Current Research and Development in Laser Beam Machining (LBM): A Review

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Abstract: ***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, heat affected zone (HAZ) and surface hardness. This paper reviews the research work carried out from the inception to the development of LBM within past few years. It reports on the LBM research relating to performance measures improvement, monitoring and process control, process variables optimization. The paper also discusses the future trend of research work in the area of LBM.***

Keywords: Laser Beam Machining, Process parameters, Monitoring, Process control, Optimization

1. Introduction

Emergence of advanced engineering materials, stringent design requirement, and intricate shape and unusual size of work piece restrict the use of conventional machining methods. Hence, it was realize to develop some nonconventional machining methods known as advanced machining processes. There are many advancement in process are being used in industries such as Electron Beam Machining (EBM), Electro Chemical Machining (ECM), Electrical Discharge Machining (EDM), Ion Beam Machining (IBM), Laser Beam Machining (LBM) and Abrasive Water Jet Machining (AWJM) etc. are increasingly being used as alternative to conventional machining techniques because of it is restricted for advanced engineering materials, stringent design requirements, intricate shape and unusual size of work piece. LBM is one of the advanced machining processes which are used for shaping almost whole range of engineering materials. Major application of laser beam is mainly in cutting of metals and non-metals, soft and difficult to machine (DTM) materials [1].

Laser is the acronym for Light Amplification by Stimulated Emission of Radiation. The first laser was invented in 1960. It was an optical pumped laser using a ruby crystal as gain medium. Afterwards the technology has been in constant development. In 1967 laser cutting was demonstrated for the first time. This was done using a focused CO2 laser and an assist gas jet. It wasn't until 1978 that the first flatbed laser cutting machine was introduced for commercial use. This machine was actually a punch/laser cutting machine, where the cutting head was a stationary unit and the work piece could be moved in the x-y directions using numerical controls. The year after 1979 Trump (German laser machine manufacturer) introduced a 500-700 W CO2 laser cutting machine. LBM have certain advantageous characteristics, which turns to achieve significant penetration into manufacturing industries.

- high precision
- small heat-affected zone
- low level of noise
- No need of special fixtures for the work piece
- No need of expensive or replaceable tools
- Low waste
- Minimum deformity

LBM is normally used for applications, ranging from military weapons to medical instruments, Cutting, Welding, Aerospace, Aeronautical industry. Material which are cut by LBM are Al alloy, wood, ceramic, rubber, plastic, Brass, Hardox-400, etc.

