

Cutting with light

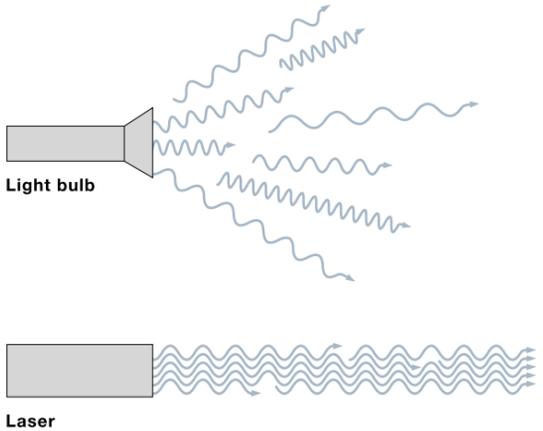
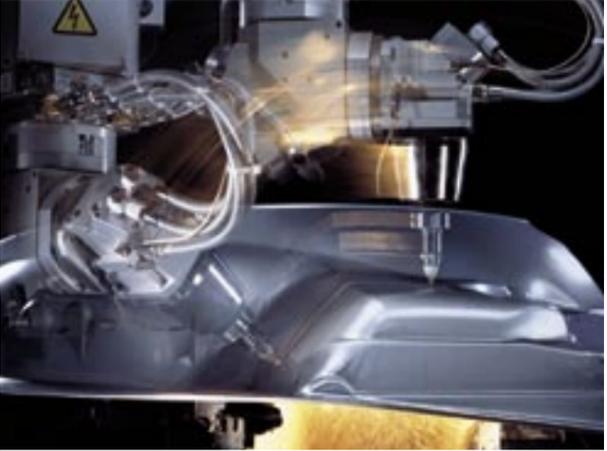
WHAT MAKES LASERS SO SPECIAL?

Many sheet metal processing techniques rely on massive tools that apply enormous mechanical forces to the material. Laser beams, however, are different. They can cut the material without even touching it. The light waves are absorbed by the material and converted into heat. The sheet becomes hot, melts, vaporizes, or it burns. For a better understanding of how this tool works, let's first take a closer look at the laser beam itself.

From 1917 to today | The term "laser" was first coined in the U.S. and is an acronym for "Light Amplification by Stimulated Emission of Radiation." In 1917, Albert Einstein's description of the principle of stimulated emission laid the theoretical groundwork for laser physics that is still valid today. It wouldn't be until decades later, however, that the first laser was actually built: a ruby laser invented by Theodore H. Maiman in 1960.

The advent of the first laser beams produced a flood of ideas on how to use the new lasers. Yet only very few of these ideas could indeed be put into practice using the laser technology that was available at the time. Today, lasers are mass-produced articles. You can find them in DVD players, CD players, scanners, and even laser presentation pointers. Nowadays, lasers also play an integral role in medical technology and telecommunications.

In the early 1970s, lasers were integrated for the first time into existing machinery as cutting tools. Machine manufacturers were instrumental in helping the new technology gain acceptance. They began developing and producing their own laser units in the mid-1980s. The laser's increased performance and ability to cut increasingly thicker material at higher speeds helped to expand its range of applications.



The difference between light from a bulb and light from a laser

- 1 A laser at work
- 2 The power density distribution of a laser beam is illustrated by a beam fired into a piece of plexiglass.

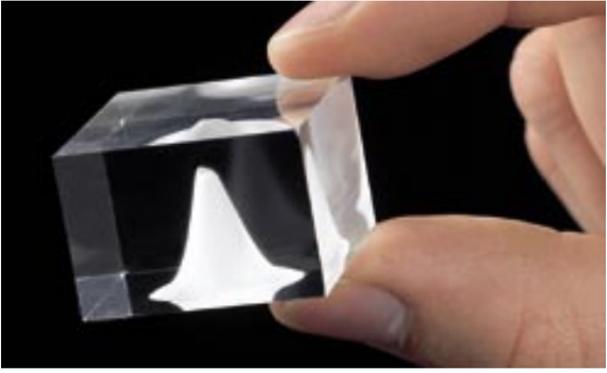
Laser light is different A light bulb emits light that is made up of different wavelengths. The energy is distributed over a large area in all directions. The light waves of a laser beam, however, all have the same wavelength and are almost perfectly parallel. Laser light, therefore, is said to be monochromatic and directional. Laser beams have a high energy density and can be focused to a small point.

	Light from a bulb	Laser light
Creation	Spontaneous emission	Stimulated emission
Wavelength	Different wavelengths (polychromatic) in the visible and infrared spectrum	One wavelength (monochromatic)
Divergence	Radial, in all directions	Directional: photons move almost perfectly parallel to one another
Coherence	No	Yes: photons are all in phase
Power spectrum	20 to 200 watts	200 to 20,000 watts in continuous wave mode and peak power of up to 50,000 watts in short pulses
Smallest focus diameter	Several millimeters	One to five tenths of a millimeter
Power density at focus	100-watt bulb: 0.08 watts per square centimeter	100-watt laser: 800,000 watts per square centimeter

Properties of laser light and the light from an ordinary bulb

The properties of laser light | The laser beam itself is not able to do anything. Before it can be used as a tool, it has to be directed, shaped, and focused. The properties of laser light make lasers well suited to this type of manipulation:

- **Wavelength** | Laser light is monochromatic. This means that all light waves have the same wavelength.
- **Coherence** | The light waves in the laser beam are all "in phase", or in step with each other.
- **Low divergence** | The light waves are almost perfectly parallel. This means that the laser beam diverges to only a small degree.
- **Power density** | The power density of a laser beam greatly exceeds that of other conventional light sources.
- **Internal structure (mode)** | The power density in the laser beam can be structured differently. Cutting generally involves the use of a beam whose power is concentrated at the center of the beam cross section and gradually diminishes toward the edges (Gaussian distribution).



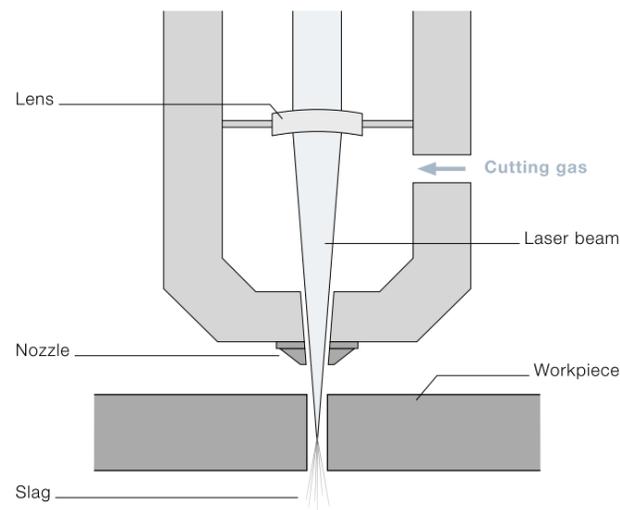
Cooking with sunlight A device invented to catch the sun's rays and focus them for cooking shows just how much energy is contained in ordinary sunlight. The focal point of a mirror shaped like a satellite dish serves as the hot plate. The parabolic shape of the mirror causes the rays of sunlight to be focused on a single spot. Unlike a satellite dish,

however, which has a receiver unit at its focal point, the parabolic mirror has a frame on which you can place a cooking pot. The invention has found use in development projects carried out in regions of Africa where firewood is scarce.

