
2	Connection zone	6	Molten layer
3	Coating	7	Workpiece
4	Processing direction		

Double-layer laser coating Fig. 48053

This procedure is suitable for partial change of workpiece surfaces. Engine valves that are strongly loaded (e.g. area in which they close and open) thus obtain a protective layer.

6. Direct Metal Deposition (DMD)

Direct Metal Deposition procedure concerns automatic build-up welding. The laser beam heats the workpiece locally and creates a weld pool on the workpiece surface. Fine metal powder is sprayed in the weld pool coaxially to the laser beam and is completely melted. It thus merges with the basic material. The layer thickness is 0.2 to 1 mm. Several layers can be set over one another. Argon is mostly used as inert gas.



1	Applied material	5	Laser beam
2	Connection zone	6	Molten powder
3	Processing direction	7	Inert gas
4	Powder feed	8	Workpiece

Automatic build-up welding, DMD Fig. 48050

The processing optics moves over the workpiece in order to apply lines, surfaces and shapes. Sensors monitor the layer thickness by measuring the expansion of the weld pool and they can control the energy supply. The layer becomes uniformly thick, as the laser power is reduced at the places, which are frequently travelled over.

A pre and post processing is always required. The surface must be removed up to the basic material before the new material is structured. Then the previously defined geometry is structured in the programming system using the laser. The refinishing operation can begin as soon as the workpiece is cooled, i.e. the old shape is recreated through milling, rotating, drilling or eroding.

Flat layers as well as three-dimensional shaped can be structured with DMD. Base bodies and applied shapes can be made up of various materials; the base body however must always consist of metal. Powder from tool steel, stainless steel, carbon or nickel alloys can be normally processed.

Due to the high focusability, the related large energy density and the good controllability, the heat application in the workpiece is extremely low as compared to conventional welding procedures. Complete hick layers are a result of complete melting of the metal powder. High-tensile and mechanically loadable connections occur with simultaneously low distortion of the basic material.

Applications

There are several applications in manufacture of tools and molds as well as in machine and system construction:

- Optimize the properties, e.g. injection molding tool: The shape-giving surface made up of wear-resistant tool steel is applied on a tool body that dissipates the heat especially well. This reduces the cycle time during injection molding and simultaneously increases the service time of the tool.
- Modify the existing tools: No new tool is manufactured in case of a design change, only the relevant area is changed.
- Repairing the damaged machine components.
- Apply corrosion protection layers for chemical and system construction.

Machine

Coordinate-directed 5-axis laser systems that construct the shape from the 3D data in a program-controlled manner are used. The workpiece is mostly fixed and the processing optics has 5 motion axes. Several programmable powder conveyors have various metal powders. Several material layers can be thus applied.

Chapter 6

Cutting processing of tubes and profiles

1. Tubes and profiles

1.1 Definitions

Tube

Empty body open at two ends, its length is greater than twice the outer diameter. For a detailed description, the tubes are differentiated as per their cross-section shape, e.g. round tube, rectangular tube, hexagonal tube etc.

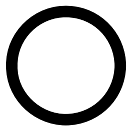
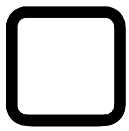
Profile

General name for the cross section of any form of any material.

1.2 What type of cross sectional shapes can be processed with a laser?

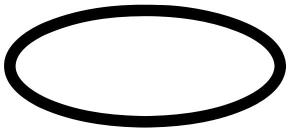
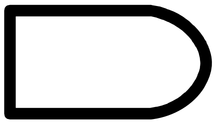
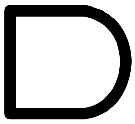
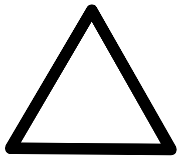
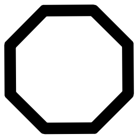
Tubes with the different cross-section shapes can be processed using a laser by using the appropriate clamping method.

Examples of standard cross sectional shapes

Round tube	
Square tube	
Rectangular tube	
Rounded oval tube	
Flat oval tube	

Tab. 6-1

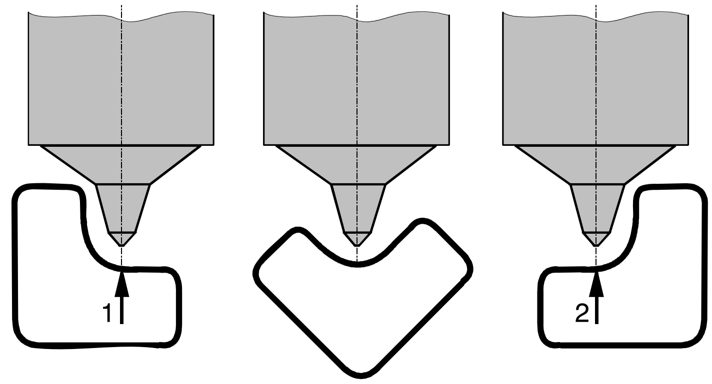
Examples of non-standard cross sectional shapes

Ellipse shaped tube	
Semi-oval tube	
D tube	
Triangular tube	
Octagonal tube	

Tab. 6-2

Profiles with inner radii

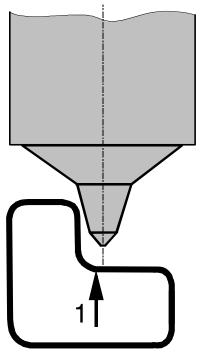
Profiles with large inner radii can be processed by rotating the profile under the laser cutting head by 90° during processing.



1 Beginning of inner radius
2 End of inner radius

Profile with large inner radius Fig. 21147

However, there are still limitations for processing profiles with inner radii. Depending on the geometry of the laser cutting head and cutting nozzle, collision between the cutting head and the workpiece is possible during processing of profiles with small inner radii.



1 Beginning of inner radius

Profiles with a small inner radius Fig. 21148

The profile with a small inner radius given in fig. 21148 cannot be processed, as the cutting head and the workpiece collide even before the profile can be rotated for processing the inner radius.

1.3 Quality

The initial quality of the tube to be processed is of considerable importance for the attainable precision of the contours on the workpiece. The quality of a tube is determined through:

- Straightness deviations.
- Diameter deviations.
- Wall thickness deviations.
- Twisting (torsion).
- Distortion rigidity.
- Manufacturing process (welded or stretched).
- Surface quality (roughness, corrosion).
- Constant of the corner radii (fluctuations within a batch).

Evaluation of laser cuts on tubes

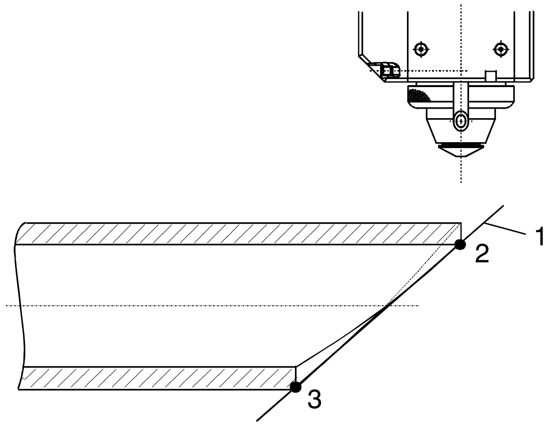
For the quality evaluation of laser cuts on tubes, one can always refer to chapter 7 "Criteria for evaluation of laser cuts". The individual criteria are described in it. To a great extent, the results can be applied to pipe and tube processing. Simply put, the roughness depth is always larger when cutting tubes with a laser than when cutting workpieces with a laser.

1.4 Possibilities and limits when processing tubes with 2D and 3D machines

In order to be able to connect connection pieces parts (plane plates, processed or unprocessed tubes) to the cutting edge of a tube, the connection piece must be on the cutting edge completely.

