A Comprehensive Review on Laser beam machining

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***Abstract*:** Modern machining methods are established to fabricate difficult-to-machine materials such as high-strength thermal-resistant alloys; various kinds of carbides, fiber-reinforced composite materials, Stellites, and ceramics. Conventional machining of such materials produces high cutting forces that, in some particular cases, may not be sustained by the workpiece. Laser beam machining (LBM) offers a good solution that is indeed more associated with material properties such as thermal conductivity and specific heat as well as melting and boiling temperatures. Laser beam machining (LBM) is one of the most use thermal base non-contacting type advance manufacturing process which can be apply for almost whole range of material.

***Index Terms* – CO2 laser, fiber laser, NDYAG laser, Advance manufacturing.**

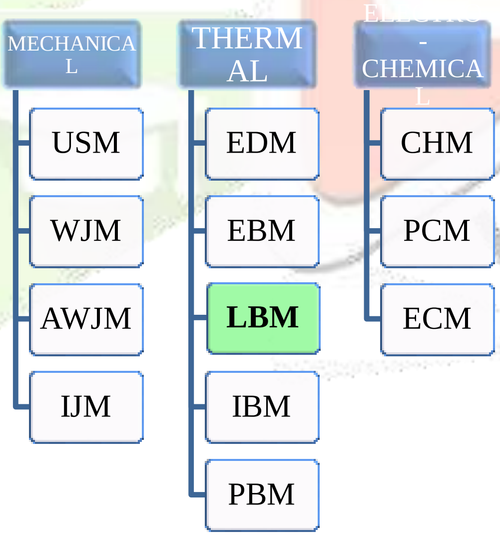
I. INTRODUCTION

Advance Machining Process

The greatly improved thermal, chemical, and mechanical properties of the new engineering materials made it impossible to machine them using the convectional machining processes of cutting and abrasion. This is because convectional machining is most often based on the removal of material using tools that are harder than the work piece. Convectional machining methods are often ineffective machining to the advanced materials, complex shapes, low-rigidity structures, and micro machined components with tight tolerances and fine surface quality. Than the introduction of the nonconventional machining processes that are well-established in modern manufacturing industries. The need for higher machining productivity, product accuracy, and surface quality led to the nonconventional machining. [A]

Classification of Advance machining process

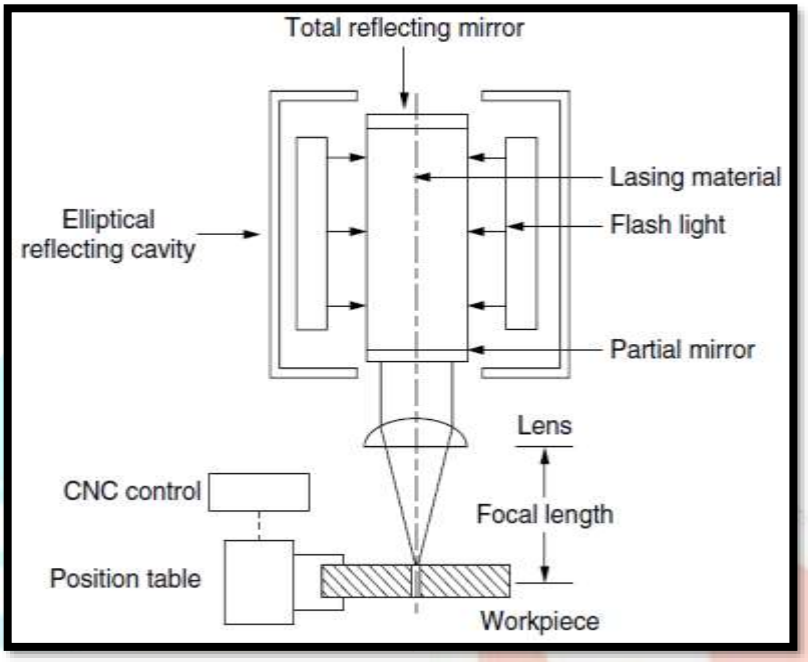
The non convectional machining methods are classified according to the number of machining actions causing the removal of material from the work piece.



