AN OVERVIEW: MACHINING TECHNOLOGY BY STIMULATED EMISSION OF RADIATION

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Abstract –

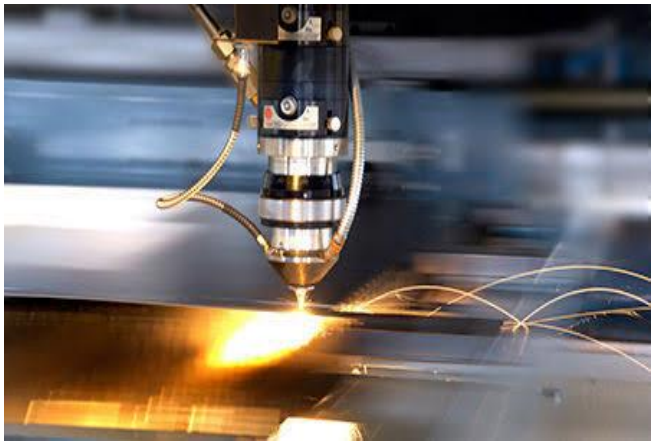
Albert Einstein first published the key principle behind the operation of the laser *[light amplification by stimulated emission of radiation*], when he hypothesized that, under the proper conditions, light energy of a particular frequency could be used to stimulate the electrons in an atom to emit additional light with exactly the same characteristics as the original stimulating light source. Lasers are considered to be the advanced material processing tools filling the gap in the precision, low cost, localized processing, and high speed of operation. The laser is electromagnetic radiation. It produces monochromatic light which is in the form of an almost collimated beam that can be focused optically on to very small spots of less than 0.002 mm diameter. In laser machining applications, a laser beams used as a heat source increasing temperature rapidly to the melting and evaporation temperature of the substrate material. Since the arrangements of the optical setting for the laser beam are very precise, the localized heating can be controlled easily. With recent advancement in laser technology and computations power, laser machining application has become almost an integral part of the aerospace, power, electronics, and sheet metal forming industries. However, in laser machining operations, the physical processes are complicated and they require deep understanding of process to secure improved end product quality

Keywords-- stimulating light, amplification, evaporation temperature, monochromatic, collimated beam radiation, emission.

I. INTRODUCTION

Laser beam machining (LBM) is a thermal energy based advanced machining process in which the material is removed by (i) melting, (ii) vaporization, and (iii) chemical degradation (chemical bonds are broken which causes the materials to degrade). When a high energy density laser bream is focused on work surface the thermal energy is absorbed which heats and transforms the work volume into a molten, vaporized or chemically changed state that can easily be removed by flow of high pressure assist gas jet (which accelerates the transformed material and ejects it from machining zone).[3]

LBM can be applied to a wide range of materials such as, metals and non-metals, soft and difficult-to-machine (DTM) materials. Among various kind of lasers now used in modern industries, CO2 and Nd:YAG [*Neodymium yttrium-aluminum garnet*] are the most mature ones. Although CO2 lasers have wide application in commercial sheet metal cutting operations, the benefits offered by Nd:YAG lasers make it an interesting field of investigation. [3] In LBM, there are many factors (variables) such as beam parameters, material parameters and machining parameters which affect the various quality characteristics, e.g. surface roughness, HAZ, recast layer, etc. A lot of theoretical and experimental studies have been done by researchers in order to develop the models that try to simulate the conditions during Nd:YAG LBM and establish the cause and effect relationships between various factors and quality Characteristics.[3]



II. ALBERT EINSTEIN THEORY BEHIND LASER [BASIC PHYSICS]

The laser would never have been developed without a profound understanding of an area of fundamental physics **quantum theory**. The principle behind the laser goes back to the world's most famous physicist, Albert Einstein, who in 1917 proposed a theory of stimulated light emission. Einstein had previously shown that light was composed of tiny packets of wave energy called photons (the wavelength depending on the energy). He theorised that if the atoms that make up a material are given excess energy and so emit photons, these photons could stimulate nearby atoms to emit further photons, creating a cascade effect. All the photons would have the same energy and wavelength and move off in the same direction. However, it was not until 40 years later that physicists were able to convert this idea into a practical laser. The principle is that the "active" material has first to be pumped with energy from another light source or an electrical current. The resulting stimulated light emission is then amplified by bouncing the light back and forth through the lasing material in a mirrored cavity, so stimulating more emission, before it escapes through a transparent mirror section as a laser beam. A device that amplified microwaves was constructed in 1953 by Charles Townes and colleagues at Columbia University. Townes shared a Nobel Prize in Physics in 1964 with **Nikolay Basov and Aleksandr Prochorov** of the Lebedev Institute in Moscow (who independently also demonstrated what came to be called a maser). [1]

