OPTIMIZATION OF KERF QUALITY CHARACTERISTICS IN ND:YAG LASER CUTTING OF Al ALLOY SHEET

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Abstract: Pulsed Nd:YAG laser is used for the purpose of cutting of 8011 sheet of aluminium. Highly reflective and thermally conductive sheets can be cut suitably with the help of laser. Qualitatively cutting of sheets have to be depended on the properties of the materials like optical and thermal. Due to the highly reflective surface of the work material i.e. aluminium sheet which is not possible to cut preciously with the help of any other machining processes. Wavelength of Nd:YAG laser is having 1.06 µm which is less as compared to CO_2 laser (10.6 µm). Wide uses of the aluminium alloy thermally conductive material in technologically advanced industrial sectors like aerospace and automobile. Complex shapes and stringent design can be cut preciously by proper controlling of the input parameters. Nd:Y_3 Al_5 O_{12} laser has widely used for the cutting of these materials therefore it has more value for the technologically advanced industrial sectors like aerospace, automobile. Complex shapes and stringent design can be cut accurately by proper controlling of the input parameters. This paper is shown the parameters optimization for lesser kerf quality i.e deviation in kerf during laser cutting. Taguchi methodology selected for determining the optimal inputvariables for cutting.

Keywords:, Deviation in kerf, Laser beam cutting, 8011 Sheet of aluminium, Analysis of variance.

1. INTRODUCTION

There are many advanced machining processes are available in market like electric discharge machining (EDM), electro chemical machining (ECM), ultrasonic machining (USM), laser beam machining (LBM) etc. Out of such machining, LBM is widely used in market due to its quality and properties. Laser beam machining can be classified as per requirements like cutting, drilling, milling, grooving, marking etc. Basically Nd:YAG and CO_2 lasers are widely used in various manufacturing area for the machining of thin reflective workpieces, Nd:YAG laser is most suitable.

By this workpiece warmth and convert the work piece into melting state which is commonly eliminate using streaming high pressure assist gas jet [1-2]. The simplified diagram of LBC is shown in Fig. 1.
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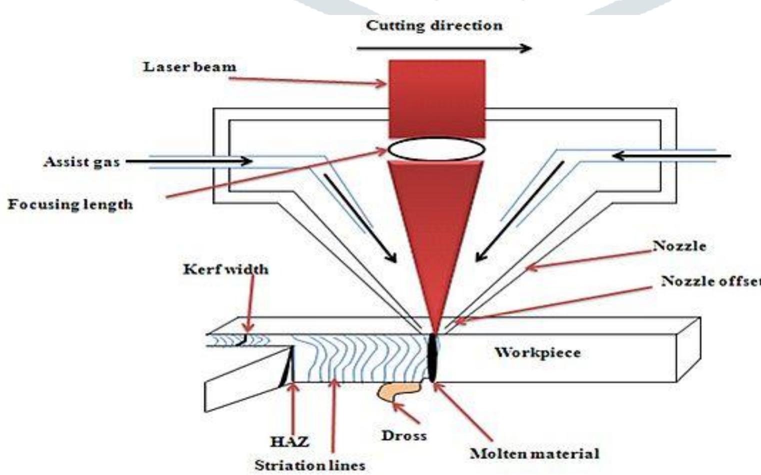

Fig. 1. Schematic of Nd:YAG laser cutting

The cutting quality of the used workpiece depends on the properties of the materials i.e. thermal and optical. No tool wear and vibrations are found in this process because of its non-contact type process [3-4].

LBC has widely used in the areas of aviation, automobile, marine, electronic industry and atomic sectors. Pulsed Nd:YAG laser becomes as an outstanding performer on thermally conductive sheets due to its less mean beam power, more laser beam intensity, excellent focusing quality and less heat affected zone (HAZ). For getting the precise results, intricate cut profile, and narrow kerf widths, it has used widely in the present scenario. Due to some very good properties like light weight, rust free and favourable thermal and electrical, aluminium and its alloys makes more famous [5].

Nowadays laser cutting is a leading field for exploration in excellent trait cut. Major challenges in producing better quality cuts in laser cutting are recast layers, adhesion of dross and heat affected zone (HAZ). The involve specification like material content and its thickness and operation mode (pulsed or CW), cutting speed, used gas type and pressure, power of beam, these the characteristics at which cutting phenomena is merely depends. A lot of theoretical and experimental investigations have been done to analyse the impact of control parameters on surface quality and geometry [6-10].

