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An Investigation and Prediction of Flatness and Surface Roughness during Plasma Cutting Operation on SS410 Material

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Abstract – The research and development in the precise and accurate machining technology of hard metals (Ferrous, non-ferrous and glass etc) is gaining much importance in the industry since last many years. Due to the tremendous competition and cost factor, the non-conventional machining technology is becoming the first choice of the engineers and technicians. In this era of advanced technological processes the CNC plasma arc machining is gaining tremendous ground in the industry. It is much more capable of producing best finished, high accurate machining of very complicated non-symmetrical profile in no time. The main objective and targets of this practical experiment is based to achieve the best possible setting and parameters of operation on a CNC plasma arc machine to achieving speedy work i.e. Rapid cutting. Finally I found CNC plasma arc machining the pierce delay was most significant effect whereas the other parameters viz. Arc voltage and cutting speed are less effective as well as the steam as the plasma gas will generate more energy than other gases for the same current value and the plasma jet generated is much narrowed when primary gas, Oxygen and secondary gas, air is used as plasma gases. The major reason of geometrical Error rate the Arc voltage &cutting speed play a very important role. Higher the value of cutting speed rate create more geometrical error.

Index Terms – Ferrous, CNC, Plasma, Geometrical, Gas.

1. INTRODUCTION

1.1 THERMAL CUTTING

Nowadays, the different types of thermal cutting techniques have been applied for cutting materials in different fields of mechanical engineering, process technology and shipbuilding. Plasma arc cutting (PAC) is one of them a very important thermal cutting process. An advanced Plasma arc cutting technique was developed at the end of the 1970s for cutting stainless steel, manganese steel, titanium alloys, copper, magnesium, aluminum and its alloys. Today metal cutting is characterized by higher quality demands and are expected to exhibit maximum dimensional accuracy. Plasma arc cutting have indirect competition with other techniques such as conventional hacksaw cutting oxy-fuel cutting, laser cutting and water jet cutting. However it can also be an alternative to the mechanical processing techniques such as punching and drilling.

1.2 PROCESS DESCRIPTION

Plasma cutting is a process that is used to cut steel and other metals (or sometimes other materials) using a plasma torch. In this process, an inert gas (in some units, compressed air) is blown at high speed out of a nozzle, at the same time an electrical arc is formed through that gas from the nozzle to the surface being cut, turning some of that gas to plasma. The plasma is sufficiently hot to melt the metal being cut and moves sufficiently fast to blow molten metal away from the cut. Plasma can also be used for plasma arc welding and other applications.

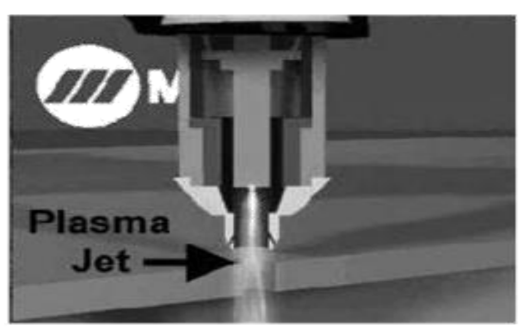


FIG. 1.1 PAC Arc Cut-Away

The plasma arc torch has a space or area surrounding the circumference of the electrode, between the inside circumference of the torch tip or nozzle. It is in this chamber that the plasma gas is heated and ionized. This heating causes the plasma gas to greatly expand in volume and pressure. The plasma gas exits from the constricting orifice of the torch nozzle or tip at very high speeds and temperatures up to 30,000 degrees F. (16,000 degrees C.) and 6000 m/s (20,000 ft/s). The intensity and velocity of the plasma is determined by several variables including the type of gas, its pressure & volume, the flow pattern, the amount of electric current, the size and shape of the constricting tip or nozzle orifice, and the tip to work distance.

