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Parameter Optimization of Plasma Cutting Process for Stainless Steel Using Taguchi Methodology

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ABSTRACT
Plasma arc Cutting is the most required process in the metal fabrication industries. CNC Plasma cutting is available in advanced machinery as 2D, 3D and pipe and tube plasma cutting machines. Although there are other metal cutting processes are available for the industries but this process keeps its own place due to the low price and easy to use process.
In the last some years there are a lot off research has been done to improve the quality of the cutting. To keep this process in the competition, researches has been made to reduce the cost of the machine and the cutting.
In the current thesis work the literature has been made a source of the information in context to the optimizing the parameters of the CNC Plasma Arc Cutting Machine. To attain the required result, Taguchi method is employed. For this a 3^3 array has been made with the Current, Voltage and Feed rate and an orthogonal array has been selected as per the number of factors and their levels to perform the necessary experiments.
In the experimentation a work piece of stainless steel (304L) is taken as a sheet metal for the cutting purpose. The study is done to optimize the roughness of the cut work piece along with optimizing the cutting cycle time. To determine the optimum values, the MINITAB software is used. Using the ANOVA table and the main effect plot, the optimum values are determined. Different set of values of the Current, Voltage and feed rate were taken in this experiment and seeking for the optimum values. From the analyses it is found that, optimum input parameters for minimum cycle time and surface roughness are:
- Current 65 A
- Voltage 105 v
- Feed rate of 2700 mm/min

KEYWORDS: Plasma Cutting, Cycle time, CNC Machine, Parameter optimization, Taguchi method, ANOVA

I. INTRODUCTION

1.1. Definition of plasma

It the high temperature ionized gas, which conducts the electricity. [1] and Plasma cutter also can be defining as the machine which, uses the highly heated plasma to melt and cut the metals. [2]
Functioning of the machine: A highly heated (30000°C) plasma is created by the machine by diffusing the compressed gas (air or inert gas) into the ions. This hot plasma is directed by the narrow nozzle on the metal which is to be cut and, the compressed air blown off the melted metal and generate the clean cut. [1]
Classification of CNC Plasma Cutter: There are three general type of CNC plasma cutter as mentioned below
- 2D Plasma Cutting: It is used to cut the flat sheet metal at 90° angle in 2 dimensions.
- 3D Plasma Cutting: It can also cut angles other than 90°, which helps it to make edge chamfer and countersink holes. [3]
- Tube and Section Plasma Cutting: These types of cutters are used to cut the tubes, pipes and other profile sections. [4]

Cutting parameters: there are various parameters are used in the plasma cutting such as cutting speed, pressure and quality of gases, current and voltage etc. the effect of the parameters is explained below
- Cutting Speed: It affect the surface quality, kerf value and heat affected zone.
- Gas: Quality and the pressure of the gas determine the cutting quality of the material.
- Current: It assure how much thick metal could be cut.
- The Height of the torch: Height of the torch define the required angle of the cut. [5]
- Voltage: It maintain the kerf value, HAZ and the surface finish. [6]

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Application of cutting: Plasma cutters are generally used in industrial construction, automotive, scrap metal operations, salvage etc. [4]

1.2. Problem Statement

During the work in the Bhartiya skill development university, Jaipur, it is found that cycle time taken in cutting a sheet of stainless steel on plasma cutting machine was not expected as per the recommended parameters. Therefore, the study was carried out with a statistical analysis to improve the parameters and to reduce the cycle time.

1.3. Objective of The Study

To optimize the parameters of plasma arc cutting for the stainless-steel sheets for reduction in cycle time.

To implement the statistical tools to optimize the parameters.

II. RESEARCH METHODOLOGY

Research methodology is defined as a systematic approach or the specific procedures or techniques to identify, select, and analyze information about the topic.

The flow chart figure 2 of the research methodology which is followed in the study is illustrated below. The chart gives a clarification to understand the basic stages of the study.

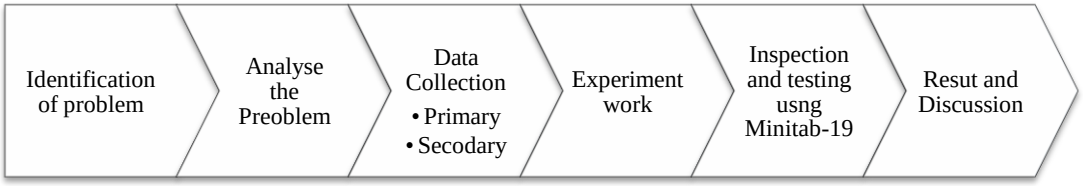

Figure *1* Research Methodology

Taguchi methods was developed by a Japanese Engineer, Genichi Taguchi to improve the quality of goods and to optimize designs for cost, quality and performance. In this research, Taguchi based design of experiments are applied to develop an L9 orthogonal array for experimental runs and statistically signify the relationships between input parameters (cutting speed, feed rate, overhanging of tool) and output responses (surface roughness). In this study, three parameters with three levels forms a Taguchi L9 orthogonal array.