It has been shown that it is more used for the preciously cutting purpose of highly thermal conductive and reflective materials like aluminium and its alloys. For accomplishing the better quality cut in these materials the laser cutting control parameters are required to be chosen and optimized. For achieving the setting of process parameters the effect of their variation on various output quality characteristics of interest is needed to be investigated[11-13].

The parameters improvement of the cutting attributes during machining of Al material of up to 0.7 mm thickness for straight profile. They have considered two kerf quality attributes, for example, kerf width and kerf deviation and estimated with optical estimating magnifying instrument. They used applied Taguchi methodology and L_9 OA for performing the experiments [14-15].

Prashant *et. al.* [16], have been discussed about the experimental study on the laser cutting of nickel based material. They have used kerf deviation as a quality characteristic and four control factors. They have been taken L_{27} orthogonal array. They have been observed 50 % improvement in kerf deviation as compared with initial parameter setting. Titanium and its alloys have very good properties so that it is more demanding for the manufacturing areas [17]. Overlapping of the beam spot affects the cutting quality of the superalloy materials [18]. It shows the effects of aluminium oxide particles on boron carbide materials [19]. It has been observed thatthe effects of parameters on advanced engineering material i.e. nickel based sheet [20-21].

This paper is shown the parameters optimization for lesser BKD during laser cutting. Taguchi methodology has been chosen for deciding the optimal parameter levels for cutting. At the end of the paper, the outcomes have also been checked by a confirmation test.

2. EXPERIMENTATION

2.1 Experimental setup

We used pulsed Nd: YAG LBM system of 200 W along CNC work table for our experiments. The O_2 gas is chosen for the removal of material.

2.2 Range of Input Parameters

The specification GP,PW,PF and CS are used as control factor as shown in Table 1. We have selected values of focal length and standoff distance (SOD). Thickness of workpiece is 0.9 mm in our experiments.

Table1. Input parameters and their levels

Symbol	Factors	Unit	Level 1	Level 2	Level 3
A	Gas Pressure	kg/cm^2	5.0	7.0	9.0
B	Pulse Width	ms	0.9	1.1	1.3
C	Pulse Frequency	Hz	16	21	26
D	Cutting Speed	mm/min	7.0	12.0	17.0

Table 2. Performance values by using L_9 OA

	Input Level				Bottom Kerf Deviation in mm			Mean Value in mm
Experiment No.	**A**	**B**	**C**	**D**	**R_1**	**R_2**	**R_3**	**Y_1**
1	1	1	1	1	0.050	0.054	0.048	0.050
2	1	2	2	2	0.080	0.075	0.084	0.079
3	1	3	3	3	0.055	0.042	0.058	0.051
4	2	1	2	3	0.064	0.072	0.057	0.064
5	2	2	3	1	0.045	0.044	0.047	0.045
6	2	3	1	2	0.085	0.088	0.072	0.081
7	3	1	3	2	0.080	0.075	0.082	0.079
8	3	2	1	3	0.050	0.048	0.042	0.047
9	3	3	2	1	0.090	0.077	0.084	0.083
R_1 = Replication 1, R_2 = Replication 2, R_3 = Replication 3, Y_1 = Average value of BKD								

3. Bottom Kerf Deviation (BKD)

A large portion of the material is evacuated from the opposite side of the workpieces. Fig. 2 shows deviation of beam on cutting portion of the workpice. Subsequently, the plausibility of kerf deflection from opposite faces increasingly because of oxide formation and recast formation. The bottom kerf deviation, contrast among most extreme and least cutting widths at the opposite face of the workpiececorresponding to the cutting part. Above output can be calculated by the difference between the higher bottom kerf width and lower bottom kerf width.