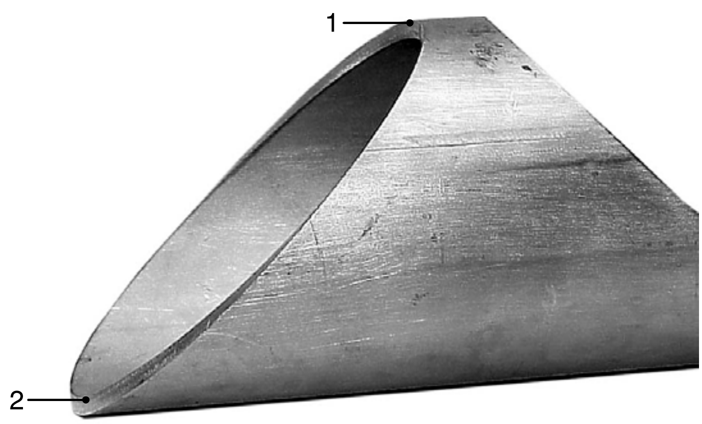
2D tube cutting

During 2D tube cutting, the laser beam is usually perpendicular to the surface of the tube, so that there is no change in the material thickness during processing. It is directed in a horizontal plane while the tube rotates around its longitudinal axis. Thus, the "ideal cutting line" is attained only at those points where the laser beam changes from the inner surface to the outer surface and vice versa.



1	Plane on which the tube is to be placed	2	Inner surface
		3	Outer surface

2D processing: plane cut   Fig. 27376



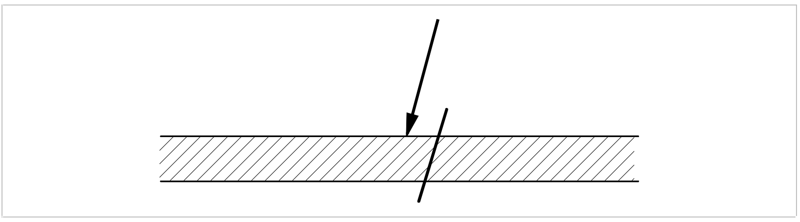
1	Outer surface	2	Inner surface

Fig. 27377

By exposing the outer part of the tube once and inner part once, a connection seam can be made which is qualitatively sufficient. However, only if the connection seam is made using a conventional welding procedure with supplementary wire.

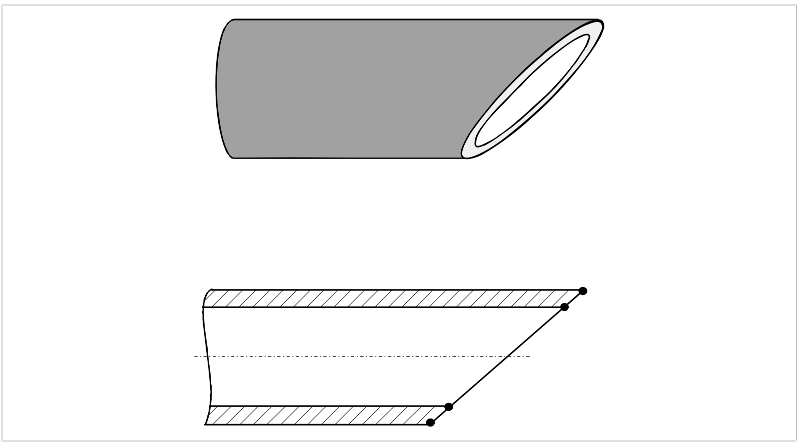
3D tube cutting

In order to create a perfectly fitting cutting edge, which lies on the connecting piece with a link to all points simultaneously with the outer and inner surface, the laser beam must be in lead angle to the tube. This is necessary if the cutting edge of a tube is supposed to be connected to the connection piece using a laser welding process.



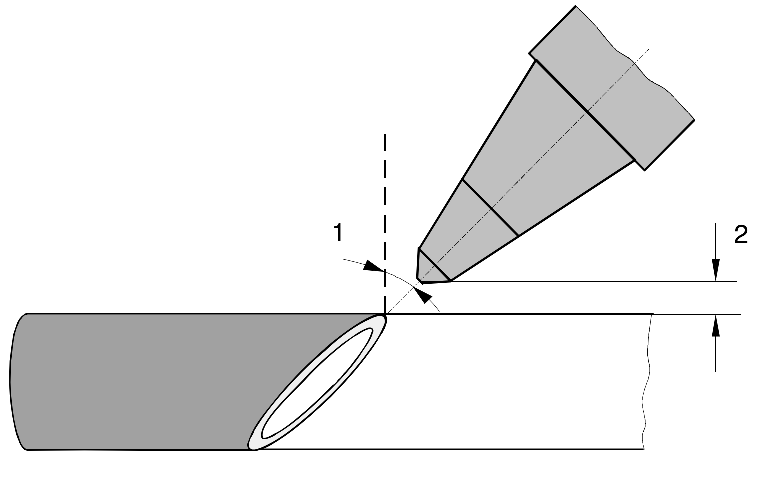
Beam guideway with 3D processing Fig. 6450

This is possible only with 3D machines:



3D processing: plane cut Fig. 6449

3D tube cutting has, however, limited possibilities due to technical reasons relating to the process. Problems occur if the angle of incidence of the laser beam to the tube is increased radically:



1 Angle of incidence 2 Cutting distance

Extreme angle of incidence during 3D processing Fig. 21149

- The material thickness changes.

  If you still want to achieve good cutting results, the cutting parameters must be continuously adjusted. Two methods of adjustment are feasible:

  - Switch between several laser technology tables, because the cutting parameters in a laser technology table are optimum only for one material thickness.
  - Select cutting parameters that only allow low cutting speeds throughout the entire machining process.

- Cutting gas is deflected.

  The emitted cutting gas is partially deflected from the tube surface and does not flow exclusively into the kerf. For oxygen cutting, this can lead to increased erosion of the cutting edges and burr formation. For nitrogen cutting, burr formation is possible, as the removal of melt from the kerf is worse.

- Cutting distance is no longer correct.

  The capacitive height regulation determines too large capacities between the nozzle and the material surface. This leads to distance errors and focusing changes which, in turn, can cause spoiled cutting edges.

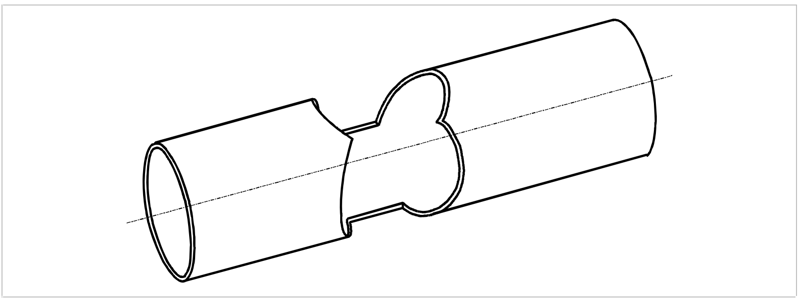
- Cutting speed decreases.

  Often the cutting speed must be drastically reduced to produce angled cuts.

2. Process curvated surfaces

2.1 Polygonalize contours

When processing curved surfaces, multicurve contours on round tubes or corner radii for multi-edged tubes are issued as polygon contours in the NC text.

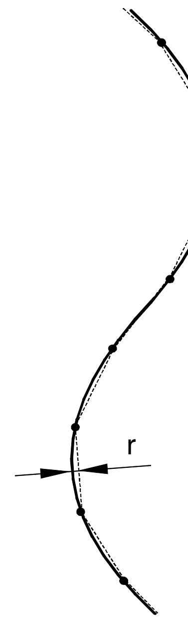


Any contour with multicurve contours on a round tube Fig. 20852

The polygon contours consist of several straight piece parts (increments), whereby the increment length depends on the curve of the moving multicurve contours and the selected contour deviation. The execution speed when processing polygonalized contours can be increased if the transitions between the individual increments are as tangential as possible. Virtually tangential transitions are achieved if the increments are reduced, i.e. more points for a multicurve contour are set.