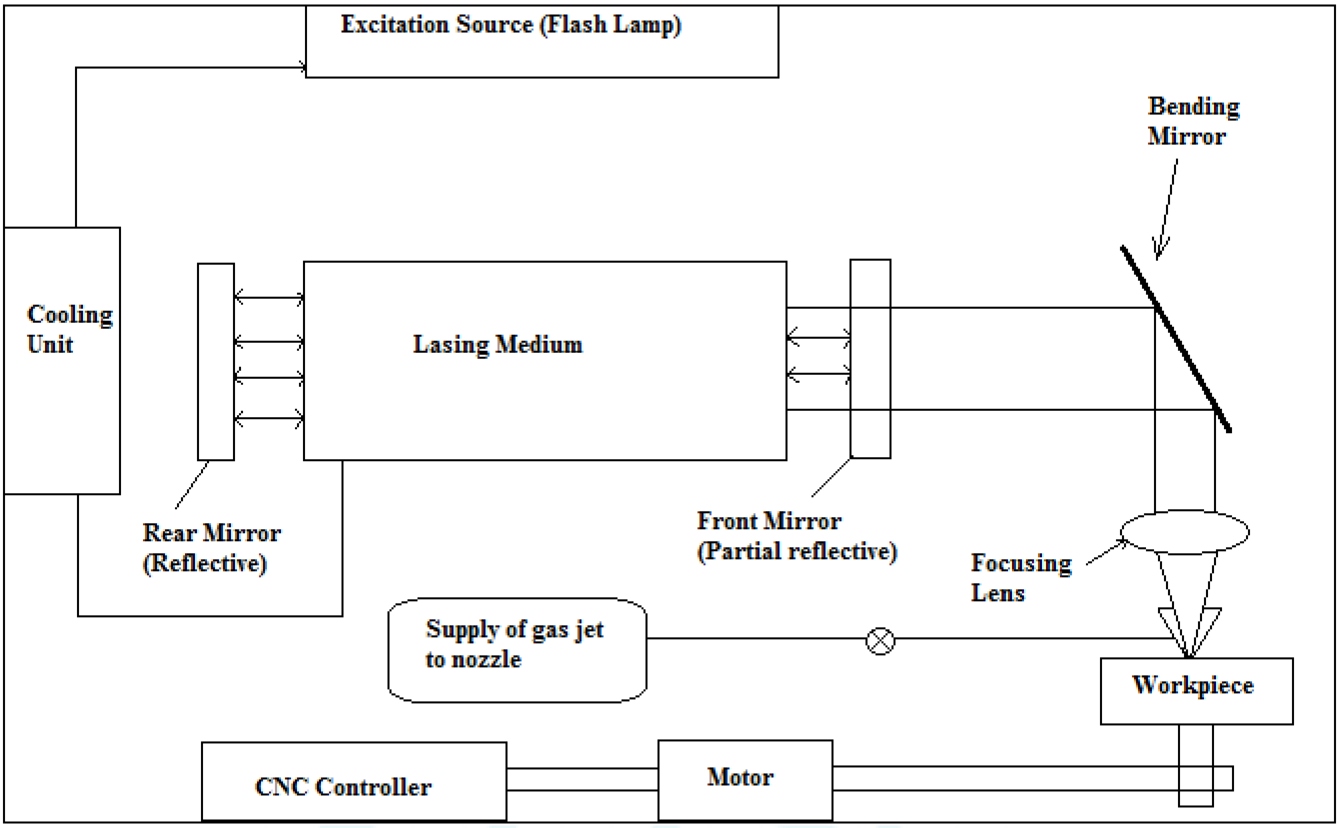

Figure 1: Laser Beam Machine Schematic diagram

2. Literature Review

A literature review of the recently published research work on LBM is carried out to understand the research issues involved and is presented here,

Singh et al. [1] studied the effect of process parameters such as laser power, cutting speed, gas pressure on heat affected zone (HAZ) for polymethyl methacrylate (PMMA) material. L-27 orthogonal array was selected for full factorial design for better understanding of interaction between process parameters. Response Surface Methodology is used to investigate the relationship between laser machining parameter with responses HAZ for polymethyl methacrylate (PMMA) material. They concluded that, HAZ was directly proportional to laser power means HAZ increases with increases in laser power and decreases with increase in cutting speed. They also concluded that gas pressure has very little effect on HAZ. The effect of laser power on the HAZ is more as compared to the effect of cutting speed.

Prabhakaran et al. [2] investigated the effect of laser cutting of thick non ferrous metal sheet i.e. aluminium alloy BS 1100 2 mm thick sheet using CO_2 laser. The effect of the control factors laser power, cutting speed, assist gas pressure and standoff distance on the cut quality characteristics surface roughness and kerf width were analyzed by them. They found that considerable improvement in the quality of surface roughness.

Abhimanyu and Satyanarayana [3] carried work on the optimization of cut quality during pulsed CO_2 laser cutting of mild steel. Various input process variables such as laser power, cutting speed and material thickness were considered for evaluation of the process. The cut quality attributes like edge surface roughness and surface hardness were considered as output parameters. They concluded that RSM was found to be effective for the identification and development of significant relationships between cutting parameters.

Argade and Arakerimath [4] studied the effect of process parameters of CO_2 laser cutting such as cutting speed, input power and gas pressure on the quality of the machined surface using laser beam on AISI 409. The quality of cut was measured in terms of response parameters such as kerf width and surface roughness. Design of experiments was implemented by using a Taguchi method design. The most influencing factors on surface roughness were cutting speed & gas pressure and for kerf width laser power & gas pressure were responsible.

