Review on Systematic Approach to Laser Beam machining Process parameters

M. M. Sayyad[1], Ravindra L. Karwande[2], Md. Irfan[3]
[1,] *PG Student, Department of Mechanical Engineering,*
[2'] *Asso. Prof. Mech. Engineering Dept., MSSCOET, Jalna.*
[3,] Research Scholar, *Dr. BAMU, Aurangabad*

Abstract-Laser Beam Cutting (LBM) is one of the most widely used manufacturing Field for generation of accurate and complex geometrical shapes on ferrous metal, nonferrous metal, stones, plastic and ceramics components with high dimensional accuracy. Laser Beam Machining is a non-conventional process in which material removal takes place through melting and vaporization of metal when the laser beam comes in contact with the metal surface. The effects of different input process parameters laser power, cutting speed, assist gas pressure, nozzle distance, focal length, pulse frequency and pulse width is studied on surface roughness (SR), Material removal rate, Heat Affected Zone (HAZ) and kerf width as a output responses. In Taguchi method L9 orthogonal array has been selected. The analysis of variance (ANOVA) has been used to determine effect of each parameter

Keywords: LBM, Process parameters, Performance parameters, Optimization.

I. INTRODUCTION

Nowadays, production companies in high-wage countries face the challenge of meeting individual customer requirements and rapidly changing market demands while keeping costs low. Providing a reliable but efficient production leads to growing complexities in the production processes. Production planning and scheduling requires a large amount of human information processing and decision making. In particular in the field of manufacturing process planning, decisions involve the consideration of the effect of multidimensional parameters on preselected criteria of the manufacturing process. For instance, one common problem is the choice of an appropriate machine parameter set those results in desirable process outputs (e.g. high output quality or minimal energy consumption). Due to a high dimensional domain space, the relationship between interdependent parameters and criteria is very difficult to achieve. In addition, they are very complex for the human mind to handle at a time. In order to handle these problems, process designers make use of modern computational approaches for modelling and simulating manufacturing processes. The conventional techniques to perform several sets of simulation run on the process, whereas each individual simulation is characterized by a high dimensional set of parameters and several criteria. The problem is that revealing the whole process behaviour requires a very large number of time-consuming experiments. It is not feasible to run full numerical simulations throughout the whole parameter space at a reasonable computational cost. Because of that, experimental simulation runs are performed by appropriate Design of Experiment (DoE) techniques as well as other, experience-based procedures. Since simulations are based on discrete sets of process parameters, they can only cover partial aspects of the process and do not provide insights into the whole process. This is essential when it comes to extract useful information.

II. THE TECHNOLOGY AND PROCESS MECHANISM OF LBM

The basic principle of laser beam cutting is shown in figure .An optical lens placed in the path of laser beam is used to focus the beam and to create a focal length suitable for the specific cutting application. The distance between the lens and material is adjusted so that the focal point of the laser beam is concentrated on or below the surface of the material depending on the material process required. Material around the focal point of the beam will melt and is blown away by the assist cutting gas that is concentric to the laser beam.

The mechanism of material removal during LBM includes different stages such as (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

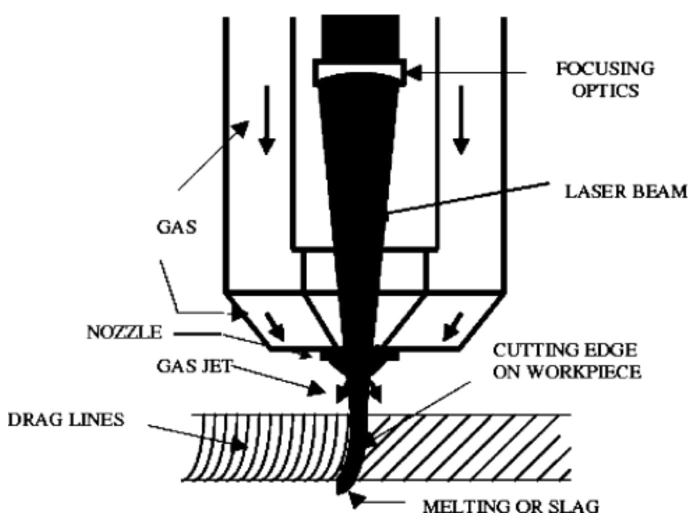

Figure: Cutting Principle

Laser beam cutting (LBC) is a thermal process. The effectiveness of this process depends on thermal properties and, to a certain extent, the optical properties rather than the mechanical properties of the material to be machined. Therefore, materials that exhibit a high degree of brittleness, or hardness, and have favorable thermal properties, such as low thermal diffusivity and conductivity, are particularly well suited for laser machining. Since energy transfer between the laser and the material occurs through irradiation, no cutting forces are generated by the laser, leading to the absence of mechanically induced material damage, tool wear and machine vibration.

