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Optimization of Laser Beam Cutting Parameters for Mild Steel

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Abstract: ***Now a day to cut metallic or nonmetallic sheets and plates, laser cutting process which is one of the advance processes is widely used. As laser cutting is non-contact process, there is no involvement of mechanical cutting forces and tool wear. Compared to other nontraditional cutting methods such as abrasive water jet cutting, plasma cutting etc., laser cutting process can cut surfaces and edges with highest precision and accuracy. This paper presents method of optimization for LBC process with mild steel material. Here in this study optimization was carried out to minimize surface roughness (SR) and improve material removal rate (MRR). Input parameters considered were nozzle dia., gas pressure, cutting speed and cutting power. By using Taguchi L18 array, experiments were conducted. To find out optimum setting of input parameter as well as to determine most significant parameter, S/N ratio technique and ANOVA technique was used respectively.***

Keywords: LBC, S/N Ratio, Taguchi Method, Mild Steel, ANOVA

1. Introduction

As per the latest trend in manufacturing for processing of advanced engineering materials laser beam cutting process is widely used. In this process focused laser light is imparted on work piece material to melt the material locally. Melted material is then come out of cavity called as kerf. Oxygen is used as assist gas which causes exothermic reaction to drag the melt away from the kerf. Laser cutting process can be effectively used for complicated design requirements and unusual size of work piece. In this process no need of post processing for cut parts as they are having good surface finish.

By the optimization of laser cutting process for st-37 steel based on the grey relational analysis and Taguchi method of orthogonal arrays, it is observed that the cutting power has high influence on responses than cutting speed [1]. Fast laser cutting optimization algorithm (FALCOA) is quick method to optimize the laser parameters for the laser fusion cutting of 1 mm aluminium sheets [2]. After experimenting on the laser cutting of Duralumin sheet and applying Fuzzy logic theory, the fuzzy multi-response performance index was calculated. With the help of confirmation tests it is concluded that there was considerable reduction of 50% to 71% in kerf deviations at top and bottom sides [3]. Striations generated leads into increased surface roughness which is observed from striation generation mechanism in inert gas laser cutting of 3mm thick low carbon mild steel [4]. Use of Taguchi Methodology (TM) and Response Surface Methodology (RSM) in combination yields best set of optimized cutting parameters during Nd:YAG laser cutting of aluminum alloy thin sheet. Optimum kerf deviation and kerf taper are obtained by applying grey relational analysis (GRA) with entropy measurement (EM) [5]. In the fusion cutting of stainless steel, the minimum roughness is reached at the maximum cutting speed. The maximum cutting speed has the higher value in the fibre-laser case at the same laser power [6].

2. Experimental Procedure

Experiments were carried out on AMADA FO3015. It is CO_2 type laser center. Power output of the machine was 2000 watt for continuous wave and co-ordinates of machine was X-3420 mm, Y-1550mm, Z-200mm. It can cut sheets of mild steel up to 12 mm thickness very effectively. The CO_2 laser cut quality for mild steel sheet of grade XT07 is diagnosed experimentally. The output parameters under consideration were surface roughness (Ra value) in µm and material removal rate (MRR) in mm/min. They were monitored with the variation in input parameters which are nozzle dia. (mm), gas pressure (MPa), cutting power (watt) and cutting speed (mm/min). Assist gas used is oxygen. The process parameters optimized by S/N ratio technique and analyzed by ANOVA technique. The work piece material used to carrying out experiment was mild steel sheet of XT07 grade. The dimensions of the work piece were "100 x 50 x 4 mm". Elongated hole of "30×20mm" size was cut on the work piece. Chemical composition of material is given in Table 1.Mild steel of grade XT07 used for generator canopy parts.

Table 1: Chemical composition of mild steel

Element	SI	S	P	C	Mn
Wt %	0.076	0.01	0.018	0.065	0.51

To measure the surface roughness Taylor-Hobson surface profile meter was used. Surface roughness was measured at all four cut faces of sheet and average of all these four values is taken as resulting surface roughness for that laser cut work piece. Measurement of material removal rate was taken by using following formula,

$$\text{MRR} = \frac{\text{Weight After(gm)} - \text{Weight Before(gm)}}{\text{Cutting Time(min)} + \text{Piercing Time(min)}} \quad - (1)$$

$$\text{Cutting Time} = \frac{\text{Perimeter(mm)}}{\text{Cutting Speed(mm/min)}} \quad - (2)$$

Perimeter=87.33 mm

2.1 Design of Experiments

To conduct experiments, design of experiment (DOE) method used was based on Taguchi Method of orthogonal array. With consideration of four factors, one at two levels and remaining at three levels each, Taguchi's L18 array was used. Parameter level and their values are given in table 2.The results of experiments for material removal rate (MRR) and Surface roughness (SR) for each 18 runs are shown in Table3.These results were further used for finding optimum parameters by S/N ratio technique as well as to determine contribution of parameters using ANOVA.