Senthilkumar et al. [5] investigated the effect of parameters associated with CO_2 laser cutting of Aluminium plate of 6 mm thickness. The experiment was designed and carried out on the basis of Taguchi's L9 orthogonal array in which the four laser cutting parameters laser power, cutting speed, assist gas pressure, and stand-off distance were arranged at three levels. The width of laser cut or kerf, quality of the cut edges were affected by laser power, cutting speed, assist gas pressure, and standoff distance between nozzle and the work-piece material. The relations between the input parameters and the response were investigated. The parameters like power, cutting speed and stand-off distance have major impact over surface roughness and kerf width. Whereas, the effect of assist gas pressure over surface roughness and kerf width was less significant.

Leone et al. [6] carried out work on laser cutting of 6061-T6 aluminium alloy sheets by means of a 150 W multimode pulsed Nd:YAG laser. Linear scans using the maximum average power and different cutting directions and pulse durations were executed to measure the maximum cutting speeds. Then, cutting tests were performed by varying beam travel direction, pulse duration and cutting speed. A 150W multimode pulsed Nd:YAG (Neodymium doped Yttrium Aluminium Garnet) laser allows to cut 1 mm-thick 6061-T6 sheets with cutting speed up to 700 mm/min, obtaining narrow kerfs (< 200 μm) with a good taper angle (< 5°) and low dross height (about 40 μm).

Madic et al. [7] studied the effect of CO_2 laser cutting process using Taguchi and dual response surface methodology. The goal was to determine the near optimal laser cutting parameter values in order to ensure robust condition for minimization of average surface roughness. Taguchi's L25 orthogonal array was implemented for experimental plan. Three cutting parameters cutting speed, laser power and assist gas pressure were used in the experiment. The average surface roughness was directly proportional with assist gas pressure but inversely proportional with cutting speed and laser power.

Prajapati et al. [8] studied the effect of laser machine processing parameters such as laser power, gas pressure, cutting speed and thickness on measured response such as surface roughness. The experiment was designed according to Taguchi L27 orthogonal array [16] with three different level of each input parameter. For result interpretation, analysis of variance (ANOVA) was conducted and optimum parameter was selected on the basis of the signal to noise ratio, which confirmed the experimental result. The result indicated that cutting speed and work piece thickness of plate have high contribution on surface roughness whereas laser power had less effect on surface roughness.

Madia and Patel [9] studied the effect of focal length on surface roughness of 1 mm thin brass sheet using oxygen as assist gas. The cutting cross section was measured surface roughness. The variation was analyzed with laser power and focal length. By using ANOVA [15] they found that focal length was most significant factor for surface roughness of brass 1 mm thin sheet. Improper focal length affects the surface roughness and cutting speed. Results revealed that good quality cuts can be produced in brass sheets, at a window of laser cutting speed 6000 mm/min and at a power of 1500 Watts surface is 4.220 μm.

Sowjanya et al. [10] investigated that the machining parameters pulse frequency, pulse width, cutting speed, energy are the primary factors influencing the kerf width and material removal rate (MRR) [17]. The approach presented in this paper provided an impetus to develop analytic models, based on experimental results for obtaining a kerf width and Material removal rate using the response surface methodology. A three factor 5- level factorial technique was used to predict the geometry of laser cut of Inconel 600 plate sheet of 1.7mm thickness. Effect of significant variables on metal removal rate, kerf width was observed by drawing main effects using DOE.

Madic et al. [11] demonstrated the application of Taguchi method for optimization of surface roughness in CO_2 laser cutting of mild steel using oxygen as assist gas. Three laser cutting parameters, cutting speed, laser power and assist gas pressure were considered in the experiment that was planned according to the Taguchi's experimental design [18] by using L25 orthogonal array. Experimental results and derived analysis concluded that cutting speed and assist gas pressure were the most significant parameters affecting the surface roughness variation, whereas the influence of the laser power is much smaller, ANOVA resulted in less than 5% error indicating that the interaction effects of the laser cutting parameters are negligible, it was observed that the cutting speed should be kept at the highest level (7m/min), assist gas pressure at the lowest level (3 bar), while laser power should be kept at an intermediate level (0.9 kW) for obtaining minimal surface roughness.

