WWW.IJRPR.COM

International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Review on Laser Cutting Machine

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ABSTRACT :

Nowadays Lasers are used in a wide range of industries. Laser cutting is a fabrication process which employs a focused, high-powered laser beam to cut material into custom shapes and designs.

Laser beam cutting is one of the important advanced machining processes. It is gaining importance over conventional machining methods due to its superior characteristics. However, significant future attempts are still required to overcome the challenges as regards to use laser beam cutting in different environment and for various materials. This process is suitable for a wide range of materials, including metal, plastic, wood, gemstone, glass, and paper, and can produce precise, intricate, and complex parts without the need for custom-designed tooling.

There are several diverse types of laser cutting available, including fusion cutting, oxidation cutting, and scribing. Each laser cutting process can produce parts with precision, accuracy, and high-quality edge finishes, and with less material contamination, physical damage, and waste than with other conventional cutting processes, such as mechanical cutting and waterjet cutting. However, while laser cutting demonstrates certain advantages over more conventional cutting processes, some manufacturing applications can be problematic, such as cutting reflective material or material requiring secondary machining and finishing work.

Keywords: Laser cutting, Laser beam, Assist gasses, Surface quality

Laser

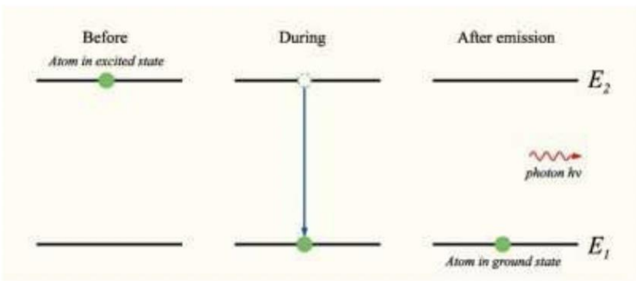
Laser is the acronym of Light Amplification by Stimulated Emission of Radiation. Laser is light of special properties, light is electromagnetic (EM) wave in visible range. Lasers, broadly speaking, are devices that generate or amplify light, just as transistors generate and amplify electronic signals at audio, radio, or microwave frequencies.

The principles of laser are divided into three divisions or sections. The first section is the formation of spontaneous and stimulated emission. This formation is formed at the initial stage of formation principles of laser. Based on quantum mechanics, the electron can have only a certain value of energy or energy level.

In these cases, we consider two energy levels which are ground and excited states that electron can occupy. Laser cutting is a technology that uses a laser to cut materials, and is typically used for industrial manufacturing applications, but is also starting to be used by schools, small businesses, and hobbyists. Laser cutting works by directing the output of a high-power laser, by computer, at the material to be cut. The material then either melts or burns or vaporizes away, or is impressed by a jet of gas, leaving an edge with a high-quality surface finish. Industrial laser cutters are used to cut flat-sheet material as well as structural and piping materials.

Working of a LASER

Formation of Spontaneous Emission

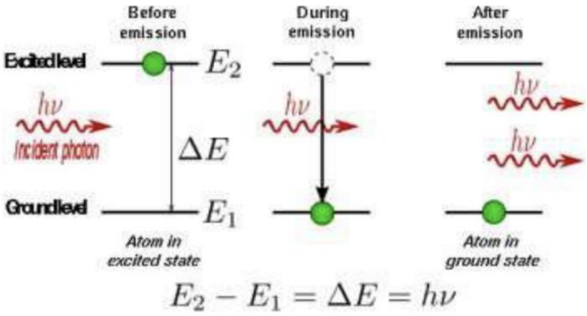


From the Figure above, there are two levels of energy where ground states relate with E1 and excited state is related to E2. At the beginning, the atom is in excited state. After spontaneous decay, the electron in excited state with energy E2 moves to the ground state with energy E1. From the formation above, we can see that it releases the energy differences in between the two states as a photon. This process is called spontaneous emission. The phase and direction of the photons move are completely random due to uncertainty principle in this spontaneous emission.