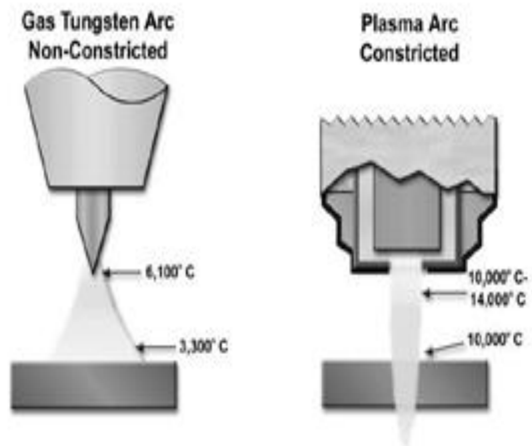


FIG. 1.2 TIG and Plasma Arcs

The PAC process uses this high temperature, constricted, high velocity jet of ionized gas exiting from the constricting orifice of the torch tip to melt a much localized area and remove the molten material from the metal being cut by the force of the plasma jet. The force of the arc pushes the molten metal through the work piece and severs the material. Extremely clean and accurate cuts are possible with PAC. Because of the tightly focused heat energy, there's very little warping, even when cutting thin gauge sheet metal thickness. PAC also offers quality gouging and piercing capabilities.

1.5 SCOPE

Generally these projects will be developing within the scopes below:

1. This project focuses on the optimization of cutting parameters of Plasma Arc Cutting (PAC).

2. The material used to cut was Stainless Steel of specification SS410.

3. Design of Experiments (DOE) layout will be used for testing and analyzing with Taguchi Method

4. All of data was analyzed by using Minitab 17 Software to produce the best combination setting in plasma cutting for Stainless Steel.

2. LITERATURE REVIEW

Deli Jia And Bo You (1) et.al, were investigated adopting digital inverted plasma arc cutting power as a hardware platform and focusing on its strong nonlinearity and time-varying property, this paper puts forward a variable interval fuzzy-PL double-mode quantification algorithm with a self-adjustable factor in the full domain. The introduction of the PID neural network is for decoupling such parameter variables as the cutting speed and torch height in the multi-parameter hybrid coupling cutting process. This control strategy reduces the complex nonlinear system modeling and realizes real-time and effective online control for the cutting process by combining the advantages of fuzzy control and PID neural network control. Furthermore, the optimized fuzzy control improves the steady-state precision and the dynamic performance of the system simultaneously. The experimental result shoes that this control compared with conventional PI control, and that plasma arc cutting power supply based on the fuzzy-neural network has excellent control performance.

Milan Kumar Das (2) et.al, were investigated the effects and parametric optimization of process parameters for plasma arc cutting (PAC) of EN31 steel using grey relation analysis. Three process parameters viz., gas pressure, arc current and torch height are considered and experiments are conducted based on L27 orthogonal array (OA). Process responses viz., material removal rate (MRR) and surface roughness parameters (centre line average roughness:Ra root mean square:Rq, skewness:Rsk) of the machined surface are measured for r=every experimental runs. For maximum MRR and minimum furface roughness characteristics process parameters are optimized based on Taguchi method coupled with grey relational analysis. Analysis of variance (ANOVA) is performed to get the contribution of each process parameters on the performance characteristics and it is observed that gas pressure is significant process parameter that affects the response. Confirmation test multo-objective optimizer in the field of PAC. Finally, using scanning electron microscopy, the surface morphology were studied.

Gurwinder Singh (3) et.al, were experimentally analyzed research and development in the precise and accurate machining technology of hard metals (Ferrous, non-ferrous and glass etc) is gaining much importance in the industry since last many years. Due to the tremendous competition and cost factor, the non-conventional machining technology is becoming the first choice of the engineers and technicians. In this era of advanced technological processes the CNC plasma arc machining is gaining tremendous ground in the industry. It is much more capable of producing best finished, high accurate machining of very complicated non-symmetrical profile in no time. The main objective and targets of this practical experiment is based to achieve the best possible setting and parameters of operation on a CNC plasma arc machine to achieving speedy work i.e. Maximum material removal rate.

Daniel Krajcarz (4) et.al, were investigated to select the best technology for cutting metal. In this article they will briefly discuss the different ways of cutting metal, such as water jet cutting, as well as laser and plasma cutting. These techniques and their comparisons are illustrated in a table to highlight the differences between them. Further comments are then provided on the key aspects of this comparative method, leading to the appropriate conclusions, which responds to the seemingly simple question: Which technology is best suited to cutting metal.

Mr.Maulik K (5) et.al, have been proved that by selecting proper process parameters we can cut any material by plasma arc machining with high MRR, lower kerf width, bevel angle and high surface finish. During last three or four years the investigation about parameters of plasma arc machining for mild steel, AISI 1017, SS304 and En 31 was already done. In this review paper the various process parameters of plasma arc cutting machine and their influence on the cutting quality of steel is to be studied. For this study the current, standoff distance, cutting speed and gas pressure are referred as process parameters. And surface roughness and material removal rate was selected as response parameters.