Contour deviation

The contour deviation is the maximum distance of the programmed cut contour to the original contour. The contour deviation is called "Roughness" in the programming system TruTops Tube. Standard value for the roughness when processing round tubes: 0.05 mm.



r Roughness

Contour deviation (roughness) Fig. 19936

The smaller the value for the contour deviation selected, the closer the polygonalized contour will lie on the original contour.

2.2 Process contours "in the plane"

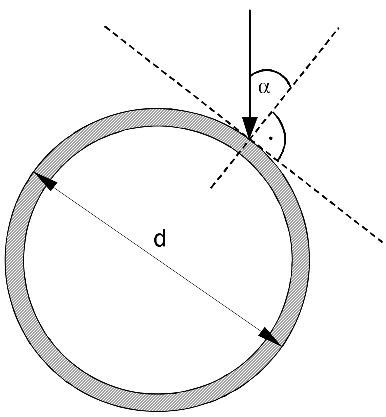
Small contours on round tubes can also be processed "in the plane". In doing so, the rotary axis is not turned during the processing. The movements of the X-axis and Y-axis are programmed. The movements of the Z-axis are controlled by the distance control system.

Advantages

- Original contour, no polygonal contour.
- Less blocks, less storage requirement.
- High processing speed.
- Parallel cutting edges.

Limit angle α

When processing contours in the plane, the laser beam should not be steeper to the tube than the limit angle α (standard value 25°). When larger cutting angles are used, the problems mentioned on page 8 will arise.



α Limit angle d Diameter of tube

Limit angle α Fig. 19935

2.3 Distance control system

A distance control system is integrated in the laser cutting head, which ensures that the cutting distance remains constant during processing.

Operating principle

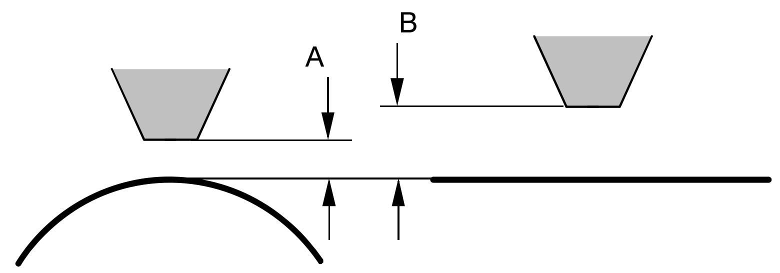
The distance control system determines the distance between the cutting nozzle and the material surface (cutting distance) capacitively. Here, the cutting nozzle and the material surface can be considered to be two condenser plates placed opposite each other. A capacitance forms between these two capacitor plates, whereby the material contributes towards the definition of this capacitance in a radius of approximately 20 mm around the nozzle end. The capacitance changes if the cutting distance changes. If you then always put a certain capacity value in relation to a certain value for the cutting distance, a characteristic curve emerges.

Sequencing during processing

A desired value for the cutting distance is given to the distance control system when a laser technology table in the NC program is called up. The distance control system allocates a capacity to this nominal value from a characteristic curve. The Z-axis then moves until the distance between nozzle and material surface forms this capacitance exactly. During processing, the distance control system continuously measures the capacitance between the nozzle and the material surface and keeps the cutting distance constant.

2.4 Cutting distance for round tubes

The cutting distance must be corrected when processing round tubes. The reason for this is that, because of the bend in the round tube at a preset capacitance between the tube surface and the nozzle, a lower cutting distance is set. The actual distance is thus less than the value programmed in the laser technology table.



A Uncorrected cutting distance B Correct cutting distance

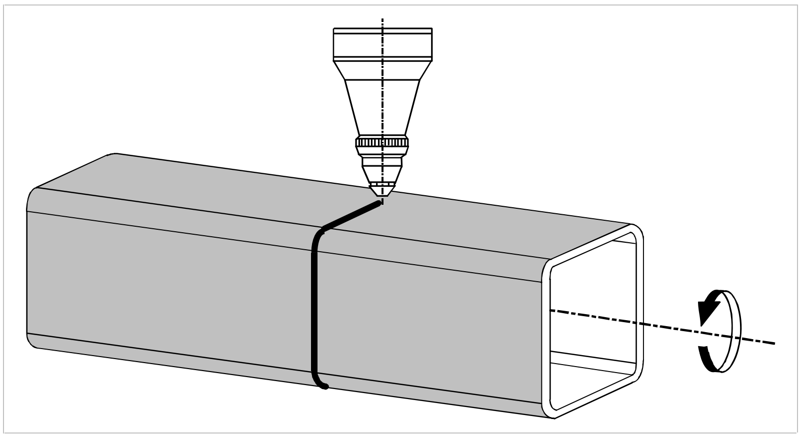
Fig. 20913

Recording characteristic curve on the round tube

With round tubes, the characteristic curve for the capacitive height regulation is directly recorded on the tube itself. This means that a lower capacitance value is allocated compared to a characteristic curve for flat processing for the same cutting distance. Despite the bend, the cutting distance during round tube machining is therefore once again consistent with the value programmed in the laser technology table.

2.5 Edge processing for multi-edged tubes

When processing multi-edged tubes, there is technological focus on edge processing.



Rectangular tube: bypassing edges Fig. 9417

Depending on the size of the corner radius and the dimensions of the tube sides, the cutting distance is corrected and the feed is restricted during processing.

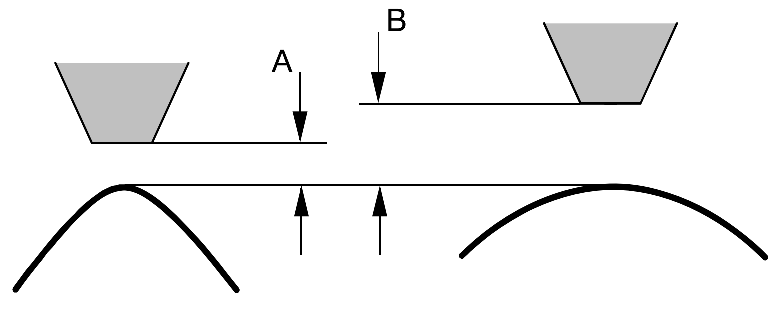
Correcting the cutting distance

In case of multi-sided tubes, the characteristic curve for the distance control system is incorporated in the center of the largest plane surface. If the cut is made in precisely this section of the flat surface, then the actual cutting distance is consistent with the programmed value. If a cut is made in the corner radius direction, the actual cutting distance, whilst the nozzle is still located above the flat surface, will decrease. The material in a radius of approximately 20 mm around the nozzle end contributes towards the capacity between nozzle and the material surface, from which the distance control system determines the cutting distance.

If the nozzle is near the corner radius, if there is no material all over in the relevant area below the nozzle, then a smaller and more actual cutting distance appears. The reduction of the actual cutting distance is quite extreme when the cutting tip is situated above the corner radius of the tube angled at 45°. With smaller corner radii, the nozzle collides with the tube if no distance correction is performed.

Cutting distance with outer radii

The smaller an outer radius to be bypassed, smaller is the cutting distance between the nozzle and the material surface in case of the specified capacitance. For this reason a distance correction must be performed when processing outer radii, while a higher value is programmed for the cutting distance.