Without the discovery of lasers, the entire fundamental field of cold atoms would never have opened up. Research in this field has led to the award of several Nobel Prizes in Physics, including the discovery of **Bose–Einstein condensates** (BEC). BEC has opened the door to a host of applications such as atom lasers, improved atomic clocks and quantum computers.[1]

III. CHARACTERISTICS OF LASER

Laser light has four unique characteristics

- Coherence
- Directionality
- Monochromatic
- High intensity

Coherence

In laser, the electron transition occurs artificially. All the photons emitted in laser have the same energy, frequency, or wavelength. The wavelengths of the laser light are in phase in space and time. In laser, a technique called stimulated emission is used to produce light. [4]

Directionality

All photons will travel in same direction. Therefore, laser emits light only in one direction. This is called directionality of laser light. The width of a laser beam is extremely narrow. Hence, a laser beam can travel to long distances without spreading [4]

Monochromatic

Monochromatic light means a light containing a single color or wavelength. In laser, all the emitted photons have the same energy, frequency, or wavelength. Hence, the light waves of laser have single wavelength or color. [4]

High intensity

In laser, the light spreads in small region of space and in a small wavelength range. Hence, laser light has greater intensity when compared to the ordinary light. Thus, even a 1 Watt laser would appear many thousand times more intense than 100 Watt ordinary lamp

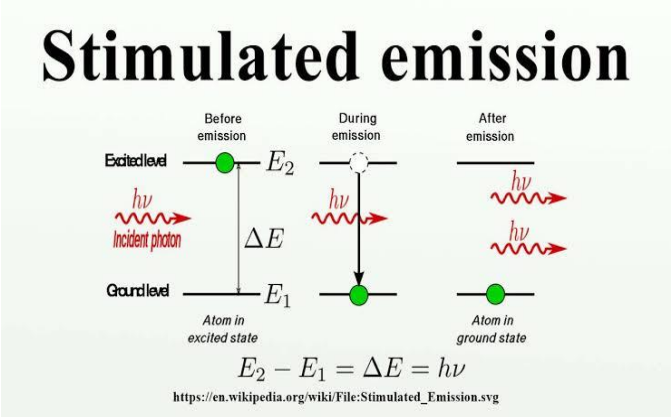
Thus, these four properties of laser beam enable us to cut a huge block of steel by melting [4]

IV. PRINCIPLE OF LASR BEAM PRODUCTION

When in the presence of an energy source, such as an external battery that supplies current, the material that emits electromagnetic radiation emits the light of the laser at various energy states. These energy levels, or quantum levels, depend on the source material itself. Higher energy states of electrons in the material are more likely to be unstable, or in excited states, and the laser will emit these through its light. Unlike other lights, such as the light from a flashlight, lasers give off light in periodic steps with itself. [2] That means the crest and trough of each wave of a laser line up with those of the waves that come before and after, making their light coherent.

Lasers are designed this way such that they give off light of specific frequencies of the electromagnetic spectrum. In many cases, this light takes the form of narrow, discrete beams that the lasers emit at

precise frequencies, but some lasers do give off broad, continuous ranges of light [2]



V. COMPONENTS OF LASER

Some lasers use pumping systems, methods of increasing the energy of particles in the laser medium that let them reach their excited states to make population inversion. The components of a laser beam also vary in how long they take to deliver energy. Continuous wave lasers use a stable average beam power. With higher power systems, you can generally adjust power, but, with lower power gas lasers like the helium-neon lasers the power level is fixed based on the content of the gas.[2]

