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Review on Laser Beam Machining Process Parameter Optimization

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Abstract

The quality of laser cut is the most important factor in laser cutting process. All cutting parameters might have significant influence on the resulting quality of work. In general, cutting parameters are adjusted and tuned to provide the quality of cut desired. But this consumes exhaustive (enormous) amount of time and effort. Therefore, it is important to investigate the impact of cutting parameters on quality of cut. The aim of this study is to relate the CO_2 laser cutting parameters namely laser power, cutting speed laser scanning speed. Laser cutting is a fairly new technology that allows metals to be cut with extreme precision. The laser beam is typically 0.2 mm in diameter with a power of 1-10 kW [1]. Depending on the application of the laser cutter a selection of different gases are used in conjunction with the cutting. When cutting with oxygen, material is burned and vaporized when heated by the laser beam to ignition temperature. The reaction between the oxygen and the metal creates additional energy in the form of heat, supporting the cutting process. For certain well defined applications, e.g. cutting metal sheet using CO_2-lasers, suppliers of laser cutting machines provide a comprehensive database for process parameters.
Keywords: Laser, CO_2, Process Parameters, Optimization

I. Introduction

Most laser cutting carried out using Nd:YAG laser or CO_2 lasers. The general principles of laser cutting are approximately similar for both types of laser although CO_2 lasers dominate in the market. Laser cutting is a very new technology that allow metals to be cut with extreme precision. The laser beam is typically 0.2 mm in diameter with a power of 1-10 kW, [1]. Laser is an acronym for Light Amplification by Stimulated Emission of Radiation. The world's first laser was demonstrated by Maiman using a ruby crystal (Maiman 1960).

Laser cutting is a common manufacturing process employed to cut many types of materials. Materials which may be cut included ferrous metal, non-ferrous metal, stone, plastic, rubber and ceramic. Laser cutting works by directing a high power pulsed laser at a specific location on the material to be cut. The energy beam is absorbed into the surface of the material and the energy of the laser is converted into the heat, which melt or vaporize the material. Additionally gas is focused or blown into the cutting region to expel or blow away the molten melt and vapor from cutting path.

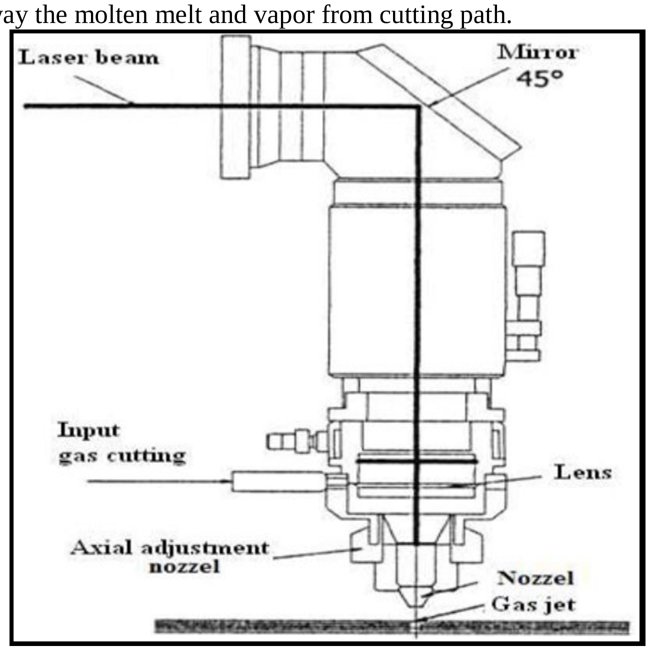

Fig. 1: Laser Beam Cutting

There are several advantage of laser cutting over mechanical cutting, since the cut is performed by the laser beam, there is no physical contact with the material therefore contaminates cannot enter or embed into the material. Laser cutting can produce high quality cut, complex cut, cut several part simultaneously, produce clean cutting edge which require minimal finishing as well as low edge load during cutting which will reduce distortion.