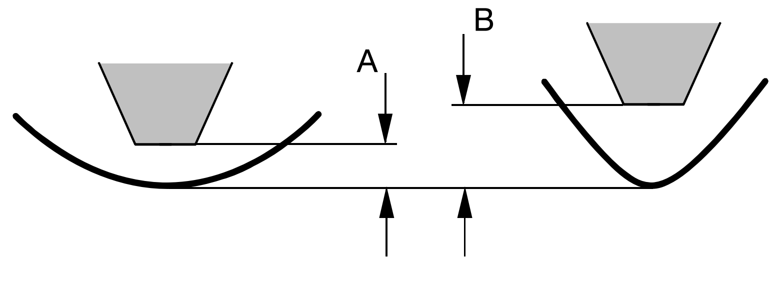
A Cutting distance when by-passing a corner with a small outer radius

B Cutting distance when by-passing a corner with a large outer radius

Bypassing outer radius without distance correction Fig. 21145

Cutting distance with inner radii

The smaller the bypassing inner radius, greater is the cutting distance between the nozzle and he material surface in case of the specified capacitance. For this reason a distance correction must be performed when processing the inner radii, while a lower value is programmed for the cutting distance.



A Cutting distance when processing a large inner radius

B Cutting distance when processing a small inner radius

Processing inner radii without distance correction Fig. 21146

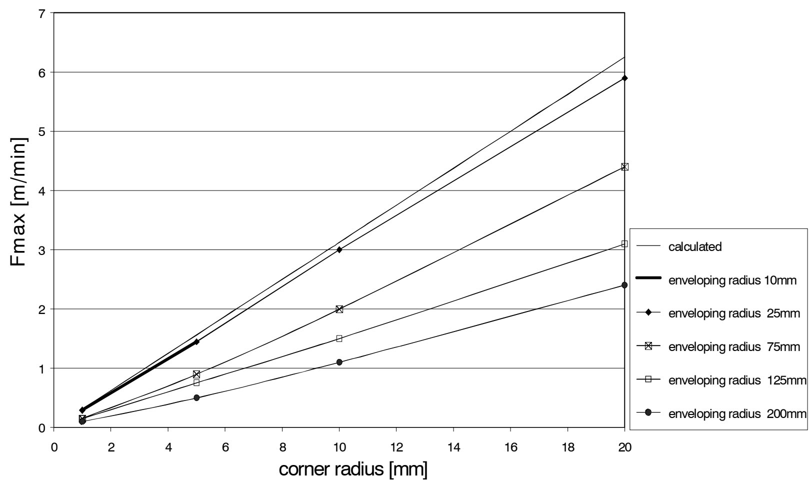
Reducing feed

How quickly the corners of a multi-edged tube may be bypassed, depends on the following factors:

- Rotary axis acceleration.

  The constructive design of the tube processing station influences the maximum feed rate for corner processing. The rotary axis of a TruLaser 3030 with RotoLas cannot be rotated so dynamically as the rotary axis of the TruLaser Tube 5000 constructed especially for tube processing. The maximum feed rate when bypassing a corner is, therefore, limited by the maximum rotary axis acceleration.
- Corner radius.

  The smaller the bypassing corner radius, smaller is the maximum feed rate during corner processing.

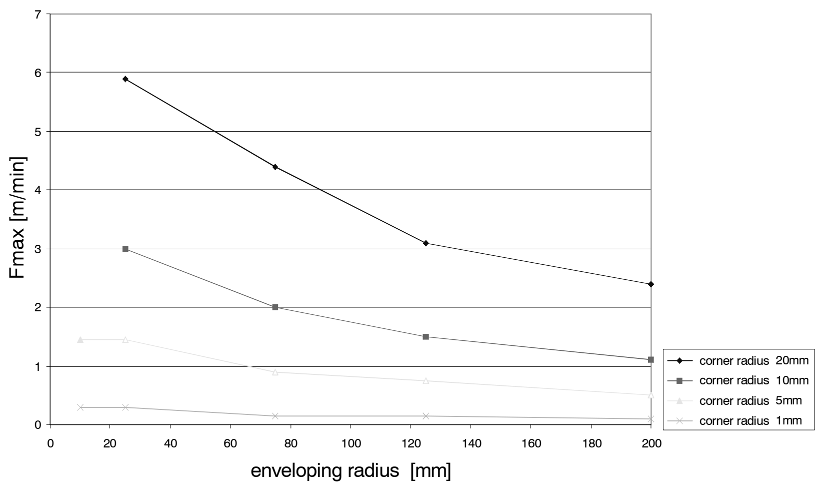


TruLaser 3030 with RotoLas: Maximum feed rate during corner processing depending on the corner radius

Fig. 20851EN

- Outer circle radius.

  The greater the outer circle radius of the tube, less is the maximum feed rate during corner processing.



TruLaser 3030 with RotoLas: Maximum feed rate during corner processing depending on the outer circle radius

Fig. 19945EN

3. Effect of the opposite side

Unlike processing of two-dimensional workpieces, a tube always has a side that is opposite to that of processing. This may cause the following problems.

- Spray the inner walls of the tube with slag or melt.
- Cut the tube on the opposite side.
- Greater heat application and thus strong heating of the material.

These problems mostly occur when machining thin-walled tubes with a small diameter or outer circle.

Problem solutions

- A splash guard inserted into the tube during tube processing can "divert" slag splash and absorb laser radiation.
- Piercing with reduced laser power.
- Cutting with reduced laser power.

4. Cut the tube sections free

An individual tube section occurs during tube processing if the processed tube end is cut free from the remaining tube. Problems can arise in this cutting-free process depending on the contour of the tube section:

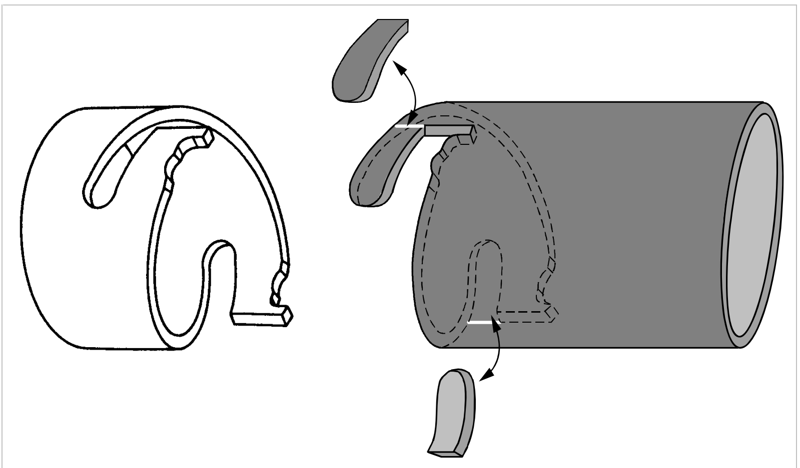
- The part can get interlocked with the remaining tube or waste parts.
- The part can tilt and collide with the nozzle of the laser cutting head.

The part interlocks during free cutting

Parts that are cut free at the tube section end due to creation of an expensive contour with several indentations, mainly get interlocked with the remaining tube or waste parts easily. A typical example of this would be the production of bayonet catches:

Bayonet catch Fig. 21179

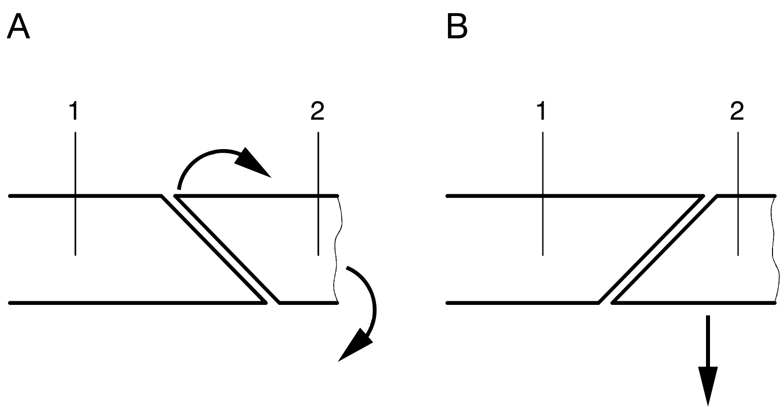
The production of the illustrated bayonet catch requires the programming of parting cuts in the scrap part. The scrap part cannot be separated without additional parting cuts.