CUTS THROUGH THICK STEEL LIKE BUTTER

When used for cutting applications, the laser beam has to be focused. Once focused, its entire power is directed at one single point whose diameter is usually less than one half of a millimeter. When the focused beam strikes the workpiece, the metal located under the beam immediately begins to melt. In some cases, the metal starts burning or simply vaporizes. It takes virtually no time at all for the laser beam to pass completely through the material.

After the laser has pierced the material, cutting can begin. As the laser beam moves along the contour of the part, it continuously melts the material in its path. Molten metal and slag are blown out downward. The result is a cut that is scarcely wider than the focused laser beam itself.



The principle of laser cutting

The cutting process | The laser cuts sheets contour by contour. Inside sections of the part are always cut out before the outer contours.

The first step in cutting a contour is to pierce the material. The piercing point is generally a short distance away from the contour on the sheet skeleton. When the laser pierces thick sheets, material flies up. The resulting hole tends to be wider than the kerf. After piercing the material, the laser beam cuts its way toward the contour. After reaching the contour, the laser begins cutting the specified shape.

Cutting gas | Cutting gas, or assist gas, is needed to blow molten metal and slag out of the kerf. The cutting gas is forced into the kerf under pressure. The gas type and gas pressure have a great influence on both the cutting process and cutting results.



- 1 Nozzles are used to shape the cutting gas flow.
- 2 Lasers can be used to cut intricate figures or steel that is several centimeters thick.

THE LASER IS HERE TO STAY

Laser cutting is still a relatively new technology. In the mid-1980s, yearly sales of laser systems had only just hit the two-digit mark. In the years to follow, sales grew at a tremendous rate. By the end of the 1990s, leading manufacturers were selling several hundred laser cutting machines per year. The trend continues today.

Laser cutting has now assumed its rightful place among other cutting technologies such as punching, nibbling, water jet cutting, and plasma cutting. Indeed, consider the many advantages that laser cutting has to offer:

- Almost any shape can be cut using a single tool.
- Lasers cut the material without actually touching it.
- One machine can process a wide variety of sheet thicknesses from 0.5 to more than 30 millimeters.
- Laser cutting is very precise and fast, while producing only a small kerf.
- The material next to the kerf is heated only slightly, which prevents the parts from becoming warped.
- If the parameters are set optimally, lasers are able to produce high-quality cut edges with minimal roughness and without burrs. This means that burrs no longer need to be removed.

ONE TOOL, MANY PROCESSES

The quality and the price of the cut vary considerably. Different cutting gases and pressures influence both the process and the cutting results. As is often the case in manufacturing, opting for fast and economical production usually means having to accept a lower quality cut.



Flame cutting | For flame cutting, oxygen is used as the cutting gas. The oxygen is blown into the kerf at pressures of up to 6 bar.

In the kerf, the molten metal reacts with the oxygen and begins to burn and oxidize. This chemical reaction releases large amounts of energy. The energy, in turn, assists the laser beam in its work. Flame cutting makes it possible not only to cut thin sheets at high speeds, but also to handle jobs involving thick plates such as mild steel with thicknesses in excess of 30 millimeters.

The disadvantage to flame cutting is the cut edge, which is covered with an oxide film. On mild steel, the oxide film has to be removed before a finish or powder coating can be applied, otherwise the finish or coating will not adhere properly to the surface. Without a protective coating, the metal is not corrosion resistant.

1 Fusion cutting produces oxide-free cut edges.

The oxide film also adversely affects the level of corrosion protection on stainless steel and can cause welding problems. As a result, it may be necessary to rework the edges.

Conclusion: flame cutting is faster and more economical than fusion cutting on mild steel. Flame cutting can also be used if having an oxide film on the cut edge is not an issue or if the costs for flame cutting plus reworking are less than those involved in using other cutting techniques.

Laser fusion cutting | Fusion cutting involves the use of gases such as nitrogen or argon. The gases are blown through the kerf at pressures ranging from 2 to 20 bar. In fusion cutting, the cutting gas does not react with metal surfaces in the kerf, as is the case in flame cutting. For this reason, the gas is said to be inert. The gas is used to blow molten metal out of the kerf and keep air away from the cut edge. Nitrogen is suitable for most types of metal except for titanium. Since titanium reacts violently with both oxygen and nitrogen, argon is used to cut this metal.

The advantage of fusion cutting is that it produces oxide-free cut edges. This means the edges do not have to be reworked. At the same time, however, the laser has to rely on its own energy for cutting. For this reason, cutting speeds as high as those in flame cutting can be achieved only in thin sheets. Piercing is also more difficult. Some cutting systems, however, allow you to use oxygen to pierce the material and then switch over to nitrogen for cutting.

Conclusion: fusion cutting produces oxide-free edges without burrs. It yields a higher-quality cut but takes longer and is more expensive due to higher gas and energy costs.

Compressed air | For those who want to avoid buying gas, compressed air can be used to cut thin sheets. Air

compressed to 5 to 6 bar is sufficient to remove the molten metal from the kerf. Since air is composed of almost 80 percent nitrogen, this means that air-assisted cutting is actually a type of fusion cutting.

On the surface, compressed air cutting seems to offer a more economical alternative to nitrogen cutting. Air, after all, is free. All you have to do is compress it, dehumidify it, and remove any oil that may be present. However, the cost advantage compared to using nitrogen is a relative one. The cut edges are rougher than those produced by fusion cutting. Also, the available pressure of the compressed air system and the laser power are what determine the thickness of the sheet that can be cut. For example, 5 kilowatts of laser power and 6 bar of compressed air are sufficient to cut a 2-millimeter thick sheet without leaving burrs. Air-assisted cutting works best on aluminum.

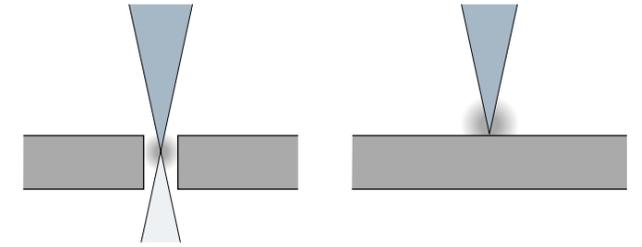
Conclusion: comparatively speaking, cutting with compressed air is fast. Nevertheless, it produces a lower-quality edge and is not always the most economical method.

Plasma-assisted cutting | All of the techniques described up to now involve blowing the molten metal immediately out of the kerf. Plasma-assisted fusion cutting using CO₂



1

Light that knows no bounds Laser beams can be focused over large distances. For example, using a focusing mirror with a diameter of 1.5 meters, you could focus a fundamental-mode CO₂ laser beam on a kettle 25 kilometers away and cause the water inside to boil. If you were to send this same beam to the moon – don't forget, that's 400,000 kilometers away – it would have a diameter of 3.2 kilometers by the time it finally reached its destination.



