Parametric Investigations on CO_2 Laser Cutting of AISI 409 to Optimize Process Parameters by Taguchi method

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Abstract: *Laser Beam Machining is one of the mostly use manufacturing technique utilized to perform cutting, engraving and welding operations on a variety of materials like metals, plastics, ceramics etc. CO2 laser cutting is mostly used for sheet metal cutting. The present work is to study the effect of process parameters of CO2 laser cutting such as cutting speed, input power and gas pressure on the quality of the machined surface using laser beam on stainless steel SS 409. The quality of cut is measured in terms of response parameters such as kerf width and surface roughness. Design of experiments is implemented by using a Taguchi method design. The effect of the process parameters on response have studied by means of main effect plots which are developed by using ANOVA. After Design of Experiment (DOE) by using Taguchi method, the analysis is carried by the Analysis of Variance (ANOVA) method.& optimum parameter is selected on the basis of the signal to noise ratio.*

Keywords *– AISI 409SS, Laser Cutting, Laser Power, Gas Pressure, Cutting Speed, Surface Roughness, Kerf Width, Taguchi Method*

I. INTRODUCTION

Laser cutting of sheet metal has become an economically viable method of production through advances in technology. The quality of laser cut is of the utmost importance in laser cutting process. CO2 laser machine has been used in industry for many applications such as laser cutting, laser engraver and laser marking. The finished product of laser cutting process does not need any further finishing process. However, poor quality of cut of metal has been rise as serious issues in industry due to the improper setting of cutting parameters. So there is necessity to find influence of cutting parameters on the resulting quality of work. In general, cutting parameters are adjusted and tuned to getthe good quality of cut. But this consumes exhaustive amounts of time and effort. Therefore, it is necessary to investigate the impact of cutting parameters on quality of cut. Grade 409 stainless steel is a Ferritic steel.It has good mechanical properties and high temperature corrosion resistance.SS409 is widely used in manufacturing of Automotive exhaust tubing ,Catalytic converter systems ,blowers fans , pressure vessels operating under high temperature corrosive environment. The finished product of laser cutting process does not need any further finishing process. However, poor quality of cut has been rise as critical issues in industry due to the improper setting of cutting parameters. In order to solve this problem, a research study on the impact of cutting parameters on quality of cut was carried out. In this research, the main objective will focus on the impact of the cutting parameters of a specify machine on the quality of cut on AISI 409 SS sheet. So the goal is to determine the near optimal laser cutting parameter values in order to ensure robust condition for minimization of average surface roughness & kerf width for SS409 by using Taguchi method.Design of Experiment can be used by implementing Design Expert Software to identify the main effects and interactions of the parameters.

II. LITERATURE SURVEY

Milos Madic, Miroslav,Radovanovic (2013) applied TM for determining of the optimal laser cutting parameter settings which minimize surface roughness in CO2 laser cutting of S355J2G3 (EN) mild steel. The laser cutting parameters such as cutting speed, laser power and assist gas pressure were considered in the experiment.& concluded cutting speed and assist gas pressure are the most significant parameters which affects the surface roughness variation, while the influence of the laser power is much smaller.[1]

B. D. Prajapati, R. J. Patel(2013) applied Taguchi method to find out the effect of laser machine processing parameters like laser power, gas pressure, cutting speed and thickness effect on measured response such as surface roughness for Mild Steel and Hardox-400, concluded that Cutting speed and thickness of plate have high contribution on surface roughness for both materials.[2]

UrveshD.Patel, V.J.Limbachiya (2015) used response surface methodology to optimize process parameters (Gas Pressure : Kg/cm2, Cutting Speed : mm/min, Stand of Distance : mm, Power : kW) for

MRR, Kerf width for ss410 & found that material removal rate is increase with increase of Gas Pressure, Cutting speed, SOD and laser Power. The surface roughness is decreasing with increase of gas pressure and cutting speed. But it is increasing with increasing of SOD and laser power. The kerf is increasing with increasing the value of Gas Pressure, SOD and laser Power. But it is decreasing with increasing cutting speed.[3]