Parting cuts in the waste part Fig. 21150

The part tilts during free cutting

Parts light tilt during free-cutting and collide with the nozzle of the laser cutting head if the contour on the tube end to be cut free is extremely sloping.



A	Part tilts	1	Remaining tube
B	Part falls	2	Part

Fig. 20914

The part can be prevented from tilting by not programming the contour end on the long side of the tube part (A), but rather on the short side (B).

A splash guard inserted into the inner tube during processing also prevents the cut off part from tilting off.

Chapter 7

Criteria for evaluation of laser cuts

1. How is the cut quality evaluated?

DIN EN ISO 9013

The DIN EN ISO 9013 is a summary and at the same time, it is an alternative for the standards DIN EN ISO 9013:1995-05 "Oxyacetylene flame cutting", DIN 2310-4 "Plasma cutting" and DIN 2310-5 "Laser cutting of metallic materials". In addition, the content of these standards has been revised.

The definitions, the criteria to determine the quality of cutting surfaces, the quality division as well as the dimensional tolerances are described in DIN EN ISO 9013. In case of laser beam cuts, it is applicable for material thicknesses from 0.5 mm to 40 mm.

TRUMPF criteria

TRUMPF deviates from DIN EN ISO 9013 partially and uses the following criteria to evaluate the cutting results:

- Burr formation (whisker formation or melting drops).
- Kerf
- Pittings
- Drag line separation *n.*
- Average roughness depth R_{Z5}.
- Perpendicularity and slant tolerance *u.*

A definition and description of the methods used in measuring or determining the criteria above is provided on the following pages.

The evaluation table at the end of the chapter should serve as a master copy to save the data required to evaluate the cut quality.

2. Burr formation

Definition

The following may be concerned in case of burr formation:

- A strongly adhesive burr that cannot be removed without post-processing.
- An adhesive slag that can be easily removed without post-processing.

Determining the burr formation

The burr formation is visually evaluated and described in words. The dimension of the burr is dependent on the focus position, amongst other things.

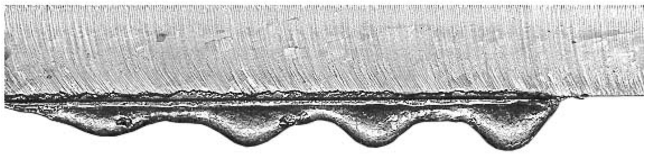
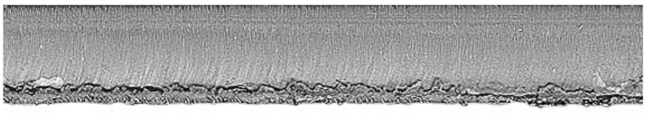
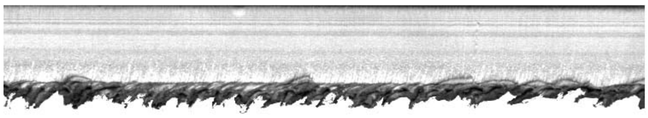
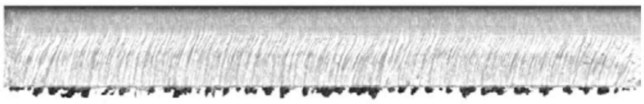
Type of burr	Description	Example
Pearl burr	Pearl-like or drop-like burr, with metallically blank surface; strongly adhesive burr. Example: Mild steel, sheet thickness 15 mm Focus position +5	
Crumb burr	Adhesion of melt as fine, crumb-like burr, easier to remove than the sharp burr. Example: Mild steel, sheet thickness 15 mm Focus position -1	
Sharp burr	Whisker-like, rough and sharp-edged burr; highly adhesive in parts. The underside of the cut surface is rough. Example: Stainless steel, sheet thickness 8 mm Focus position -4	
	Fine, but sharp-edged burr, whisker-like adhesive on the underside. Example: Stainless steel, sheet thickness 8 mm Focus position -11	

Fig. 25110, 25111, 25112, 25113

Tab. 7-1

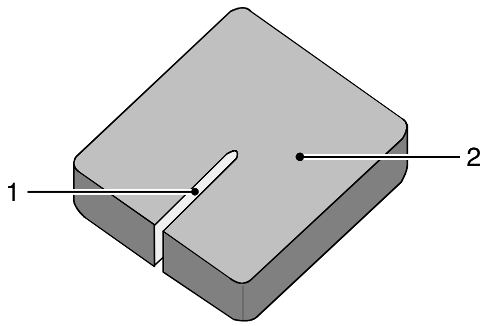
3. Kerf

Definition

A kerf occurs during laser cutting, which usually becomes narrower from the upper edge of the cut to the lower edge of the cut. The kerf – also referred to as the kerf breadth – is given in [mm].

Measuring the kerf

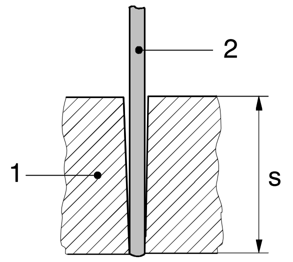
The kerf is measured in the slit of a rectangle.



1 Slit 2 Workpiece

Rectangle with slit: measure kerf Fig. 25395

A value is detected with the help of a feeler gauge: penetration depth s.



1 Workpiece s Sheet thickness = penetration depth
2 Feeler gauge

Measurement of the kerf Fig. 25396

With material strengths of more than 3 mm, the exact measurement of the kerf is carried out by cutting a rectangle and using the slide gauge to measure the edge length. The difference to the programmed edge length is the kerf.

Example 1

Programmed edge length:	100 mm
Measured edge length:	99.7 mm
Calculated kerf:	0.3 mm

Note
TRUMPF standard values for kerf widths are given in the data collection for your machine.

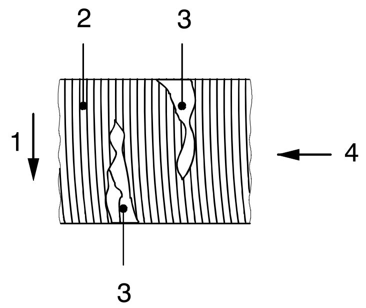
Example 2
Specifications from the data collection for TruLaser 2525, TruLaser 3030, TruLaser 3040, TruLaser 3060 with control system SINUMERIK 840D and TruFlow 3000.

Material	Sheet thickness [mm]	Kerf [mm]
Mild steel (QSt 37-2)	1-3 4-6 -15 20	0.15 0.2-0.3 0.35-0.4 0.5
Stainless steel (1.4301), high-pressure cutting with N_2	1-3 4-8 10-12	0.15 0.2 0.5
Aluminum alloys ($AlMg_3$, $AlMgSi_1$), high-pressure cutting with N_2	 1-3 4-8	 0.15 0.2-0.3

Tab. 7-2

4. Pittings

Definition
Pittings are erosions of non-uniform width, depth and form that intercept an otherwise uniform cutting surface.



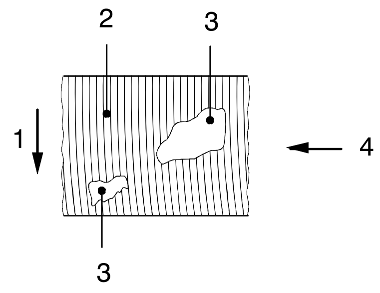
1 Cutting beam direction
2 Workpiece
3 Pittings
4 Cutting direction

Pitting

Fig. 25397

Determination
During the cutting quality evaluation, the present pittings are visually evaluated in their version and described in words. If no pitting is detectable, this criterion is ignored.

Erosions occurring during change of direction are listed separately.