Left: plasma inside the kerf increases absorption of the CO₂ laser beam. Right: plasma over the kerf blocks the laser beam.

sheet thickness depends on the laser power. A 6-kilowatt laser, for example, can handle a 4-millimeter thick aluminum sheet. Conclusion: plasma-assisted cutting is good for high-speed cutting when the roughness of the part edges is not a crucial factor.

lasers, however, works differently. This technique takes advantage of an effect that also occurs during laser welding: the formation of a plasma cloud composed of ionized metal vapor and ionized gas in the kerf. Plasma arises when slag, molten metal, and gas accumulate in the kerf. For a long time, plasma was regarded solely as a nuisance or warning sign. This is because breaks in the cut would usually occur shortly after the appearance of the plasma cloud. The laser beam no longer passed through the material, and the machining error made the part unusable.

Later, people noticed that you could cut even faster with plasma if the parameters were set right. The plasma enables more energy to be channeled into the workpiece, causing it to melt more quickly. This technique permits cutting speeds of 40 meters per minute and more, although the cut edges are rougher than those produced by fusion cutting. The maximum

Other applications	Description	Application
Microjoints	Small connecting tabs are left in the contour to keep parts from falling out of the sheet skeleton. The parts are later removed by hand.	Prevents displacement of parts on thin sheets resting on a single support slat. Automated unloading: parts are removed from the machine together with the sheet skeleton.
Microweld spots	The cut part is reattached to the remainder sheet with one or more tiny weld spots. The weld spot remains visible later on.	Prevents displacement of parts in sheets of medium thickness. However, only suitable for parts that do not require perfect edges.
Marking and center marking	The laser beam removes the surface material or alters its color to create a mark.	Labeling parts. Marking joining points or holes to be drilled.

An overview of other applications showing the incredible versatility of laser cutting machines

TWO LASERS FOR CUTTING

CO₂ gas lasers and solid-state lasers are firmly established tools in the field of industrial material processing. Both deliver the high power, proper wavelength, and good beam quality required for laser cutting. In addition to this, laser units and machine components have now become so sophisticated that they are able to operate reliably even in multiple production shifts.

CO₂ gas lasers | “A true workhorse” – this is probably the most fitting term to describe a CO₂ laser. With an output of up to 6 kilowatts, CO₂ lasers can cut sheets that are anywhere from 0.5 to more than 30 millimeters thick. CO₂ lasers achieve their peak power in continuous wave mode. A variety of lower power levels can be attained by switching from continuous operation to operation in short bursts, or pulses. In this case, the laser power is calculated on the basis of the pulse frequency, duration, and power.



1

The light of a CO₂ laser has a wavelength of 10,600 nanometers, putting it in the far-infrared spectrum. The light is created in a gas mixture made up of carbon dioxide (CO₂), nitrogen (N₂), and helium (He). The carbon dioxide molecule emits the laser light, while the other gases support the laser process. Mirrors are usually used to deflect the beam, which is then focused with a lens or mirror.

Solid-state lasers | Solid-state lasers are ideal for delicate and intricate work, but can also be used to cut steel sheets with thicknesses of up to 10 millimeters. The laser light of solid-state lasers is generated in doped crystals such as yttrium aluminum garnets with individual neodymium or ytterbium ions integrated into their structure. The wavelength of the laser light depends on the type of laser-active ions involved. Thus, the wavelength is either 1,030 nanometers (ytterbium) or 1,064 nanometers (neodymium), putting it in the near-infrared spectral band and outside the visible spectrum.



2

These wavelengths allow the laser beam to be transported via fiber optic cables, which, in turn, make it possible to send the beam from the laser unit to the workstation without any loss of power or beam quality. Beams are typically transported anywhere from 10 to 50 meters. Distances over 100 meters are also possible.

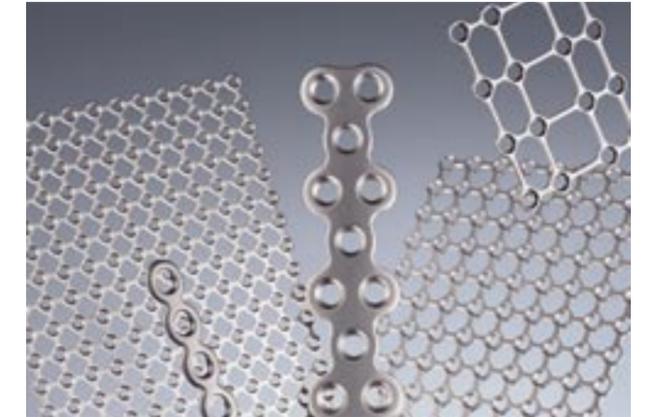
For cutting, solid-state lasers rely on an output of 0.2 to 3 kilowatts. Solid-state lasers are frequently used in pulsed mode. The pulses can attain a peak power of up to 50 kilowatts, which is higher than the maximum power of the CO₂ laser. Short, powerful pulses of a few kilowatts are used to cut delicate contours, which are accurate to a tenth of a millimeter for high-precision products such as medical implants or electronic components. Peak pulses of up to 50 kilowatts are used primarily for drilling.

CUTTING A WIDE RANGE OF MATERIALS

The concept is simple: if the laser beam can melt the material, then it can also cut it. The material first has to be heated locally to its melting point. For this to work, a sufficient amount of laser energy has to be absorbed by the material. At the same time, however, the heat should not dissipate too quickly. The material's absorption capability and heat conductivity determine how well the material can be processed by the laser.

Steel | Among unalloyed and high-alloy steel sheets, mild steels and stainless steels produce some of the best cutting results. This is because iron and alloys such as chromium and nickel absorb laser energy well, while exhibiting a relatively slow rate of heat dissipation. Steel manufacturers now also offer special fine-grained steels that are optimized for laser cutting applications.

- 1 Square design: a 6-kilowatt flowing gas CO₂ laser
- 2 A low-power solution: a diffusion-cooled CO₂ laser
- 3 Intricate medical implants require the delicate touch of a solid-state laser.
- 4 A disk laser is a common type of solid-state laser.



3



4

Non-ferrous sheet | Aluminum alloys, titanium, and titanium alloys all produce good cutting results. CO₂ lasers, however, can cause burr formation if they are used to cut pure aluminum sheets thicker than 6 millimeters.

- 1 In the case of solid-state lasers, the beam is routed through a fiber optic laser cable.
- 2 Lasers can be used to cut other materials such as semiconductors.

Copper, copper alloys, and precious metals | Metals such as these present a real challenge to CO₂ lasers: they have a high level of heat conductivity but absorb hardly any of the laser beam energy, meaning that the CO₂ laser beam is largely reflected. The wavelength of solid-state lasers, on the other hand, is absorbed better. That is why solid-state lasers are used in the jewelry industry for processing gold and silver.

Exotic materials | Lasers are able to cut more than just metals. CO₂ lasers can be used to cut cardboard, wood, leather, ceramics, glass, and plastics. Solid-state lasers, meanwhile, can cut silicon for semiconductors. Cutting these materials, however, produces gases and hazardous substances that are different from those produced when cutting sheet metal. This makes the use of special laser cutting machines necessary.