Grepl et al. [12] investigated the effects on the Inconel 625 nickel alloy using a CO_2 gas laser with the help of metallographic methods. The cut quality was evaluated according to partial criteria, among which were roughness, shape and width of the cut, an area influenced by temperature, and sticking slag (burr). Due to a change in laser cutting parameters there was a significant limitation of burrs at the straight part of a sample therefore it would be useful to focus on the sample part, where changes of shape take place.

Zaied et al. [13] carried out work to analyse surface roughness parameters as a function of Laser power and cutting speed. The surface roughness parameters were determined after statistical analysis (ANOVA) and propose simple mathematical model. Design/methodology/approach machining were carried out by Laser cutting (CO_2) of sheet metal (low carbon steel, S235) produces good surface quality.

Rajpurohit and Patel [14] investigated the effect of Laser cutting using multi-mode Ytterbium Fibre laser machine with continuous emission was applied for mild steel. On the cutting cross section surface roughness and kerf width was measured. Their variation was analyzed with laser power, cutting speed and gas pressure. A full factorial experimental design was applied for two particular values of the surface roughness and the kerf width. From ANOVA they concluded that cutting speed was most significant parameter for surface roughness.

3. Conclusion

So many investigations so far had done on LBM process. Study of process parameters such as laser power, cutting speed, assist gas pressure, nozzle distance, focal length, pulse frequency, pulse width, stand-off distance and performance measures as surface roughness (SR), material removal rate (MRR), kerf width, heat affected zone (HAZ), surface hardness is carried out more by researchers.

From the literature review it is observed that mostly combinations of process parameters like laser power, cutting speed, assist gas pressure and performance measures as SR, kerf width are investigated. Decreasing power and increasing feed rate generally lead to a decrease in kerf width and HAZ. Increasing feed rate generally lead to increase surface roughness. Laser power has small effect on surface roughness. So it is important to find the optimum conditions for process parameters to give better quality of cutting surface. It was found that many researchers have employed different optimization techniques like Taguchi method, ANOVA, Regression analysis to find out the optimum cutting condition for LBM operation. But less work has been reported on Multi-objective optimization of LBM process. Also very little work has been reported on effect of nozzle distance and pulse duration. So, more work is required to be done in this area.

