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LASER BEAM MACHINING PARAMETERS AND CHARACTERISTICS

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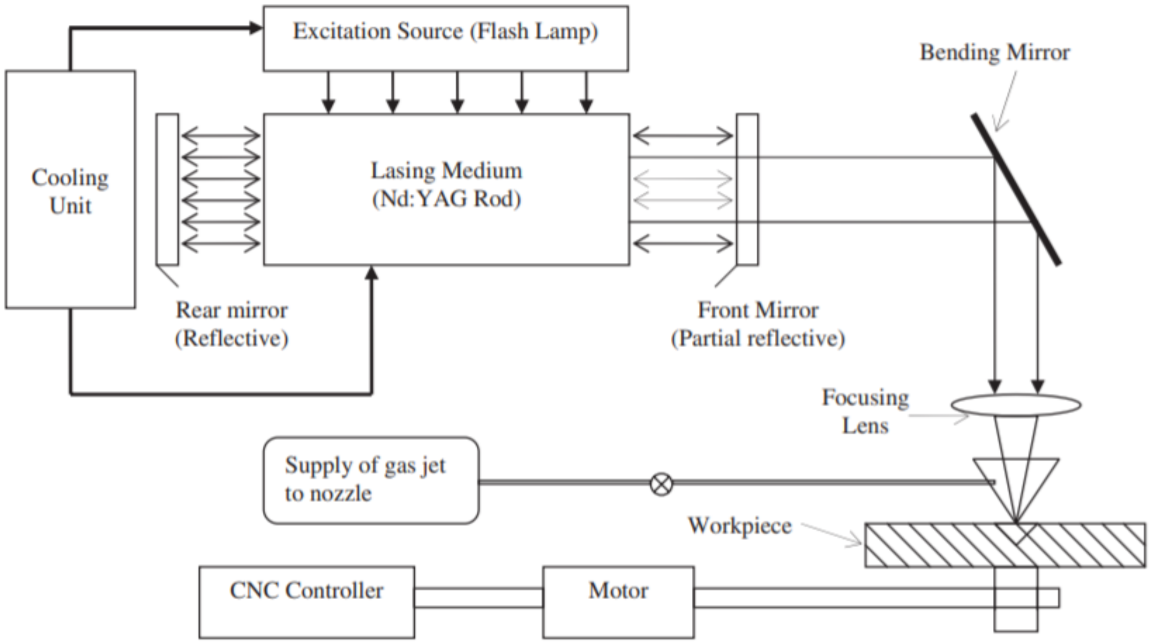
ABSTRACT: *Laser beam machining (LBM) is one of the most widely used thermal energy based non-contact type advance machining process which can be applied for almost whole range of materials. Laser beam is focussed for melting and vaporizing the unwanted material from the parent material. It is suitable for geometrically complex profile cutting and making miniature holes in sheetmetal. Since last four decades laser beams are being used in various manufacturing processes. CO2 and Nd:YAG lasers are most widely used in machining of engineering materials. In recent years the researchers have explored the number of ways to improve the quality of cutting, drilling and micromachining of different materials (metals, alloys, ceramics and composites) using Nd:YAG lasers. This paper reviews the experimental investigations carried out to study the effect of various factors/process parameters on the performance of laser beam machining and the recent innovations in improvement of laser beam machining.*
KEY WORDS: *Laser beam machining, cutting parameters, Process Parameters, Stand-Off Distance, Cutting Speed.*

INTRODUCTION

Emergence of advanced engineering materials, stringent design requirements, intricate shape and unusual size of workpiece restrict the use of conventional machining methods. Hence, it was realized to develop some nonconventional machining methods known as advanced machining processes (AMPs). Nowadays many AMPs are being used in the industry such as LASER beam machining. The acronym "LASER" stands for Light Amplification by Simulated Emission of Radiation is a coherent and amplified beam of electromagnetic radiation. The key element in making a practical laser is the light amplification achieved by stimulated emission due to the incident photons of high energy. Laser comprises of three components namely lasing medium, lasing energy source and optical delivery or feedback system. Laser light differs from ordinary light because it has the photons of same frequency, wavelength and phase. Thus, unlike ordinary light laser beams are high directional, have high power density and better focussing characteristics. These unique characteristics of laser beam are useful in processing of materials. The laser beams are widely used for machining and other manufacturing processes such as, cutting, drilling, micromachining, marking, welding, sintering, and heat treatment. Among different type of lasers, Nd:YAG and CO2 are most widely used for LBM application. CO2 lasers have wavelength of 10 mm in infrared region. It has high average beam power, better efficiency and good beam quality. It is suitable for fine cutting of sheet metal at high speed. Nd:YAG lasers have low beam power but when operating in pulsed mode high peak powers enable it to machine even thicker materials. Also, shorter pulse duration suits for machining of thinner materials. Due to shorter wavelength (1 mm) it can be absorbed by high reflective materials which are difficult to machine by CO2 lasers.