1

THE QUALITY OF THE CUT

Process technicians use both measurable and optical criteria in order to determine the quality of the edge that is cut by a laser. Measurable criteria include roughness, perpendicularity, and kerf width. When optical criteria are used, a person simply takes a close look at the part and describes its appearance in words. Such optical criteria include burr formation, pitting, striations, erosion, and the heat-affected zone (HAZ) of the material.

Keeping it practical | Both optical and measurable criteria need to be taken into account in order to obtain a clear picture of the cut quality. The first step in doing this is to decide which criteria are important for the function of a part. Afterwards, the part can be examined according to the criteria and the cutting process optimized. So which criteria are relevant to which situations?



2

ELECTRICITY FOR 140,000 PEOPLE

Everyone knows where electricity comes from: the electrical wall outlet. Later on in school, we discover how electricity is actually produced: generators, we are told, convert mechanical energy, or movement, into electric energy. So what do generators have to do with lasers? Günter Seidel, Laser Coordinator at Siemens Power Generation's generator manufacturing plant in Erfurt, Germany, explains: "Laser beams are used to cut the sheet metal parts that go to constructing the outer casing, stator, and rotor of a new generator." Inside the generator, the stator produces a magnetic field in which the rotor turns. Up to 85 megawatts of electricity are generated in the rotor, depending on the size of the Erfurt generator. "That's enough energy for a city with 140,000 inhabitants," says Seidel.

The stator and parts of the rotor are made up of thousands and thousands of sheets. "We build generators that are up to nine meters long. The stator assembly alone may comprise as many as 160,000 individual sheet metal parts," explains Günter Seidel. These sheet metal parts are circular segments with teeth on the inside or outside like a comb. Positioned between the components, there are coils that generate the magnetic field and produce the electricity.

Parts are made from 0.5 to 1-millimeter thick sheets with a high silicon content. These electrical sheets, as they are sometimes called, have excellent magnetic properties. To prevent a short circuit in the generator, the sheets are coated with a thin finish. The parts must meet very strict standards. Seidel summarizes: "Edges have to be perfectly burr-free, and the kerf must be uniform. Tolerances are around 0.05 millimeters."

"Even though laser cutting is already several decades old, there is still something glamorous about it in a modern, high-tech sort of way. Some of the old hands in the industry are still amazed when they see just how fast some of the cutting strategies are. I'm still always impressed by the speed and elegance with which the cutting head moves and the apparent ease with which the laser beam slices through centimeter-thick sheet."
Jörg Müller, Documentation



Power generators can have up to 160,000 sheet metal parts.

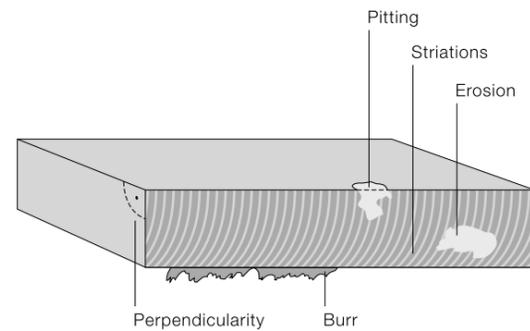
For a long time, only punch presses could deliver this degree of accuracy. Today, this is done using laser cutting machines. The flexibility of laser cutting is a big advantage. Lasers can cut both large circular segments and segments for smaller generators. "This saves us the trouble of having to deal with multiple punching tools," says Seidel. His plant has a laser cutting machine with two cutting heads which produces two parts at the same time. This has doubled the number of parts that can be manufactured per time unit.

The laser cutting machine has changed things a lot. "We can now manufacture and test new designs very quickly, since we no longer need to use punching tools," says Seidel. Manufacturing replacement parts is another area. "Occasionally, we'll cut replacement parts for generators whose punch templates were thrown away long ago. No doubt about it: lasers have become an invaluable tool for us."

- 1 Different techniques, different results: fast and rough with plasma-assisted fusion cutting (rear) or slow and smooth with conventional fusion cutting (front).



1



Good cut, bad cut. Criteria for evaluating the quality of the cut edge.

Roughness | As the laser beam cuts the contour, vertical striations are formed on the cut surfaces. The depth of these striations is referred to as “roughness”. The roughness affects both the appearance of the edge and its function. An attempt should be made to minimize the degree of roughness if the visible edges are not going to be reworked after being cut or if the cut surfaces slide against other components in the finished product. The average roughness of thin sheets up to 4 millimeters is very low – usually less than 10 micrometers. The resulting degree of roughness, however, increases with the sheet thickness.

Perpendicularity | The perpendicularity of the cut edge is especially important on parts with a sheet thickness over 10 millimeters. It describes the degree to which the cut edge deviates from the vertical. For example, it is possible to cut a 10-millimeter thick sheet, while maintaining a vertical deviation of only 0.1 millimeters.

Kerf width | The kerf width ordinarily does not affect the quality of the cut part. It becomes an important factor, however, when particularly delicate contours or slits inside the part are cut. As the sheet thickness increases, so does the kerf width. On materials only a few millimeters thick, the kerf width is around 0.15 millimeters. On sheets thicker than 20 millimeters, the kerf width can grow to half a millimeter.

Striations | When working thick sheets at high cutting speeds, the molten metal no longer exits the kerf vertically from under the laser beam but, instead, comes out slightly behind the beam. As a result, curved striations are literally left in the wake of the laser beam as it moves forward during the cutting operation.

What does Hollywood know about lasers? Film stars just love pulling out a laser when they’re in a pickle. Take James Bond, for instance. In one of the older films, he used a red laser beam to cut open a steel door. Unfortunately, you can’t believe everything you see in the movies, no matter

how great the special effects are. An unfocused laser beam without cutting optics or cutting gas simply cannot cut through steel. Brandishing a red laser presentation pointer is not going to help you either.

The degree of striation is a factor used in evaluating the quality of the cut. Nevertheless, it is usually not relevant to the function of the part.

Even so, striations can cause problems during processing. When a hole is cut, for example, dross may adhere to the lower part of the cut. To correct this problem, the feed rate is reduced at the end of the cut to eliminate striations.

Burr formation | Burr formation is one of the most important factors in determining the quality of a laser cut, since removing burrs from cut edges always requires an additional work cycle. Laser cutting can produce a variety of burr types, from brittle slag, which is easy to remove, to sharp metal burrs firmly adhering to the bottom of the cut.

Pitting and erosion | Signs of pitting or erosion can adversely affect the surface of the cut edge. They detract from the appearance of the edge and are among the main cutting errors that should generally be avoided. The quality of the sheet can also play an important role: lower-grade sheets may contain foreign substances such as sulfide, which can burn uncontrollably, causing pitting or erosion.

Heat-affected zone (HAZ) | During processing, parts of the workpiece can get very hot and become discolored or deformed. The area of the workpiece affected by the heat is called the heat-affected zone. In laser cutting, however, this zone is only a few tenths of a millimeter in size and normally does not play a role in the function of the part.