Classification of Advance manufacturing process

Laser Beam Machining

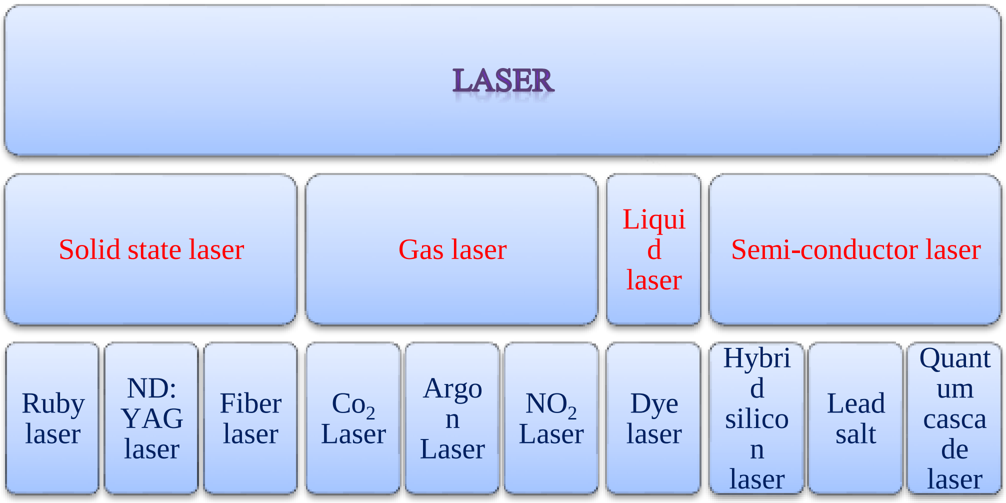
Laser is the acronym of Light Amplification by Stimulated Emission of Radiation. Laser is light of special properties, light is electromagnetic wave in visible range. Main six-processes are doing for Light Emission: Absorption, Spontaneous Emission, Stimulated Emission, Population Inversion, Gain and Loss. A laser device is consisted of: (1) Laser medium like atoms, molecules, ions or semiconductor crystals; (2) Pumping process to excite these atoms into higher quantum mechanical energy levels; and (3) suitable optical feedback that allow the beam of radiation to either pass once through the laser medium or bounce back and forth repeatedly through the laser medium.[A]



Schematic Diagram of Laser Beam Machining [A]

Laser cutting is a thermal based non-contact process capable of cutting complex contour on material with high degree of precision and accuracy. It involves process of heating, melting and evaporation of material in a small well defined area and capable of cutting almost all materials. The word LASER stands for Light Amplification by Simulated Emission of Radiation. Laser has a wide range of applications, ranging from military weapons to medical instruments. In industries laser is used as an unconventional method for cutting and welding. The main advantage of laser cutting is that, it is a non-contact operative method from which a good precise cutting of complicated shapes can be achieved. Also laser can be used to cut variety of materials like wood, ceramic, rubber, plastic and certain metals. [A]

