International Journal of Research Publication and Reviews

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

Advancements in CNC Laser Cutting Machines: Revolutionizing Precision Manufacturing

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ABSTRACT:-

This article describes the design and fabrication of a low-power, three-degree-of-freedom laser cutting machine for applications such as wood, textiles, etc. An off-the-shelf 10-watt laser gun is used to provide the cutting mechanism. The results show that such a machine is feasible and affordable for applications where speed and repeatability are more important than precision and high throughout. Reducing production costs and total processing times is essential for industries in developed countries to maintain their competitive advantage. It is especially suitable for small batch production of difficult-to-cut materials, such as aerospace alloys, high-hardness materials used in the energy sector, tools and manufacturing components as well such as high-precision special alloy designs popular in medical device manufacturing. The heat transfer simulation problem is related to the optimization of CNC programs. Current physically-based simulation tools use numeric or analytic algorithms which provide accurate but slow solutions due to the underlying mathematical description of the model. Some visualisational experiments were also performed for further understanding of the micro- and macro-mechanics of the cutting process. This article presents a preliminary study to evaluate the effect of the processing parameters (laser power and cutting velocity) under the quality of the cut for several polymeric materials. The objective was to evaluate the quality of the cut (presence of burr and dimension of heat affected zone (HAZ).

KEYWORDS:- Speed and Repeatability, Production Cost Reduction, Feasibiliy and Affordability, Tools and Manufacturing.

1. INTRODUCTION: -

1.1 CNC LEASER:-

A kind of machinery used for precisely cutting materials with a laser beam is called a CNC (Computer Numerical Control) laser cutting machine. The computerized control of the machine, or CNC, is what makes very precise and complex cuts possible. The main elements and features are broken down as follows:

i. **CNC Management:** A computer that processes a design file, usually in CAD software, and transforms it into numerical control signals operates the machine. The machine can precisely follow the cutting path given in the design thanks to CNC technology

ii. **Laser Pointer:** Depending on the material being cut, the laser source creates a concentrated beam of light that is usually a CO2 or fiber laser.For non-metal materials, CO2 lasers are frequently utilized, however fiber lasers are preffered for metals.

iii. **Cutting Surface:** The item that has to be cut is laid out on a cutting bed, which could contain slats or a grid to support it while letting the laser beam through.

iv. **System of Motion**: The laser head of the machine is accurately moved along the X, Y, and Z axes to follow the preprogrammed cutting path by use of a system of motors and driving mechanisms.

v. **Gas Provision**: Assistance gases (such oxygen or nitrogen) are sometimes utilized to improve the cutting process. The material being sliced determines the sort of gas.

vi. **Exhaust system**;-It's common practice to incorporate an exhaust or ventilation system to get rid of the waste and pollutants produced while cutting.

FIG: CNC LEASER CUTTING MACHINE

1.2 WORKING OF CNC LEASER CUTTING MACHINE:-

A CNC laser cutting machine operates in a number of steps, most of which are guided by three fundamental ideas:

vii. **Design Development:** A digital design, often known as a computer-aided design, or CAD file, is created at the start of the process. The exact measurements for the required cuts are included in this file.

viii. **Importing Files:** The control software for the CNC laser cutting machine is then opened by importing the CAD file. This software deciphers the design and transforms it into a set of machine- understandable instructions.

ix. **Preparing the Materials:** The material to be cut is laid out on the machine's cutting bed. The material can be made of wood, plastic, metal, or another material based on the laser cutting machine's capabilities.

x. **Configuration of the Machine:** By choosing the proper cutting parameters, such as laser power, cutting speed, and assist gas settings, the operator configures the CNC laser cutting machine. The material being cut frequently dictates these parameters**.**

xi. **Setting and Adjusting:** The device is calibrated to guarantee precise laser beam alignment. This could entail aligning the laser optics and homing the device to a reference point.

xii. **Implementation:** The operator starts the cutting operation when everything is set up. The laser beam is directed onto the material by the CNC system, which also moves the laser head along the preprogrammed cutting path.

xiii. **Laser Engraving:** Along the cutting path, the material is heated, melted, or vaporized by the laser beam that is emitted by the laser source. High precision is possible with the concentrated laser beam, enabling complex and detailed cuts.

xiv. **Help Gas (if applicable):** Assist gasses are sometimes utilized to improve the cutting process. For instance, inert gases like nitrogen can be applied to materials like acrylic to avoid oxidation, while oxygen can be used to cut metals since it helps with combustion.

xv. **Material Elimination:** The surplus material is either melted, evaporated, or blasted away by the support gas when the laser slices through it. The end product satisfies the design parameters with a precise and clean cut.