PRINCIPLE OF LASER BEAM MACHINING

The mechanism of material removal during includes different stages such as absorption and heating, melting, vaporization and chemical degradation. When a high energy density laser beam is focused on work surface the thermal energy is absorbed which heats and transforms the work volume in to a molten, vaporized or chemically changed state that can easily be removed by flow of high pressure assisting gas jet.



LASER CUTTING PARAMETERS

The process of laser cutting involved many parameters, which can be generally divided into two main categories—beam parameters and process parameters.

Beam Parameters

These are parameters that characterize the properties of the laser beam which include the wavelength, power, intensity and spot size, continue wave and pulsed power, beam polarization, types of beam, characteristics of beam, beam mode.

1. **Wavelength**
   The wavelength depends on the transitions in the process of stimulated emission with respect to the physical mechanisms involves in energy coupling and the process efficiency, stability and quality, the wavelength plays a most decisive role. It has important effect on material‘s surface absorptivity. For a specific material type, there is a certain wavelength which can have maximum absorption of laser energy with a lowest reflection. Due to the shorter wavelength of fibre lasers (in the range of 1 µm almost the same as Nd-YAG laser) compared to CO2 lasers (10.6µm), it leads to the higher absorption in metallic material.

2. **Power, intensity and spot size**
   The size of a laser system is usually specified in the term of power. The power of laser system is the total energy emitted in the form of laser light per second. Without sufficient power, cutting cannot be started. The intensity of the laser beam is the power divided by the area over which the power is concentrated. The high intensity of laser beam causes rapid heating of the

material, which means that little time is available for heat to dissipate into the surrounding material. Additionally, the reflectivity of most metals is much lower at high intensities, compared to the low beam intensity. Moreover, the intensity determines the thickness of material which can be cut. Spot size is the irradiated area of laser beam. In laser cutting application, it is required to focus beam into minimum spot size. Due to the better beam quality of fiber laser with very low divergence, the user can get spot diameters smaller than conventional lasers producing longer working distances.

3. **Continuous wave (CW) and pulsed laser power**
   Both the continuous wave and pulsed laser power can achieve the high intensity needed for laser cutting. The cutting speed is determined by the average power level. Average power level with CW laser is higher compared to the pulsed laser.

PROCESS PARAMETERS

These are parameters that characterize the properties of the laser beam which include focusing of laser beams, focal position and dual focus lens, process gas and pressure, nozzle diameter, stand-off distance and alignment, and cutting speed.

1. **Focusing of Laser Beams**
   The focal length of lens is about the distance from the position of focal lens to the focal spot. In the fibre laser system, the laser beam is delivered by the fiber optics and use a collimator to form the divergent laser beam. After that, it comes to the focusing lens or mirror and it focuses the parallel laser beam onto the work piece. The cutting process requires the spot size is small enough to produce the high intensity power. The focal length of the lens has a large impact on size of the focal spot and the beam intensity in the spot.

2. **Focal Position**
   In order to get optimum cutting result, the focal point position must be controlled. There are two reasons: the first reason is that the small spot size obtained by focusing the laser beam results in a short depth of focus, so the focal point has to be positioned rather precisely with respect to the surface of the work piece; the other one is differences in material and thickness may require focus point position alterations.