The two main laser sources which are widely used in Laser cutting are CO_2 and Nd:YAG lasers. The latter having an advantage of shorter wavelength (1.06 μm) which results in better absorption of laser energy in metals (Inconel, hardened steel, Titanium), metal matrix composites and ceramics without any coating. Most of the research works have been focused on the benefits of Laser cutting and addressed the challenges in conventional machining. The machining results of Laser cutting depend on both machining process parameters and laser parameters. The main operating parameters associated with laser assisted machining are: Laser power, spot diameter of the laser beam, cutting speed, feed rate and depth of cut. The optimal setting for Laser cutting is difficult due to the many control parameters and their interactions. A statistical study based on design of experiments is needed to investigate the effect of process parameter and their interactions. The present work aims to analyze the machinability characteristics with special reference to cutting forces and surface temperature of Inconel 718 at different cutting conditions using Taguchi method. The influence of cutting parameters namely cutting speed (s), feed rate (f) and laser power (p) on the workpiece surface temperature (Ts) and the cutting forces (Fx, Fy, and Fz) were analyzed using main effect plots. The Taguchi Methodology has been used in this study to arrive the optimal setting of laser machining parameters. In addition to this, the present work highlights the general benefits of Laser cutting compared with conventional machining.

II. 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 [3,5,6].

A. 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 fiber 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.

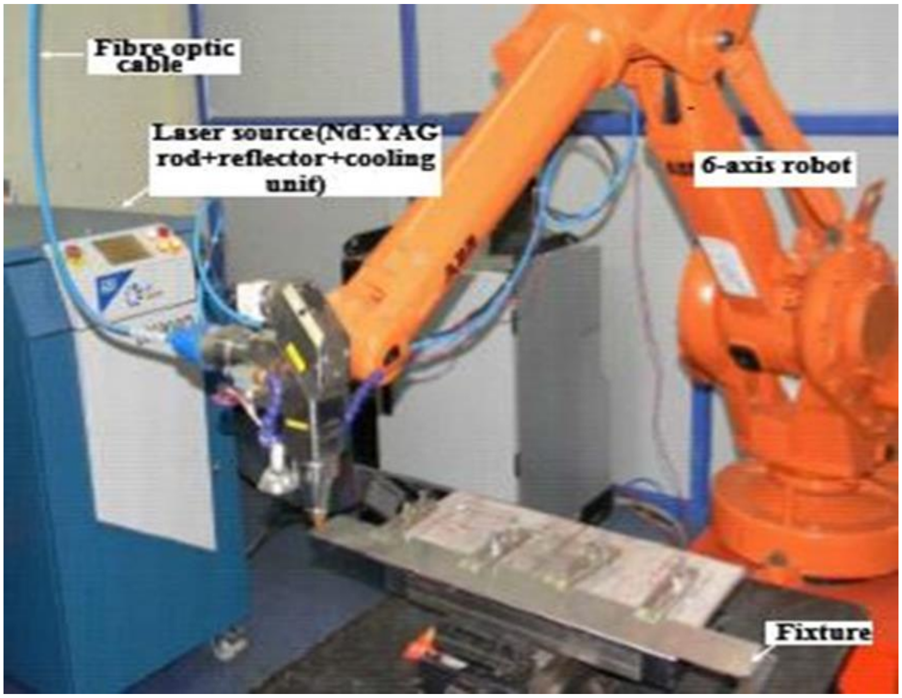

Fig. 2: Laser Cutting Setup

B. 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 fiber 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 [03,4}.

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 [4].

3) Process Gas and Pressure

The process gas has five principle functions during laser cutting. An inert gas such as nitrogen expels molten material without allowing drops to solidify on the underside (dross) while an active gas such as oxygen participates in an exothermic reaction with the material. The gas also acts to suppress the formation of plasma when cutting thick sections with high beam intensities and focusing optics are protected from spatter by the gas flow. The cut edge is cooled by the gas flow thus restricting the width of the HAZ. The commonly used gases are the oxygen and nitrogen. Nitrogen is mainly used for stainless steel and aluminum, whereas the oxygen is used for mild steel [3, 4].

In the process of oxygen cutting, the presence of oxygen contributes to an exothermic reaction, which effectively increases the laser power. It results into high cutting speeds and the ability to cut thick material. When cutting thick material, the gas pressure must decrease with the increasing thickness, in order to avoid the burning effect, whereas the nozzle diameter is increased [3, 4].

4) 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 [3, 4].

5) 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.

III. LITERATURE REVIEW

In March 2015, M Madic has been worked on an experimental analysis and optimization of CO2 laser cutting process on stainless steel plates. In this paper, multi-objective optimization of the cut quality characteristics such as surface roughness, width of HAZ and kerf width in CO2 laser cutting of stainless steel was presented [7]. The applied methodology integrates modelling of the relationships between the laser cutting factors (laser power, cutting speed, assist gas pressure and focus position) and cut quality characteristics using ANNs, formulation of the multi-objective optimization problem using weighting sum method and solving it by CSA (Comparative Sequence Analysis).Cuckoo search method is used for optimization purpose.