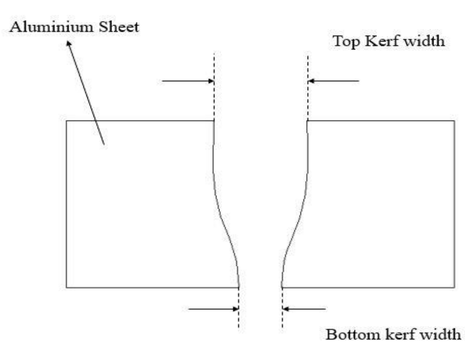

Fig. 2. Schematic representation of kerf profile

Level 1, Level 2 and level 3 of each input parameters have been taken as mentioned above. A number of experiments have been performed to determine the range of parameter for the cutting purpose. The experiments are designed as per standard L_9orthogonal array [12] selected for the present problem as shown in Table 2. BKD vs Number of experiments is shown in Fig. 3.

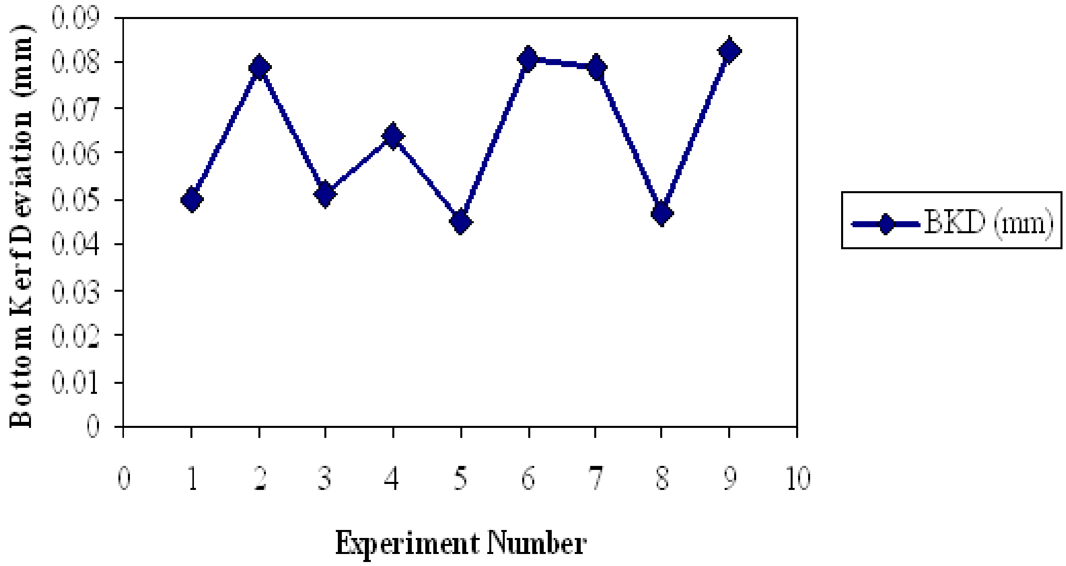

Fig. 3. Variation of BKD (mm) with experiment number

3.1. Model Development for BKD

Regression Analysis: BKD versus A, B, C, D

For finding the BKD equation MINITAB 14 software is used. Eq. (1) is given here:

$$\text{Bottom Kerf Deviation} = 0.0432 + 0.00234\ A + 0.0173\ B - 0.00012\ C - 0.00056\ D \quad (1)$$

Table 3. Analysis of variance for generated model

Name of Source	DOF	Sum of Square	Mean Sum of Squares	F value	P value
Regression	4	0.10218	0.02554	5.57	0.003
Residual Error	4	0.01831	0.00457		
Total	8	0.12049			

For this model the value of square of R is 0.91, i.e. for R value is 0.95. It is proved that the model is perfectly ok. The above mentioned table shows the value of F is 5.57, it shows the reliability of the created model. This model might be utilized for the minimization of BKD. The analysis of variance is shown in Table 3. Response graph of residual for BKD is shown in Fig. 4.

