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Optimization in Wire-Cut EDM of Nimonic-75 Using Taguchi's Approach

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Abstract

Wire electrical discharge machining removes electrically conductive material by means of spark discharges resulting from local explosion of a dielectric liquid. WEDM machining is used for hard material parts that are difficult to machine by conventional machining processes. This paper presents the investigation on material removal rate and surface roughness of Nimonic-75 using WEDM process. Taguchi's design of experiments approach has been used for planning and designing of experiments. Experiments are performed by using L9 OA. The four input parameters considered were pulse on time, pulse off time, peak current, servo voltage for experimentation.

Keywords WEDM, Nimonic-75, OA

1.Introduction

Recent developments in mechanical industry have fuelled the demand for materials having high toughness, hardness and impact resistance. These materials are difficult to machine with traditional methods. WEDM is an electro thermal process in which metal is eroded from the workpiece using a series of sparks generated by a thin wire electrode in the presence of dielectric. WEDM can easily machine any conductive metal irrespective of their hardness. Wire-cut EDM process generates a large amount of heating at the machining area which results in melting and vaporization of metal from localized area. The dielectric is fed continuously to the machining area to flush away the eroded particles. Wire EDM efficiency and productivity have been improved through progress in different aspects of WEDM such as quality, accuracy, precision and operation. V et al. [2010] conducted the experiment by optimizing the WEDM parameters on machining of INCOLOY800 with various performance characteristics such as MMR, surface roughness and kerf based on the Grey-Taguchi Method. The authors considered various process parameters like a 50V Gap Voltage, 10 µs Pulse ON-time, 6 µs Pulse Off-Time and 8mm/min Wire Feed rate. Taguchi's L_9 Orthogonal Array was used to conduct experiments. The experiments were carried out on a four -axes Electronica Ecocut CNC WEDM machine. The electrode material used was.25 mm diameter brass and a small gap of .025mm to .05mm was maintained in between the wire and workpiece. The results obtained from the experiments were analysed by using the ANOVA to find the significance of each input factor on the measures of process performance, MMR, surface roughness and kerf width. The result comes out to be by using Grey Taguchi Method such as MMR showed an increase value of.05351 g/min to .05765 g/min, the surface roughness showed a decrease value of 3.31 µm and kerf width also reduced from .324 to .296 mm respectively. Kumar et al. [2012] was focuses on machinability

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of nimonic-90 with wire electrical discharge machining process. The effects of different WEDM parameters were studied in this paper. The results showed that there was considerable effect of parameters like discharge current (Ip), pulse on time (Ton), pulse off time (Toff), servo voltage (SV) and wire feed rate (WF) on Cutting speed of Nimonic-90. Goswami et al. [2012] investigates the influence of machining parameters on cutting speed and material removal rate for machining of nimonic-80A with brass wire as tool electrode using CNC wire electrical discharge machining machine. The authors concluded that cutting speed and material removal rate increases with increase in pulse on time and peak current while machining of the above mentioned workpiece. Goswami et al. [2014] studied the material removal rate and surface roughness along with surface topography of the machined surface. The authors were used the taguchi's approach and utility concept for wire electrical discharge machining of nimonic-80A alloy. In this paper it is assumed that the overall utility is the sum of utilities of individual quality characteristics. In this research, block of 25mm is used as a workpiece.L27 orthogonal array with six input variables was selected for experimentation. They found that by increasing the pulse-on time, discharge energy produced will be higher, hence increased in material removal was increased. They result came out to be from the experiment was that pulse on time was found to be the major factor effecting the MRR with 46.09% followed by pulse-off time with 32.97%, peak current 1.45%, spark gap voltage 6.68%, wire feed .84% and wire tension 44%. In this research, the best MMR was found to be .112g/min and surface roughness was .16 micron on pulse off time 54 micro seconds, pulse on time 106 micro seconds, input current:80A, spark gap set voltage :50v, wire feed:10 respectively. Sreenivasa Rao M, Venkaiah et al. N Nimonic-263 material has been machined using WEDM of Electronica (India) make. The size of the workpiece material is 120mm×110mm×18.5 mm and 10 mm diameter holes were produced on it. Process parameters considered in the present work are pulse on time, pulse off time, peak current and servo voltage. After conducting trial experiments, levels of each process parameter has been fixed as pulse-on time (Ton): 105-125 µs, pulse-off time (Toff): 50-60 µs, peak current (Ip): 10-12 A and servo voltage (Sv): 40-60 V. Material removal rate and surface roughness have been considered as performance measures and aimed to optimize these responses with RSM. B.C. Khatri et.al. the study has been made to optimize the process parameters during machining of Inconnel-600 by wire electrical discharge machining (WEDM) using response surface methodology (RSM). Four input process parameters of WEDM (namely Peak Current (IP), Pulse on time (TON), Pulse off time (TOFF) and Wire Feed rate (WF)were chosen as variables to study the process performance in terms of Material Removal Rate (MRR). In the present work, the parametric optimization method using Taguchi's robust design is proposed for wire-cut electric discharge machining of Inconel-600. This material is gained dominance, where high strength and/or hardness is required at elevated temperatures. So, experimentation has been done by using Taguchi's Mixed L18 (21x33) orthogonal array. Finally it concluded the effects of Pulse On time, Pulse Off time, Peak Current, Wire Feed rate setting are experimentally investigated in machining of Inconel-600 using CNC Wire-cut EDM process. The level of importance of the machining parameters on the material removal rate is determined by using ANOVA and it is shown that Pulse on, Pulse Off, Peak current are most significant.