In 2014, K Venkatesan & R Ramanujam have been worked on an experimental Analysis of Cutting Forces and Temperature in Laser Assisted Machining of Inconel 718 using Taguchi Method [9]. This paper discussed about L9 orthogonal array, S/N ratio and ANOVA were adopted for finding the optimal process parameter for the performance measures of feed force (Fx), thrust force (Fy) and cutting force (Fz).

In 2013, M Lakshmi Chaitanya & A Gopal Krishna have been worked on Multi-objective Optimization of Laser Beam Cutting Process [10]. The material used for experiments was silicon carbide (SiCp) reinforced aluminum metal matrix composite which are the most advantageous engineering materials due to their properties such as low weight, heat-resistant, wear-resistant and low cost. Their work was about machining conditions involving the minimization of HAZ and Ra. The mathematical models for the HAZ and Ra are developed through the response surface methodology (RSM).A very popular evolutionary algorithm, non-dominated sorting genetic algorithm II (NSGA-II), was used to retrieve the multiple optimal sets of input variables [10].

In September 2012, Ruben Phipon & B.B.Pradhan have been worked on Control Parameters Optimization of Laser Beam Machining Using Genetic Algorithm. Their work was on Heuristic analyses using GA (genetic algorithm) for optimizing the cut quality namely kerf taper and surface roughness during pulsed Nd:YAG laser cutting of thin Al-alloy sheet for straight profile is performed.

In 2011, Koji Hirano and Remy Fabbro have investigated striation generation mechanism in inert gas laser cutting of steel by observation of hydrodynamics of melt layer on the kerf front [12]. Melt flows in the regions of kerf side and kerf front exhibit instability in different velocity ranges. They used 8 KW disk laser beam which was focused on to 3 mm thick low carbon steel with beam diameter 1.7 mm. the gas pressure of nitrogen was set to 2.5 bar and cutting speed was varied from 1 to 6 m/min. They observed melt dynamics exhibited instability depends upon the cutting velocity. In lowest velocity ranges ($v < 2$ m/min) the melt flow in the both the central and side region of the kerf front are instable. In intermediate velocity range (2 m/min $< v <$ 6 m/min) the central flow becomes stable, while the side region remains unstable. The unstable region becomes more restricted to the side with increase of v, until whole region becomes stable at $v = 6$ m/min. The observed instability can be explained by a combination of thermal instability of melting process and hydro dynamical instabilities due to surface tension[12].

In 2008, Avanish Dubey In laser beam cutting (LBC) process, It has been found that the kerf width during LBC is not uniform along the length of cut and the unevenness is more in case of pulsed mode of LBC[8,14]. In this paper, two kerf qualities such as kerf deviation and kerf width have been optimized simultaneously using Taguchi quality loss function during pulsed Nd: YAG laser beam cutting of aluminium alloy sheet (0.9 mm-thick) which is very difficult to cut material by LBC process. A considerable improvement in kerf quality has been achieved. [8,14]

In 2007 Ramesh Singh et al. have presented experimental characterization of a novel hybrid laser assisted mechanical micromachining (LAMM) process designed for 3D micro-grooving that involves highly localized thermal softening of the hard material by focusing a solid-state continuous wave laser beam in front of a miniature cutting tool[13]. Micro-scale grooving experiments are conducted on H-13 mold steel (42 HRc) in order to understand the influence of laser variables and cutting parameters on the cutting forces, groove depth and surface finish. The results show that the laser variables significantly influence the process response. Specifically, the mean thrust force is found to decrease by 17% and the 3D average surface roughness increases by 36% when the laser power is increased from 0 to 10W. The groove depths are found to be influenced by the machine (stage) deflection and tool thermal expansion, which affect the actual depth of cut, in the presence of laser heating. In particular, it is found that the accuracy of groove depth improves with laser heating.[13]

IV. CONCLUSIONS

Many works have already discussed on the optimization of the cutting parameters of CO2 laser on mild steel. However, parameters on cutting stainless steel have not yet discussed much. Therefore this experimental work discusses on the optimization of laser cutting parameters on stainless steel because, stainless steel is widely applied in industries. The purpose of this experimental work is to optimize the process parameters on cutting stainless steel by laser beam machining technology. This optimization process reduces the time and cost.

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