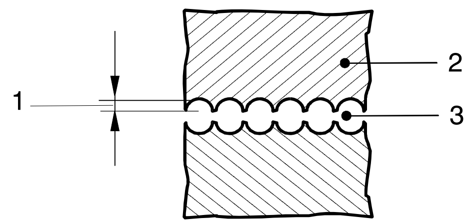
1	Cutting beam direction	3	Erosions
2	Workpiece	4	Cutting direction

Erosion Fig. 25398

5. Average roughness depth

Definition of roughness

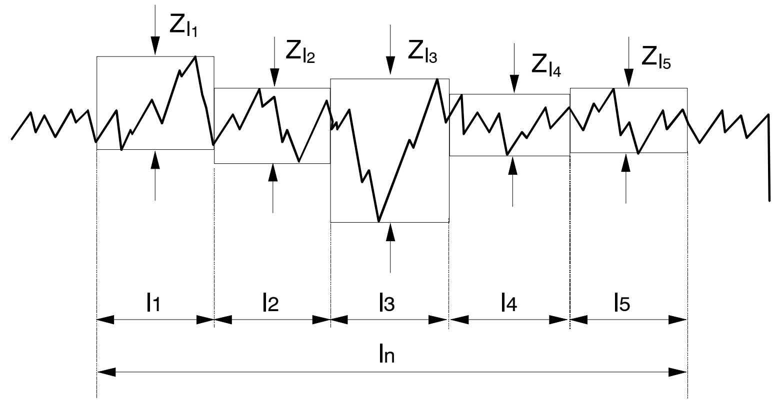
Roughness = Groove depth



1	Roughness	3	Kerf
2	Workpiece		

Sketch of roughness, increased top view Fig. 25246

The **average roughness** R_{z5} is the arithmetic mean of individual roughnesses of five adjacent, representative individual measuring paths. The roughness is stated in [μm].



Zl1 to Zl5 individual roughnesses ln total measuring path

l1 to l5 individual roughnesses

Presentation: Roughness over five individual measuring paths Fig. 25454

Measuring the average roughness R_{z5}

The average roughness R_{z5} is measured with a gating cutting device as per ISO 3274. The measurement itself takes place as per ISO 4288 at continuous intervals in the cutting direction.

The point of measurement of the roughness depends on the sheet thickness and the type of material. Deviating to the standard, in case of TRUMPF, the points that visually indicate the greatest roughness first are used for measurement. The standard procedure is to use the upper third of the top of the cut as the measuring point.

The following table specifies the **point of measurement of roughness**, depending on the sheet thickness and the type of material. Taking the present state of technology into consideration, these values should be considered as standard values. They are detected with a TruFlow 4000.

Sheet thickness s [mm]	Point of measurement [mm] Mild steel	Point of measurement [mm] Stainless steel	Point of measurement [mm] Aluminum
1	-0.5	-0.5	-0.5
2	-1	-1	-1
3	-2	-1	-2
4	-2.6	-2.6	-2.6
5	-3.3	-1.6	-3.3
6	-4	-4	-4
8	-5.3	-7	-5.3
10	-1	-9	-
12	-1	-11	-
15	-1	-	-
20	-1	-	-

Tab. 7-3

Note
The maximum roughness creeps from the lower to the upper side of the sheet in the case of mild steel with a thickness of > 8 mm. This is not the case with stainless steel and aluminum.

Standard values for average roughness R_z

In the following table, maximum values for the standard roughness are given, for your orientation. In case of TRUMPF, the values are detected with a TruFlow 4000.

Sheet thickness s [mm]	Mild steel Maximum values R_z [µm]	Stainless steel Maximum values R_z [µm]	Aluminum Maximum values R_z [µm]
1	9	6	18
1.5	8	-	13
2	15	10	17
2.5	7	-	14
3	17	10	22
4	5	10	20
5	6	10	19
6	6	13	14
8	7	19	46
10	28	43	-
12	23	38	-
15	28	-	-
20	28	-	-

Tab. 7-4

Note
These values are standard values determined on the basis of the current state of the technology.

Pittings

Pittings must be dealt with separately, as they cannot be calculated by measuring the roughness. The expansions of the pitting exceed the range of the measuring device.

6. Drag line separation

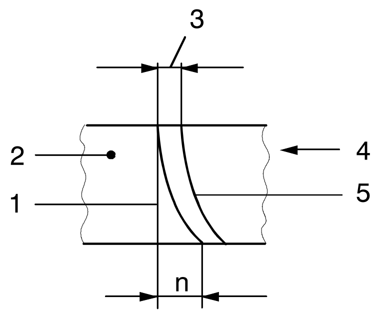
Definition

In laser cutting, the edges of the workpiece have a characteristic grooved pattern. At low cutting speeds, the grooves run almost parallel to the laser beam. The greater the cutting speed, greater is the twisting of the grooves against the cutting direction. Drag line separation *n* indicates the greatest distance between the two drag lines in the cutting direction.

Measuring *n*

The drag line separation is visually evaluated.

The evaluation is carried out on a photo or cut sample with the aid of a magnifying glass or stereo microscope. A reference line serves as a construction line.



1	Reference line	4	Cutting direction
2	Workpiece	5	Drag lines
3	Groove width	n	Drag line separation

Measure drag line separation Fig. 25399

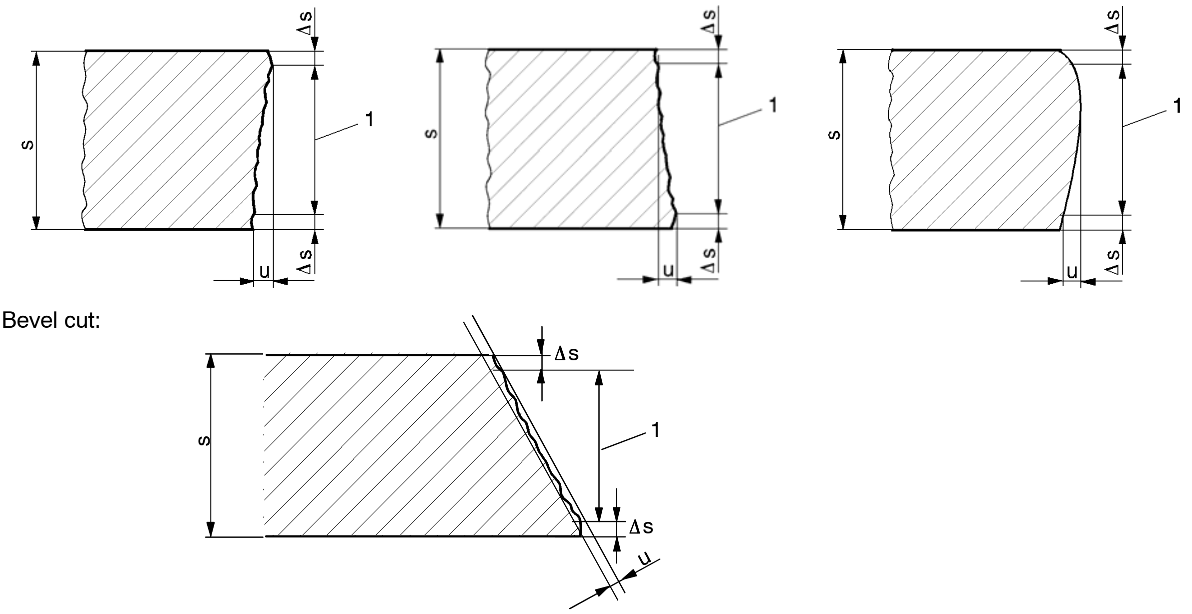
7. Perpendicularity and slant tolerance

Definition

The perpendicularity and slant tolerance *u* is the distance between two parallel lines between which the cut surface profile must be less than the theoretically correct angle, thus in case of perpendicular cuts, less than 90°. The perpendicularity and slant tolerance encompasses the deviation from both straightness and flatness.

The perpendicularity and slant tolerance are measured in [mm] in the case of perpendicular cuts or bevel cuts.