References

[1] Kaushal Pratap Singh, Susheel Kumar Upadhyay, Deepak Kumar Gupta, Sahil Panu, Girish Dutta Gautam, “An Analysis the Effect of Process Parameters on Heat Affected Zone in Laser Cutting Using Response Surface Methodology” , International Journal of Emerging Technology and Advanced Engineering, Vol. 4, Issue 2, pp. 850-855, February 2014.
[2] M. Prabhakaran, A.N. Patil, Nagaraj Raikar, Sidharth. K, “Experimental Investigation on Gas Laser Cutting”, 4th International Conference on Recent Trends in Engineering Science and Management, ISBN 978-93-86171-01-6, pp. 127-138, 7th August 2016.
[3] N. Abhimanyu, Dr. B. Satyanarayana, “Optimization of CNC Laser Cutting Process Parameters”, International Advanced Research Journal in Science, Engineering And Technology, Volume 3, Issue 5, pp. 206-210, May 2016.
[4] P.V.Argade, Dr. Rachayya Arakerimath, “Parametric Investigation on CO2 Laser Cutting of AISI 409 to Optimize Process Parameters by Taguchi Method” , International Journal of Engineering Trends and Technology, Vol. 37, Number 6, ISSN No. 2231-5381, pp. 311-316, July 2016.
[5] V. Senthilkuma, N. Periyasamy, A. Manigandan, "Parametric Investigation of Process Parameters for Laser Cutting Process”, International Journal of Innovative Research in Science, Engineering and Technology, Vol. 4, Issue 5, pp. 2773-2779, May 2015.
[6] C. Leone, S. Genna, A. Caggiano, V. Tagliaferri, R. Molitierno, “An Investigation on Nd:YAG Laser Cutting of Al 6061 T6 Alloy Sheet”, 3rd CIRP Global Web Conference, pp. 64-69, 2015.
[7] M. Madić, M. Radovanović, M. Manić, M. Trajanović, “Optimization of CO2 Laser Cutting Process using Taguchi and Dual Response Surface Methodology”, vol. 36, No. 3 (2014), pp. 236-243.
[8] B. D. Prajapati, R. J. Patel, B. C. Khatri, “Parametric Investigation of CO2 Laser Cutting of Mild Steel and Hardox-400 Material”, International Journal of Emerging Technology and Advanced Engineering, Volume 3, Issue 4, pp. 204-208, April 2013.
[9] Mayank N Madia, Prof. Dhawal M Patel, “Effect of Focal Length on Surface Roughness of 1mm Thin Brass Sheet by Using Assist Gas O2”, International Journal of Innovative Research in Science, Engineering and Technology, Volume 2, Issue 9, ISSN 2319-8753, pp. 4539-4543, September 2013.
[10] M. Sowjanya, Dr.G. Harinath Gowd, “Empirical Modeling and Analysis of Laser Beam Cutting Process”, International Journal of Innovative Technology and Research, Vol. 1, Issue 5, ISSN 2320-5547, pp. 411-416, August-September 2013.
[11] Milos Madić, Miroslav Radovanović, Laurentiu Slatineanu, “Surface Roughness Optimization in CO2 Laser Cutting by Using Taguchi Method”, U.P.B. Sci. Bull., Series D, Vol. 75, Iss.1, ISSN 1454-2358, 2013.
[12] M. Grepl, J. Petru, R. Ceo, L. Petrkovska, T. Zlamal “The Effect of Process Parameters on Result Quality of Cut During Laser Cutting of Material”, 23RD International DAAAM Symposium, Vol. 23, No.1, ISSN 2304-1382, pp. 1035-1038, 2012.
[13] M. Zaied, E. Bayraktar, D. Katundi, M. Boujelbene, I. Miraoui, “Effect of Laser Cutting Parameters on Surface Quality of Low Carbon Steel (S235)”, Journal of Achievements in Material and Manufacturing Engineering, Vol. 54, Issue 1, pp. 128-134, September 2012.
[14] Shiplesh R Rajpurohit, Prof. Dhawal M Patel, “Application of Full Factorial Design Experiments for Laser Cutting”, International Journal of Engineering and Science Research, Vol.2, Issue 10, ISSN 2277-2685, pp. 1432-1436, Oct 2012.
[15] Pravin R. Kubade, V. S. Jadhav, “An Experimental Investigation of Electrode Wear Rate (EWR), Material Removal Rate (MRR) and Radial Overcut (ROC) in EDM of High Carbon-High Cromium Steel (AISI D3)”, International Journal of Engineering and Advanced Technology (IJEAT), Volume 1, Issue 5, pp.135-140, 2012.
[16] Pravin R. Kubade, Sunil S. Jamdade, Ravindranath G. Kshirsagar, Rahul C. Bhedasagaonkar, “Parametric Study and Optimization of WEDM Parameters for Titanium Diboride TiB_2”, International Research Journal of Engineering and Technology, Volume 2, Issue4, pp.1-5, 2015.
[17] Sudhakar R. Lohar, Pravin R. Kubade, “Current Research and Development in Abrassive Water Jet Machining (AWJM): A Review”, International Journal of Science and Research (IJSR) ISSN(Online):2319-7064, Volume 5, Issue 1, Jan 2016, pp. 996-999.
[18] Pravin R. Kubade, Palshh Patil, Akshay Papti, Pranav Potdar, Ravindranath G. Kshirsager “Parametric Optimization of Abrassive Water Jet Machining of Inconel-718 Material”, International Research Journal of Engineering and Technology (IRJET), Volume3, Issue 08, August-2016.