Helium-neon laser

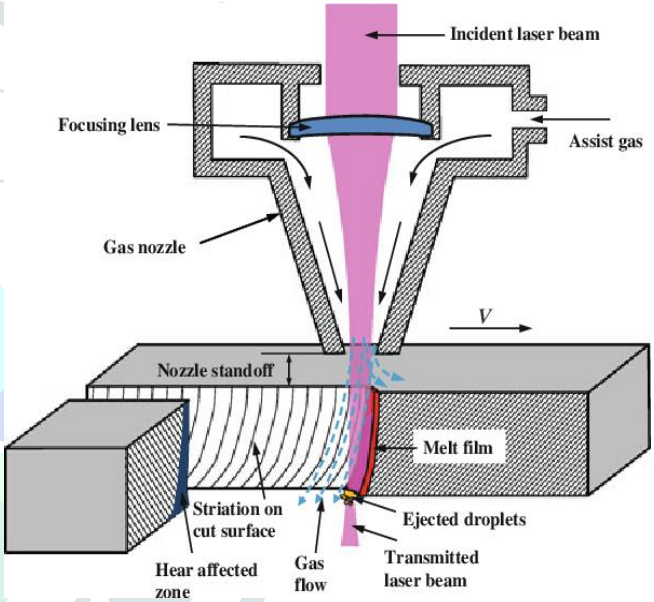
The helium-neon laser was the first continuous wave system and is known to give off a red light. Historically, they used radio frequency signals to excite their material, but nowadays they use a small direct current discharge between electrodes in the tube of the laser.

When the electrons in helium are excited, they give off energy to neon atoms through collisions that create a population inversion among the neon atoms. The helium-neon laser can also function in a stable manner at high frequencies. It's used in aligning pipelines, surveying and in X-rays.[2]

Argon, Krypton and Xenon Ion Lasers

Three noble gases, argon, krypton and xenon, have shown use in laser applications across dozens of laser frequencies that span ultraviolet to infrared. You can also mix these three gases with each other to produce specific frequencies and emissions. These gases in their ionic forms let their electrons become excited by colliding against one another until they achieve population inversion.[2]

Many designs of these kinds of lasers will let you select a certain wavelength for the cavity to emit to achieve the desired frequencies. Manipulating the pair of mirrors within the cavity can also let you isolate singular frequencies of light. The three gases, argon, krypton and xenon, allow you to choose from many combinations of light frequencies. These lasers produce outputs that are highly stable and don't generate much heat. These lasers show the same chemical and physical principles that are used in lighthouses as well as bright, electric lamps like stroboscopes.[2]



Carbon Dioxide Lasers

Carbon dioxide lasers are the most efficient and effective of continuous wave lasers. They function using an electrical current in a plasma tube that has carbon dioxide gas. The electron collisions excite these gas molecules that then give off energy. You can also add nitrogen, helium, xenon, carbon dioxide and water to produce different laser frequencies.

When looking at the types of a laser that may be used in different areas, you can determine which ones can create large amounts of power because they have a high efficiency rate such that they use a significant proportion of the energy given to them without letting much go to waste. While helium-neon lasers have an efficiency rate of less than .1%, the rate for carbon dioxide lasers is about 30 percent, 300 times that of helium-neon lasers. Despite this, carbon dioxide lasers need

special coating, unlike helium-neon lasers, to reflect or transmit their appropriate frequencies.[2]

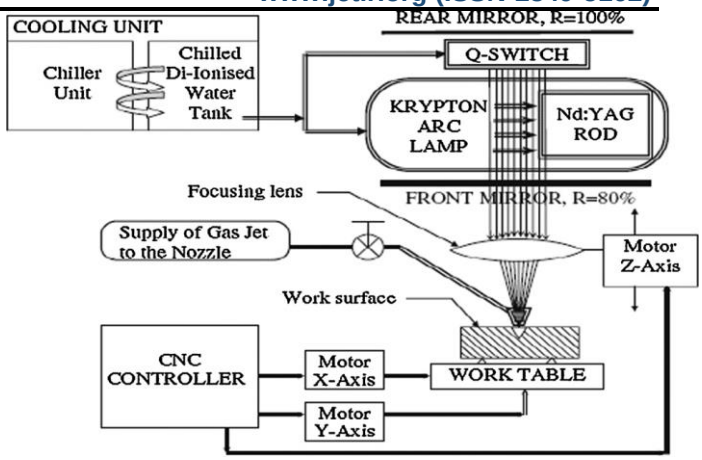
Excimer Lasers

Excimer lasers use ultraviolet (UV) light that, when first invented in 1975, attempted to create a focused beam of lasers for precision in microsurgery and industrial microlithography. Their name comes from the term "excited dimer" in which a dimer is the product of gas combinations that are electrically excited with an energy level configuration that creates specific frequencies of light in the UV range of the electromagnetic spectrum.[2]