Signal-to-Noise Ratio SNR or S/N ratio is a useful parameter that compares the level of desired signal to the level of background noise. It is also used to analyze the data obtained and could predict the results. A large S/N ratio is always desirable as it represents good quality. S/N ratio is separated into three groups or three performance characteristics: -

- Smaller the better S/N = −10 *log (Σ (Y2)/n)) (1)
- Nominal the best S/N = −10 *log (σ2) (2)
- Larger the better S/N = −10 *log (Σ (1/Y2)/n) (3)

In this study, smaller the better consideration is taken into account because the surface roughness values should be as low as possible for better quality.

Analysis of Variance (ANOVA) ANOVA is developed by Ronald Fisher. It uses the statistical models to analyze and compare more than two groups at the same time to determine the relationship between them. In this study, a two-way ANOVA is used to tests the effects of two factors (cutting speed & feed rate) at the same time on the output parameter (surface roughness)

III. EXPERIMENTAL WORK

1.4. Machine Specification (Cut Fire 100i)

Table:1

Power Source	Plasma Torch
Plasma Torch – Flash 100 G/L	Cutting Range – 1 to 20 mm
Main Voltage – 3x400 V, 50 Hz	Plasma gas – Air
Open Circuit Voltage U0 – 330 V DC	Torch Cooling – Air cooled
Arc Voltage – 88 to 130 V DC	Air Consumption – 195 l/ min I 265 l/ min
Cutting Current Is – 20 to 100 A	Pressure – 5.0 bar I 6.5 bar
Pilot arc current IPB - max. 25 A	Torch shaft diameter – 36 mm

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1.5. Material Used: Sheet Metal 304L

Properties

- Density – 8.03 g/cm3
- 0.2% Offset Yield Strength, psi (MPa) – 25,000 (170)
- Ultimate Tensile Strength, psi (MPa) - 70,000 (485)
- Hardness, Max., Brinell (RB) – 201 (92)
- Melting Point - 1400°C
- Thermal Conductivity @ 100°C 16.3 W/m·K

1.6. Design of experiment

The basic need of this research is to analyzed the cycle time and to find the statically result. In this, the Taguchi method is most popular and effective for the design of experiments; this is a method to reduce number of experiments required for reaching the research objectives. Taguchi design and the ANOVA analysis is an engineering methodologies for enhancing the quality of work at low cost. The steps for the analyzing the Taguchi methods:

- To select the quality characteristics
- To select the signal factors (control factors)
- Selection of noise factors
- Orthogonal array
- Analysis of result
- Report

1.6.1. Selection of parameters

Design Summary

Table:2

Taguchi Array	L9(3^3)
Factors:	3
Runs:	9

Columns of L9(3^3) array: 1 2 3

Table:3

S. No.	Current (A)	Voltage (V)	Feed
1	65	95	2300
2	70	100	2500
3	75	105	2700

Orthogonal Array

Table:4

S. no.	Current (A)	Voltage (V)	Feed
1	65	95	2300
2	65	100	2500
3	65	105	2700
4	70	95	2500
5	70	100	2700
6	70	105	2300
7	75	95	2700
8	75	100	2300
9	75	105	2500

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IV. RESULT AND DISCUSSION

Completion of experimentation, cycle time and surface roughness of 9 specimens measured. Their results are given in table 5

Table:5

S. no.	Current (A)	Voltage (V)	Feed	Cycle time	roughness	SNRA1	MEAN1
1	65	95	2300	9.77	13.790	-21.5475	11.7800
2	65	100	2500	9.70	8.624	-19.2548	9.1620
3	**65**	**105**	**2700**	**8.85**	**4.999**	-17.1312	6.9245
4	70	95	2500	9.63	11.688	-20.5946	10.6590
5	70	100	2700	9.30	8.749	-19.1125	9.0245
6	70	105	2300	9.95	9.819	-19.8993	9.8845
7	75	95	2700	9.23	7.015	-18.2738	8.1225
8	75	100	2300	10.29	7.970	-19.2790	9.1300
9	75	105	2500	9.70	7.441	-18.7349	8.5705

1.7. Signal to Noise Ratios

The SN ratio is calculated by using the following equation S/N = - 10 log10 (MSD) For the S/N ratio to be large, MSC must have a value that is small. For the present work, smaller is the best quality characteristic;

MSD =Y1_ + Y2_ + − − − + Yn/N

Where, Y1, Y2 ---------- Yn, are the quality characteristic.

Level average response analysis

The level average analysis is based upon the experimental and observed data or the SN values. The S/N data at each level of each factor is shown in Table 2.