3. MATERIAL AND ITS PROPERTIES

3.1 Composition

Table 3.1 Composition ranges for 410 grade stainless steel

Grade	410	
	MIN	MAX
C%	-	0.15
Mn%	-	1
Si%	-	1
P%	-	0.04
S%	-	0.030
Cr%	11.5	13.5
Mo%	-	-
Ni%	-	-
N%	-	-

3.2 Mechanical Properties

Table 3.2 Mechanical properties

PROPERTIES	
Density (×1000 kg/m3)	7.7
Poisson's Ratio	0.27-0.30
Elastic Modulus (GPa)	160-200
Tensile Strength (MPa)	517
Yield Strength (MPa)	265
Elongation (%)	30

4. TAGUCHI DESIGN

4.1 DESIGN OF EXPERIMENTS (DOE)

Design of Experiments (DOE) is a powerful statistical technique introduced by R.A. fisher in England in 1920s to study the effect of multiple variables simultaneously DOE can highly effective when:

a). Optimize product and process design , study the effect of multiple factor on process.

b). Study the influence of individual factors on the performance and determine which factor has more influence, and which one has less. It can also find which factor should have higher tolerance and which tolerance should be relaxed. In industry, designed experiments can be used to systematically investigate the process or product variables that influence product quality. After you identify the process conditions and product components that influence product quality, you can direct improvement efforts to enhance a product's manufacturability, reliability, quality, and field performance. Because resources are limited, it is very important to get the most information from each experiment you perform. Well-designed experiments can produce significantly more information and often require fewer runs than haphazard or unplanned experiments. In addition, a well-designed experiment will ensure that you can evaluate the effects that you have identified as important. Designed experiments are often carried out in four phases: a) Planning, b) Screening (also called process characterization), c) Optimization, and d) Verification. Taguchi methods are most recent additions of tool kit design process for manufacturing engineers and quality assurance experts.

4.2 DESIGN OF EXPERIMENT

Table: 4.1 Process parameter and their levels

Levels	Process parameters		
	Arc Voltage volt	Cutting Speed mm/min	Pierce Delay µs
1	152	3000	0.25
2	155	3500	0.35
3	160	4000	0.50

4.3 PROCESS PARAMETER-L9ARRAY

Table: 4.2 Process parameter array

SL.NO	Arc Voltage volt	Cutting Speed mm/min	Pierce Delay µs
1	152	3500	0.25
2	152	3750	0.50
3	152	4000	0.75
4	155	3500	0.50
5	155	3750	0.75
6	155	4000	0.25
7	160	3500	0.75
8	160	3750	0.25
9	160	4000	0.50

5. GEOMETRICAL MEASURING SYSTEM THROUGH CMM

5. 1 OVER VIEW OF CMM

The typical 3 "bridge" CMM is composed of three axes, an X, Y and Z. These axes are orthogonal to each other in a typical three-dimensional coordinate system. Each axis has a scale system that indicates the location of that axis. The machine will read the input from the touch probe, as directed by the operator or programmer. The machine then uses the X, Y, Z coordinates of each of these points to determine size and position with micrometer precision typically. A coordinate measuring machine (CMM) is also a device used in manufacturing and assembly processes to test a part or assembly against the design intent. By precisely recording the X, Y, and Z coordinates of the target, points are generated which can then be analyzed via regression algorithms for the construction of features. These points are collected by using a probe that is positioned manually by an operator or automatically via Direct Computer Control (DCC). DCC CMMs can be programmed to repeatedly measure identical parts, thus a CMM is a specialized form of industrial robot.

5.2 Physical Principles:

Optical probes and/or laser probes can be used (if possible in combination), which change CMMs to measuring microscopes or multi-sensor measuring machines. Fringe projection systems, theodolite triangulation systems or laser distant and triangulation systems are not called measuring machines, but the measuring result is the same: a space point. Laser probes are used to detect the distance between the surface and the reference point on the end of the kinematic chain (i.e.: end of the Z-drive component). This can use an interferometrical function, focus variation, light deflection or a beam shadowing principle.