Perpendicular cut:



s	Sheet thickness	1	Determination range in which the measurement is taken	Δs	Dimension by which the determination range of the perpendicularity tolerance is reduced. This dimension varies with the sheet thickness:
u	Perpendicularity tolerance				

Perpendicularity and slant tolerance

Fig. 3800, 11181, 11182, 25243

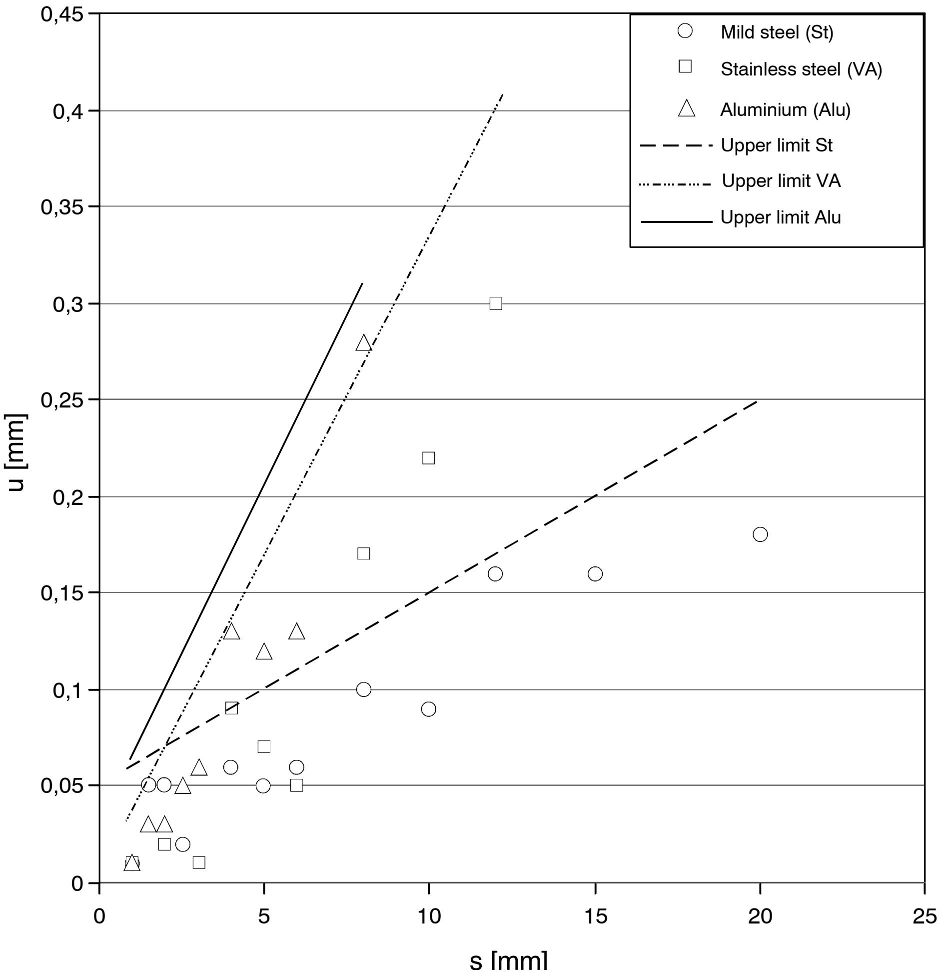
In the DIN EN ISO 9013, three ranges are specified for cutting with the laser: ranges 1 to 3.

Deviating from the standard, TRUMPF defines ranges from the following formulas, dependent on the material:

	Formula for upper limit (s = sheet thickness)	
Mild steel (Flame cutting)	u = 0.05 + 0.01 s	
Stainless steel (Fusion cutting)	u = 0.005 + 0.033 s	
Aluminum (Fusion cutting)	u = 0.03 + 0.035 s	

Tab. 7-5

In case of TRUMPF, values were detected with the TruLaser 3030 and the TruFlow 4000. The values are represented in the following diagram:



u [mm] Edge slant s [mm] Sheet thickness

Edge slants in case of mild steel, stainless steel and aluminum

Fig. 25393EN

8. Evaluation table

General data

Date:	Person responsible:
Type of material:	Cutting speed:
Laser type:	Lens:
Laser power:	Focus position:
Gating frequency:	Nozzle geometry:
Cutting gas pressure:	Nozzle distance:
Cutting gas:	

Tab. 7-6

Data calculated

Material thickness [mm]	Kerf [mm]	Roughness [μm]	Drag line separation (yes/no, low/high)	Perpen-dicularity tolerance [mm]	Pittings (yes/no, separate/ frequent)	Erosions after change in direction (yes/no)	Current radius after 90° change in direction [mm]	Miscel-laneous
Remarks:								

Tab. 7-7

Glossary

Absorption

(= lat. absorption) In material processing with lasers, it means absorption of the laser light by the workpiece. The degree of absorption specifies the amount of laser light that the workpiece absorbs. In case of same wavelength, it varies from material to material. On the other hand, materials show different degrees of absorption for different wavelengths. Besides, the degree of absorption depends on the angle of incidence, the temperature, the state of matter and the surface procurement of the material.

Active gas

Gas used to influence the machining process. During fusion cutting, the active gas removes the melt from the kerf. During welding using the CO_2 laser, it prevents a plasma cloud from being formed.

Active medium

Substance in the beam source that emits the laser light. Many substances are considered as active mediums for a laser: gasses, solids such as crystals or semiconductors as well as liquids. CO_2 gas mixtures, doped crystals or glasses and semiconductors are mainly used in material processing.

Beam guideway

The path between the beam source and the processing optics as well as components directing the laser beam. Laser beams can be freely directed, in beam protection tubes and bellows for example. Laser beams from solid and diode lasers can be guided in laser light cables for processing.

Beam quality

Basic property of the laser beam. The beam quality describes the divergence behaviour of the laser beam and thus its focusability. The beam quality is determined through the divergence of the laser beam as per the first beam waist and its diameter. Parameters describing the beam quality are the beam parameter product, the M^2 value and the K-number.

Beam source

(Laser device) Device that generates the laser beam. Basic components of a beam source are: the active medium that transmits the laser light; the resonator that adjusts the laser beam and ensures that it always passes through the active medium; the pumping source that excites the active medium; the cooling system that dissipates the heat.

Build-up welding

During laser build-up welding, the filler is melted in wire or powder form and put on the workpiece surface. The manual build-up welding and the automatic build-up welding – also known as Direct Metal Deposition – are differentiated.

CO_2 gas laser

The common laser type for material processing. The laser light occurs in a gas mixture of carbon dioxide (CO_2), nitrogen (N_2) and helium (He). The CO_2 molecule generates the laser light. Nitrogen and helium serve as assist gasses. The wavelength of CO_2 lasers lies in remote infrared with 10.6 micrometers.

Coating

Procedure to make the workpieces corrosion-resistant or wear-resistant. The laser melts the filler and applies a layer on the workpiece surface. The filler is either supplied as powder during processing or is applied on the workpiece as a layer previously.

Coherence

Property of the laser light: The electromagnetic waves swing in common mode – they have the same phase position.

Continuous wave operation

(cw operation) Operating mode of beam source: In contrast to pulsed CW operation, the active medium is continuously excited and generates an uninterrupted laser beam as regards the time.

Crossjet

Gas current that protects the processing optics against spatters occurring during the processing. For example, crossjets are used for welding and drilling.

Deep welding

Joining process for metals. The laser beam melts and evaporates material along the seam point. A narrow, deep evaporation capillary (keyhole) is formed in the metal, which moves with the laser beam through the material. The melts flow together behind the evaporation capillary and strengthen. This gives rise to deep and thin seams.

Diode laser

Laser type that uses the semiconductor as an active medium. The laser light occurs during recombination of electrons and holes at the transition between an n- and a p-doped semiconductor layer. The wavelength of a diode laser primarily depends on the composition of the semiconductor and ranges from visible to infrared light.