The Equation of Spontaneous emission:

$E2 - E1 = h\,\omega$

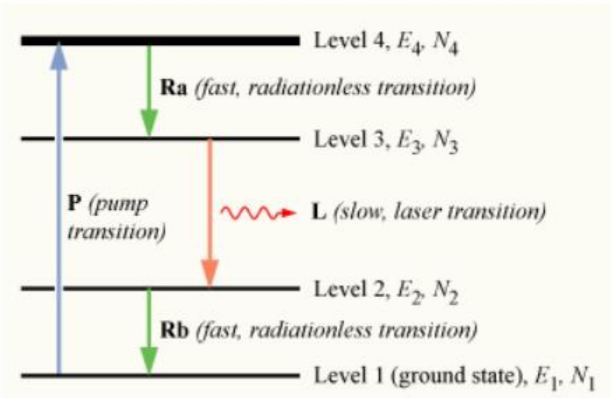
Formation of Stimulated Emission



Based on the above equation a photon with frequency 'ω' will be absorbed by the electron at ground state. Next, the electron will get back to the excited state and will remain for a while and return to its ground state. The formation and absorption of spontaneous emission will not give amplification of light. The best way to make it useful is by formation of photon absorbed and emitted simultaneously.

The formation of a second photon which is same in frequency and in the same phase as with the first photon that was influenced by an electric field. photon in excited state is needed to make this atom will decay again into ground state. This process will be called stimulated emission.

After the stimulated emission occurred, this process will go to the next section which is population inversion of the gain medium. At this section, higher energy state will have more population than lower energy state. By this kind of formation, it will result in the light to increase in intensity called population inversion. By the way, this formation can't be achieved by two states because electron will reach equilibrium position with exciting process of spontaneous and stimulate emission.



Thus, to achieve non-equilibrium conditions, we must use the method of an indirect method of populating the excited state. To understand how this is done, we may use a slightly more realistic model, that of a three-level laser.

Types of Lasers used for Cutting

There are three main types of lasers used in laser cutting.

The CO2 laser is suited for cutting, boring, and engraving.

The neodymium (Nd) and neodymium yttrium-aluminum garnet (Nd-YAG) lasers are identical in style and differ only in application. Nd is used for boring and where high energy but low repetitions are required. The NdYAG laser is used where very high power is needed and for boring and engraving. Both CO2 and Nd/ NdYAG lasers can be used for welding. Common variants of CO2 lasers include fast axial flow, slow axial flow, transverse flow, and slab. CO2 lasers are commonly "pumped" by passing a current through the gas mix (DC-excited) or using radio frequency energy (RFexcited).

The RF method is newer and has become more popular. Since DC designs require electrodes inside the cavity, they can encounter electrode erosion and plating of electrode material on glassware and optics. Since RF resonators have external electrodes they are not prone to those problems.CO2 lasers are used for industrial cutting of many materials including mild steel, aluminum, stainless steel, titanium, paper, wax, plastics, wood, and fabrics. YAG lasers are primarily used for cutting and scribing metals and ceramics.

Overview of Laser Machine Components and Mechanics

In contrast to mechanical cutting, which utilizes cutting tools and power-driven equipment, and waterjet cutting, which utilizes pressurized water and abrasive material, laser cutting employs a laser cutting machine to produce cuts, engravings, and markings. While laser cutting machines vary from model to model and application to application, the typical setup includes a laser resonator assembly, mirrors, and a laser cutting head which contains a laser focusing lens, a pressurized gas assembly, and a nozzle. The basic laser cutting process includes the following stages:

- beam generation
- beam focusing
- localized heating and melting
- material ejection
- beam movement

Each stage is integral to the laser cutting process and, when properly executed, producing a precise cut.

Beam Generation

The term "laser" comes from the acronym LASER or Light Amplification by Stimulated Emission of Radiation. Essentially, this acronym summarizes the basic principles of laser generation—stimulation and amplification. Along with these principles, the laser resonator employs the processes of spontaneous emission and stimulated emission to produce a high-intensity beam of light that is both spatially and spectrally coherent (i.e., a laser beam).