MilošMadić, MiroslavRadovanović (2014)studied multi-objective optimization for the quality characteristics in CO_2 laser cutting of AISI 304 stainless steel & found optimal laser cutting parameters like laser power, cutting speed, assist gas pressure, and focus position for the prediction of cut quality characteristics such as surface roughness, kerf width and heat affected zone.[4]

M. Madić (2014)approached for optimization of CO_2 laser cutting process for 2 mm thick structural steel S355J2G3 EN 10025 sheet 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 &determined the near optimal laser cutting parameter values in order to achive robust condition (maximize the S/N ratio) for minimization of average surface roughness.[5]

Avanish Kumar Dubey, VinodYadava**:** This paper presents a hybrid Taguchi method and response surface method (TMRSM) for the optimization of a laser beam cutting process. Taguchi quality loss function toobtain the optimum level of input cutting parameterssuch as assist gas pressure, pulse width, pulse frequency and cutting speed is used. The optimum input parameter settings are further used as the central values in the response surface method to develop and optimize the second-order response model. The two quality characteristics Kerf width (KW), and material removal rate (MRR), which has of different nature (KW is of the smaller-the-better type, while MRR is of the higher the better type), have been selected for simultaneous optimization. [6]

III. METHODOLOGY

Taguchi's method is a powerful technique for the design of a high quality system. It provides not only, an efficient, but also a systematic way to optimize designs for performance and quality. Furthermore, Taguchi parameter design can reduce the fluctuation of system performance and quality to the source of variation.

The methodology used:

- Identify the quality characteristics and select process parameters to be evaluated.
- Select the appropriate orthogonal array and assign these parameters to the orthogonal array & design the matrix.
- Conduct the experiments as per design matrix based on the arrangement of the orthogonal array.& Recording of responses
- Analyze the experimental results using the signal to noise(S/N) ratio and analysis of variance (ANOVA) by using Design Expert software.

IV. EXPERIMENTATION

A. Material for Experiment

Stainless Steel Grade AISI 409 is used for this experiment. The chemical compositional ranges of grade 409 stainless steels are given below:

TABLE I.
CHEMICAL COMPOSITION OF SS 409

Grade	C	Mn	Si	P	S	Cr	Ni	Ti
min	-	-	-	-	-	10.5	-	6xC
max.	0.008	1	1	0.045	0.045	11.75	0.5	0.75

B. Profile Specification

The profile cut using the CO_2 laser. The 9 specimen of size 100*50 mm is to cut from SS 409 sheet of 4mm thick, with half translational cut from center.

C. Experimental Details

The experimentation has to carry out on AMADA make CO_2 laser cutting machine (model FOM II 2412 NT) having maximum laser power 2500 Watt.

1) ***Selection of Process Parameters & Levels:***Process parameters and their ranges were determined by the Literature survey& by taking the review of experienced people working on laser cutting machine. Also surface roughness, kerf width is to measure as a response.

TABLE II.
PROCESS PARAMETERS WITH LEVELS

Sr. No.	Parameter	Symbol	Unit	Levels		
				1	2	3
1	Power	A	Watt	1500	2000	2500
2	Cutting Speed	B	mm/min	1000	2000	3000
3	Gas Pressure	C	bar	0.4	0.6	0.8

2) *Selection of Orthogonal Array:* Selection of an appropriate orthogonal array for the experiments is done on the basis of number of process parameters and its levels. As no. of parameters is 3 & no. of levels are 3, L9 orthogonal array is selected.

TABLE III.

ORTHOGONAL ARRAY

Experiment no.	Process variables		
	Laser power(P)	Cutting speed (C)	Gas pressure(G)
1	1500	1000	0.4
2	1500	2000	0.6
3	1500	3000	0.8
4	2000	2000	0.6
5	2000	3000	0.8
6	2000	1000	0.4
7	2500	3000	0.8
8	2500	2000	0.6
9	2500	1000	0.4

D. Response Measuring Techniques

In order to attain good cutting results, measurement of work piece parameters after the laser cutting process is done and check for quality of cut. The work piece parameters include measurement of Kerf width, Surface roughness over the quality of cut is to be measure. The work piece parameter and effect of process parameter over the work piece after laser cutting is to measure by using Tool Makers Microscope.