These lasers use reactive gases like chlorine and fluorine alongside amounts of noble gases argon, krypton and xenon. Physicians and researchers are still exploring their uses in surgical applications given how powerful and effective they can be used for eye surgery laser applications. Excimer lasers don't generate heat in the cornea, but their energy can break intermolecular bonds in corneal tissue in a process called "photo ablative decomposition" without causing unnecessary damage to the eye.[2]

VI. LASER BEAM MACHINING COMPONENTS

- Laser cutter frame
- Laser generator
- Laser lenses
- CNC system
- Regulated power supply
- Cutting head
- Control platform
- Motor
- Water chiller
- Gas cylinders
- Air compressor, gas storage tank
- Air cooling dryer, filter
- Dust extractor
- Slag discharge machine



1) ***Laser cutter frame***

It's the mechanical part to realize the movement in X, Y, Z-axis, including cutting working platform. Fiber laser cutting machines have very high requirements for machine tool stability. High precision and high stability machine tools help to improve the precision of laser cutting.

At present, the mainstream machine tools on the market are gantry type, cantilever type, beam type. Different machine tools have different functions, such as beam type machine tools mainly used for material cutting by large manufacturers. There are also models for specific fields, such as 3D fiber laser cutting, mainly used in the automotive industry. [5]

2) ***Laser generator***

A device that produces a laser light source Laser generators are the most "power source" of laser equipment, just like the car engine, and the most expensive part of fiber laser cutting machines.

At present, the imported brands of fiber laser generator in the market include German IPG, ROFIN, and British SPI etc. With the development of technology, China's domestic laser brands such as Raycus and Max have also emerged, and they are gradually recognized by the market with high-cost performance.[5]

3) ***Laser lenses***

Laser lenses are the most used in the entire fiber laser cutting equipment.

Many optical devices contain laser lenses. Different lenses have different functions, such as full-reflex lenses, semi-reverse lenses, and

focusing lenses. The quality of the lens directly affects the output power of the laser, which also affects the performance of the whole machine. [5]

The same lens is also divided into domestic and imported. The life and cutting effect of domestic lenses are not as good as imported lenses, but the price is far cheaper to import lenses.

4) *CNC system*

The control system is the leading operating system of the fiber laser cutting machine, which mainly controls the machine tool to realize the movement of the X, Y and Z axes, and also controls the output power of the laser. Its quality determines the stability of the operating performance of the fiber laser cutting machine. Through the precise control of the software, the accuracy and cutting effect can be effectively improved. [5]

5) *Regulated power supply*

The connection between the laser generator, laser cutter and power supply system, mainly to prevent the external power network interference

6) *Cutting head*

The cutting head is a laser output device of a fiber laser cutting machine, which is composed of a nozzle, a focusing lens and a focus tracking system.

The cutting head drive device is used to drive the cutting head moves along the z-axis in accordance with the program, which is composed of the servo motor, screw rod or gear, etc. However, the height of the laser cutting head needs to be adjusted and controlled under different materials, different thicknesses and different cutting methods. [5]

7) *Control platform*

The process of controlling the whole cutting device

8) *Motor*

The motor of the laser cutting machine is the core component of the motion system. The performance of the motor directly affects the processing effect and production efficiency of the product.

At present, the commonly used motors include stepping motor and servo motor, which are configured according to the industry and product of the processing object.

Stepper motor: It has a fast-starting speed and sensitive response and is suitable for engraving and cutting processing. The price is lower. Stepper motors have many brands and different performances. [5]

Servo motor: Fast moving speed, smooth movement, high load, stable performance; smooth edge processing and fast cutting speed; high price, suitable for industries and products with high processing requirements.

9) Water chiller

Used for cooling laser generator. A laser generator is a device that converts electrical energy into light energy, such as a CO2 laser with a conversion rate of 20%, and the remaining energy is converted to heat. The cooling water takes the excess heat away to keep the laser generator working properly. The chiller is also cooling the external optical path reflector and focusing mirror to ensure the stable beam transmission quality and effectively prevent the lens from being too hot and causing deformation or crack. [5]

10) *Gas cylinders*

Includes laser cutter working medium gas cylinders and auxiliary gas cylinders mainly act as industrial gases for the supplement of laser oscillations and auxiliary gas for supplying cutting head use.