Types of Laser



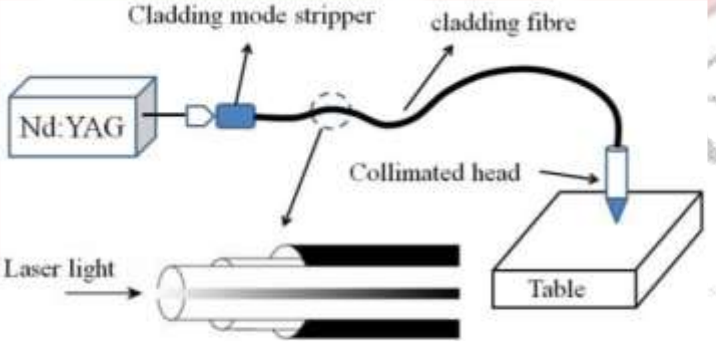
Types of Laser

The Most Commonly Used Types of Laser for Cutting

- Fiber laser
- Nd: YAG laser
- CO_2 laser

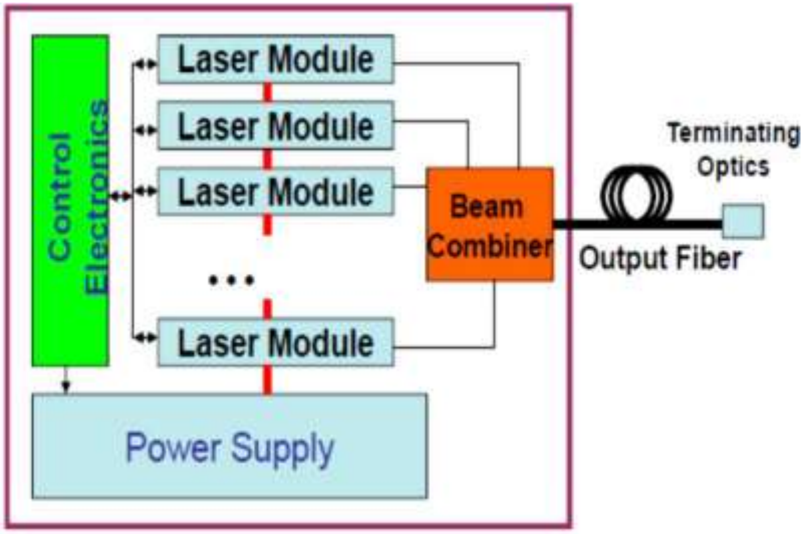
Fiber Laser

A single emitter fiber laser is established using an Ytterbium fiber laser system and has a wavelength from 1.06 µm to 1.08 µm, with power output up to 3 kW available by IPG Laser Company. A single mode fiber has been reported to deliver a laser beam from a typical flash pumped Nd: YAG system for precision machining at peak power of 225 W.



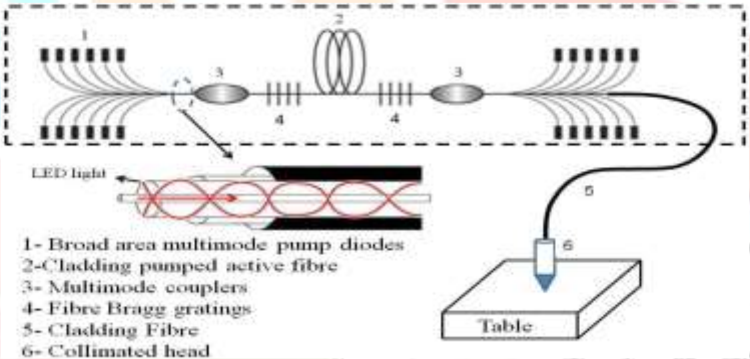
Schematic Showing a Single Emitter Fiber Laser Machine [i]

In modular fiber lasers, fiber lasers deliver their energy through an integrated flexible optical fiber that can be up to 200 meters long. Each module yields some part of the total power, and a beam combiner combines the outputs of the modules. In contrast with single emitter lasers, the output fibers from the modular can be single or multiple. IPG photonics has developed the modular system up to 10 kW output power. For example the fiber laser cutting machine, which is used in this research, had five modules of 500 W and the maximum output power is 2000 W, with one module reserved as a backup.



Multi Mode (modular) Fiber Laser Structure [i]

In contrast, in high power fiber laser systems a double cladding doped fiber (active fiber) and two groups of multimode high power laser diodes are used. Two groups of multimode pump diodes are coupled on the both side of an active fiber. A coil of the active fiber with two Bragg gratings form the laser medium. The Bragg gratings reflect particular wavelength of laser and transmit others.[i]

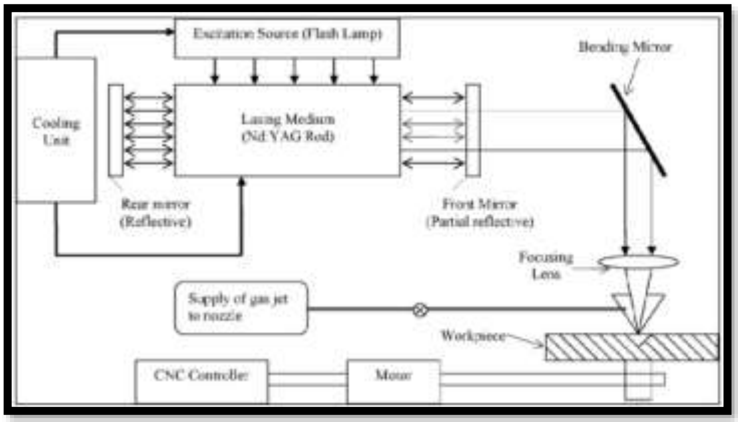


Schematic Structure of Multimode Fiber Laser Beam[i]