III. APPLICATIONS, ADVANTAGES AND LIMITATIONS OF LBM

Applications

Fiber lasers have a wide range of applications and hence have the potential to dominate the material processing market in the future. These lasers are demonstrating process and cost advantages across the entire spectrum of material processing applications including: metal cutting, welding, silicon cutting, ceramic scribing, spot welding, bending, powder deposition, surface modification and marking. The applications by industry include:

- Automotive: welding transmission components, welding a sheet metal, cutting hydro- formed parts, marking, remote welding
- Computer: spot welding, annealing, silicon cutting
- Aerospace: welding Aluminum and Titanium, surface build up on blades, cutting aerospace components
- Medical device: marking, cutting, spot welding.

Advantages

- Laser beam cutting is an advantageous technology choice. A careful evaluation of the features of the most suitable cutting system guarantees optimum results in the following aspects:
- Reduction of total work time
- Increase in production quality
- Laser cutting is precise, clean and silent.
- Good reliability & lifetime
- High stability of laser output leading to consistency of processing
- Small size of overall unit
- Generally longer Warranty than standard lasers.
- Option of Air Cooled or Water Cooledup to a few hundred Watts output power.
- Lower price than equivalent power traditional laser.

- In laser cutting process, there is no physical tool. Thus no machining force or wear of the tool takes place. Though laser processing is a thermal processing but heat affected zone especially in pulse laser processing is not very significant due to shorter pulse duration.
- Total absence of mechanical pressure on work piece.
- Absence of wear in the instrument.
- Cutting capability independent of hardness of material.
- Capability of cutting coated or surface treated materials.
- Laser cutting also has high degree of automation and flexibility able to offer the ease of integration with other automated systems, very high trimming capability and capability of adapting immediately to changes in production requirement.

Limitations

- High initial capital cost
- High maintenance cost
- Very large resonator cavity required per cutting head, therefore, not normally used in multiple-head configuration;
- High capital equipment cost
- Requires isolation of cutting head for safety
- Mirror alignment critical and power level reduces as mirrors degrade
- Double material thickness is equal to one-half the cutting speed
- Generally not used for steel above 20 mm.
- Presence of heat affected zone-specially in gas assist co2 laser cutting.
- Thermal Process, not suitable for heat sensitive materials like aluminium, glass, fiber.
- Laser also has limitation capability on machining above two dimensional geometries compare to other machining methods. It means that in order to machine 3 dimensional and above level of geometries, suitable jigs and fixtures or special laser equipment laser systems are required to clamp work pieces.

IV. LITERATURE REVIEW

The specific analysis is performed in the different areas as discussed by this review paper

A D Tura et.al. (2021): A laser beam machine is a non-traditional manufacturing technique that uses thermal energy to cut nearly all types of materials. The quality of laser cutting is significantly affected by process parameters. The purpose of this study is to use a genetic algorithm (GA) in conjunction with response surface approaches to improve surface roughness in laser beam cutting CO2 with a continuous wave of SS 304 stainless steel. The effects of the machining parameters, such as cutting speed, nitrogen gas pressure, and focal point location, were investigated quantitatively and optimized. The tests were carried out using the Taguchi L9 orthogonal mesh approach. Analysis of variance, main effect plots, and 3D surface plots were used to evaluate the impact of cutting settings on surface roughness. The CO2 LBM parameters applicable for cutting of SS 304 stainless steel, namely Cutting speed, Nitrogen gas pressure, and Focal point position were considered for experimental purpose. Other parameters were kept constant for the scope of this research. Different settings of input process parameters with their levels used in the experiment are summarized in Table 3. The operating level was chosen as recommended by manufacturer. Taguchi's design of experiments was chosen to perform laser cutting experiments to provide efficient design of experiments with minimal testing. An experiment design matrix was created using the Taguchi L_9 (3 ^ 3) orthogonal matrix based on the selected cutting process parameters and levels. Table 4 shows the experimental design using the Taguchi L-9 and the experimental results of surface roughness.

R.S. Barge1et.al. (2019): Laser cutting is one of the widely used non-contact type and thermal based non-conventional machining process. Due to its increasing use and demand lots of researches had been carried out in last few years. The main aim of these researches is to optimize the process parameters of the laser beam machining process. Laser beam machining is a process in which the quality of the output machined component depends upon various input parameters. Considering this an attempt has made in this paper after referring various research works to explain in detail about the relation between the input parameters and output quality and the effect on the output quality parameters by changing the input parameters. This paper will provide an idea about the range of input parameters required for obtaining the desired quality at the output. The quality of the material after the laser cutting is very important. Major development require in LBM is improvement in surface quality by reducing the spreading of heat affected zone and increasing the accuracy in particularly micromachining. Any improvement in this area will have a very great importance in the field of machining and manufacturing. Laser machining is a very complex thermal process and numerous techniques and methods are developed to optimize the process parameters of the LBM. Therefore, it is the aim of this paper to help you in proper understanding of various parameters.