Spontaneous emission: The laser resonator contains an active laser medium (e.g., CO2, Nd:YAG, etc.), the electrons of which are stimulated by an external energy source, such as a flash lamp or electrical arc. As the medium receives and absorbs energy, its atoms experience a process known as spontaneous emission. During this process, energy absorbed by an atom causes the atom's electrons to briefly jump to a higher energy level and then return to their ground state. Upon the electrons' return to their ground state, the atom emits a photon of light.

Stimulated Emission: The photons that are produced by spontaneous emission travel within the medium, which is contained in a cavity of the laser resonator between two mirrors. One mirror is reflective to keep photons traveling within the medium, so they continue to propagate stimulated emissions, and the other mirror is partially transmissive to allow some photons to escape. Stimulated emission is the process in which a photon (i.e., the incident photon) stimulates an atom that is already at a higher energy level. This interaction forces the stimulated atom to drop to its ground state by emitting a second photon of the same fixed wavelength or coherent with the incident photon.
The process of one photon propagating the emission of another photon amplifies the strength and intensity of the light beam. Thus the stimulated emission of light photons (i.e., a type of electromagnetic radiation) causes the amplification of light; in other words, light amplification by stimulated emission of radiation. Improperly aligned photons within the resonator pass through the partially transmissive mirror without being reflected into the medium, generating the initial laser beam. Once generated, the beam enters the laser cutting head and is directed by mirrors into the focusing lens.

Beam Focusing

The focusing lens focuses the laser beam through the center of the nozzle at the end of the laser cutting head incident to the workpiece's surface. By focusing the beam, the lens concentrates the beam's energy into a smaller spot, which increases the beam's intensity (I). The following equation illustrates the underlying principle behind this occurrence:

$$\boldsymbol{Power\ Density\ (Intensity)} = \frac{\boldsymbol{P}}{\boldsymbol{\pi r^2}}$$

Where P represents the power of the initial laser beam, and πr^2 represents the cross-sectional area of the beam. As the lens focuses the laser beam, the radius (r) of the beam decreases; this decrease in radius reduces the cross-sectional area of the beam, which in turn increases its intensity since its power is now distributed across a smaller area.

Localized Heating and Melting, and Material Ejection

As the beam strikes the material's surface, the material absorbs the radiation, increasing the internal energy and generating heat. The high intensity of the laser beam allows it to heat, melt, and partially or completely vaporize a localized area of the workpiece's surface. The weakening and removal of the affected area of the material forms the desired cuts. Siphoned into the laser cutting head and flowing coaxially to the focused beam, the assist gas—also referred to as the cutting gas—is used to protect and cool the focusing lens, and may be used to expel melted material out of the kerf—the width of the material removed and of the cut produced—and support the cutting process. Laser cutting employs several different types of material cutting and removal mechanisms, including fusion cutting, chemical degradation cutting, evaporation cutting, scribing, and oxidation cutting.

Fusion Cutting: Also referred to as inert gas melt shearing or inert gas cutting, fusion cutting is employed by CO2 and Nd:YAG laser cutting machines. The laser beam produced by the cutting machine melts the workpiece, and melted material is expelled through the bottom of the kerf by a jet of the assist gas employed. The assist gas and the assist gas pressure employed are dependent on the type of material being cut, but the inert gas is always chosen based on its lack of chemical reactivity in regards to the material. This mechanism is suitable for laser cutting most metals and thermoplastics.

Chemical Degradation: Chemical degradation is employed by CO2 laser cutting machines and is suitable for laser cutting thermoset polymers and organic material, such as wood. As thermoset and organic materials do not melt when heat is applied, the laser beam burns the material instead, reducing it to carbon and smoke.

Evaporation Cutting: Evaporation cutting is employed by CO_2 laser cutting machines and is suitable for materials such as laser cutting acrylic and polyacetal due to the closeness of their melting and boiling points. Since the laser evaporates material evaporates along the cut, the edge produced is generally glossy and polished.