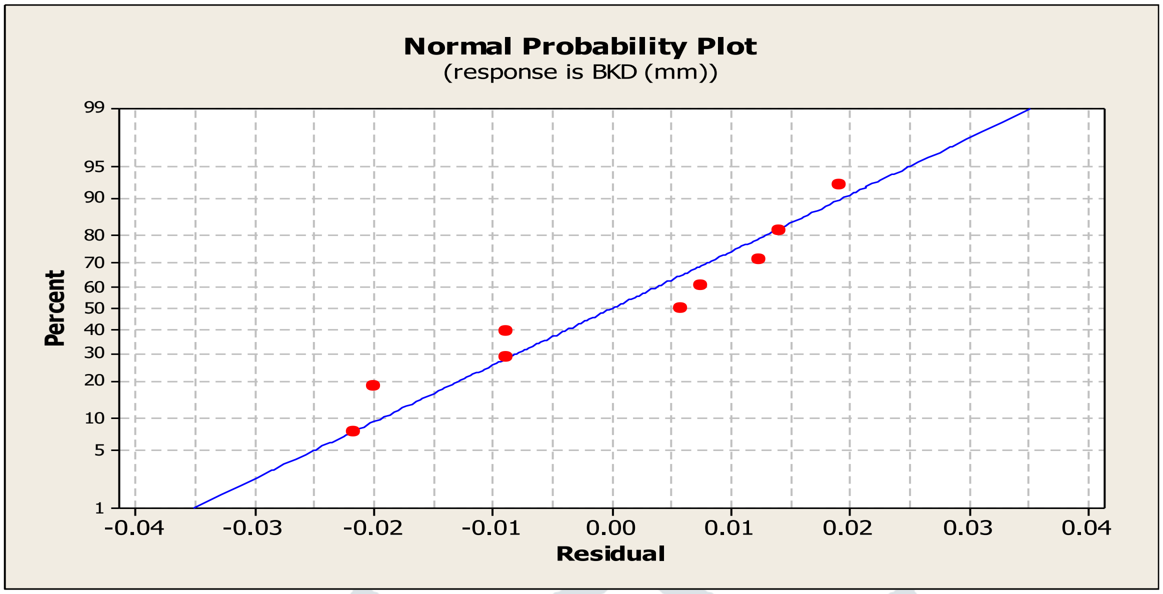

Fig. 4. Response graph for BKD in mm

3.2 Optimization of BKD

For achieving optimize result of BKD, the following equation is required. Where signal (S) to noise (N) ratios have been found by utilizing Eq. (2). Ratios have been determined individually for each test [13]. These qualities are given in Table 4.

$$S/N = -10 \log_{10} (MSD) \qquad (2)$$

The calculated values for signal (S) to noise (N) ratio for individual input for each level have been given in Table 5. The values have been shown on graph in Fig. 5. From the chart unmistakably the most extreme normal S/N proportion is acquired at level 1 of A, level 2 of B, level 3of C and level 3of D, i.e. the final factor setting for BKD obtained on $A_1B_2C_3D_3$.

Table 4. Signal (S) to Noise (N) ratio for BKD

Exp. No.	Signal (S) to Noise (N) ratio (decibel) for BKD
1	26.020
2	22.047
3	25.848
4	23.876
5	26.935
6	21.830
7	22.047
8	26.558
9	21.618
Overall mean (η_m)	24.086

Table 5. Values for signal (S) to noise (N) ratio

Level	A	B	C	D
1	**23.636**	22.980	23.801	23.855
2	23.211	**24.16**	21.511	20.975
3	22.405	22.096	**23.941**	**24.424**
Delta	1.231	2.064	2.43	3.449
Rank	4	3	2	1

3.3NoteworthyInput Variables

Positioning thevariousinput variables in Table 5have done based in contrast among higher and lower estimations of signal (S) to noise (N) ratioamong all degrees of particular input variables. From the table maximum values have been taken for more progressively input variable. On the other way, the contribution of each input variable in the form of percentage is shown in Fig 6. The values for Analysis of Variance for signal to noise ratios of BKD are given on Table 6.