V. RESULT AND DISCUSSION

A. Surface Roughness

Taguchi method of design of experiment is used to reduce the number of experiments, yet cover the entire parameter space with the help of a special design of orthogonal array. The results of such experiments are then transformed to a signal to noise(S/N) ratio to find out the deviation of the performance characteristics from the desired values. In this experiment, the desired characteristic for surface roughness is lower the better.

$$S/N = -10 \log [1/n \sum^{n}_{i=1} (y_i^2)] \qquad (1)$$

TABLE IV.
AVERAGE SURFACE ROUGHNESS VALUE AND THEIR CORRESPONDING (S/N) RATIOS.

Sr No.	Laser Power	Speed	Gas Pressure	SR(Ra)	SNRA
1	1500	800	0.1	2.32	5.89
2	1500	1200	0.3	2.65	5.31
3	1500	1600	0.6	2.90	4.92
4	2000	800	0.3	2.45	5.65
5	2000	1200	0.6	1.92	6.71
6	2000	1600	0.1	3.28	4.38
7	2500	800	0.6	2.10	6.32
8	2500	1200	0.1	3.16	4.55
9	2500	1600	0.3	3.39	4.24

Table 4 shows the average surface roughness value and their corresponding signal to noise (S/N) ratios.

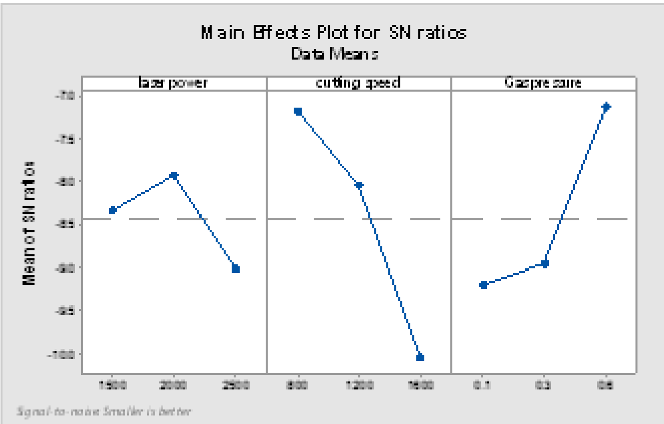

Fig.1. Signal to Noise Plot for Surface Roughness

TABLE V.
RESPONSE TABLE FOR SURFACE ROUGHNESS S/N RATIOS (SMALLER IS BETTER)

Level	Laser Power watt	Cutting speed mm/min	Gas Pressure Bar
1	-8.341	-7.179	-9.207
2	-7.922	-8.042	-8.951
3	-9.014	-10.056	-7.119
Delta	1.092	2.877	2.088
Rank	3	1	2

TABLE VI.
ANALYSIS OF VARIANCE FOR SURFACE ROUGHNESS

Source	DF	Adj SS	Adj MS	F Value	P-Value	% contri bution
laser power	2	0.1841	0.09204	1.42	0.413	8.22
cutting speed	2	1.2684	0.63418	9.80	0.093	56.62
Gas pressure	2	0.6582	0.32908	5.09	0.164	29.38
Error	2	0.1294	0.06471			5.78
Total	8	2.2400				

Table 4 shows the response table of Signal to Noise ratios for surface roughness. Based on this analysis, low surface roughness is obtained at laser power 2000, cutting speed 1200 & gas pressure 0.6. In the analysis,cutting speed is shown as the most influencing parameter followed by gas pressure and laser power. On the basis of ANOVA results in table 6 the percentage contribution of various factors to surface roughness is identifiable. Here,cutting speed is the most important factor followed by gas pressure. The percentage contribution of cutting speed and gas pressure towards surface roughness is 56.62% and 29.38% respectively.
The optimal combination from table 5:
Laser power = 2000 watt
Cutting speed = 800 mm/min
Gas pressure = 0.6 bar

Regression equation
SR=2.6856- 0.062 laser power_1500-
0.136 laser power_2000 + 0.198 laser power_2500-
0.396 cutting speed_800-
0.109 cutting speed_1200+ 0.504 cutting speed_1600
+ 0.234 Gas pressure_0.1+ 0.144 Gas pressure_0.3-
0.379 Gas pressure_0.6.

