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# Performance Characterization & Multi-Objective Optimization of Laser Beam Cutting Process on Steel

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***Abstract: Laser cutting is a popular process, which finds wide application in various manufacturing industries because of its precision of operation and low cost. Laser cutting, being a non-contact process, does not involve any mechanical cutting forces and tool wear. To maintain a high production rate and an acceptable level of quality for the cut parts, there is need to select the optimum combination of process parameters. This paper presents method of optimization for multi performance characteristics of LBC process for mild steel. Surface roughness (SR) and material removal rate (MRR) are multi performance characteristics and nozzle dia., gas pressure, cutting speed and cutting power are taken as input process parameters. Grey relational analysis (GRA) technique is used for optimization. ANOVA technique is also used to find significant and sub significant parameter. This experimental work will be helpful in deciding optimum parameters and to improve LBC process.***
***Keywords: LBC, Grey Relational Analysis, Taguchi Method, Mild Steel, ANOVA***

## I. INTRODUCTION

Laser beam cutting process uses focused laser light, by which work piece material is locally melted. The melt is then coming out of the kerf with an assist gas that flows coaxial with the laser beam. When using oxygen as assist gas, it will drag the melt away as well as provide exothermic reaction in the cutting section enhancing the energy available for increasing the cutting speed. $CO_2$ laser cutting is one of the processes which is used to cut sheets and having ability to produce accurate cut edges and surfaces with higher accuracy and surface finish. Post processing is not required for laser cut parts.

Ulas Caydas et al. (2008) presented an effective approach for the optimization of laser cutting process of st-37 steel based on the grey relational analysis and Taguchi method of orthogonal arrays. B.Adelmann et al. (2011) reported on a fast laser cutting optimization algorithm (FALCOA) to optimize the laser parameters for the laser fusion cutting of 1 mm aluminium sheets. Avanish Kumar Dubey et al. (2012) experimented on the laser cutting of Duralumin sheet and Fuzzy logic theory has been applied to compute the fuzzy multi-response performance index. The confirmation tests show considerable reduction of 50% to 71% in kerf deviations at top and bottom sides. Koji Hirano et al. (2011) observed striation generation mechanism in inert gas laser cutting of 3mm thick low carbon mild steel. Vinod Yadava et al. (2013) optimized cut quality characteristics during Nd:YAG laser cutting of aluminium alloy thin sheet with the use of Taguchi Methodology (TM) and Response Surface Methodology (RSM) in combination. Optimum kerf deviation and kerf taper are obtained by applying grey relational analysis (GRA) with entropy measurement (EM). 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 (V.B.Shulyatyev et al. 2014).

## II. EXPERIMENTAL PROCEDURE

Experiments were carried out on AMADA FO3015. It is $CO_2$ type laser centre. 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 analysed 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 I*. Mild steel of grade XT07 used for generator canopy parts.

TABLE I
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

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

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

Perimeter=87.33 mm

*A. 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 II*. The results of experiments for material removal rate (MRR) and Surface roughness (SR) for each 18 runs are shown in *TABLE III*. 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 III 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 IIIII Observations for L18 experimentation

| Sr. No. | ND | GP | CS | CP | SR(Ra) | MRR |
|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 1 | 1.69 | 34.5030 |
| 2 | 1 | 2 | 1 | 2 | 2.11 | 28.5437 |
| 3 | 1 | 3 | 1 | 3 | 1.89 | 24.2399 |
| 4 | 1 | 1 | 2 | 1 | 2.14 | 16.2466 |
| 5 | 1 | 2 | 2 | 2 | 1.34 | 15.7482 |
| 6 | 1 | 3 | 2 | 3 | 1.82 | 14.1399 |
| 7 | 1 | 2 | 3 | 1 | 1.64 | 9.5568 |
| 8 | 1 | 3 | 3 | 2 | 1.72 | 8.8584 |
| 9 | 1 | 1 | 3 | 3 | 2.34 | 14.1399 |
| 10 | 2 | 3 | 1 | 1 | 2.14 | 40.1388 |
| 11 | 2 | 1 | 1 | 2 | 1.94 | 32.4808 |
| 12 | 2 | 2 | 1 | 3 | 1.78 | 27.2699 |
| 13 | 2 | 2 | 2 | 1 | 1.86 | 22.9365 |
| 14 | 2 | 3 | 2 | 2 | 2.33 | 21.6538 |
| 15 | 2 | 1 | 2 | 3 | 2.42 | 24.2399 |
| 16 | 2 | 3 | 3 | 1 | 2.38 | 21.9808 |
| 17 | 2 | 1 | 3 | 2 | 1.97 | 20.6696 |
| 18 | 2 | 2 | 3 | 3 | 1.86 | 20.1999 |