Table:6

Table			
Level	**Current (A)**	**Voltage (V)**	**Feed**
1	-19.31	-20.14	-20.24
2	-19.87	-19.22	-19.53
3	-18.76	-18.59	-18.17
Delta	1.11	1.55	2.07
Rank	3	2	1

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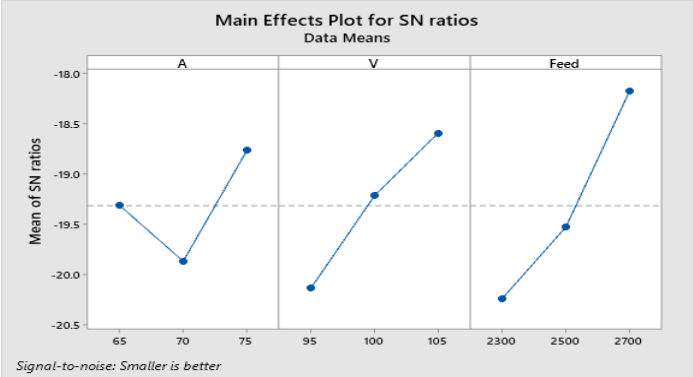

Figure 2: Main effect plot for SN Ratio

Smaller is better

It is clear from the figure that S/N ratio is increasing with increasing Current and with increasing Voltage and Feed. So, on the basis of the results obtained from table, optimum input parameters for minimum cycle time and surface values are given below.

- Current 65 A.
- Voltage 105 V.
- Feed rate of 2700 mm/min.

1.8. Analysis of Variance: ANOVA for Cycle Time

Factor Information

Table:7

Factor	Type	Levels	Values
A	Fixed	3	65, 70, 75
V	Fixed	3	95, 100, 105
Feed	Fixed	3	2300, 2500, 2700

Analysis of Variance

Table:8

Source	DF	Adj SS	Adj MS	F-Value	P-Value
A	2	0.13769	0.068844	51.21	0.019
V	2	0.11962	0.059811	44.49	0.022
Feed	2	1.17776	0.588878	438.01	0.002
Error	2	0.00269	0.001344		
Total	8	1.43776			

5.1 Estimated model coefficients for Ra

It is evident from the table 9 that null hypothesis (H0) is accepted for all three input variables at 95% confidence level as F-value is less than the F0.05 table value whereas null hypothesis is accepted for two input variables and rejected for one input variable (cutting speed) at 90% confidence level as F-value is greater than F0.10 table value.

It is also evident from the table 9 that P-value is more for feed rate than overhanging of tool and minimum for cutting speed so feed rate is most significant followed by overhanging of tool and cutting speed and thus affects the average surface roughness.

Model Summary

Regression analysis

Regression analysis is a statistical method for approaching the relationships between variables. It is a method for modelling different variables. It helps to understand how the dependent variable turns when any one of the independent variables is changed. Regression analysis were carried out for cycle time taking Current (A), Voltage (V) and Feed as independent variables and Cycle time and Surface Roughness will be the dependent variable. Normal probability of regression equation was also plotted in figure 5 for Cycle Time.

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1.9. Analysis of Variance: ANOVAfor Roughness

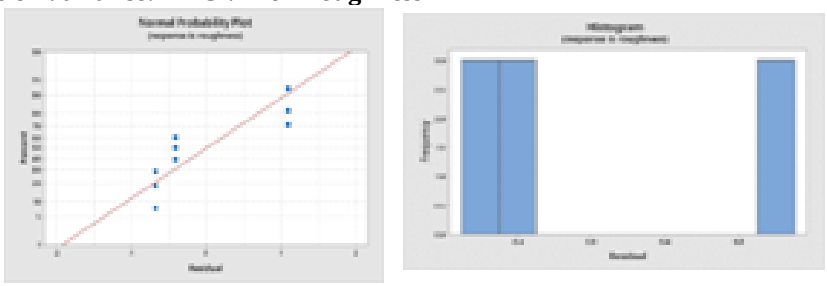

Figure 3: Normal probability graph

5.1 Estimated model coefficients for Ra

S = 0.101379 R-Sq = 94.13% R-Sq (adj) = 76.51%

It is evident from the table 9 that null hypothesis (H0) is accepted for all three input variables at 95% confidence level as F-value is less than the F0.05 table value whereas null hypothesis is accepted for two input variables and rejected for one input variable (cutting speed) at 90% confidence level as F-value is greater than F0.10 table value.

It is also evident from the table 9 that P-value is more for feed rate than overhanging of tool and minimum for cutting speed so feed rate is most significant followed by overhanging of tool and cutting speed and thus affects the average surface roughness.

Table:9

Source	DF	Adj SS	Adj MS	F-Value	P-Value
A	2	10.474	5.237	1.91	0.344
V	2	18.374	9.187	3.35	0.230
Feed	2	20.054	10.027	3.65	0.215
Error	2	5.492	2.746		
Total	8	54.393			

Regression Equation

roughness = 8.899 + 0.238 A_65 + 1.186 A_70 - 1.424 A_75 + 1.932 V_95 - 0.452 V_100 - 1.480 V_105 + 1.627 Feed_2300 + 0.352 Feed_2500 - 1.978 Feed_2700

V. CONCLUSION

In this thesis it is tried to find the optimum result of the cutting parameters for the CNC plasma cutting machine. The parameters used in this thesis are current, voltage and feed rate. The following result for cutting of sheet metal of stainless steel (304L) of 3 mm thick is concluded.

- Current 65 A
- Voltage 105 v
- Feed rate of 2700 mm/min

The above results can be used for the cutting of the sheet metal of 3 mm thick stainless steel (304L).

From the above result we can say that current, voltage and feed rate should be at the side of higher value.

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