ONE BEAM – MANY PARAMETERS

Laser cutting is a complex process influenced by numerous parameters. A number of parameters are determined by the

technical data and design of the laser cutting machine. Those that aren’t, however, have to be specified and optimized by the operator and programmer. Important parameters are:

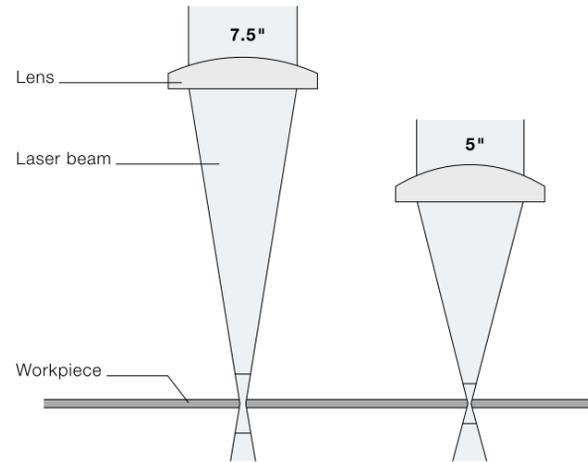
- Machine parameters such as the lens focal length and nozzle diameter
- Laser parameters, including, for instance, the laser power and operating mode
- Process parameters such as cutting speed, gas type, gas pressure, and focus position
- Workpiece parameters such as material thickness, surface, alloy, and workpiece geometry

Some of these parameters can have a strong influence on the cutting results and are examined below.

Lens focal length | The lens in the cutting head focuses the laser beam before it hits the workpiece. For laser cutting, lenses with different focal lengths are used for various material types and thicknesses. The focus diameter and depth of focus – sometimes also called depth of field – are key factors to consider when choosing a lens.

The lens focal length is a measurement of the distance from the lens to the focal point. At the same time, it determines the focus diameter and depth of focus. The following rule applies here: the smaller the focal length of the lens, the smaller the focus diameter and depth of field. Typical lens focal lengths range from 3.75 to 10 inches. 5-inch lenses are used for material thicknesses up to 3 millimeters and a laser power of 5 kilowatts. 7.5-inch lenses with a larger focus diameter and a greater depth of field are used when processing sheets of greater thickness.

Concentrated energy Laser light has a high degree of focusability. The power of a 2.6-kilowatt CO₂ laser can be concentrated on a single spot with a diameter of 0.15 millimeters, resulting in a mean power density of 15 megawatts per square centimeter. By comparison, a 1-kilowatt hot plate with a diameter of 15 centimeters has an intensity of 5.6 watts per square centimeter. This means the intensity of the laser is roughly 2.7 million times greater than that of the hot plate.

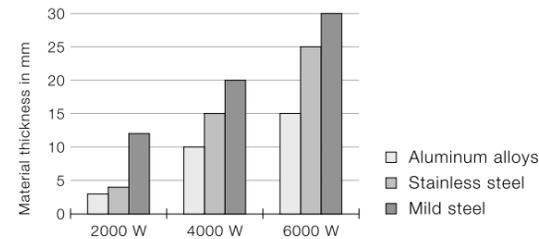


The focal length determines how intensely the laser beam is focused.

Nozzle diameter | During laser cutting, the cutting gas is blown out through a nozzle. The diameter of the nozzle determines the amount of gas exiting the nozzle and the shape of the gas flow. When thin sheets are cut, all that is needed is a fine stream of gas to blow molten metal and slag out of the kerf. The thicker the material is, the larger the diameter of the gas jet has to be.

For this reason, a variety of nozzles with different diameters are frequently utilized. Diameters between 0.6 and 3 millimeters are common. They are suitable for use with both oxygen and nitrogen.

Laser power | The power needed for cutting depends on the type and thickness of the material. This is why the laser power always has to be adjusted. The peak power is also the



A higher laser power makes it possible to cut through thicker material.

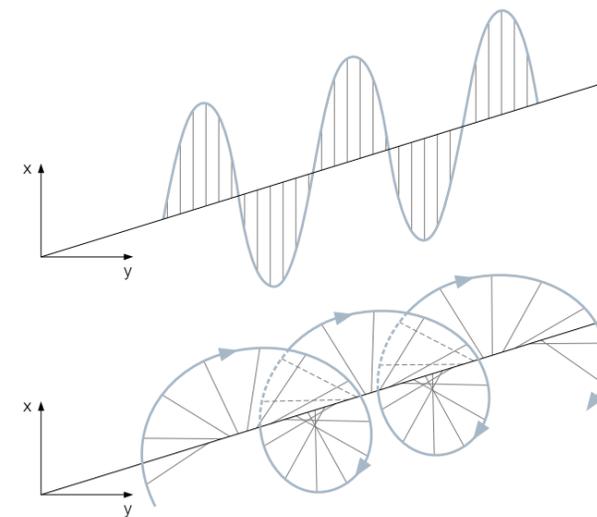
maximum power of the laser. Power levels can be adjusted to any output under this amount. Low laser power from 80 to 180 watts can also be used to produce markings on a part, such as ID numbers. Other applications include center marking or vaporizing the foil on foil-coated stainless steel sheets.

Beam quality | The beam quality is an indication of how well the laser can be focused. Laser manufacturers design their laser units so that they produce beams of high quality. The beam quality depends on the laser; there is no way to improve the quality outside of the laser.

Degree of polarization | Polarization refers to the direction in which light waves oscillate in a laser beam. Some CO₂ lasers produce linearly polarized laser light in which the sinusoidal light waves all oscillate in a direction perpendicular to their direction of propagation. When contours are cut with this type of laser beam, different results are obtained depending on the direction: if the light oscillates parallel to the cutting direction, the edge will be smooth. However, if the light oscillates perpendicular to the cutting direction, burrs are produced. In extreme cases, the laser is not even able to cut the material.

For this reason, circularly polarized light is used for cutting with CO₂ lasers. This kind of light oscillates in circular fashion with respect to the direction of propagation, enabling good cuts to be achieved in any direction. Specially coated bending mirrors change the linearly polarized light into circularly polarized light. The degree of polarization is crucial for the cut quality. It shows the degree to which circular polarization has been reached and is usually around 90 percent.

The polarization does not have to be changed when solid-state lasers are used. As a result of having been routed through the fiber optic laser cable, the light waves already oscillate in different directions. The laser beam, in such a case, is said to be “stochastically polarized”, making it possible to cut in any direction.



Linearly polarized (top) and circularly polarized (bottom) laser light

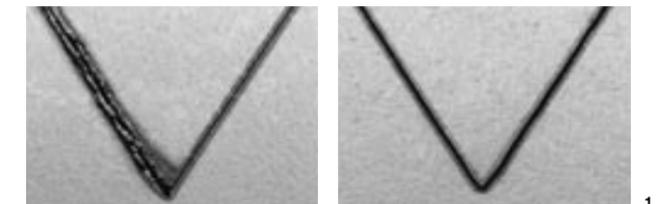
1 Left: linearly polarized laser light produces an irregular edge. Right: circular polarization ensures a uniform cut.