2. Methodology

2.1 Design of experiment based on taguchi's method and Material

Experiments were performed on Electronica Sprintcut CNC wire electrical discharge machine, (as shown in fig. 2) to study the material removal rate and surface roughness, affected by machining process variable at different setting of Pulse on-time (Ton), Pulse off-time (Toff), servo voltage (SV) and peak current (IP).

Fig.1.1 CNC WEDM Sprintcut model

Brass wire electrode of diameter 0.25mm (900N/mm2 tensile strength) was used for performing the experiments. The experiments were conducted by L9 orthogonal array. Nimonic-75 is a nickel based alloy which is used as a workpiece material for the experiments. NIMONIC-75 is a nickel chromium alloy with good corrosion, oxidation and heat resistant, precipitation hardenable and good mechanical properties at elevated temperature. Due to its properties it is used in aerospace industry. The chemical composition of NIMONIC-75 is shown below. Signal to noise ratio was obtained using Minitab 16 software. Higher is better (HB) for MRR and lower is better (LB) for WWR were taken for obtaining optimum machining characteristics. Experiments were conducted thrice to minimize the chances of error. Material removal rate (MRR) was calculated by using the formula:

MRR=Cutting rate × Workpiece thickness × Wire diameter

And Cutting speed is calculated by taking mean of three trials. For each trial the value of cutting speed is shown on sprint cut machine display screen.

Surface Roughness is measured with the help of tester named Mitutoyo. The specimen is placed on the horizontal table and the Stylus of tester is placed on it which moves forward and backward and measures the roughness and displays on the screen of the instrument. Taking mean of all the three trials for surface roughness to get the results more accurate.

Table 2.1 Chemical Composition of NIMONIC-75

Material	Percentage
Cr	18.9-21
Fe	5.0
Ti	.2-.6
C	.2
Si	.08-.15
Mn	1.0
Cu	.5
Ni	Balance

Table 2.2 Physical properties

Density	8.37g/cm^3
Melting point	1380 ^{0}C
Co-efficient of expansion	11 um/m^{0}C
Specific heat j/kg. °C	461 J/Kg.^{0}C
Thermal conductivity W/m.^{0}C	11.7 W/m.^{0}C

3. Schematic of machining

The experiments were carried out on a four axes electronica sprintcut CNC WEDM machine. The electrode material used was a .25mm diameter brass wire. The gap of

.025mm to .05 mm is maintained in between the wire and workpiece. The high density erodes the material from both the wire and workpiece by local melting and vaporizing. The dielectric fluid is continuously flashed through the gap along the wire, to the sparking area to remove the debris produced during the erosion. A collection tank is located at the bottom to collect the used wire erosions and then is discarded. The wire once used can't be reused again, due to the variation in dimensional accuracy.

4. Parameters and design

Input process parameters such as pulse on time, pulse off time, peak current, servo voltage. Each factor is investigated at three levels to determine the optimum settings for the WEDM process. These parameters and their levels were chosen based on the review of literature, experience, significance and their relevance as per the few preliminary pilot investigations. The smallest 3-level OA L9 is chosen for this case.