M. Baluljeben et.al. (2018): Effect of the various laser cutting parameters such as laser power and cutting speed, on the laser cutting quality. In this study, cutting quality was evaluated by measuring the Quadratic mean roughness Rq of the machined surface. A simple and practical model was proposed to predict the Quadratic mean roughness Rq as a function of namely parameters; laser power P, cutting speed V and fixed assistance oxygen flow rate Q. The adequacy of the proposed model was tested by Analysis Of Variance (ANOVA). The Experimental data were compared with modeling data to verify the capability of the proposed model. The results indicate that laser power and cutting speed are determinant cutting-parameters on the quadratic mean roughness of the cutting surface. The surface roughness parameter is determined from ANOVA statistical analysis by providing simple analytical model. The quadratic mean roughness is the result of the micro-geometric modification of a surface caused by the intensive bombardment of this surface by projectiles while giving roughness as called peaks and cavities called hollows. The roughness of a surface explains adhesion, slippage, rolling, or the sensitivity to wear or corrosion. Quadratic mean roughness or quadratic mean deviation of the profile Rq; This is the mean of the absolute values of the deviations, between the peaks and the troughs. It measures the distance between this average and the centre line. It corresponds to the quadratic mean of all the values of the roughness profile R calculated over the evaluation length

Mr. Amitkumar et.al. (2017): This study investigates the influence of Laser Beam Machining (LBM) process parameters on surface roughness and kerf width while machining Stainless Steel (SS 304). Laser Beam Machining (LBM) is a non conventional process in which material removal takes place through melting and vaporization of metal when the laser beam comes in contact with the metal surface. There are so many process parameters which affect the quality of machined surface cut by LBM. But, the laser power, cutting speed, assist gas pressure, nozzle distance, focal length, pulse frequency and pulse width are most important. However, the important performance measures in LBM are Surface Roughness (SR), Material Removal Rate (MRR), kerf width and Heat Affected Zone (HAZ). Experiments are carried out using L27 Orthogonal array by varying laser power, cutting speed and assist gas pressure for stainless steel SS 304 material. The results showed that the assist gas pressure and laser power are the most significant parameters affecting the surface roughness and kerf width respectively, whereas the influence of the cutting speed is much smaller.

V.Senthilkumar.al. (2016) Laser machining is a popular manufacturing process utilized to cut various types of materials economically. In this project CO2 laser machining of Mild Steel has been investigated. Mild

Steel is soft because of its high strength and malleability. The width of laser cut or kerf, quality of the cut edges are affected by laser power, machining speed, assist gas pressure, and stand-off distance between nozzle and the work piece material. The experiment was designed and carried out on the basis of standard L16 Taguchi's orthogonal array in which the four laser machining parameters were arranged at four levels. From the analysis of mean values of variance, the significant laser machining parameters were identified. The Machining Time reduces with significantly with decrease in Power and Cutting Speed .The Surface Roughness decreases with the increase in Power, Cutting Speed, and Stand Off distance. The Hardness of the material increases with the increase in Power and at low Stand Off Distance. The Kerf Width is reduced with the increase in Power and Cutting Speed

V. PROCESS PARAMETERS OF LBM

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. Cutting Speed: When cutting speed is increases interaction between Laser beam and material is decreases. That is Heat generation decreases which leads to minimum side burning. 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 deposited 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.

2. Process Gas Pressure: By increasing the Gas pressure, the Heat Generated by exothermic is increased which results in self burning of the cut surface and hence the increase in the surface roughness. When the pressure of the cutting gas is too high, the influence on the cutting quality: the cutting surface is rough, and the slit is wide; at the same time, the cut section is partially melted, and a good cutting section cannot be formed When the pressure of the cutting gas is insufficient, the following effects will be affected on the cutting quality: the melting will occur during cutting, and the cutting speed cannot meet the production efficiency 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.

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. Laser Power: Surface roughness value decreases with increase in cutting laser power, In general, it is evident that the surface roughness decreases with an increase in cutting speed . A decrease in laser power, generally increases surface roughness, however the effect of laser power should be considered through interaction with cutting speed and assist gas pressure. Similarly, an increase in gas pressure increases surface roughness. The effects of cutting speed and assist gas pressure were more pronounced than the effect of laser power on surface roughness characteristics

4. 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

5. 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].

6. 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.

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.

VI. CONCLUSIONS

- Most of the research work in LMB focused on the improvement of material removal rate, heat affected zone, surface roughness and kirf width but very few researchers have analyzed surface integrity aspects such as metallurgical changes, surface morphology, recast layer (RL), microstructural modification and phase change in the machined surfaces.
- Micro hardness can study
- Most of the research worked with Stainless steel, mild steel low carbon steel with different grades now we can work same experiment with other types of grades and material
- In this study only three parameters are chosen. A detailed study may be carried out for other parameter also.
- This technique also used to investigate the study of more mechanical such as fatigue life; toughness etc. to give a complete solution of commonly used material.
- The advanced soft computing techniques can be utilized to enhance the process Capability of LBM parameters and reduce the error in the experimental results.
- No published research work on Finite element modeling and simulation of process parameters in LBM

VII. ACKNOWLEDGMENT

I would like to express my deepest gratitude and sincere thanks to my guide **Prof. Ravindra Karwande**, Associate professor of mechanical engineering department of Matsyodari Shikshan Sanstha's College of Engineering and Technology Nagewadi, Jalna for thier valuable time and keen interest in my research work. thier intellectual advice has helped me in every step of my research work and motivated my efforts

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