Cutting speed | Finding the right balance of laser power and cutting speed for the workpiece is crucial. A cutting speed that is too high or too low can increase the roughness of the contour and cause burr formation. In extreme cases, excessively high cutting speeds can prevent proper cutting of the material, leading to breaks in the cut. As a general rule, the cutting speed decreases with increased sheet thickness.

Operating mode | Most lasers emit light in two different ways: either as a continuous beam or in short bursts, or pulses. The parameters of pulsed mode are pulse power, pulse duration, and pulse frequency.

High pulse frequencies produce several thousand pulses per second. This type of pulsed operation allows continuous adjustment of the laser power to meet the requirements of the particular task at hand. Here's an example: a CO₂ laser generates 1,000 pulses per second, each with a duration of 0.1 milliseconds, and 5 kilowatts of power. After each pulse, there is a short pause during which the laser does not emit any light. The power of the 5-kilowatt laser is then reduced to only 0.5 kilowatts, or 10 percent of its power.

Low pulse frequencies are used to cut delicate contours having a diameter and web width that are considerably smaller than the sheet thickness. An example of such a contour is shown by the centering ring below. The projections of the



1 One delicate cutting job: the projections of this centering ring are only 0.16 millimeters wide.

ring are only 0.16 millimeters wide. The sheet thickness, on the other hand, is 1.5 millimeters. The laser cuts the projections using 10 pulses per second and a very low-range medium power. Long pauses between the pulses allow the heat to dissipate into the surrounding material.

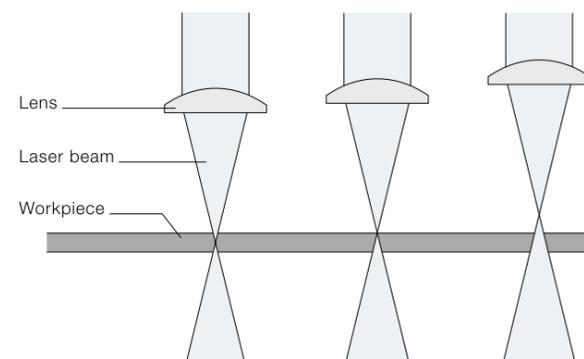
Gas purity and gas pressure | The purity and pressure of the gas also influence the cutting result.

For flame cutting with oxygen, the gas has to be very pure. As little as 0.4 percent nitrogen is sufficient to cause burr formation. Types of gas that are sold specially for laser cutting provide a gas purity of 99.95 percent. On steels commonly used today, the greater the material thickness, the lower the gas pressure that is used. This is because thin materials are normally cut at high speeds. The high gas pressure ensures that the molten metal is blown fast enough out of the kerf. On thicker sheets, the gas pressure is reduced to prevent uncontrolled oxidation, which can lead to cutting errors.



For fusion cutting with nitrogen, the gas has to be even cleaner. A purity of 99.995 percent (or, ideally, 99.999 percent) is required to prevent oxidation of the cut surface, which can be caused by even the most minute traces of oxygen (0.02 percent). Unlike flame cutting, fusion cutting involves the use of a higher gas pressure for thicker material. This means a higher flow rate is required to blow the viscous molten metal out of the kerf.

Focus position | The focus position has an effect on the processes that occur in the kerf and influences the shape of the kerf. The focal point is the spot with the greatest intensity and power density. After this point, the beam begins to spread out and the power density diminishes. For flame cutting, the focal point is located close to the surface of the material. For fusion cutting, meanwhile, the focal point is located deeper in the material. In both cases, the optimum focus position depends on the material used.



Focus position: in the part, on the surface, and above the part

Thinner sheets mean faster cutting Once a laser machine has begun to cut a large number of complex parts from a 20-millimeter thick sheet, all that is left for the operator to do is sit back and relax for the next couple of hours until the machine is done. However, if the sheet is the same size, but only 2 millimeters thick, the operator will have to hustle to get the machine loaded and unloaded. The machine is usually ready for the next sheet after only a few minutes.

MEASURING, CUTTING, AND WELDING

As if by magic, an automotive body shell glides into a production cell where an optical measuring device and two robots are waiting. The measuring device starts measuring the length and position of the main chassis beams on the left and right sides of the engine compartment. Afterwards, the robots cut the chassis beams to size and weld the bulkhead plate to each beam. After roughly a minute, it's all over. The cell opens up, and the next vehicle glides in.

Klaus Löffler, Head of Joining Processes at VW in Wolfsburg, Germany, was involved in designing the production cell and believes it offers many benefits. "Lasers have become an integral part of production at VW. The production cell shows just how profitable combining optical technologies can be."

When the car body rolls into the production cell, the length of the chassis beams may vary from vehicle to vehicle by around a millimeter. The position of the bulkhead plate, however, has to be accurate to 0.1 millimeter. "The measurement system and automatic adjustment of the cutting and welding programs have replaced the meticulous alignment work that used to be necessary, while allowing greater tolerances in earlier production steps," reports Klaus Löffler.

Although the cutting process may seem simple, it involves some specific challenges. "The cut has to be perfect, so that we can start welding immediately without any reworking," says Löffler. That means the cut edges have to be square and spatter free and also have a rough surface. As the galvanized bulkhead plate is being welded, the zinc layer is vaporized in the seam, so the only place it can escape is through the striation grooves on the cut edge. The robots are each



Measuring, cutting, and welding in a VW production cell

equipped with cutting and welding optics offset from each other at 90 degrees, allowing them to perform both tasks. A fiber optic laser cable is attached to each set of optics. "The robots access the laser pool located 25 meters away via a laser network," explains the laser specialist. A sophisticated control system ensures that the laser units are fully utilized by other production stations during breaks.

"The use of combined production cells is an approach aimed at manufacturing the car body in a way that is cost effective, while adding the required level of precision in the last step," says Klaus Löffler. "It's an approach that gives you cost advantages and quality assurance all in one." And these are two very good reasons why production cells of this type featuring a measurement system and two combination cutting/welding robots are used on the production lines of several different models.

COMPUTERS MAKE IT POSSIBLE

Fortunately, the first laser cutting machines were built after the advent of NC and CNC technology. Without this technology, it would be nearly impossible to calculate, define, and control the complex array of laser cutting processes manually.

Programming software and control technology are still making life easier for programmers and operators today and one reason why they enjoy working with laser machines. These tools eliminate a great deal of the overall calculation work and make laser cutting more reliable and trouble-free.