Table 4.1 Degree of Freedom of various parameters

Sr.No	Parameters	Symbol	Units	No. of Level	D.O.F
1	Pulse On Time	TON	µs	3	2
2	Pulse Off Time	TOFF	µs	3	2
3	Peak Current	PC	Ampere	3	2
4	Servo voltage	SV	Volts	3	2
	Total		-	-	8

The selected orthogonal arrays must have number of experiments greater than the total degrees of freedom of the input parameters. Once the minimum number of experiments are decided the further selection of orthogonal array is based on the number of independent variables and number of factor levels for each independent variable. Now as the number degree of freedom for the selected four parameters is eight, the orthogonal array should have number of experiments greater than eight. For this case L9 orthogonal array having nine experiment trials is found most suitable.

Table No: 4.2 Input Variables with Level values

Sr. No	Input factors	LEVEL 1	LEVEL 2	LEVEL 3
1.	Pulse on Time	108	112	116
2.	Pulse off Time	35	45	55
3.	Peak Current	90	130	170
4.	Servo Voltage	25	35	45

Table shows the nine experimental runs with the assigned levels of the process parameters according to the selected L9 OA.

5. Effect of different input parameter on Surface Roughness

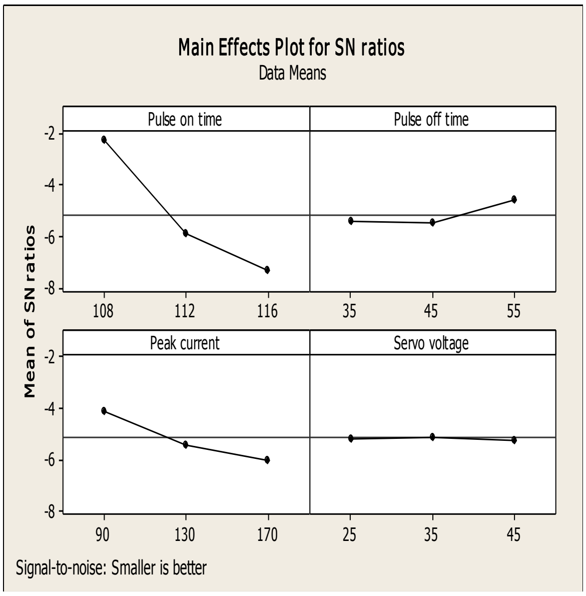

Fig 5.1

The effect of varying pulse on time on surface roughness is shown fig 5.1. It shows that the surface roughness increases with increase in value of pulse on time. It may be due to increase in pulse current produces stronger spark and higher temperatures. This causes more melting of the material and eroding the workpiece and consequent increase in surface roughness. The effect of varying pulse off time on surface roughness is shown in fig 5.1. It shows that with the increased value of pulse off time, surface roughness decreases. This may be because of higher the value of pulse off time, lesser is the number of discharges in a given time, resulting in non-uniform sparking and lesser number of particles dislodged near surface of work material. This causes more hills and valleys rather than uniform rounded surface. Similar results have been shown by Subramanyam et al. (2013) who conducted experiments for Evolution of optimal parameters for machining with Wire-Cut EDM using Grey-Taguchi method. The effect of varying peak current on surface roughness is shown in fig5.1. The value of surface roughness will increase with increase in value of peak current. The results are inline with Subramanyam et al. (2013), who conducted experiments for evolution of optimal parameters for machining with Wire-Cut EDM using Grey-Taguchi method and found that the surface roughness decreases with increase in value of peak current. The effect of varying servo voltage on surface roughness is shown in fig 5.1. It shows that with increase in value of servo voltage there is very much negligible change in the value of surface roughness. With increase in servo voltage surface roughness decreases.