Table 2: Parameter level and values

Process Parameter	Level 1	Level 2	Level 3
Nozzle Diameter(mm)	1.2	2.0	-
Gas Pressure(MPa)	0.12	0.14	0.16
Cutting Speed (mm/min.)	2300	2500	2700
Cutting Power(W)	1800	1900	2000

Table 3 Observations for L18 experimentation

Sr.No.	*ND*	*GP*	*CS*	*CP*	*SR (Ra)*	*MRR*
1	1	1	1	1	1.69	34.50
2	1	2	1	2	2.11	28.54
3	1	3	1	3	1.89	24.24
4	1	1	2	1	2.14	16.24
5	1	2	2	2	1.34	15.75
6	1	3	2	3	1.82	14.14
7	1	2	3	1	1.64	9.56
8	1	3	3	2	1.72	8.86
9	1	1	3	3	2.34	14.14
10	2	3	1	1	2.14	40.14
11	2	1	1	2	1.94	32.48
12	2	2	1	3	1.78	27.27
13	2	2	2	1	1.86	22.94
14	2	3	2	2	2.33	21.65
15	2	1	2	3	2.42	24.24
16	2	3	3	1	2.38	21.99
17	2	1	3	2	1.97	20.67
18	2	2	3	3	1.86	20.20

Where, ND-Nozzle Diameter, GP-Gas Pressure, CS- Cutting Speed CP-Cutting Power, SR- Surface Roughness, MRR-Material Removal Rate

3. Results and Discussion

Above given data is analysed to determine optimum setting of parameters. For analysing the data, statistical tools like ANOVA and S/N ratio are used. Results of the analysis are discussed as follows

3.1 Analysis by S/N ratio

In the Taguchi method, the term 'signal' represents the desirable value (mean) for the response characteristic and the term 'noise' represents the undesirable value (S.D) for the output characteristic. So that the S/N ratio is the ratio of the mean to the S.D. S/N ratio is used to measure the quality characteristic deviating from the desired value. By calculating S/N ratio of each input parameter for both the response parameter, optimum setting of input parameters can be find out. Table 4 gives result of S/N ratio analysis for smaller the better characteristics i.e. surface roughness (Ra). S/N ratio analysis for material removal rate is given in Table 5. Material removal rate is higher the better characteristics. To calculate S/N ratio for different kind of response characteristics, following formulas are used

$$S/N = -10log\frac{1}{n}\sum_{1}^{n} {y_i}^2 \quad - \text{for lower the better characteristics}$$

$$S/N = -10log\frac{1}{n}\sum_{1}^{n} \frac{1}{{y_i}^2} \quad - \text{for higher the better characteristics.}$$

$$S/N = -10log\frac{1}{n}\sum_{1}^{n} \frac{\bar{y}^2}{s} \quad - \text{for nominal the better characteristics.}$$

Table 3 S/N ratio results for surface roughness

Level	Nozzle Diameter	Cutting Speed	Cutting Power	Gas Pressure
1	-5.104	-5.492	-5.832	-6.312
2	-6.289	-5.794	-5.249	-4.526
3		-5.867	-6.032	-6.155
Delta	1.185	0.375	0.783	1.786
Rank	2	4	3	1

Table 4: S/N ratio results for material removal rate

Level	Nozzle Diameter	Cutting Speed	Cutting Power	Gas Pressure
1	24.48	29.76	26.78	27.04
2	27.99	25.46	25.88	25.78
3		23.47	26.04	25.88
Delta	3.51	6.29	0.91	1.25
Rank	2	1	4	3

From Table 3 and Table 4 we get the results of S/N ratio analysis for surface roughness and material removal rate respectively. For each level of input parameter S/N ratio is calculated. Higher value of S/N ratio for the level shows that the particular level can give optimum value of response parameter. In this way optimum setting of input parameters is predicted for both the response parameters.