In table abbreviations are as ND-Nozzle Diameter, GP-Gas Pressure, CS- Cutting Speed CP-Cutting Power, SR- Surface Roughness, MRR-Material Removal Rate

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## III.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

### *A. Design of Experiments*

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 IV* 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 V*. Material removal rate is higher the better characteristics. To calculate S/N ratio for different kind of response characteristics, following formulas are used

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

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

$$S/N = -10log\frac{1}{n}\sum_{1}^{n} \frac{\bar{y}^2}{s} \quad \text{– for nominal the better characteristics.} \qquad (3)$$

TABLE IVV
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 V
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 IV* and *TABLE V* 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.

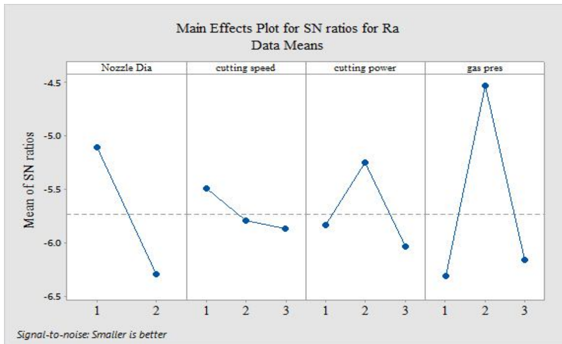


Fig. 1 Main effect plot for SR data S/N ratio

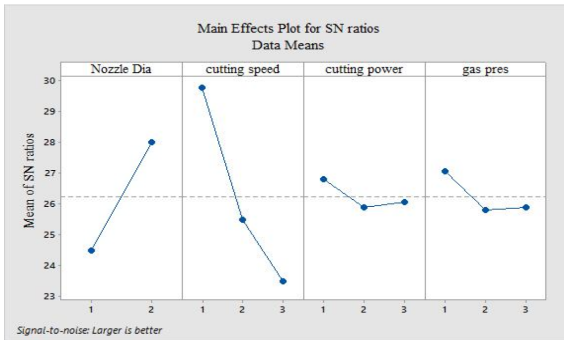


Fig. 2 Main effect plot for MRR data S/N ratio

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.

### *B. 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 VI* and *TABLE VII* 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 VI ANOVA table for surface roughness

| Source | DF | Adj.SS | Adj 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 VI that gas pressure, cutting power and nozzle diameter are the significant parameters which affecting the surface roughness. The observation from TABLE VII is that nozzle diameter and cutting speed are the significant parameters affecting on the material removal rate

Table VII Anova table for Material removal rate

| Source | DF | Adj SS | Adj 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 $2^{nd}$ contribution with 35.40% followed by cutting power and gas pressure with 3.14% and 2.04% contribution respectively.

## IV. CONCLUSION

1) The Taguchi method with L18 array is used successfully to conduct experiments. S/N ratio analysis suggests the optimum setting of laser cutting parameters for surface roughness at nozzle diameter 1.2 mm, cutting speed 2300 mm/min, cutting power 1900 watt and gas pressure 0.14 MPa. For material removal rate method gives optimum settings as 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 shown in *TABLE VII* with the help p-values we can find for surface roughness gas pressure, cutting power and nozzle diameter are significant and for MRR nozzle diameter and cutting speed are significant as they are having p-value less than 0.05.
3) Contribution of each parameter in percentage is also calculated and is given as follows. For surface roughness nozzle diameter (mm) is most affecting parameter 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% 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.