B. *Kerf Width*

For Kerf Width, the desired characteristic for kerf width is lower the better. The results of taguchi experiments are then transformed into a signal to noise (S/N) ratio to measure the deviation of the performance characteristics from the desired values.

$$S/N = -10 \log[1/n \sum^{n}_{i=1} (y_i^2)] \qquad (2)$$

TABLE VII.
SIGNAL TO NOISE RATIO FOR KERF WIDTH

Sr No.	Laser Power	Cutting Speed	Gas Pressure	Kerf Width	SNRA
1	1500	800	0.1	0.25	15.56
2	1500	1200	0.3	0.27	15.22
3	1500	1600	0.6	0.29	14.918
4	2000	800	0.3	0.51	12.46
5	2000	1200	0.6	0.48	12.73
6	2000	1600	0.1	0.24	15.74
7	2500	800	0.6	0.88	10.09
8	2500	1200	0.1	0.72	10.96
9	2500	1600	0.3	0.80	10.51

Table 7 shows the average kerf width value and their corresponding signal to noise (S/N) ratios.

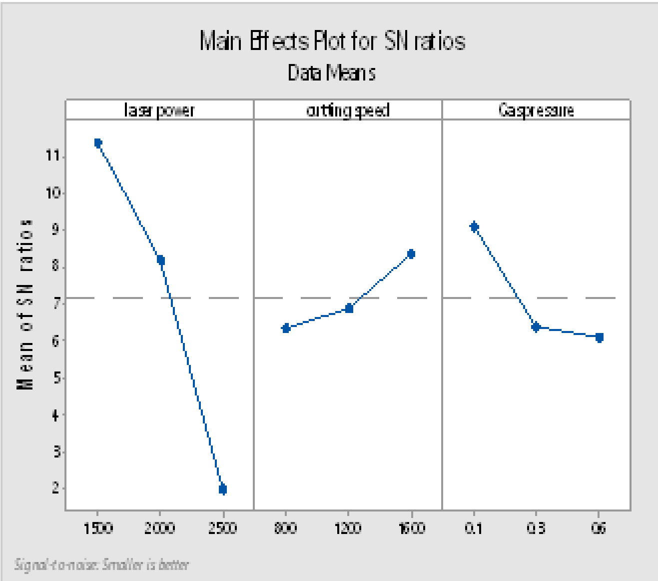

Fig.2. Signal to Noise Plot for Kerf Width

TABLE VIII.
RESPONSE TABLE FOR SURFACE ROUGHNESS SN/RATIOS (SMALLER IS BETTER

Level	Laserpower	Cuttingspeed	GasPressure
1	11.39	6.33	9.10
2	8.21	6.87	6.39
3	1.97	8.36	6.08
Delta	9.42	2.03	3.02
Rank	1	3	2

TABLE IX.
ANALYSIS OF VARIANCE FOR SURFACE ROUGHNESS

Source	DF	Adj SS	Adj M	F-Value	P-Value	% contribution
laser power	2	0.18	0.09	1.42	0.41	8.22
cutting speed	2	1.27	0.6	9.8	0.09	56.63
Gas pressure	2	0.66	0.33	5.09	0.16	29.38
Error	2	0.13	0.06			5.78
Total	8	2.24				

Table 7 shows the response table of Signal to Noise ratios for Kerf Width. Based on this analysis, low Kerf Width is obtained at laser power 2000, cutting speed 1200 & gas pressure 0.1. In the analysis, laser power is shown as the most significant parameter as its P value is less than 0.05.Followed by gas pressure and cutting speed & having percentage contribution 88.74, 7.3 &3.15 respectively.
The optimal combination is:
Laser power = 1500 watt
Cutting speed = 1600 mm/min
Gas pressure = 0.1 bar

Regression Equation

Kerf Width = 0.4933 - 0.2233 laser power_1500-
0.0833 laser power_2000+ 0.3067 laser power_2500+
0.0533 cutting speed_800-
0.0033 cutting speed_1200-
0.0500 cutting speed_1600-
0.0900 Gas pressure_0.1+ 0.0333 Gas pressure_0.3
+ 0.0567 Gas pressure_0.6