5.1 Analysis of S/N Ratio For Surface Roughness

The results observed for the surface roughness are shown in table 5.2. In this table,value of surface roughness is given for each work and also calculate value of S/N ratio in last column for all the nine treatments. In this design situation, surface roughness is find out lower is better, which is a logarithmic function based on a mean square deviation and given by

$$\left(\frac{S}{N}\right)_{LB} = -10\log(MSD_{HB})$$

$$MSD_{LB} = -10log\left[\frac{1}{r}\sum_{j=1}^{r}(y_{i^2})\right]$$

Where,

MSD_{LB} = Mean square deviation for lower − the − better response

r= Number of tests in a trial

y_j = Observed value of the response characteristics

$\sum_{L=1}^{r} y_{i^2}$ = Summation of all response values under each trail

Table 5.1 Response table for signal to noise ratio "Smaller is Better"

Level	Ton	Toff	Ip	Sv
1	-2.210	-5.380	-4.073	-5.156
2	-5.908	-5.481	-5.384	-5.087
3	-7.322	-4.579	-5.984	-5.197
Delta	5.112	.903	1.911	.110
Rank	1	3	2	4

Table 5.3 Calculated S/N ratios for CR, MRR and Ra.

SR. NO.	T on	T off	I p	V	C.R.	M.R.R.	S/N Ratio	Ra	S/N Ratio
1	108	35	90	25	1.60	6	15.563	1.172	-1.378
2	108	45	130	35	1.22	4.57	13.198	1.368	-2.721
3	108	55	170	45	0.54	2.02	6.107	1.338	-2.529
4	112	35	130	45	2.33	8.73	18.820	2.096	-6.427
5	112	45	170	25	2.40	9.0	19.084	2.262	-7.089
6	112	55	90	35	.86	3.22	10.157	1.623	-4.206
7	116	35	170	35	3.12	11.70	21.363	2.610	-8.332
8	116	45	90	45	1.86	6.97	16.864	2.146	-6.632
9	116	55	130	25	1.56	5.85	15.343	2.239	7.001

Table 5.4 Pooled Analysis of Variance for Surface Roughness (Ra)

S.NO	Source	Sum of Squares	D.O.F	Mean Square	F-ratio	P	Percentage Contribution
1.	PULSE ON TIME	41.813	2	20.906	56.694	.001	85.263
2.	PULSE OFF TIME	1.467	2	_	_		2.991
3.	PEAK CURRENT	5.722	2	2.861	7.758	.042	11.668
4.	SERVO VOLTAGE	.008	2	_	_		.016
5.	POOLED ERROR	1.475	4	.36875			

	TOTAL	50.485	12				

DF- degree of freedom, SS-sum of squares, MS-mean squares, F-ratio of variance of a source to variance of error, $P \leq 0.05$ - determines significance of a factor at 95% confidence level.

6 ANALYSIS OF S/N RATIO FOR MATERIAL REMOVAL RATE:

Results observed for the material removal rate are shown in table 5.2. The table consists of material removal rate in g/min for all the treatments and also the values of S/N ratio for material removal rate for all treatments. The experimental results for material removal rate were analysed, using ANOVA calculations for S/N ratio. In case of material removal rate, higher is better option has been chosen for calculation of S/N ratio.

$$\left(\frac{S}{N}\right)_{HB} = -10\log(MSD_{HB})$$

$$MSD_{HB} = \frac{1}{r}\sum_{j=1}^{r}\left(\frac{1}{y_{j^2}}\right)$$

Where,

$\sum_{j=1}^{r}\left(\frac{1}{y_{j^2}}\right) =$ Summation of all response values under each trial.

$MSD_{HB} =$ Mean square deviation for higher-the-better response.

R = Number of tests in a trial.

$y_i =$ Observed value of the response characteristics.

Table 6.1 Response table for signal to noise ratios "Larger is Better"

Level	Ton	Toff	Ip	Sv
1	11.62	18.58	14.19	16.66
2	16.02	16.38	15.79	14.91
3	17.86	10.54	15.52	13.93
Delta	6.23	8.05	1.59	2.73
Rank	2	1	4	3