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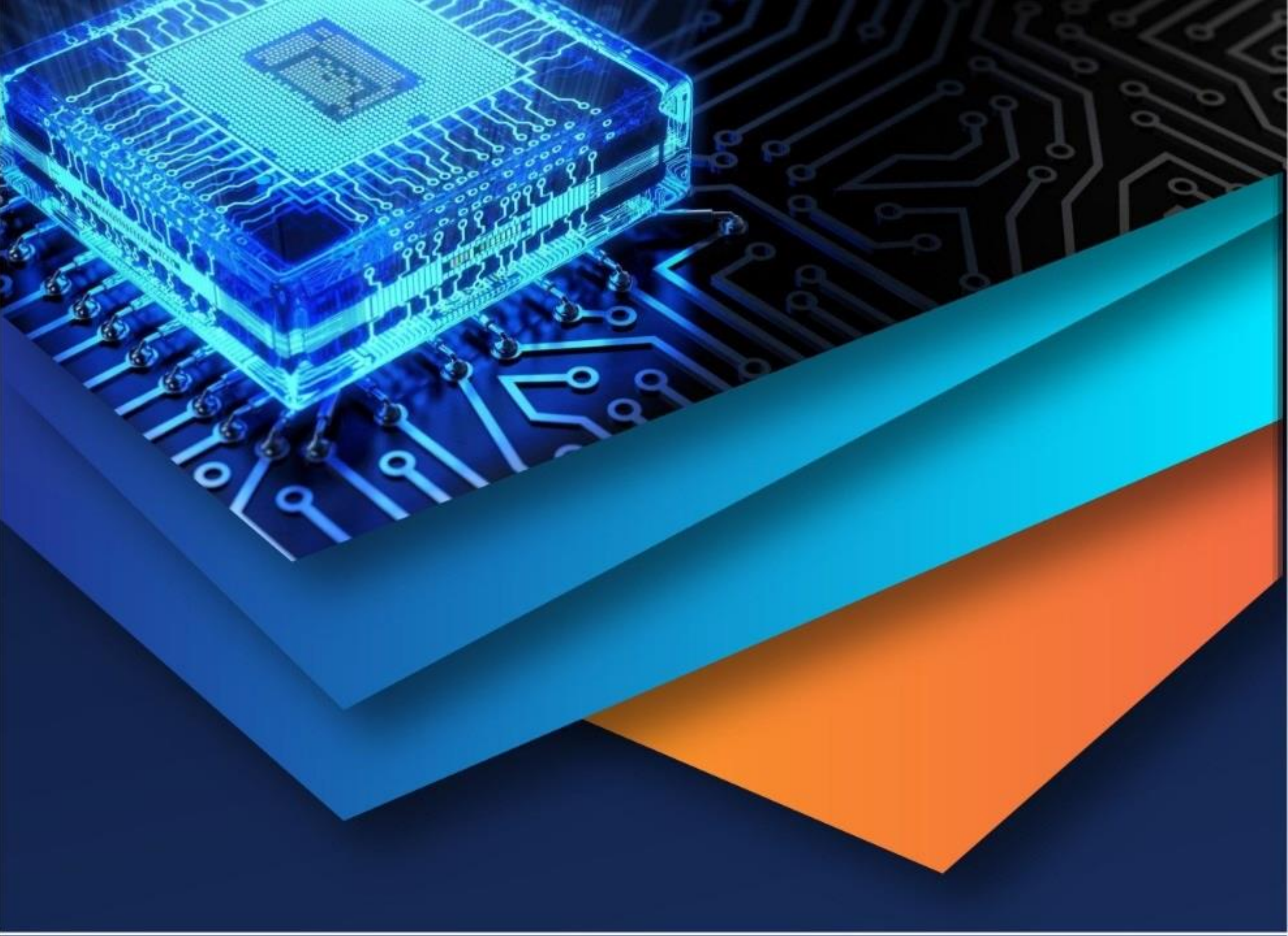


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