6. OUT PUT RESPONSE AND OPTIMIZATION

6.1CMM RESULT

Table: 6.1 various geometrical error results obtained from CMM

PROFILE	SS410 STEEL								
S.NO	1	2	3	4	5	6	7	8	9
Paralleism-1(3,1)	0.633	0.662	0.426	0.328	0.366	0.259	0.633	0.252	0.554
Paralleism-2(4,2)	0.284	0.315	0.316	0.354	0.309	0.185	0.284	0.617	0.221
Perpendicularity-1(2,1)	0.511	0.748	0.384	0.596	0.238	0.465	0.511	0.027	0.399
Perpendicularity-2(4,3)	0.713	0.456	0.400	0.353	0.240	0.308	0.713	0.011	0.761
Flatness-1	0.021	0.016	0.012	0.018	0.003	0.000	0.021	0.003	0.10
Flatness-2	0.034	0.015	0.019	0.019	0.041	0.009	0.034	0.395	0.004
Flatness-3	0.023	0.033	0.009	0.012	0.005	0.025	0.023	0.936	0.019
Flatness-4	0.009	0.011	0.001	0.021	0.007	0.013	0.009	0.004	0.014

The graph were plotted Arc voltage and parallelism

Fig: 6.1 Graph for Arc Voltage and Parallelism

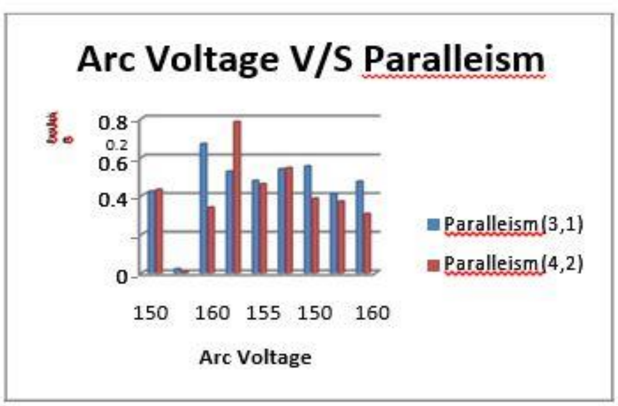
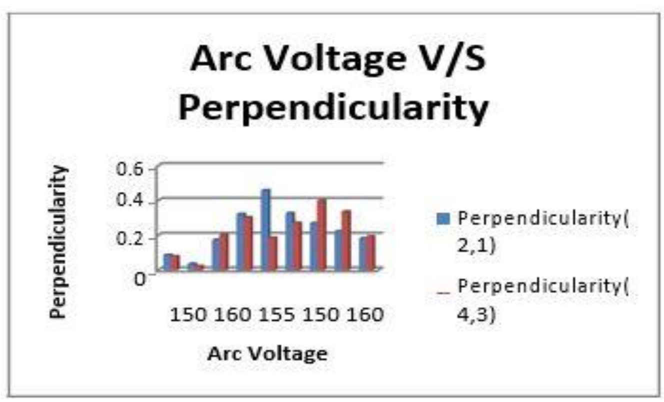


Fig: 6.2 Graph for Arc Voltage and Perpendicularity



6.2 HARDNESS OF THE CUTTING ZONE AND NOT AFFECTED AREA

Table: 6.2 Hardness values of Heat affected and Non-heat affected area

S.NO	Arc Voltage volt	Cutting Speed mm/min	Pierce Delay µs	Centre Area HRC	Haz Area HRC
1	152	3500	0.25	22	22
2	152	3750	0.50	17	17
3	152	4000	0.75	18	18
4	155	3500	0.50	20	20
5	155	3750	0.75	22	22
6	155	4000	0.25	19	19
7	160	3500	0.75	17	17
8	160	3750	0.25	19	19
9	160	4000	0.50	18	18

The cutting zone temperature and remaining area are same both area Hardness are same

6.3 EXPERIMENTAL DATA FOR SS410 STEEL

Table 6.3 Experimental data for SS410 STEEL

SL.NO	Arc Voltage volt	Cutting Speed mm/min	Pierce Delay µs	Per Pen dicular Error	Sur face Rou gh	Para lleism Error
1	152	3500	0.25	0.511	2.216	0.633
2	152	3750	0.50	0.748	1.346	0.662
3	152	4000	0.75	0.34	2.738	0.426
4	155	3500	0.50	0.596	1.519	0.328
5	155	3750	0.75	0.238	1.332	0.366
6	155	4000	0.25	0.465	1.765	0.259
7	160	3500	0.75	0.511	1.614	0.633
8	160	3750	0.25	0.027	1.916	0.252
9	160	4000	0.50	0.399	1.804	0.554