Direct Metal Deposition (DMD)

Automatic build-up welding. The laser beam melts a powdery filler and thus applies layers and shapes on the surface of a workpiece. The filler metal powder is supplied to the optics through a powder nozzle.

Divergence

(= lat. expansion) Laser beams are directed. They are not parallel beams, but expand increasingly. This expansion is known as divergence. The opening angle (divergence angle) specifies how strong the laser beam expands.

Emission

(= lat. transmission) In laser technology, the term indicates transmission of laser light in the active medium.

Energy

Physical size. In material processing with the laser, the entire incoming energy is mostly important, that is, the energy having an effect on the workpiece. This energy corresponds to the laser power multiplied with the duration of effect. In some cases, the energy of individual laser photons is also important. This photon energy depends on the wavelength. The following is applicable: the shorter the wavelength, greater is the energy.

Fillers

All materials that are supplied to the workpiece during the processing.

Flame cutting

Slitting process for mild steel. The laser beam heats the metal so strongly that it reacts with the active gas oxygen and burns (oxidation). The chemical reaction releases a lot of energy. It supports the cutting process.

Focal length

Parameter of a focusing lens or a focusing mirror. The focal length specifies the distance from the main lens or mirror plane to the focus of an ideal and focused parallel beam. Thus, the following is generally applicable: the smaller the focal length, stronger if the focusing of the laser beam and smaller is the focal diameter.

Focus

The point after the focusing lens or the focusing mirror at which the laser beam has its smallest cross-section. The cross-section surface of the focus determines the power density. The focus usually has a circular cross-section. There are other cross-sections as well, the line focus for example.

Frequency

Vibration property. With reference to the laser technology: property of the laser beam. The frequency specifies the vibrations of the electromagnetic waves per second. The unit of the frequency is Hertz (Hz).

Hardening

Procedure to increase the resistance of the workpiece surfaces. The laser beam heats the edge layer of the workpiece and thus causes a joint conversion in metal (austenitization). Then the surrounding cold material cools the layer very quickly. Thus, a new joint (martensitic) is formed and the degree of hardness increases. Carbon steels and cast materials can be hardened.

Heat conduction welding

Joining process for metals. The laser beam melts the joining partner along the seam point on the surface. The melts merge and freeze. Seams with even surfaces occur during heat conduction welding. The procedure is thus especially suitable for view edges.

Labeling

Creating labels with the laser beam. Various procedures are considered for this: engraving, removing a cover layer, changing the color of plastic materials, [tempering labeling of steel and titanium, foaming plastic materials.

Laser

Acronym for Light Amplification by Stimulated Emission of Radiation. It actually means: Light amplification through stimulated emission of radiation. The acronym laser describes the physical procedure of the laser principle: laser light occurs when a photon causes an excited atom or molecule to emit another photon. The emitted photon has the same wavelength and the same phase position as the first photon. The term laser is often a synonym for beam source or laser beam.

Laser forming

Also: direct laser forming. Procedure for layerwise construction of parts from metal powder.The laser beam always melts the component cross-section. The part occurs layer by layer.

Laser fusion cutting

Slitting process for meltable materials, mainly metals. The laser beam melts the workpiece continuously along the part contour. An inert active gas like helium, argon or nitrogen is blown in the kerf with high pressure and removes the melt.

Light

Physically seen: electromagnetic radiation with a specific wavelength. The term mainly stands for the visible spectrum (480 to 780 nano-meter) and also comprises the infrared and ultraviolet range of the electromagnetic spectrum.

Mode

Proper distribution of power density in the laser beam occurring as a result of optical resonance in the resonator. The basic mode is the Gauss mode. Higher-level modes are also applicable, the ring mode and the overlap of modes, the so-called multimode for example.

Monochromatic

One color. Property of the laser light: all electromagnetic waves in the laser beam have the same wavelength.

Plasma

State of matter that lies over the gaseous form seen as regards the energy. The components of a material are present in atomic, ionized form. Plasma is the subproduct in material processing. For example, metal plasma absorbs CO_2 laser beams and thus influences the processing.

Polarization

Direction of swinging of the light waves. One differentiates between unpolarized laser light where the light waves swing incidentally (statistically) in various directions, linear polarized where the direction of swinging is in one plane and circular polarized where the direction of swinging rotates. Unpolarized and circular polarized laser light is mainly used in material processing. Some laser types generate linear polarized laser light. This is converted into circular polarized laser light using so-called phase shifter mirrors.

Power

Also: laser power. Parameter of the laser beam and parameter for material processing. Power is defined as energy per time. Or graphically seen: The laser power corresponds to the energy of all photons in the laser beam which pass on a specific monitoring point within a second.

Power density

Also known as intensity. Parameter of the laser beam and parameter for material processing. The power density is defined as power per surface. The power density is the greatest in the focus.

Process parameter

Influencing variables allowing the processing. Examples are: laser power, laser density, focal diameter, focus position, processing speed and operating mode.

Processing optics

The processing optics focuses on the laser beam through mirrors or lenses. It also contains interfaces to the machine, for example, for sensors and can supply fillers and additional gasses. Processing optics can be structured extremely differently and are mostly specialists for one procedure.

Pulse operation

Operating mode of the beam source. Unlike the continuous wave operation, the active medium is not excited continuously but in pulses. It emits a laser beam that is interrupted depending on the time. Important parameters for material processing are: duration and energy of such a laser pulse as well as the pulse frequency.

Pumping

It means excitation of the active medium. Energy is supplied to the active medium during pumping, either optically, electrically or through a chemical reaction. The objective is to generate a filling inversion in the active medium. Then there are more atoms and molecules in the excited state than in the basic state and the laser process can take place.

Rayleigh length

The Rayleigh length is a dimension for the sharpness depth of the focused laser beam. It indicates the distance from the focus at which the cross-section surface of the laser beam has doubled against the cross-section surface in the focus. The double Rayleigh length is often known as sharpness depth by users.

Reflection

Reflection. In the laser technology: reflection of laser light on limit layers. Examples: The workpiece surface reflects a large part of the laser light during processing. In the glass fiber of the laser light cable, the laser beam is guides through total reflection.

Remelting

Procedure for surface treatment of metals. The laser beam continuously melts the workpiece surface. A new joint (new crystallization) is formed during freezing. This joint is finer, more uniform and shows changed properties, such as higher wear resistance and higher corrosion resistance.

Removing

Procedure used for labeling and generation of depressions. The laser beam removes the basic material or a cover layer.

Resonator

Generally: system that is capable of swinging and swings especially strongly is it is excited with the individual frequency. In the laser technology: system that is capable of swinging for laser light. The resonator mostly consists of two mirrors. The mirrors ensure that the laser beam always passes through the active medium and is thus amplified. The resonator thus also determines the direction of divergence of the laser beam.

Shielding gas

Gas used to protect the processing result from undesired reactions with the ambient air. During welding, the inert gas shields the surface of the weld seam from the ambient air and prevents its oxidation. Insert gasses are used as helping gasses.

Solid-state laser

The common laser type in material processing. The active medium is a doped crystal or a doped glass. Typical examples are: Nd:YAG and Yb:YAG (Neodym-doped and Ytterbium-doped Yttrium-Aluminium garnet) as well as Yb:glass. There are more, such as Nd:YVO4 (neodymium-doped yttrium-vanadate). The wavelength of a solid-state laser mainly depends on the doping material and has around 1 millimeter for the specified mediums.

Wavelength

Vibration property. With reference to the laser technology: property of the laser beam. The wavelength indicates the distance between the two wave crests of an electromagnetic wave. The unit of wavelength is meter.

Welding

Thermal joining process. Heat conduction welding and deep welding of metals as well as through-radiation welding of plastics are some of the laser welding processes.

Working distance

The distance between the housing of the processing optics and the workpiece. It varies from procedure to procedure. During fusion cutting, the distance is only 1 to 2 millimeters, so that the cutting gas flows into the kerf.

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