3. **Nozzle Diameter, Stand-Off Distance**
   Nozzle is used to deliver the assist gas. The nozzle has three main functions in the laser cutting process: to ensure that the gas is coaxial with the beam; to reduce the pressure to minimize lens movements and misalignments; and to stabilize the pressure on the work piece surface to minimize turbulence in the melt pool [3, 4]. The stand-off distance, which is the distance between the nozzle and the work piece, is also an important parameter. The stand-off distance is usually selected in the same range as the diameter of cutting nozzle-between 0.5 and 1.5 mm-in order to minimize turbulence. A short stand-off distance provides stable cutting conditions, although the risk of damage to the lens from spatter is increased. The stand-off distance is optimized to maximum the cutting speed and quality.

4. **Cutting Speed**
   The cutting speed must be balanced with the gas flow rate and the power. As cutting speed increases, the cutting time decreases and less time for the heat to diffuse sideways and the narrower the HAZ. The kerf is also reduced due to the need to deposit a certain amount of energy to cause melting. However, striations on the cut edge become more prominent, dross is more likely to remain on the underside and penetration is lost. When the cutting speed is too

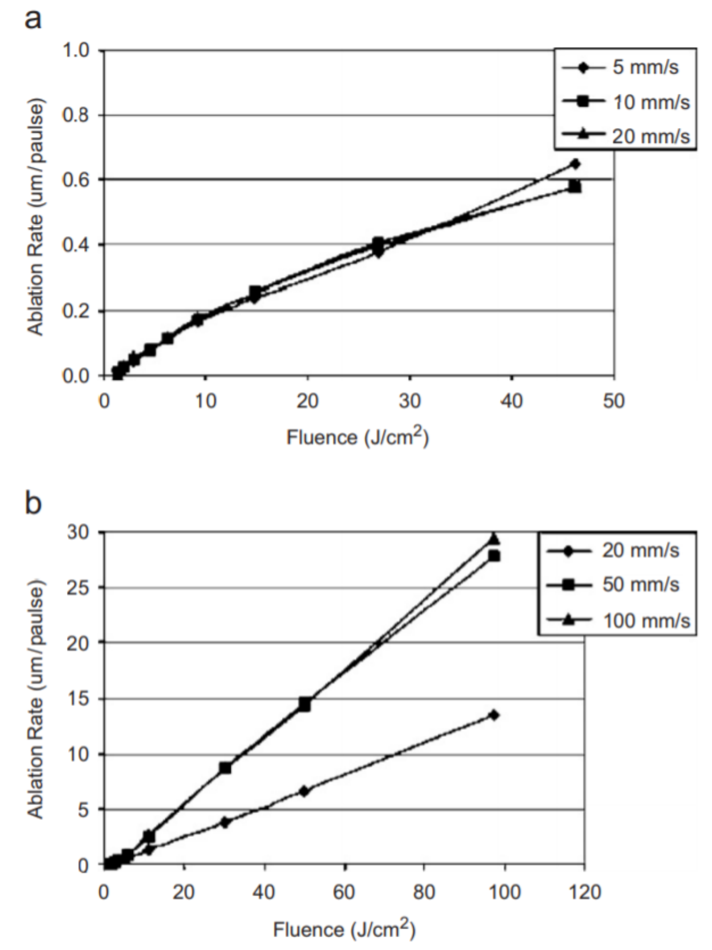
low, excessive burning of the cut edge occurs, which degrades edge quality and increases the width of the HAZ. In general, cutting speed for a material is inversely proportional to the thickness.

EXPERIMENTAL REVIEW

Many experiments are being conducted on LBM so as to understand the characters and performance. This paper gives a brief review on it.

Material removal rate (MRR)