General parameters															
Sheet thickness	mm	1	1.5	2	2.5	3	4	5	6	8	10	12	15	20	25
Lens focal length	inches	5	5	5	5	5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Nozzle diameter	mm	0.8	0.8	0.8	0.8	0.8	0.8	1.0	1.0	1.2	1.2	1.4	1.7	2.0	2.3
Cutting large contour															
Contour processing															
Laser power	W	1500	1200	1200	2500	2600	4500	5300	5700	5700	5700	5700	5700	5700	5600
Cutting speed	m/min	8.2	6.4	5.4	5.2	5	4.7	4.2	3.8	3.1	2.65	2.15	1.75	1.2	0.9
Gas pressure	bar	4.5	4.5	4.5	0.8	0.8	0.8	0.8	0.8	0.6	0.6	0.6	0.6	0.5	0.5
Contour approach															
Cutting speed	m/min									1.5	1.1	0.9	0.7	0.4	0.2
Cutting medium contour															
Contour processing															
Laser power	W									2000	2000	3000	3000	4000	5000
Cutting speed	m/min									1.8	1.6	1.5	1.2	1.1	0.8
Gas pressure	bar									0.8	0.8	0.8	0.8	0.6	0.6
Contour approach															
Cutting speed	m/min									0.7	0.5	0.5	0.5	0.65	0.3
Cutting small contour															
Contour processing															
Laser power	W	300	300	300	300	300	300	350	450	450	550	650	1200	1000	
Cutting speed	m/min	0.6	0.5	0.4	0.35	0.3	0.3	0.15	0.1	0.1	0.1	0.1	0.1	0.1	
Gas pressure	bar	4.5	4.5	4	4	4	4	2	3	0.8	0.8	0.6	0.6	0.7	

Technology tables contain the parameters and their corresponding values. Shown here is a table used for cutting steel with a CO₂ laser.

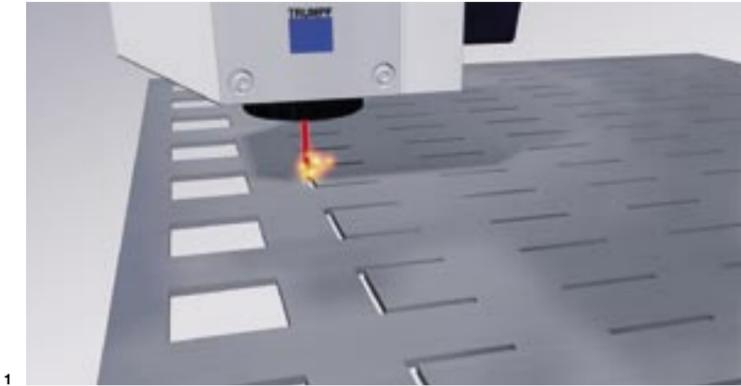
Programming software | Programmers use programming software to create the NC program required for the production job. All it takes is a few mouse clicks to nest parts, create common slitting cuts where needed, or add microjoints or microweld points to areas where parts might become displaced. The system automatically calculates the tool path of the laser. It specifies the processing sequence, puts piercing points in the right place, rounds sharp corners, and adds a few turns here and there. To do this, the programming software relies on the strategies selected by the programmer. The programmer, meanwhile, uses a simulation to see how the sheet will be processed. The complex, multidimensional movements of three-dimensional parts and tubes are also calculated automatically by the programming software.

To ensure proper cut quality, the NC program provides the control system with the necessary values for machining parameters such as cutting speed, laser power, and nozzle standoff. These values are stored in tables called “technology tables”, which are accessed by the system.

Technology tables | Technology tables form a type of knowledge base. They are created for each new material type and thickness. They contain consistent and reliable values for all machining parameters such as laser power and cutting speed. Other details that are taken into account are laser type, contour size, and lens focal length.

Each technology table has a number and is stored in the machine control. The table can be maintained and updated centrally and is available for use on any production job. Parameter values are no longer included in the NC program. Instead, the NC program is supplied with the number of the technology table containing the values. The control can then access these values during the machining process.

1 Doing it the fast way: instead of cutting out each square individually, the laser cuts all the sides arranged in a single line at one time.



Everything under control | The job of the control system is to carry out the instructions given in the NC program. It calculates the movements of the machine axes and adjusts the laser power and gas supply accordingly. Additionally, it receives measurement data and signals from sensors monitoring the cutting process.

One of the greatest challenges facing control engineers is to find the optimum balance of laser power and cutting speed. For example, when the laser beam is about to cut a corner, the cutting speed and the laser power have to be reduced at the same time.

Some cutting strategies require switching the laser beam on and off within fractions of a second while the cutting head moves quickly over the sheet. Here's an example: 25 squares with sides 10 millimeters long are to be cut from a sheet to create a series of ventilation openings. The squares are arranged in five rows of five squares each. One way to approach this job would be to cut each square out individually. It is much faster, however, to cut all the sides in a single

- 1 Lasers can cut tubes just as easily as they do sheets.
- 2 Brochure display rack: intelligent snap-lock design for easy assembly

row at one time. In other words, first the top sides of all the squares, then all the bottom sides, and then all the left and right sides. The start and end points of each cut must line up perfectly in order to produce precise shapes. To do so, the control system must switch the laser beam on and off with an accuracy of 100 microseconds (0.0001 seconds).

THE LASER ADVANTAGE: TUBES AND PROFILES

Many parts used in steel construction and metal/machine technology are manufactured from tubes and profiles and cut with lasers. Parts such as these include everything from furniture, frames, and railings to sports equipment.

In these areas, lasers offer a number of benefits. Laser cutting reduces the number of production steps, shortening the overall manufacturing process. Lasers are able to cut both holes and complex contours in a single work cycle and take care of the trimming, too. This makes laser cutting an ideal substitute for conventional procedures such as sawing, scribing, drilling, milling, and punching.



Innovative forms | Laser cutting enables the use of new tube constructions that simplify downstream operations.

Plug-in parts and snap-lock connections make assembling components easier and can be used instead of welding. If welding is still necessary, joining aids are available for reducing preparation times. Microjoints, meanwhile, make it possible for tubes to be bent by hand. These are only a few examples of the wide array of tube processing options made possible by laser cutting.

Many design engineers are not aware of the possibilities open to them. Seminars for laser-optimized design provide useful information on how to get the most out of tube machining with lasers.

Technical challenges | Tube processing on laser cutting machines is almost as easy as cutting flat sheets. Extensive technological knowledge and sophisticated machining strategies make it possible. In the following, we'll take a look at some important aspects of tube machining.



Reality or fiction? In one of the James Bond movies, the villain threatens to wipe out an entire city using a special high-powered laser fired from a satellite orbiting the Earth. Would this really be possible? Hardly. Satellites in orbit are located more than 1,000 kilometers above the Earth's surface.

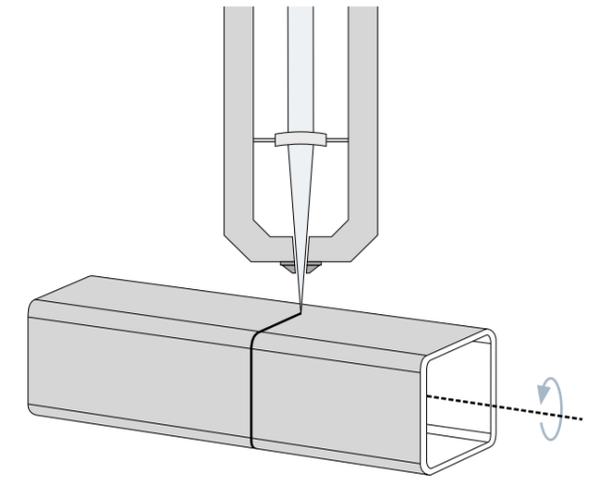
Compensating for irregularities | Tubes and profiles tend to have more geometry errors than sheets: they may be slightly bent or twisted, and their thickness and diameter can vary. To ensure accurate contours and suitable quality, the machine has to compensate for these irregularities. A distance control system maintains the correct standoff between the cutting head and the material at all times, while measuring cycles and clamping fixtures in the machine guarantee proper positioning.