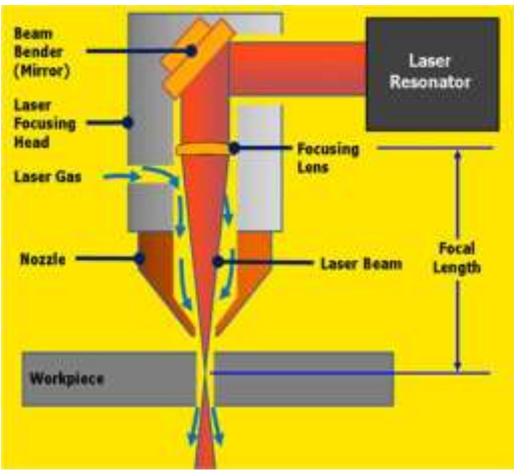

FIG.WORKING OF LEASER

1.3 CNC:-

CNC stands for "Computer Numerical Control." It refers to the automation of machine tools and 3D printers by means of computer systems. In the context of CNC machines, a computer converts a design created in a Computer-Aided Design (CAD) software into numerical code, and this code is used to control the movements of the tool or workpiece. CNC technology allows for precise and automated control of machining processes, leading to increased accuracy and efficiency in manufacturing and other applications. CNC is widely used in various industries, including metalworking, woodworking, plastic machining, and more.

2. LITERATURE

2.1 LASER CUTTLNG AT LOW POWERS (FUNDAMENTALS)

Laser cutting of materials is currently a viable and well-studied process. Its use in industry has steadily increased over the past two decades, with great success, especially in the manufacturing industry where most large industrial lasers are used for cutting. It finds a variety of applications in automobiles, aircraft, and other high-tech companies. Laser Market It is also impressive that in recent years the demand for low power compact lasers has increased surprisingly significantly. In the range from 10 to 200 watts. This is because is affordable, easy to maintain, safe, and cheap. When used in conjunction with a CNC beam delivery system connected to the PC- unit, these are referred to as "laser desktops". This is because they require more physical space to support their operations compared to large industrial units. The range of possible materials and applications remains vast.

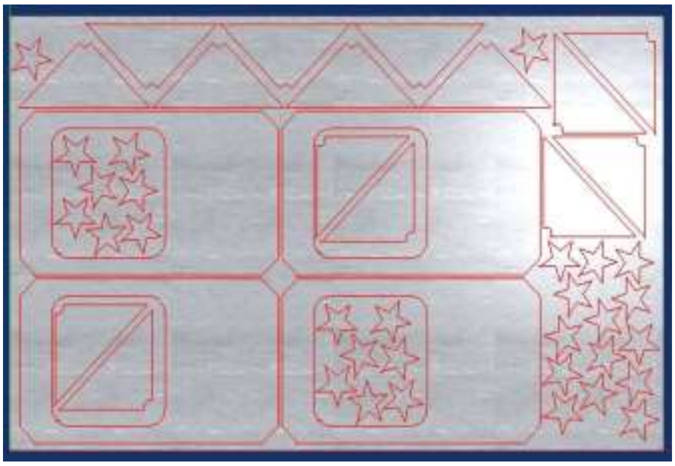

FIG. Overall 3D visualization of the CNC simulation

i. **CUTTING MEATAL: -**Cutting Metal When cutting metal, when a laser beam is focused on a very small diameter spot in the substrate, the temperature of the material increases to the point where a phase change from solid to liquid occurs. If the applied light power is pulsed and high enough , evaporation of the formed weld pool will occur and locally pressure will increase. This drains the molten material from the pool. The melt leaves the region as a droplet, and the walls of the resulting blind hole solidify rapidly after the laser pulse ends, leaving a stressed zone that can be connected to another zone by the next pulse. Once the entire depth of the material has been drilled , the laser beam can begin moving and deliver its power continuously or in pulses .The cut plane is then maintained where the solid is melted and the molten material is forced out from under the sheet using high pressure gas jets. Made of ferrous alloys such as low carbon steel or stainless steel The sheet requires optical processing. Up to 1 kW of power that can be successfully cut. For highly conductive and reflective metals such as copper and aluminum and their respective alloys, the power density of the to initiate a local melting zone is on the order of 2 kW. Most metals and metal alloys have high melting and boiling points due to strong metallic bonds, and when the metal melts, its viscosity and surface tension create strong resistance to fluid movement away from the cutting surface