Voisey has studied the melt ejection phenomena in metals (aluminium, nickel, titanium, mild steel, tungsten, copper and zinc) by conducting Nd:YAG laser drilling experiments at different power densities. It was found that MRR first increases and then decreases after a critical value with increasing power density for all metals tested. The critical value was found as type of metal dependent. Some investigators have used machining speed and/or machining time to represent the MRR. Cutting speed of continuous wave (CW) and pulsed Nd:YAG laser beam was compared in for cutting bare and coated metal plates (0.8–2.0 mm thick) of car frame using oxygen assist gas. The cutting speed obtained was more in case of CW laser, bare metal and thinner plate and the highest cutting speed recorded was 5 m/min at an optimum oxygen pressure of 3 bar. Experimental study for cutting stainless steel sheets (up to 2 cm thick) from a long distance (1 m) without using any assist gas was performed in pulsed mode taking pulse frequency (100–200 Hz), peak power (2–5 kW) and cutting velocity (0.05–0.5 m/min) as process variables. The study reveals that low pulse frequencies and high peak powers were found to be favourable for higher cutting speeds. The experimental study of micromachining of sapphire (381 mm) and silicon (533 mm) wafers show that the MRR increases with beam energy density irrespective of machining speed. The MRR of mullitealumina ceramic during laser cutting was increased by proper selection of off-axis nozzle angle (optimum value 451) and distance between the impinging point of the gas jet and the laser beam front (optimum value 3 mm). Experimental study by Lau shows that compressed air removes more material in comparison to argon inert gas during laser cutting of carbon fibre composites. The effect of pulse intensity (kW) on depth of cut or MRR during pulsed Nd:YAG laser cutting shows increasing effect for all metal matrix composites, carbon fibre composites and ceramic composites. The MRR during laser machining of concretes shows increasing trend with both laser power and scan speed.



SURFACE ROUGHNESS

Surface roughness is an effective parameter representing the quality of machined surface. The graph shows that surface roughness value reduces on increasing cutting speed and frequency, and decreasing the laser power and gas pressure. Also nitrogen gives better surface finish than oxygen. surface roughness value was found to be reduced on increasing pressure in case of nitrogen and argon but air gives poor surface beyond 6 bar pressure. Also, surface finish was better at higher speeds. shows that the laser power and cutting speed has a major effect on surface roughness as well as striation (periodic lines appearing on the cut surface) frequency. They have shown that at optimum feed rate, the surface roughness is minimum and laser power has a small effect on surface roughness but no effect on striation frequency. Chen has not found the good surface finish up to 6 bar pressure (of inert gas) during CO2 laser cutting of 3 mm thick mild steel. shows that surface finish improves on increasing the spot overlap. Recently, Li has proposed the specific cutting conditions for striation free laser cutting of 2 mm thick mild steel sheet. Micromachining of 0.5 mm thick NdFeB ceramic (magnetic material) using pulsed Nd:YAG laser gives better surface finish in water as compared to air. The experimental investigations on pulsed Nd:YAG laser cutting of 2.15 mm thick silicon nitride ceramic sheet using air as assist gas show that the optimum value of surface roughness falls in the middle range of operating parameters pulse frequency (6–8.5 Hz), lamp current (22–27 amp) and cutting speed (17–22 mm/s). Laser cutting of thick (1–10 mm) alumina ceramic substrates through controlled fracture using two synchronized laser beams, focused Nd:YAG (for scribing the groove crack) and defocused CO2 (to induce thermal stresses) show that surface finish obtained at 60 W laser power (for both Nd:YAG and CO2) and 1 mm/s cutting speed was much better than conventional laser cutting.

The surface roughness of thick ceramic tiles during CO2 laser cutting is mainly affected by ratio of power to cutting speed, material composition and thickness, gas type and its pressure. Use of nitrogen assist gas and lesser power intensities reduce the surface roughness. Pulsed mode CO2 laser cutting gives better surface finish than CW mode.

CONCLUSION

The work presented here is an overview of recent developments of LBM and future research directions. From above discussion it can be concluded that:

1. LBM is a powerful machining method for cutting complex profiles and drilling holes in wide range of workpiece materials. However, the main disadvantage of this process is low energy efficiency from production rate point of view and converging diverging shape of beam profile from quality and accuracy point of view.

2. Apart from cutting and drilling, LBM is also suitable for precise machining of micro-parts. The micro-holes of very small diameters (up to 5 mm) with high aspect ratio (more than 20) can be drilled accurately using nanosecond frequency tripled lasers. Cutting of thin foils (up to 4 mm) has been done successfully with micro-range kerf width.

3. The performance of LBM mainly depends on laser parameters (e.g. laser power, wavelength, mode of operation), material parameters (e.g. type, thickness) and process parameters (e.g. feed rate, focal plane position, frequency, energy, pulse duration, assist gas type and pressure). The important performance characteristics of interest for LBM study are HAZ, kerf or hole taper, surface roughness, recast layer, dross adherence and formation of micro-cracks.

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