6.4ANALYSIS OF RESULT-PERPENDICULAR ERROR

Table: 6.4 SN ratio value of the perpendicular error

Arc Voltage volt	Cutting Speed mm/min	Pierce Delay µs	PPERROR	SN RATIO
152	3500	0.25	0.511	5.8316
152	3750	0.50	0.748	2.5220
152	4000	0.75	0.340	9.3704
155	3500	0.50	0.596	4.4951
155	3750	0.75	0.238	12.4685
155	4000	0.25	0.465	6.6509
160	3500	0.75	0.511	5.8316
160	3750	0.25	0.027	31.3727
160	4000	0.50	0.399	7.9805

6.4.1 PERPENDICULAR ERROR RESPONSE FOR EACH LEVEL

Table 6.5 Response Table for perpendicular error

LEVELS	Arc volt	Cutting Speed	Piece Delay
1	5.908	5.386	14.618
2	7.871	15.454	4.999
3	15.062	8.001	9.223
Delta	9.154	10.068	9.619
Rank	3	1	2

6.4.2ANALYSIS OF VARIANCE (ANOVA)

Table 6.6 Analysis of Variance (ANOVA) results for the Perpendicular Error

Source	DF	Adj SS	Adj MS	F	P	% contribution
Arc Volt	2	0.07325	0.03663	0.70	0.589	21
Feed	2	0.06377	0.03188	0.61	0.622	18
Peck Incr	2	0.10919	0.05460	1.04	0.490	31
Error	2	0.10501	0.05251			30
Total	8	0.35122				100

Model Summary

S R-sq R-sq(adj) R-sq(pred)0.229144 70.10% 0.00%0.00%

6.5 SURFACE ROUGHNESS RESPONSE FOR EACH LEVEL OF THE PROCESS PARAMETER OF SS410 STEEL-PLASMA CUTTING

Table: 5.7 SN ratio value of the surface roughness

Arc Voltage	Cutting Speed	Pierce Delay	Surface Rough	SN RATIO
152	3500	0.25	2.216	-6.91140
152	3750	0.50	1.346	-2.58090
152	4000	0.75	2.738	-8.74867
155	3500	0.50	1.519	-3.63116
155	3750	0.75	1.332	-2.49008
155	4000	0.25	1.765	-4.93489
160	3500	0.75	1.614	-4.15807
160	3750	0.25	1.916	-5.64791
160	4000	0.50	1.804	-5.12473

6.5.1 RESPONSE TABLE FOR SIGNAL TO NOISE RATIOS

Table 5.8 Response Table for surface roughness

Levels	Arc volt	Cutting Speed	Piece Delay
1	-6.080	-4.900	-5.831

2	-3.685	-3.573	-3.779
3	-4.977	-6.269	-5.132
Delta	2.395	2.696	2.052
Rank	2	1	3

6.5.2 ANALYSIS OF VARIANCE (ANOVA)

Table 5.9 Analysis of Variance (ANOVA) results for the Roughness

Source	DF	Adj SS	MS	F	P	% contribution
Arc Volt	2	0.4761	0.2380	1.35	0.425	30
Cutting Speed	2	0.4914	0.2457	1.40	0.417	31
Pierce Delay	2	0.2871	0.1435	0.82	0.550	18
Error	2	0.3515	0.1758			22
Total	8	1.6060				100

Model Summary

S R-sq R-sq(adj) R-sq(pred)0.419250 78.11% 12.44%0.00%

5.6 PARALLEISM RESPONSE FOR EACH LEVEL OF THE PROCESS PARAMETER OF SS410 STEEL-PLASMA CUTTING

Table: 5.10 SN ratio value of the parallelism Error

Arc Voltage	Cutting Speed	Pierce Delay	Para. error	SNRA1
152	3500	0.25	0.633	3.9719
152	3750	0.50	0.662	3.5828
152	4000	0.75	0.426	7.4118
155	3500	0.50	0.328	9.6825
155	3750	0.75	0.366	8.7304
155	4000	0.25	0.259	11.7340
160	3500	0.75	0.633	3.9719
160	3750	0.25	0.252	11.9720
160	4000	0.50	0.554	5.1298