Nd: YAG Laser

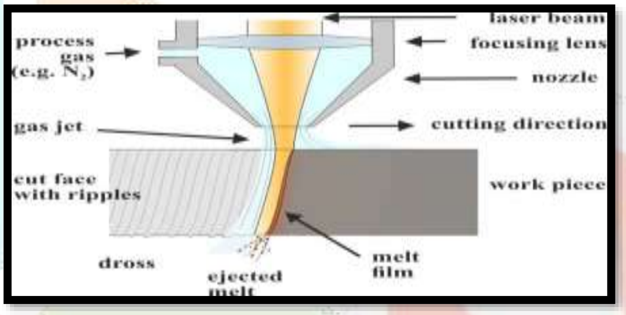
The neodymium (Nd) and neodymium yttrium-aluminium-garnet (Nd-YAG) lasers are identical in style and differ only in application. Nd: YAG laser use a crystalline material for a lasing action.

The Nd: YAG lasers are commercially available in power up to 5 KW. The Nd: YAG were commonly used because of its high intensity, low mean beam power, good focusing characteristic, and narrow heat affected zone (HAZ). Due to its shorter wavelength in comparison to CO_2 laser, it is reflected to a lesser extent by metallic surfaces and this high absorptive of the Nd: YAG laser enables cutting of even highly reflective materials with relatively less power. The Nd-YAG laser is used where very high power is needed and for boring and engraving. [ii]

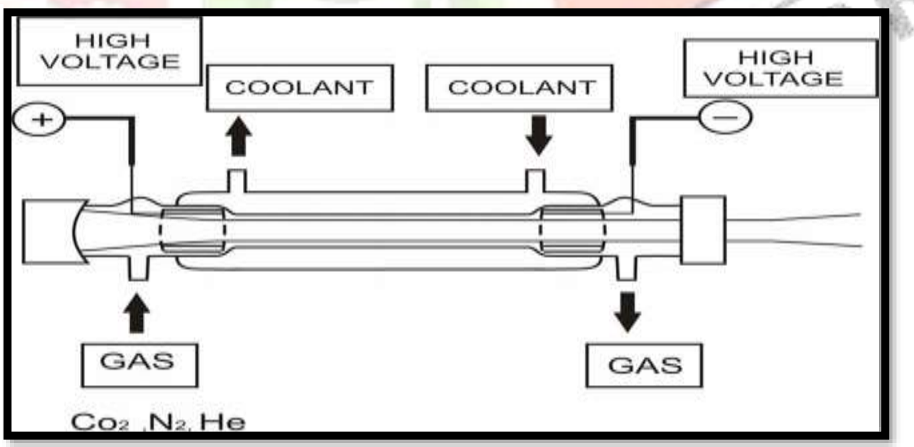


Schematic of Nd: YAG Laser Beam Cutting System [ii]

CO_2 Laser



Principle of Laser Beam Machining [i]



Construction of CO_2 Laser [A]

A CO_2 laser can be axial flow, transverse flow and folded axial flow. The power of a CO_2 laser is typically around 100 Watt per metre of tube length. Thus to make a high power laser, a rather long tube is required which is quite inconvenient. For optimal use of floor space, high-powered CO_2 lasers are made of folded design. In a CO_2 laser, a mixture of CO_2, N_2 and He continuously circulate through the gas tube. Such continuous recirculation of gas is done.

Working of CO_2 Laser

A CO_2 acts as the main lasing medium whereas Nitrogen helps in sustaining the gas plasma. Helium on the other hand helps in cooling the gases. High voltage is applied at the two ends leading to discharge and formation of gas plasma. Energy of this discharge leads to population inversion and lasing action. At the two ends of the laser we have one 100% reflector and one partial reflector. The 100% reflector redirects the photons inside the gas tube and partial reflector allows a part of the laser beam to be issued so that the same can be used for material processing. Typically the laser tube is cooled externally as well.