ii. **CUTTING OF NON-METALS: -**Most nonmetallic materials, such as polymers, wood, ceramics, and organic materials, have very high absorption at the CO_2 laser wavelength (10.6 μm), reaching almost 90% at room temperature. Therefore, when cutting in the initial stage, the energy density required for the process is lower than for metal cutting. Laser cutting of nonmetals involves three mechanisms, one of which is more dominant for certain nonmetallic materials. These are melt shear, evaporation, and chemical decomposition. These determine the quality of possible cut edges.

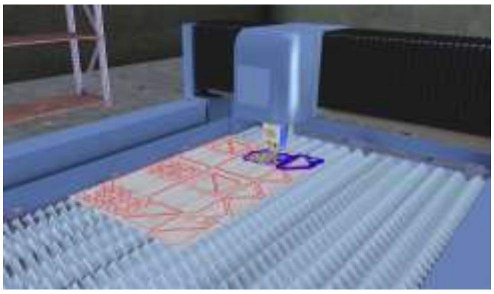

FIG. Stimulation of Sheet

iii. MELT SHEARING:- Most thermoplastics (nylon, polystyrene, etc.) are cut quickly with high quality edges that can be covered by fine waves associated with evacuation of the melt from the cutting zone. The CO2 laser produces a small molten pool that is blown away by a gas jet acting coaxially with the beam. The material discharged during cutting using an inert gas jet has the same chemical nature as the material being cut, and therefore only a solid-to-liquid phase transition occurs.

iv. VAPOURIZATION:-polymethyl methacrylate (acrylic) and polyacetal are commonly laser cut by this mechanism. In the case of acrylic, it boils to give off a vapor of methyl methacrylate and the process is mostly a physical phase change from solid to liquid to vapor with minimal breaking of chemical bonds. The cut edge is of extremely high quality and superior to flame polished or mechanically cut edges. The vapor of methyl methacrylate formed when cutting acrylic is highly absorptive of the laser radiation and can be ignited by the beam. This has to be avoided as it damages the surrounding acrylic. One way to prevent this is increasing the feed rate or the pressure of the assist gas. Cutting polyacetal produces large volumes of gaseous formaldehyde but the cut edge is flat, smooth and has a polished appearance similar to acrylic cuts.

v. CHEMICAL DEGRADATION:-most thermoset polymers, wood-based products. This mechanism is used to laser cut rubber products and epoxy resin. Laser beams have many chemical effects when cutting (burning).The energy emitted by the laser helps improve the integrity of the material by breaking chemical bonds. When wood is cut, large cellulose molecules are reduced and broken down into their constituents carbon and water vapor. The cut edges generated by this mechanism tend to be flat and smooth but covered in a fine layer of residual carbon dust.PVC is also cut by this process, giving off highly toxic fumes of HCI while polyurethane gives off HCN fumes .When cutting cellulosic materials (wood, fiberboard, hardboard, paper etc.) the temperature in the zone can reach over 2000PC depending in the density of the material .The oxidation of the carbon content is an exothermic process which supplies the cut front with energy .The quality of the cut edge is superior to a mechanical one, being smooth and splinter free .This process tends to generate a carbon based smoke and residual carbon deposit on the cut edge .In summary a focused low power CO2 laser beam will produce a temperature raise at the focal spot due to the amount of heat applied locally .The thermal gradient will be enough to Stan a phase change, the breaking of the molecule bonds or both; thus inducing the melting, vaporization and chemical degradation of the material .The application of an inert assist gas at high pressure is useful for removing the vapors and products of combustion out of the cut zone hence increasing the depth of penetration of the cut and preventing, as in the case of polymers and woods, the sudden ignition of the fumes given off.