Just 'round the bend | Cuts made around the corner of rectangular profiles present an extra challenge. The control system has to make sure that a constant standoff is maintained between the cutting head and the workpiece. This is done by raising and lowering the cutting head as the profile rotates. The workpiece material may also be thicker at the corners. In such cases, the laser power is increased and the cutting speed is reduced to prevent breaks in the cut. It may also be necessary to adjust the gas pressure if the cutting gas gets diverted at the corner and no longer flows entirely into the cut.

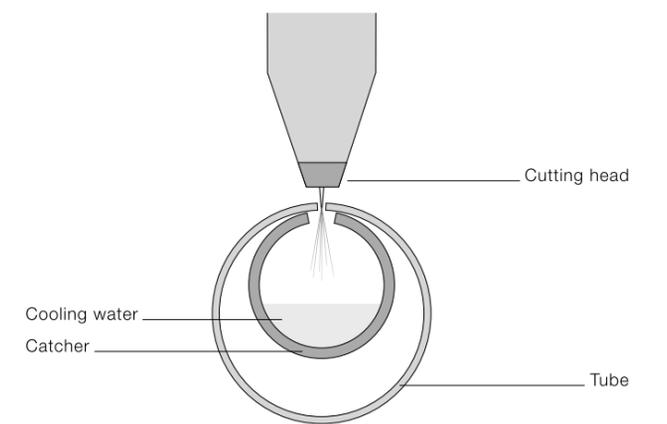
The other side of the story | As the cut is being made, what's left of the beam shoots out of the bottom of the kerf together with molten metal and slag. Spatter may end up on the opposite side and damage the material. Optimum parameter settings can largely eliminate spatter, leaving the other side mostly untouched. Technology tables provided for the machine by the machine manufacturer can help.

For special operations such as trimming round tubes, a part called a catcher is inserted into the tube to trap the remaining beam, slag, and molten metal. Catchers frequently include an integrated extraction system.

The laser beam would have to travel the entire distance without becoming wider. Plus, the beam would need a focus diameter of several meters and an immense energy density. Satellites not only lack the energy to generate a beam of this kind, but they are also too small to hold the focusing optics.



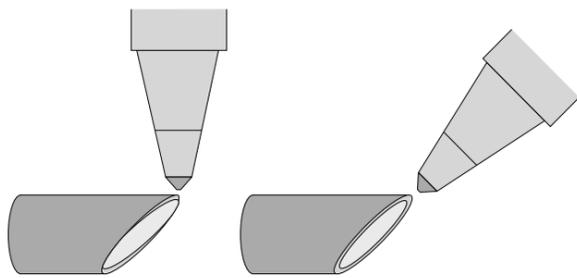
The cutting head moves upward to accommodate rotation of the profile.



A catcher is used to trap the remaining beam and spatter.

Diagonal cuts | If you've ever been to a deli and ordered a sandwich, you might have noticed the guy behind the counter slicing salami on a machine. Sometimes the salami is cut diagonally, leaving behind a slanted, but flat, surface. The same procedure is used in tube processing. Tubes are often cut at an angle and then joined to a flat surface or to other tubes. This technique works well as long as the edges are flat and there is good surface-to-surface mating contact. So how is it done?

In 2D tube processing, the laser beam creates a cut that is perpendicular to the tube surface. This produces a surface that is slightly distorted, but adequate for most applications. To create a slanted surface that is perfectly flat, you need a 3D cutting head that can be positioned at an angle to the surface. This method allows diagonal cuts of up to 45 degrees in steel and approximately 15 degrees in aluminum.



Left: a 2D cutting head produces cut surfaces that are slightly distorted. Right: a 3D cutting head makes it possible to produce flat surfaces.

Separating parts | When tubes are cut, the finished part usually drops away from the remaining material as soon as the contour is cut. Sometimes, however, the contours of the part can get caught in the remaining tube, with the consequence that the part gets stuck. Bayonet catches provide a good illustration of this problem. They require additional cuts to ensure that the part is separated completely from the remaining tube. The extra cuts are automatically added by the programming software.

On some parts, interlocking contours are actually desired. Products such as cable conduits, chains, and decorative napkin rings are composed of individual elements that, while connected, are still able to move.



1

"A growing number of companies are discovering the benefits of cutting tubes with lasers: innovative designs, fewer production steps, and lower manufacturing costs. The result has been a continuous increase in the demand for tube cutting systems. The trend clearly points to the use of lasers for tube cutting." *Norbert Beier, Tube Cutting System Sales*

LASERS: ENABLING THE IMPOSSIBLE

"At first we thought we wouldn't be able to manufacture the wheel fork on our tube cutting system," recalls Jörg Pielemeier, spokesperson for the laser tube cutting group at Meyra GmbH + Co. KG in Kalletal-Kalldorf, Germany. Then he pulls out the finished part, proving they were wrong. Wheel forks are designed to hold the two small caster wheels of the wheelchairs manufactured by Meyra. Meyra used to buy the parts from a supplier, but now produces them in-house on a tube cutting system equipped with a 2.4-kilowatt laser.

"Laser cutting has given us the competitive edge," says Jörg Pielemeier. It wasn't easy, though. Lots of experience and a few tricks were needed. The first challenge was the open aluminum profile from which the wheel fork is cut.



This wheel fork is used for wheelchair caster wheels.

To prevent the profile from being compressed, Meyra developed special clamping jaws that were able to hold the profile on only two sides. But there were other problems, too. The profile thickness, for example, varied between 4 and 8 millimeters. "Lasers without focus width adjustment are not able to compensate for such variations," explains Pielemeier. Things were complicated by the fact that 2.4-kilowatt lasers are usually only able to cut aluminum with a thickness of up to 4 millimeters.

Using a cutting head with a long focal length turned out to be the answer. "Our team discovered the solution by performing tests and working closely with the manufacturer," recalls Pielemeier. The long focal length produces a high depth of focus and a large focus diameter, which creates a wider kerf. The cutting machine now manufactures the wheel forks at cutting speeds of 0.3 meters per minute on the corners and up to 2.7 meters per minute on flat surfaces.

Production of the part used to involve three steps: sawing, drilling, and milling. Today, the cutting system does it all in a single work cycle. "This has reduced production time, including tooling and machining time, by around 40 percent," says Pielemeier. As a result, Meyra has found it more advantageous to make the part itself. Since the wheel forks can now be manufactured as they are needed, storage costs have also been reduced. But, as Pielemeier points out, the benefits don't stop there: "Laser cutting gives us greater flexibility in terms of design. We can produce prototypes quickly straight from the design data." The group is proud of its achievement: "I am certain that our wheel fork is among the most demanding parts produced with this type of laser tube cutting system worldwide."