The standard output of these lasers is at 10.6 mm, and output power can range from less than 1W to more than 10 kW. Unlike atomic lasers, CO_2 lasers work with molecular transitions (vibration and rotational states) which lie at low enough energy levels that they can be populated thermally, and an increase in the gas temperature, caused by the discharge, will cause a decrease in the inversion level, reducing output power. To counter this effect, high-power cw CO_2 lasers use flowing gas technology to remove hot gas from the discharge region and replace it with cooled (or cooler) gas. With pulsed CO_2 lasers that use transverse excitation, the problem is even more severe, because, until the heated gas between the electrodes is cooled, a new discharge pulse cannot form properly. A variety of types of CO_2 lasers are available. High-power pulsed and CW lasers typically use a transverse gas flow with fans which move the gas through a laminar-flow discharge region, into a cooling region, and back again. Low-power lasers most often use waveguide structures, coupled with radio-frequency excitation, to produce small, compact systems. However, the major difference is that the gases in the system are extremely corrosive and great care must be taken in the selection and passivation of materials to minimize their corrosive effects. A system built for CO_2 would fail in minutes, if not seconds. The principal advantage of a CO_2 laser is its very short wavelength. The laser output beam can be focused to a spot diameter that is approximately 40 times smaller than the CO_2 laser beam with the same beam quality. Furthermore, whereas the long CO_2 wavelength removes material thermally via evaporation (boiling off material), the CO_2 lasers with wavelengths near 200 nm remove material via ablation (breaking molecules apart), without any thermal damage to the surrounding material. [I]

Advantage of Laser Cutting

- No limit to cutting path as the laser point can move any path
- The process is stress less allowing very fragile materials to be laser cut without any support. Very hard and abrasive material can be cut.
- Sticky materials are also can be cut by this process.
- It is a cost effective and flexible process.
- High accuracy parts can be machined.
- No cutting lubricants required
- No tool wear
- Narrow heat effected zone

Disadvantages of Laser Cutting

- Uneconomic on high volumes compared to stamping
- Limitations on thickness due to taper
- High capital cost
- High maintenance cost
- Assist or cover gas required

Applications

- LBM can make very accurate holes as small as 0.005 mm in refractory metals ceramics, and composite material without warping the work pieces.
- This process is used widely for drilling and cutting of metallic and non-metallic materials.
- Laser beam machining is being used extensively in the electronic and automotive industries.

II. LITERATURE REVIEW

Table 2.1 Literature Review

Sr. No.	Title	Author	Publisher and year	Journal	Materials	Problem Discussed & Outcome
1	Laser cutting of polymeric materials: An experimental investigation	I.A. Choudhury et al	Elsevier 2010	Optics and laser technology	polypropylene (PP), polycarbonate (PC) and polymethyl methacrylate (PMMA)	The dimension of HAZ for all polymers investigated is directly proportional to the laser power and inversely proportional to cutting speed and compressed air pressure
2	Effect of cutting speed on surface quality and heat-affected zone in laser cutting of 316L stainless steel[1]	Piotr Löschner et al	Elsevier2016	Procedia engineering	AISI316L stainless steel.	The use of highest researched cutting speed (vc= 16.5 mm/s) produces cut surfaces with good roughness and negligible heat-affected zone. The lower of used cutting speeds (vc= 9.17 mm/s) produces a surface with lower roughness.
3	Surface roughness analysis and improvement of PMMA-based microfluidic chip chambers by CO2 laser cutting	Yongguang Huang,	Elsevier2010	Applied surface scince	polymethyl methacrylat e (PMMA)	CO2 laser processing is expected to be an excellent method of machining the PMMA-based micro fluidic chip chambers.
4	Laser cutting of polymeric materials: An experimental investigation	A.M. Orishicha, et al	Elsevier 2014	Physics procedia	stainless steel	The optimal speed corresponding to the minimal roughness coincides with the maximal speed.