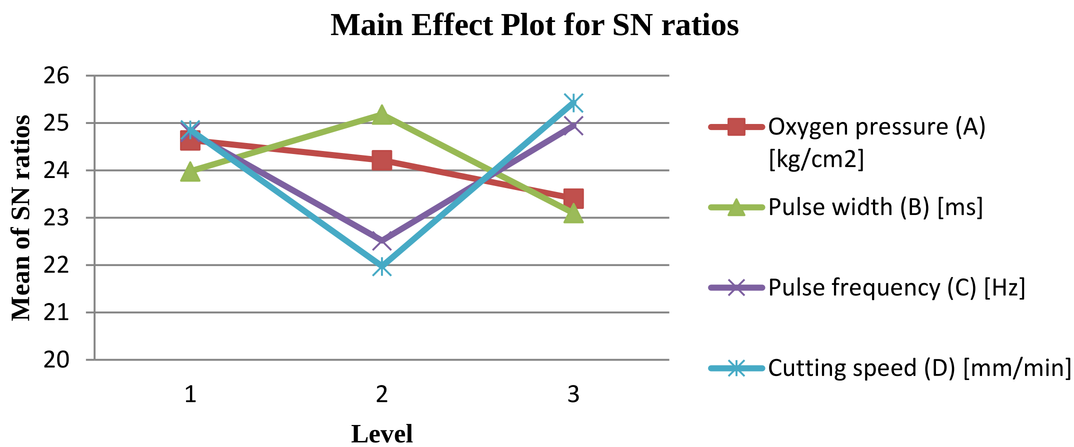

Fig. 5. Signal to noise ratio performance graph of BKD

Table 6. Values of ANOVA for signal to noise ratio

Source	DOF	Sum of Squares	Mean Sum of Squares	F-value	Percentage of contribution
A	2	0.68187	0.38083*	-----	5.75
B	2	2.17400	1.08200	2.7822	16.12
C	2	3.71144	1.8506	4.7785	27.46
D	2	6.65366	3.3265	8.7540	50.61
Error	2	0.76187	0.390937		
Total	8	13.22097			100

*Pooled factor

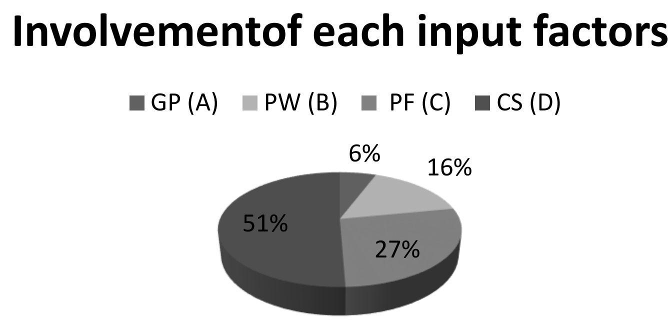

Fig.6. Pie chart for contribution of each input parameters

The estimated vales of signal to noise ratio have been calculated by the Eq. (2) and found 24.06.

$$\varsigma_{opt} = \varsigma_m + \sum_{i=1}^{p}(\varsigma_i - \varsigma_m) \tag{3}$$

Where $\zeta_i = The\ mean\ value\ of\ signal\ to\ noise\ ratio$ of ithinput variables at ideal level, ζ_m is the general mean of the values of signal to noise ratio of output. The signal to noiseproportion at anticipated ideal case contrasted and that of signal to noise proportion for introductory input value setting in Table 7. Level of progress is determined by pursues:

$$Percentage\ improvement = \frac{Experimentald\ \ result - \Pr edicted\ \ result}{Experimental\ \ result} \times 100\% \tag{4}$$

The affirmation explore is directed on ideal input variables. This discovered, bottom kerf deviation esteem is diminished 0.051mm to 0.021 mm. It is proved thatgot 59% result in BKD. The signal to noise proportion on anticipated ideal parameter level hasgot by 1.927 decibel when contrasted with introductory parameter setting.

Table 7. Confirmation table

	Initial Setting	Prediction	Experiment
Level	A_1 B_1 C_1 D_1	A_1 B_2 C_3 D_3	-----------
Signal to Noise ratio, decibel	25.017	23.090	-----------
Bottom kerd deviation mm	0.051	----------	0.02

Signal to noise ratio in decibel = 1.927

4. Results and Discussion

A trial observation of pulsed neodymium aluminium garnet (Nd: $Y_3Al_5O_{12}$) laser has been done some improvement in BKD on Al 8011 sheet. Taguchi techniquehas adopted for decreasing of the output quality variable BKD. Optimized value has been found on input factor setting i.e $A_1B_2C_3D_3$. Generated model for the quality characteristics has shown the perfection of data. Cutting speed and PF are two noteworthy input variables for BKD in the present preparing system. The signal to noise proportion at the anticipated ideal parameter level is improved by 1.927 decibel as contrasted and starting input sets. Likewise output esteem has diminished, 0.051 to 0.02 millimetres. The affirmation tests directed on ideal input sets found that the output bottom kerf deviation esteem has improved by 59%.

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