Scribing: Scribing is employed by CO_2 and Nd:YAG laser cutting machines to produce partial or fully penetrating grooves or perforations, usually on ceramics or silicon chips. These grooves and perforations allow for mechanical breaking along the weakened structural lines.

Oxidation Cutting: Also referred to as flame oxygen cutting, oxidation cutting is employed by CO_2 and Nd:YAG laser cutting machines and is suitable for laser cutting of mild and carbon steel. Oxidation cutting is one example of the reactive gas melt shearing cutting mechanism, which specifically employs chemically reactive assist gases. As with inertness, the reactivity of an assist gas is relative to the material being cut. Oxidation cutting, as the name implies, employs oxygen as the assist gas, which exothermically reacts with the material. The heat generated accelerates the cutting process and produces an oxidized melted edge which can be easily removed by a gas jet to allow for a cleaner, laser-cut edge.

Beam Movement

Once the localized heating, melting, or vaporizing has started, the machine moves the area of material removal across the workpiece to produce the full cut. The machine achieves the movement either by adjusting the reflective mirrors, controlling the laser cutting head, or manipulating the workpiece. There are three different configurations for laser cutting machines, defined by the way in which the laser beam moves or is moved over the material: moving material, flying optics, and hybrid laser cutting systems.

Moving Material: Moving material laser cutting machines feature a stationary laser beam and a movable cutting surface to which the material is affixed. The workpiece is mechanically moved around the stationary beam to produce the necessary cuts. This configuration allows for a uniform and consistent standoff distance and requires fewer optical components.

Flying Optics: Flying optics laser cutting machines feature a movable laser cutter head and a stationary workpiece. The cutting head moves the beam across the stationary workpiece in the X- and Y-axes to produce the necessary cuts. The flexibility of flying optics machines is suitable for cutting materials with variable thickness and sizes, as well as allowing for faster processing times. However, since the beam is continually moving, the changing beam length has to be taken into consideration throughout the process. The changing beam length can be controlled by collimation (alignment of the optics), using a constant beam length axis, or employing an adaptive optics or capacitive height control system capable of making the necessary adjustments in real time.

Hybrid: Hybrid laser cutting machines offer a combination of the attributes found on moving material and flying optics machines. These machines feature a material handling table that moves on one axis (usually the X-axis) and a laser head that moves on another (usually the Y-axis). Hybrid systems allow for more consistent beam delivery, and reduced power loss and greater capacity per watt compared to flying optics systems.

Lasers are produced as either pulsed beams or continuous wave beams. The suitability of each depends on the properties of the material being cut and the requirements of the laser cutting applications. Pulsed beams are produced as short bursts of power output, while continuous wave beams are produced as continuous, high power output. The former is typically employed for scribing or evaporation cutting applications and is suitable for cutting delicate designs or piercing through thick materials, while the latter is suitable for high-efficiency and high-speed cutting applications.

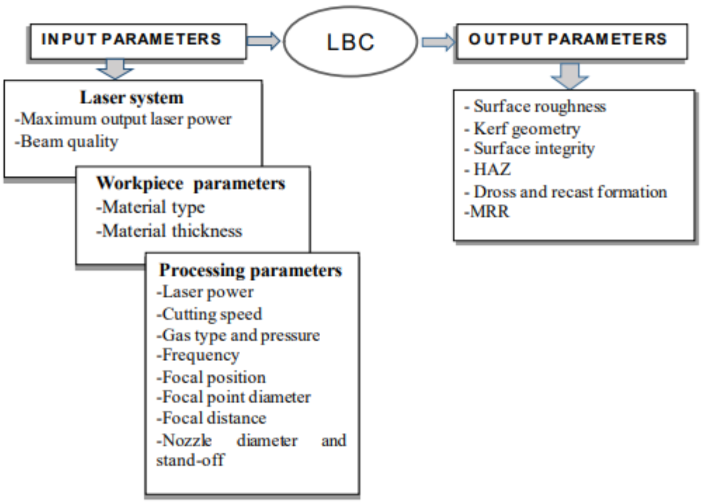
Laser beam cutting process parameters

Laser beam cutting process parameters Laser cutting is a complex process governed by a multitude of factors with difficult to predict interaction. The parameters of laser cutting process can be classified as system parameters, the workpiece parameters and process parameters.