5	A method to decrease surface roughness in laser shock processing	F.Z. Dai et al’	Elsevier 2015	.Surface and coating technology	LY2 Aluminum	A final value of surface roughness is increases with increasing laser power intensity and decreases with increasing dynamic yield strength of the contact foil
6	Parametric Optimization Of Co2 Laser Machining On Polypropylene[2]	Chaudhari Nimesh kumar M	IJARIIE 2016	IJARIIE	Polypropylene (pp)	Low laser power and high cutting speed are necessary for PP cutting However, supplied air pressure has different effects on cut quality of all thermoplastics.
7	Parametric analysis of laser machining with response surface method on SS-304	D. J. Kotadiya et al	Elsevier2016	Procedia technology	(SS) sheet (ASTM 304).	After DOE analysis total 17 run have identified for experiment with sheet metal operation (5 mm thick) SS 304 as work piece material. It has found that the laser power is most significant compare to cutting speed and gas pressure.
8	Parametric Investigation of Process Parameters for Laser Cutting Process	V.Senthilkuma et al	IJIRSET 2015	IJIRSET	Aluminium plat	Laser cutting process depends on the input process parameters.The parameters such as laser power, cutting speed, stand-off distance have major impact on surface roughness and kerf width.
9	Experimental investigations on fusion cutting stainless steel with fiber and CO2 laser beams	S. Stelzera et al	Elsevier 2013	Physics Procedia	stainless steel	Under the defined experimental conditions, this transition occurs between 4 and 6 mm in case of fiber laser cuts and between 8 and 10 mm for CO2 laser cutting trials.
10	CO2 Laser Cutting	Ahmet Cekic et al	Elsevier2014	Procedia	alloy steels	During laser cutting of alloy steels 1.4571

	of Alloy Steels using N2 Assist Gas			Engineering	1.4571 and 1.4828	and 1.4828 with nitrogen as assist gas. Its gives better quality of cutting surface by use of N2 as assist gas.
11	Experimental investigation on densification behavior and surface roughness of AlSi10Mg powders produced by selective laser melting	Lin-zhi Wang et al	Elsevier 2017	Optics and laser technology	AlSi10Mg	The densities of AlSi10Mg parts produced by SLM increase significantly and then decrease slowly with the increasing laser energy density
12	Computational Modeling of Dissimilar Metal CO2 Laser Welding: Applied to Copper and 304 Stainless Steel	V.B. Shaibu at al	Elsevier 2015	Procedia engineering	AISI 304 Stainless steel	The considered model has to extract some key features of the process such as differential heating of the dissimilar metals, development of asymmetric weld pool, and mixing of molten metal's
13	Performance analysis of CO2 laser polished angled ribbon fiber	Ik-Bu Sohn a et al	Elsevier 2017	Optical fiber technology	ribbon fibers	The CO2 laser polished curve edged angled fibers have lower probability of mechanical damage while connecting with various optical device because of their curved structure.
14	A numerical simulation of machining glass by dual CO2-laser beams	Junke Jiao at al	Elsevier 2008	Optics and laser technology	glass plates.	The thermal stress can be reduced by means of the dual-laser-beam method.

15	Numerical Simulation of Laser Beam Cutting of Carbon Fiber Reinforced Plastics	Tomasa Ohkuboa,et al	Elsevier 2014	Physics procedia	carbon fiber reinforced plastic	To develop the new calculation model, thermo gravidity analysis (TGA) and differential thermal analysis (DTA) applied to calculate heat transfer inside CFRP and succeeded in simulating HAZ formation.
16	Energy Efficiency Assessment of Laser Drilling Process	Fysikopoulos Apostolos et al	Elsevier 2012	Physics procedia		The main results of this study are the identification of the process parameters window with the most energy efficient performance and the introduction of processing strategies for low laser power (100-1000W) drilling processes. Higher laser power results in improved energy efficiency
17	Parametric Investigation in LaserFormingof8mm FE410PlateusingHigh Power CO2 Laser and Its Bend Angle Prediction	AgnelD'Souza	Elsevier2015	Materialstoday proceeding	steel sheets of FE410	Experiments were performed on 8mm steel sheets using CO2 Laser with maximum energy of 3000W. Various parameters were varied namely power (2KW to 3KW), number of passes (1to 210), scan speed (10 to30 mm/s), laser spot diameter (9mm to 13mm) and frequency(500Hz to 20000Hz) to get maximum bend angle

Conclusion

The present survey indicates that laser power, cutting speed, assist gas pressure, focus distance, number of pass have major influence on cutting quality like kerf width, surface roughness, depth of cut which also varies with material thickness. As well as laser beam machining is able to cut advance material like ceramic, granite, polymer, glass etc. Laser beam machining is highly flexible in terms of verity of material and process parameter like power , cutting speed and number of passes.

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