C. *Gray Relational Analysis*

As we have got two different cutting parameter settings for surface roughness and kerf width. So we don't get minimum surface roughness and kerf width. If we have to cut material with both Ra and W minimum then we can find out it by grey relational analysis. Grey data processing must be performed before calculation of GRCs. In this study, a linear normalization of SN ratios for Ra and W were performed in the range of 0 and 1. By normalizing SN ratios deviation sequence calculated, which are used to calculate grey relational coefficient (GRCs). By taking weighting sum of GRCs we will get grey relational grade (GRG). So to get optimum parameters for minimum Ra and W we used GRG as response for taguchi analysis.

TABLE X.
GRAY RELATIONAL GRADE FOR SS 409

Exp No.	SR	Kerf Width	SNRA For SR	SNRA For Kerf Width	GRC		GRG
1	2.32	0.25	-7.31	12.04	0.43	0.34	0.38
2	2.65	0.27	-8.46	11.37	0.54	0.35	0.45
3	2.9	0.29	-9.25	10.75	0.65	0.37	0.51
4	2.45	0.51	-7.78	5.85	0.47	0.54	0.51
5	1.92	0.48	-5.67	6.38	0.33	0.52	0.43
6	3.28	0.24	-10.32	12.40	0.90	0.33	0.62
7	2.1	0.88	-6.44	1.11	0.37	1.00	0.69
8	3.16	0.72	-9.99	2.85	0.80	0.76	0.78
9	3.39	0.8	-10.6	1.94	1.00	0.87	0.94

TABLE XI.
RESPONSE TABLE FOR SIGNAL TO NOISE RATIO FOR GRG SMALLER IS BETTER

Level	Laser Power	Cutting Speed	Gas Pressure
1	7.073	5.836	4.881
2	5.859	5.524	4.508
3	1.987	3.559	5.530
Delta	5.087	2.277	1.022
Rank	1	2	3

From table XI delta value of laser power is greater than cutting speed and gas pressure which shows laser power is more influencing factor on GRG for SS 409 material.

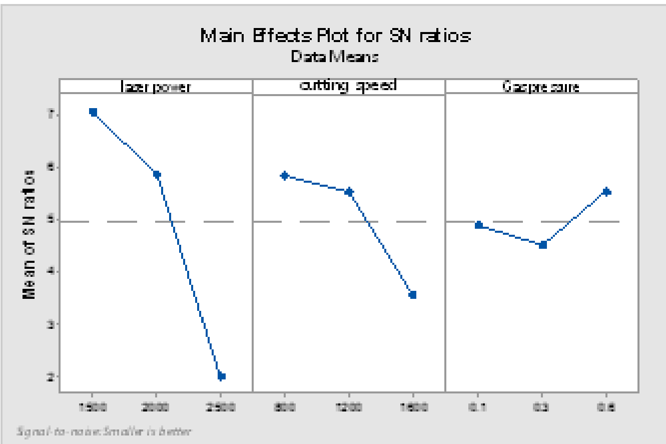

Fig.3 Main effect plot of SN ratios for GRG for SS 409 material

Fig. 3.shows direct effect of laser power, cutting speed and gas pressure on GRG.
So it is clear that GRG increases with increase in laser power and cutting speed and decreases with increase in gas pressure.
The optimal combination from table 5:
Laser power = 1500 watt
Cutting speed =800 mm/min
Gas pressure = 0.6 bar

VI. CONCLUSION

In this study, CNC laser cutting operation is done under various experimental conditions and the surface roughness, kerf width were measured. 9 levels of experiments had been done. The most effecting factors on surface roughness is cutting speed & gas pressure, on Kerf width is laser power & gas pressure.
From main effect plots as laser power & cutting speed increases surface roughness also increases with decreasing value of gas pressure. And kerf width increases with increasing laser power & gas pressure and decrease in cutting speed.
Gray Relational Grade for SS 409 increases with increase in laser power and cutting speed and decreases with increase in gas pressure.
The optimal combination for SS 409 are laser power = 1500 watt, cutting speed =800 mm/min and Gas pressure = 0.6 bar.

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