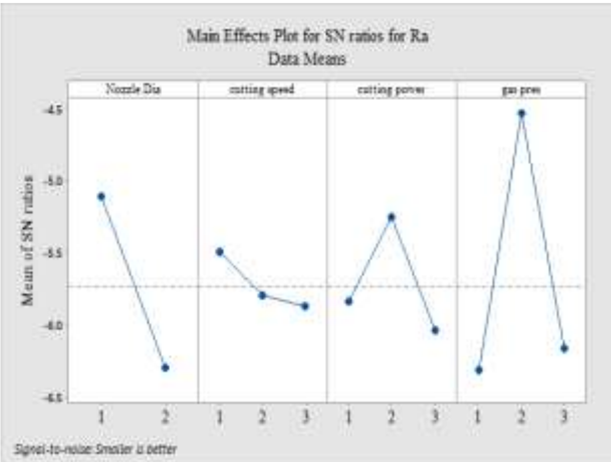

Figure 1: Main effect plot for SR data S/N ratio

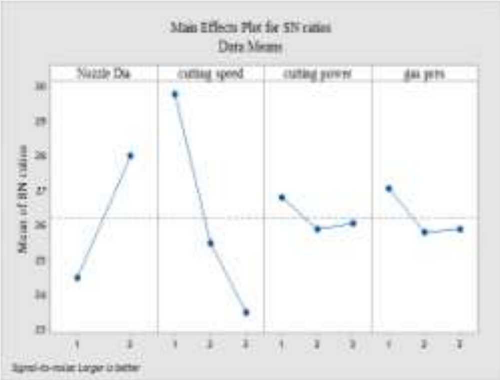

Figure 2: Main effect plot for MRR data S/N ratio

Figure 1 and Figure 2 shows the plot of S/N ratio and factor levels. From this plot and above table we can predict that for optimum value of surface roughness can be obtained by setting nozzle diameter at level 1, cutting speed at level 1, cutting power at level 2 and gas pressure at level 2 . Similarly for MRR setting should be nozzle diameter at level 2, cutting speed at level 1, cutting power at level 1 and gas pressure at level 1.

3.2 Analysis of Variance (ANOVA)

The analysis of variance (ANOVA) technique is generally used to investigate or to determine which input process parameters are significantly affects the performance characteristics. Table 5 and Table 6 Shows the results of analysis of variance for surface roughness (Ra) and material removal rate respectively. This analysis is carried out for 5% significance level, i.e. the confidence level for process is 95%. The selected process parameter is significant or not is determined by the P-value. When P-value for the factor is less than 0.05 then that factor is having significant effect on responses.

Table 3: ANOVA table for surface roughness

Source	DF	SS	MS	F-Value	P-Value
Nozzle Dia.	1	0.4533	0.4533	16.42	0.003
Cutting Speed	2	0.1728	0.08639	3.13	0.093
Cutting Power	2	0.2356	0.11781	4.27	0.050
Gas Pressure	2	0.7331	0.3665	13.28	0.002
Error	9	0.2484	0.02760		
Total	16	1.4286			
S= 0.1661 R-sq= 82.61%					

We can conclude from Table 4 that gas pressure, cutting power and nozzle diameter are the significant parameters which affecting the surface roughness. The observation from Table 5 is that nozzle diameter and cutting speed are the significant parameters affecting on the material removal rate.

Table 4 ANOVA for material removal rate

Source	DF	SS	MS	F-Value	P-Value
Nozzle Dia.	1	239.03	239.03	20.42	0.001
Cutting Speed	2	778.83	389.41	33.27	0.002
Cutting Power	2	42.42	21.21	1.81	0.213
Gas Pressure	2	27.64	13.82	1.18	0.346
Error	10	117.06	11.71		
Total	17	1204.97			
S= 3.42139 R-sq= 90.29 Rsq(adj)= 83.49%					

By how much percent input parameter is significant is also calculated. It indicates that the nozzle diameter (mm) is most affecting parameter on surface roughness with 42.79% and gas pressure (MPa) is contributing 34.86% followed by cutting power (W) and cutting speed (mm/min) with 33.48 and 2.68% contribution respectively. On material removal rate cutting speed is most affecting parameter with 57.67% and nozzle diameter has 2nd contribution with 35.40% followed by cutting power and gas pressure with 3.14% and 2.04% contribution respectively.

4. Conclusion

1) The Taguchi method with L18 array is used successfully to conduct experiments. S/N ratio analysis suggests the setting of laser cutting parameters at nozzle diameter 1.2 mm, cutting speed 2300 mm/min, cutting power 1900 watt and gas pressure 0.14 MPa leads to optimum results for surface roughness values & for material removal rate, method gives optimum results for nozzle diameter 2.0 mm, cutting speed 2300 mm/min, cutting power 1800 watt and gas pressure 0.12 MPa.

2) From the ANOVA results it is evident that gas pressure, cutting power and nozzle diameter are significant for surface roughness and nozzle diameter, cutting speed are significant for MRR as they are having p-value less than 0.05.

3) Contribution of each parameter in percentage for surface roughness values implies that the nozzle diameter (mm) is most influencing parameter with 42.79% and gas pressure (MPa) is contributing 34.86% followed by cutting power (W) and cutting speed (mm/min) 33.48 and 2.68% respectively. On material removal rate cutting speed is most influencing parameter with 57.67% and nozzle diameter has 2nd contribution with 35.40% followed by cutting power and gas pressure with 3.14% and 2.04% contribution respectively.

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