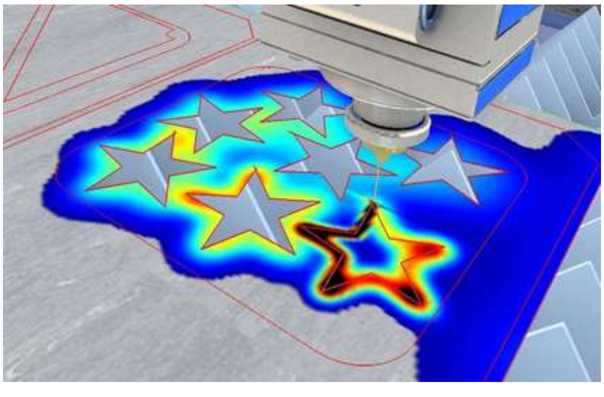

FIG. Detailed inspection near a recent cut. Heat affects posterior cuts

vi. CUTTING PARMETERS:-The interaction time between the laser beam and the material is an important parameter that must be considered when cutting soft materials such as fabrics, textiles, and wood. The optimal velocity (feed rate) of the jet relative to the surface controls the amount of energy delivered to the material. The amount of energy input must be sufficient to vaporize and chemically decompose the material to prevent the combustion front from spreading across the cutting surface .Many nonmetals combine low thermal conductivity with high coefficients of expansion. At lower feed rates , the exposure time is longer, resulting in more localized heating from the laser , reducing the accuracy and repeatability of material cutting , and resulting in severe edge burn.If the feed rate of the CNC is set too high, the cutting front will not have enough time to completely penetrate the material, and furthermore, the waste material will not leave the interaction zone at the bottom of the cut.

Although the cutting quality and speed of fiber laser machines are excellent for thin sheet materials, they are still unsatisfactory for thick sheet materials, leaving this area to CO2 lasers. Fiber lasers cannot cut optically transparent materials such as glass, quartz, or acrylic due to their low absorption. Additionally, fiber lasers have several other aspects that prevent them from completely replacing CO2 laser machines .Fiber lasers are highly complex devices due to sophisticated pumping concepts, numerous fiber splices, beam combiners, etc .The long- term durability of such devices has not yet been fully proven.

- In laser cutting applications a focusing systems, assembled as shown in Fig.1, is used.Its function is the loss-less delivery of the laser
- beam to the machining point without affecting beam quality and the focusing of the laser beam onto the workpiece achieving the required power density for the cutting process. In particular the focusing system consists of the following optical components:

1. **Feeding fiber:-** which routes the laser radiation from the laser source to the focusing system
2. **Fiber outcoupling,:-**where the end of the fiber is usually connected to a cylindrical extraction block made of fused silica. Collimator, where the divergent beam leaving the feeding fiber is paralleled. A doublet lens is typically used here, as well as singlets or aspheric lenses

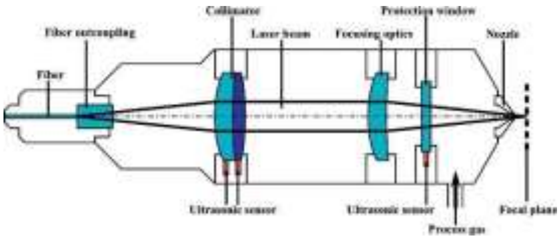

Fig. 1. Schematic cross section of a cutting head with temperature monitoring of the collimator and protection window.

3. **Focusing optic:-** used to focus the collimated beam onto the workpiece. Typically a doublet or singlet lens is used here. The spot size in the focus is related to the core diameter of the feeding fiber and the magnification of the whole focusing system. The magnification is the ratio of the focal lengths of focusing optic and collimator
4. **Protection Window:-**protecting the focusing optic against contamination from the cutting process and secluding the process gas volume. The power and high beam quality of fiber lasers expose the limitations of traditional focusing systems. The optic is typically made of fused silica and has an anti-reflection coating on its surface. Although high purity materials are used, a small portion of the high power laser beam is absorbed by each of his optical components and anti-reflection coatings.

2.2 RESARCH OBJECT:-

- To perform a comparative analysis, two items were cut from S235JR steel and Figure 1 was created.One he cut with a CO2 laser and the other with a fiber laser.
- The cutting parameters (Table 2) were chosen such that the linear energy was 55. 4 kJ/m in both cases. The thickness of the product is 6mm.