11) *Air compressor, gas storage tank*

Provide and store compressed air.[5]

12) *Air cooling dryer, filter*

Used to supply clean dry air to the laser generator and beam path to maintain the normal work of the pathway and reflector.

13) ***Dust extractor***

The smoke and dust produced during the process of fabrication shall be filtered and treated to meet the environmental protection standards.[5]

VII. MACHINING OPERATION

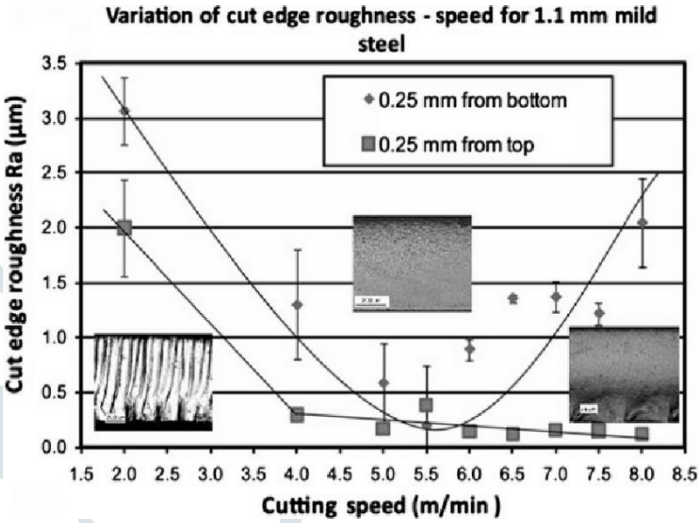
In operation, the work piece to be cut is placed on the aluminum work table (which is resistant to being cut by laser beam). The laser head is traversed over the work piece and an operator visually inspects the cut while manually adjusting the control panel. The actual profile is obtained from a linked mechanism, made to copy the master drawing or actual profile, placed on a near-by bench. The laser in short pulses has a power output of nearly 10 kw 'cm of the beam cross-section. By focusing a laser beam on a spot 1/100 of a square mm in size, the beam can be concentrated in a short flash to a power density of 100,000 kW/cm and energy of several joules lasting for a minute fraction of a second. For machining short pulses of say, 100 joules energy are required.

Experimental setup available at Merasha Shapers Pvt. Ltd., Five Star M.I.D.C., Kagal, Kolhapur, Maharashtra, India

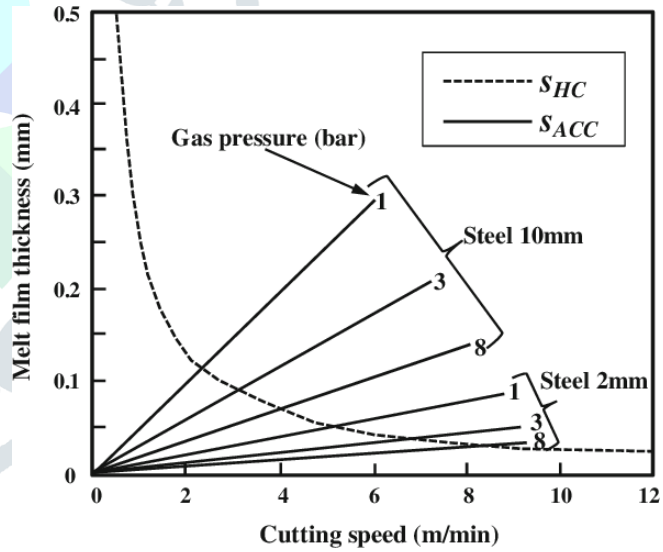
The laser can, therefore, provide enough heat of melt and vaporize any of the known materials. The mechanism by which a laser beam removes material from the surface being worked includes a mixture of melting and evaporation process. However, with some materials, the mechanism is pure of evaporation [5]