The system parameters are inherent to the particular laser system used while all other parameters may be changed to meet desired outputs. The workpiece parameters refer to the material type and thickness to be cut. Materials with lower reflectivity and thermal conductivity are most suitable for processing with laser.

Both CO2 and Nd:Yag laser machines have excellent capabilities for cutting the most common material used in manufacturing industries which is steel in all variants: mild steel, stainless steel, tool steel or alloy steel.

Aluminium, titanium and nickel-based alloys, which are increasingly used in the aircraft industry, are also fairly good processed by both laser systems. However, materials that are highly reflective like copper and its alloys, gold and silver, are difficult to cut. The thickness of the piece to be cut influences the power required to melt or vaporize the material and the cutting speed. For thicker materials, slower cutting speed and higher laser power is required. Alloy carbon steel of 40-50 mm thickness may be cut with CO2 laser and oxygen as the assist gas, with a good cut quality, while the same system was used to successfully cut steel and stainless steel up to a thickness of 300 mm.



Laser power also known as the heat input, is dependent of the type of material to be cut and its thickness, and the desired cutting rate. Materials like stainless steel and aluminium will require about 1000 W of heat input for cutting 1 mm thick sheet while mild steel and titanium of the same thickness, around 400 W of heat input.

Cutting speed is the rate at which the laser beam travels on the path to be cut. Laser cutting is the most efficient process in terms of its feed rate. Maximum cutting speed can be used when matched with the appropriate level of power and assist gas pressure to successfully cut a given thickness with good cut quality. The cutting speed influences the width of HAZ, the formation of dross and burnt material at the bottom of the cut and the surface quality.

The assist gas used in laser cutting may be an inert gas such as nitrogen, argon and helium, or a reactive gas such as oxygen. The main role of the assist gas is to aid in the ejection of the molten metal from the cut zone. The pressure of the assist gas has an influence on the dross and striation formation on the cut surface. Stainless steel and Ni-based alloys are commonly cut with nitrogen as assist gas, whereas for titanium alloy argon is the choice.

The other function of the inert gas is to provide cooling of the cut edge and help reduce the HAZ. Oxygen is generally used for cutting mild steel if the cut quality is not important. When using oxygen as an assist gas, an oxide layer will be formed on the cut surface that may need removal. For better cut quality, nitrogen assist gas is recommended while for higher productivity oxygen assist gas is suggested.

Types of Assist Gases

Laser cutting employs a variety of assist gases to aid the cutting process. The cutting process employed and the material being cut determine the type of assist gas—either inert or active—that is most suitable for use.

Inert gas cutting (i.e., fusion cutting or inert gas melt shearing), as indicated by the name, employs chemically inert assist gases. The particular assist gas employed depends on the material's reactive properties. For example, since molten thermoplastics do not react with nitrogen and oxygen, compressed air can be used as the assist gas when laser cutting such materials. On the other hand, since molten titanium does react with nitrogen and oxygen, argon—or another similarly chemically inert gas—must be used as the assist gas in laser cutting applications involving this material. When laser cutting stainless steel via the inert gas cutting process, nitrogen is typically used as the assist gas; this is because molten stainless steel chemically reacts with oxygen.

When laser cutting material via the reactive melt shearing process, an active (i.e., chemically reactive) assist gas—typically oxygen—is employed to accelerate the cutting process. While in inert gas cutting the material is heated, melted, and vaporized solely by the power of the laser, in reactive gas cutting the reaction between the assist gas and the material creates additional heat which aids the cutting process. Because of this exothermic reaction, reactive gas cutting typically requires lower laser power levels to cut through a material compared to the power level necessary when cutting the same material via the inert gas cutting process.