5.6.1Response Table for Signal to Noise Ratios-Smaller is better

Table 5.11 Response Table for parallelism Error

Levels	Arc volt	Cutting Speed	Piece Delay
1	4.989	5.875	9.226
2	10.049	8.095	6.132
3	7.025	8.092	6.705
Delta	5.060	2.220	3.094
Rank	1	3	2

5.6.2ANALYSIS OF VARIANCE (ANOVA)

Table 5.12 Analysis of Variance (ANOVA) results for the Parallelism Error

Source	DF	SS	MS	F	P	% contribution

Arc Volt	2	0.100 62	0.050 31	1.5 1	0.39 8	46
Cuttin g Speed	2	0.025 14	0.012 57	0.3 8	0.72 6	11
Pierce Delay	2	0.028 12	0.014 06	0.4 2	0.70 3	13
Error	2	0.066 61	0.033 31			30
Total	8	0.220 50				100

Model Summary

S R-sq R-sq(adj) R-sq(pred)0.182500 69.79% 0.00%0.00%

5.7FLATNESS RESPONSE FOR EACH LEVEL OF THE PROCESS PARAMETER OF SS410 STEEL-PLASMA CUTTING

Table: 5.13 SN ratio value of the Flatness Error

Arc Voltage	Cutting Speed	Pierce Delay	**Flatness Error**	SN RATIO
152	3500	0.25	0.009	40.9151
152	3750	0.50	0.011	39.1721
152	4000	0.75	0.001	60.0000
155	3500	0.50	0.021	33.5556
155	3750	0.75	0.007	43.0980
155	4000	0.25	0.013	37.7211
160	3500	0.75	0.009	40.9151
160	3750	0.25	0.004	47.9588
160	4000	0.50	0.014	37.0774

5.7.1RESPONSE TABLE FOR FLATNESS ERROR

Table 5.14 Response Table for Flatness Error

Levels	Arc volt	Cutting Speed	Piece Delay
1	46.70	38.46	42.20
2	38.12	43.41	36.60
3	41.98	44.93	48.00
Delta	8.57	6.47	11.40
Rank	2	3	1

5.7.2 ANALYSIS OF VARIANCE (ANOVA)

Table 5.15 Analysis of Variance (ANOVA) results for the Flatness error

Source	DF	Adj SS	AdjMS	F	P	% contri bution
Arc Volt	2	0.000070	0.000035	8.54	0.105	26
Cutting Speed	2	0.000050	0.000025	6.03	0.142	18
Pierce Delay	2	0.000147	0.000073	17.86	0.053	53
Error	2	0.000008	0.000004			3
Total	8	0.000275				100

Model Summary

1. R-sq R-sq(adj) R-sq(pred)0.0020276 97.01% 88.04% 39.43%

7. RESULT&CONCLUSION

This Investigation investigates the application of the Taguchi method to the optimization of the machining parameters of CNC Plasma Arc Cutting Machine. It has been shown that Material Removal Rate can be significantly improved in the CNC Plasma Arc Cutting process using the optimum level of parameters. From experimental analysis done on SS410, it was concluded that:

1. In CNC plasma arc machining the Pierce delay is the parameter has a significant effect whereas the other parameters viz. Arc voltage and cutting speed are less effective.
2. The steam as the plasma gas will generate more energy than other gases for the same current value and the plasma jet generated is much narrowed when primary gas, Oxygen and secondary gas, air is used as plasma gases.
3. For geometrical Error rate the Arc voltage &cutting speed play a very important role. Higher the value of cutting speed create more geometrical error.

6.1OPTIMAL CONTROL FACTOR-

1. Perpendicular Error- A3 (ARC VOLT 160)B1(CUTTING SPEED -3500mm)C2(PIERCE DELAY0.50)
2. Surface Roughness-A2(ARC VOLT 155)B1(CUTTING SPEED -3500mm)C3(PIERCE DELAY0.75)
3. Paraellisim Error- A1(ARC VOLT 152)B3(CUTTING SPEEE -4000mm)C2(PIERCE DELAY0.50)
4. Flatness Error- A2ARC VOLT 155)B3(CUTTING SPEEE -4000mm)C1(PIERCE DELAY0.25)

6.2 PERCENTAGE OF CONTRIBUTION OF PROCESS PARAMETER

1. Perpendicular Error-Pierce Delay-31%
2. Surface Roughness-Cutting speed-31%
3. Paraellisim Error-Arc Voltage-42%
4. Flatness Error-Pierce Delay-53%

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