VIII.PROCESS PARAMETES

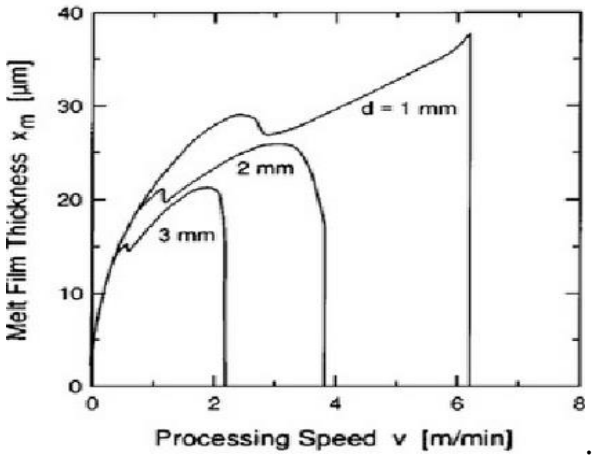
Power density and laser beam-work piece interaction time are the most important variables determining whether the beam will weld, cut, mark, or heat, treat.

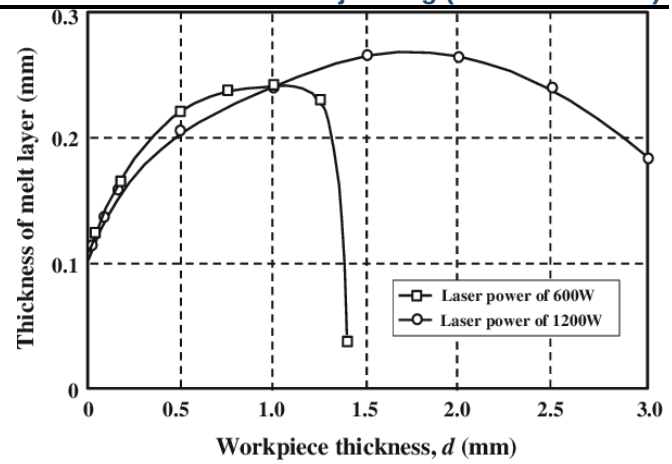


1. Cutting speed V/s melt film thickness [6]



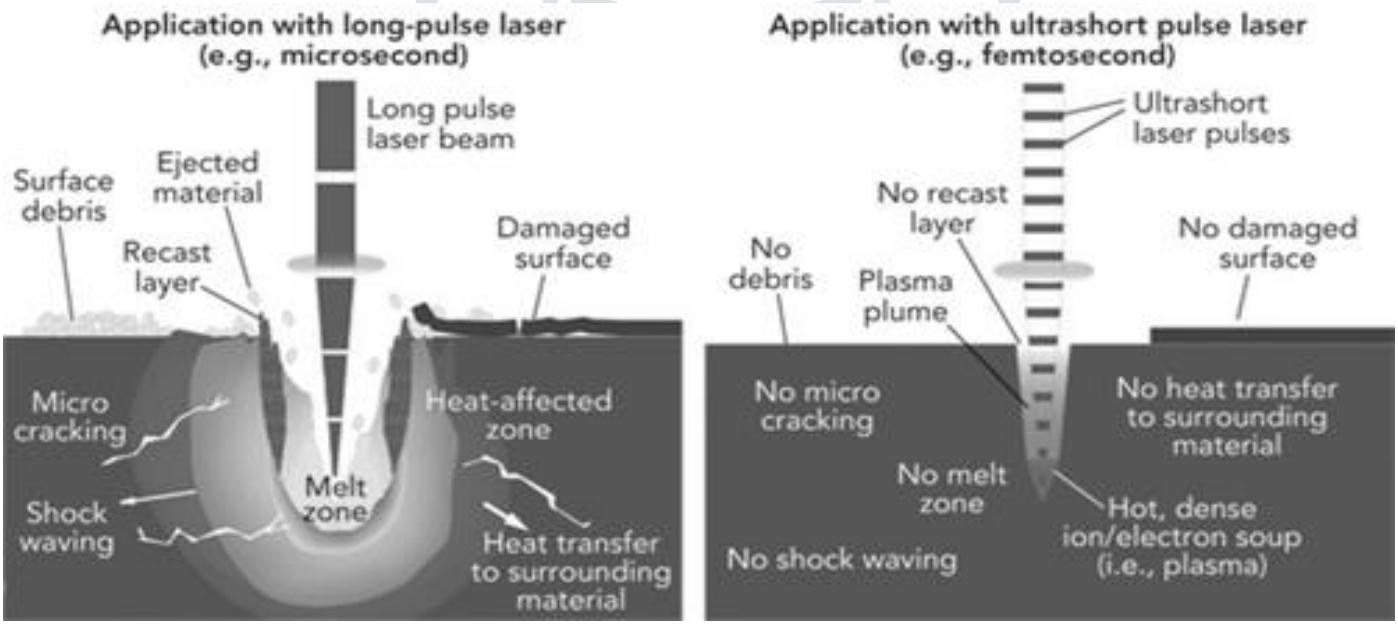
2. Melt film thickness V/s processing speed [6]