The cutting pressure of the assist gas employed is also determined by the cutting process employed and the properties and thickness of the material being cut. For example, polymers typically require gas jet pressures of 2–6 bar during the inert gas cutting process, while stainless steel requires gas jet pressures of 8–14 bar. Accordingly, thinner materials also generally require lower pressures, and thicker materials generally require greater pressures. In oxidation cutting, the opposite is true: the thicker the material, the lower the pressure required and the thinner the material, the higher the pressure required.

Focal point diameter refers to the minimum diameter of the beam spot where the laser beam is focused after being passed through a focusing lens. This focal point has the highest power density and can be positioned above the surface of the material to be cut, on the surface, or below it somewhere along the thickness of the material. This parameter has an influence on the melting zone (MZ) as a higher diameter will result in increased depth of the melting zone.

The focal length is the distance between the focusing lens and the focal spot with minimum diameter. Longer focal lengths are required for cutting thick sections, while for thin sections a lens with shorter focal length is suggested. The nozzle has the role to guide the assist gas in a coaxial fashion with the laser beam, and their good alignment plays a role in the cut quality. When misaligned, the gas may flow on the surface of the workpiece, creating undesirable burning or spatter of the molten metal resulting in a poor quality cut.

The distance between the nozzle and the top surface of workpiece to be cut is called the stand-off distance and ranges between 0.5 and 1.5 mm to minimize turbulence during cutting. There are few standard nozzles designs used in industry like parallel, conical, convergent, convergent-divergent nozzle, etc. The nozzle diameter should be selected function of the type and thickness of the material and must deliver a good gas flow with uniformity in pressure and no shock waves that may adversely influence the cut quality.

The process performance is measured by output parameters (i.e. cut surface quality in terms of surface roughness and integrity, kerf geometry, and material removal rate MRR) as presented. MRR is an indicator of the process productivity. Surface quality can be measured in terms of surface roughness and geometrical errors, Geometric error in laser is kerf.

Heat affected zone is yet another output indicator in laser cutting type thermal process. Laser machining offers significant productivity advantage over other advanced manufacturing methods owing to its high cutting speed rates, however due to the dynamic nature of the process parameters interaction, the process productivity has to be carefully tuned with the desired cut quality.

Advantages and limitations of laser beam cutting

Following are the significant advantages of laser beam cutting process-

- As LBC is a non-contact process that does not require tools, therefore there is no tool wear or tool change to consider nor any tooling associated costs.
- The process is fast and flexible, fully CNC controlled with no requirements for special clamping or jigging therefore easy to switch from one cutting job to another.
- The system is stable, reliable and very accurate; intricate profiles can be cut with cutting precision of about +/_0.05 mm.
- Same system may be used to cut a variety of materials.
- Minimum material waste as the cut width (kerf) is extremely narrow.
- Suitable for mass production with high efficiency and accuracy when product replicas are required.
- Each system used for laser beam cutting has its own advantages. The CO2 lasers works better with thicker materials, has high efficiency, and provides good edge quality with very small HAZ.
- The Nd:Yag system is great with thinner sections, and can cut highly reflective materials, such as aluminium, copper, and brass etc.
- Laser cutting process is computer program controlled hence less human intervention except for observation and maintenance which reduces the risk of accidents and injuries.
- Low running costs.
- Short set-up time as each job is planned initially in a CAD environment with minimum material wastage and easily exported to the machine computer interface.
- It requires lower power consumption than other cutting processes.

The limitations of laser beam cutting are as follows

- Not all metals can be cut by laser beam as the reflectivity of the material creates beam reflections issues that affect the optical lens system that focuses the laser beam.
- Parts processed with the high intensity laser beam are exposed to heat that will result in a narrow heat affected zone along the cut edge.
- Improper settings of the machine can cause burns on the material.
- High initial capital cost.
- The thickness of sheet metal to be cut is limited by the laser power of the machine and the cut quality required.
- Safety procedures must be followed strictly

Comparison of Laser Cutting with other Processes

Although laser cutting can produce high tolerance, complex, and precision parts, it may not be appropriate for every manufacturing application, and other cutting processes may be more suitable and cost-effective.