Table 2. CUTTING PARAMETER USED FOR CUTTING TEST ACCURACY

	Power, kW	**Focus, mm**	**Pressure, bar**	**Cutting speed, m/s**
CO2	2.0	Auto	0.8	0.03667
Fiber	2.0	- 1.6	0.6	0.03667

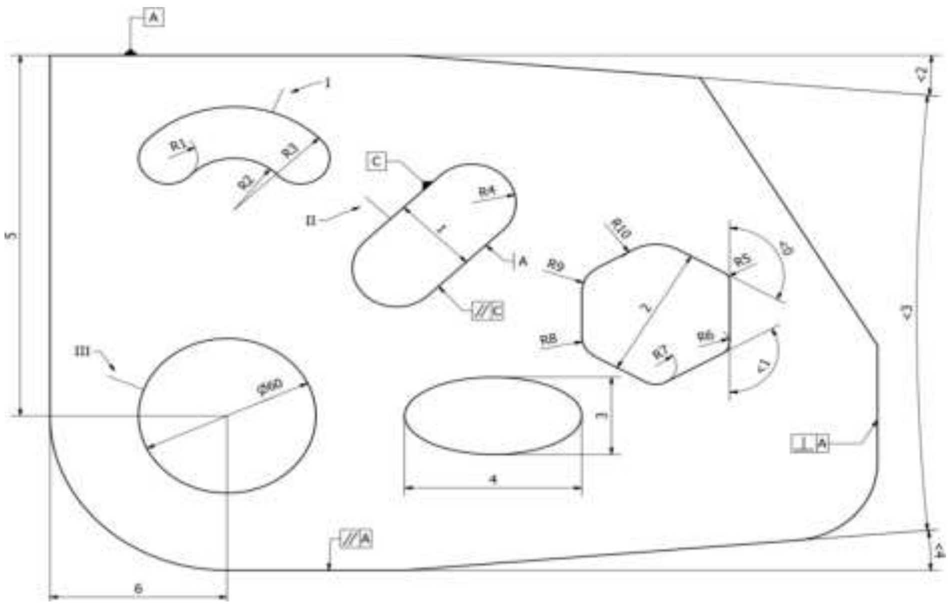

Fig. 2. Detailed drawing of the item

2.3 Applications Of CNC Leaser Cutting:-

i. **Fabrication of Metal:**

Usage: The metal manufacturing industries make substantial use of CNC laser cutting. Application: It is used to cut complex forms, patterns, and holes in a variety of metals, including stainless steel, aluminum, and steel. This is essential for making parts that go into aeronautical constructions, automobile parts, and architectural components.

ii. **Textile Sector:**

Usage: The textile and apparel industries make use of CNC laser cutting.

Application: Fabrics and textiles are accurately cut for apparel production using laser cutting equipment. This technique is particularly useful in the production of clothing and fashion since it provides excellent accuracy, lowers waste, and permits complex designs and patterns.

iii. **Manufacturing of Medical Devices:**

Usage: Medical device manufacturing employs CNC laser cutting.

Application: It is employed in the cutting and shaping of materials, including polymers, titanium, and stainless steel, to produce parts for medical equipment. For the production of small and complex parts used in stents, implants, and diagnostic equipment, laser cutting precision is crucial.

iv. **Automobile Sector:**

Usage: The car production industry makes extensive use of CNC laser cutting. Application: Sheet metal is sliced with laser cutting machines to create body panels, chassis pieces, and automobile components. The car industry benefits from efficient manufacturing processes facilitated by the high precision and speed of laser cutting.

3. CONCLUSION

The paper explores the complexities of heat transfer modeling while recognizing that improving CNC programs is a difficult task. It draws attention to how current simulation tools compromise between computing speed and accuracy, highlighting the necessity of a well- rounded strategy. The study gains depth from the visual trials, which shed light on the cutting process's macro- and micromechanics. A prospective exploratory research on the effects of processing factors (laser power and cutting velocity) on the quality of cuts in polymeric materials rounds off the study. The evaluation criteria, which demonstrate a thorough commitment to expanding the capabilities and understanding of CNC laser cutting technology, include the presence of burrs and the size of the heat-affected zone (HAZ).

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