3. Thickness of melt layer V/s work piece thickness in accordance with laser power [6]

IX. HEAT AFFECTED ZONE ON WORK PIECE DURING MACHINING



[7]

X. CURRENT DEVELOPMENT AND TRENDS

The laser machining process is at present found to be suitable only in exceptional cases like machining very small holes and cutting complex

Profiles in thin, hard materials like ceramics. It is also used in partial cutting or engraving. Other applications include steel metal trimming, blanking and resistor trimming. Though LBM is not a mass material removal process, it is possible to use this process in mass micro-machining Production Laser cutting is used to optimize processes, applications, and production across a wide range of industries including electronic, automotive, medical, metalworking, woodworking, printing, packaging, HVAC and other specialty industries. [8]

When you need just-in-time manufacturing, laser technology is the ideal converting solution. Machines with this capability increase the accuracy of your overall production by ensuring clean lines and precise detailing on your finished products. You may want to consider laser cutting if you are currently converting components from the following materials: Label Stock & PSA, Laminates VHB Tapes, Films, Foils, Papers Foams Rubber Coated Fabrics, Mats, Double Sided Adhesives Gaskets, Plastics, and Textiles. Difficult and abrasive materials Aggressive Adhesive Materials

The laser machining process is at present found to be suitable only in exceptional cases like machining very small holes and cutting complex profiles in thin, hard materials like ceramics. It is also used in partial cutting or engraving. Other applications include steel metal trimming, blanking and resistor trimming.

Though LBM is not a mass material removal process, it is possible to use this process in mass micro-machining production [8]

Advantages of Your Business Investing in a Laser Cutter

- 100% Savings in Tooling Costs
- 40% Increase in Material Yields
- 40% Reduction in Job Changeovers
- Increased Flexibility in Designs
- Increased Precision Levels & Edge Quality
- Increased Depth of Cut Control
- Total Cut, Kisscut & Engrave on Same Layout
- Increased Productivity on Short and Long Runs
- Ease of Use and Increased Throughput [9]

Application of Laser Beam Machining

- The laser machining process is at present found to be suitable only in exceptional cases like machining very small holes and cutting complex profiles in thin, hard materials like ceramics.
- It is also used in partial cutting or engraving.
- Other applications include steel metal trimming, blanking and resistor trimming.
- Though LBM is not a mass material removal process, it is possible to use this process in mass micro-machining production.[9]

Advantages of Laser Beam Machining

Any solid material which can be melted without decomposition can be cut with the laser beam. Other major advantages of the laser beam machining include the following:

- There is direct contact between the tool and the work piece.
- Machining of any material including nonmetal is possible.

- Drilling and cutting of areas not readily accessible are possible.
- Heat affected zone is small because of the collimated beam.
- Extremely small holes can be machined.
- There is no tool wear.
- Soft materials like rubber and plastics can be machined. [9]

Disadvantages of Laser Beam Machining

One of the main limitations of the laser that it cannot be used to cut metals that have high heat conductivity or high reflectivity, e.g., Al, Cu, and their alloys. In addition, the process has the following disadvantages:

- Its overall efficiency extremely low (10 to 15%).
- The process is limited to thin sheets.
- It has a very low material removal rate.
- The machined holes are not round and straight.
- The laser system is quite inefficient since the life of the lash lamp is short.
- Cost is high. [9]

XI. CONCLUSION

The work presented here is a review of the basic laser machining process. The present review gives the knowledge of evolution and theory of laser, basis beyond the quantum physics, stimulated emission, Einstein theory behind laser, population inversion and so on.

We mainly contrite on the machining operations, machining equipments, microstructure level of heat affected zones, process parameters effecting the laser beam machining, Current trends and applications. The present laser beam machining is CNC based machining.

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