Comparisons between Laser Cutting and Mechanical Cutting Processes

Advantages	**Laser Cutting**	**Mechanical Cutting**
Precision/Tolerances	✔	
Intricate Design Capabilities	✔	
No Mechanical Distortion	✔	

Material Costs (Less Waste)	✔	
Equipment Costs		✔
Operational Costs		✔
Maintenance Costs	✔	

Mechanical cutting is a fabrication process which employs power-driven equipment—e.g., lathes, mills, and presses—to cut, form, and shear material into custom shapes and designs. As illustrated above, laser cutting holds several advantages over mechanical cutting; it allows for greater precision and higher tolerances, as well as offers lower material (e.g., less waste) and maintenance costs. However, laser cutting also typically requires much higher initial investment and operational costs than mechanical cutting due to the expensive laser cutting equipment and high power and energy consumption of the equipment.

Comparisons between Laser Cutting and Waterjet Cutting Processes

Waterjet cutting is a fabrication process which employs pressurized water—as well as abrasives, such as garnet or aluminum oxide—to cut and form material into custom shapes and designs. As illustrated above, laser cutting can produce parts with greater precision and intricacy than waterjet cutting, while waterjet cutting can produce parts from thicker and multi-layer materials that may be problematic for the laser cutting process. While there is less risk of mechanical distortion with laser cutting, waterjet cutting offers a lower risk of thermal distortion. Compared to laser cutting, waterjet cutting also generates more noise and more waste—i.e., used water and abrasive mixtures—which require cleanup and disposal, increasing operation costs.

Applications of laser beam cutting

Laser beam cutting process has experienced a growing popularity in the automotive industry. In general, lasers are used to process complete vehicle bodies with all the versatility offered by cutting, drilling marking and welding with laser beam.
There are a wide range of uses of laser cutting process of components and functional parts, mainly sheetmetal parts required for BIW (body in white) or bumpers, crossbeams and supports, for car interior such as dashboards and consoles, etc. The process is used to cut a wide variety of materials and this are just few examples of the many uses of the process in car manufacturing industry.

The aerospace industry, just like the automotive industry, have found the process to be crucial for cutting of components in various shapes and sizes mainly from high strength aluminium and titanium alloys with high precession, perfect finish and low heat affected zone. Electronic industry uses this technology to cut small and intricate parts with great accuracy in a variety of materials often with multiple layers. The process is used to cut the plastic and metal component that encases mobile phones, cutting of USB cards, printed circuit boards and microprocessors.

As the process main advantage is to produce clean and highly accurate cuts with smooth finish, this render the process as ideal for fabrication of much smaller products, components and devices. From cutting silicon wafers to creating micro channels for biomedical devices and micro-fluidic applications, stents for coronary arteries etc., laser beam machining proved once more its capabilities and versatility.

Advantages	Laser Cutting	Waterjet Cutting
Precision/Tolerances	✔	
Intricate Design Capabilities	✔	
Composite/Multi-layer Material		✔
Thick Materials		✔
No Mechanical Distortion	✔	
No Thermal Distortion		✔
Operational Costs	✔	
Quiet Operation	✔	

Laser micromachining processes are microdrilling, micro-cutting, micro-grooving, micro-milling and micro-turning resulting in very small surface or 3D structures with dimensions ranging in the micron domain. For that, lasers with very short pulse duration of nano, pico even femtosecond are used to minimize thermal effects.

Conclusion

Laser cutting is a non-traditional machining method that uses an intensely focused, coherent stream of light called a laser to cut through the material. Laser cutting is highly accurate and can easily and precisely create complex shapes. In this review work, we have gone through several research papers and other sources to get a better understanding of the working principle, construction and the parameters that effect the cutting and engraving of a work piece in a laser cutting machine. Several research and review work has been done on laser cutters to make laser cutting a cost effective, flexible and fast method of production over conventional cutting machines. All the papers had one thing in common, which was the parameters aspect which plays an important role in the construction of a laser cutter, as it determines the thickness and type of material the machine can cut for large scale productions. We have also gone over the influence of assist gasses on laser cutting as well as the different types of materials that can be worked on with a laser cutting machine.

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