The effect of varying pulse on time on material removal rate is shown in fig 5.5. It shows that with increase in value of pulse on time, the material removal rate increases significantly. Increased material removal rate is due to the higher current, stronger spark producing greater heat and causing more material to erode from workpiece. Similar results have been shown by Shah et al. (2013) and Reddy et al. (2012) who found that material removal rate increases with increase in pulse on time. The effect of varying pulse off time on material removal rate is shown in fig. 5.5. It shows that material removal rate decreases with increase in value of pulse off time. It may be due to decrease in pulse current produces less intense spark and consequently lower temperatures, causing less material to melt and erode from the workpiece. Also decrease in the spark efficiency and causing less material to melt and erode from the workpiece. Also decrease in the spark efficiency and decreased cutting rate leads to evolution of lower heat and thereby lesser material removal rate. The effect of varying peak current on material removal rate is shown in fig 6.1. It shows that material removal rate increase with increase of peak current. This is because the discharge energy increases with the increase in peak current leading to a faster material removal rate. The results are inline with Shah et al.(2013) and Sarkar et al. (2005) who found that material removal rate increases in peak current. The effect of varying servo voltage on material removal rate is shown in fig. 6.1. It shows that the material removal rate decreases with increase in value of servo voltage. The decrease in material removal rate is due to the arcing effect that decreases number of discharges which reduces material removal rate. Muthuraman et al. (2012) conducted an experiment to investigate the influences of process variables during WEDM of O1 steel and found that the material removal rate decreases with increase in value of servo voltage

Table 6.2POOLED ANALYSIS OF VARIANCE FOR MATERIAL REMOVAL RATE

S.NO	SOURCE	SS	D.O.F	MEAN SQUARE	F-RATIO	P	%C
1.	Pulse On Time	61.583	2	30.791	7.755	.042	33.982
2.	Pulse Off Time	103.773	2	51.886	13.069	.017	57.263
3.	Peak Current	4.372	2	_			2.412
4.	Servo Voltage	11.510	2	_			6.351
	Pooled Error	15.882	4	3.9705			
	Total	181.22	12				

.6.1Effect of Different Input Parameter on Material Removal ate

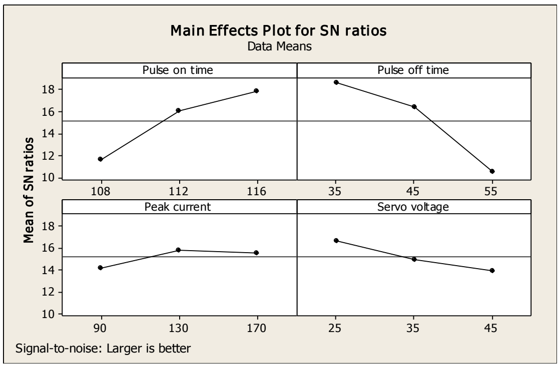

Fig 6.1

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7.1 CONCLUSION

In this thesis study, the effect of four input parameters or control parameters or process parameters of wire electrical discharge machining such as pulse on time, pulse off time, peak current and servo voltage on the output parameters are studied and also the experimental investigation is done on WEDM. The optimal set of response or output parameters which gives maximum cutting speed and material removal rate and minimum surface roughness of WEDM process is obtained. L9 orthogonal array of Taguchi's design of experiments was used in this study. The parameters that are kept fixed during the entire work of experimentations are wire feed, wire tension, flushing pressure and wire speed. The coated wire electrode is used in this set of experiments which zinc coated and having diameter of 0.25mm. The work piece on which the experiments were performed is titanium alloy grade five which is a hard alloy commonly known as hard to machine alloy. Analysis of variance was performed on raw data mean and S/N ratio data. The following conclusions have been made after performing set of experiments and made conclusions are:

- **Material Removal Rate, MMR (mm^3/min)**

  From the ANOVA tables of raw data and S/N ratio data it was concluded that the four factor such as pulse on time, pulse off time, peak current and servo voltage significantly affect the mean and variance of material removal rate and cutting speed. The optimum levels of such parameters for maximum material removal rate and cutting speed are found as:

Table 7.1 Parameters for maximum material removal rate

1	Pulse on time	µs	116
2	Pulse off time	µs	35
3	Peak current	A	130
4	Servo voltage	V	25

- **Surface Roughness, Ra (µm)**

From the ANOVA tables of raw data and S/N ratio data it was concluded that the four factors such as pulse on time, pulse off time, peak current and servo voltage significantly affect the mean and variance of surface roughness. The optimum levels for such parameters for minimum surface roughness are found as:

Table 7.2 Parameter setting for minimum surface roughness

1	Pulse on time	µs	116
2	Pulse off time	µs	35
3	Peak current	A	170
4	Servo voltage	V	45

7.2 FUTURE SCOPE

The following suggestions may useful for the future study:

- In present study the experiments are made on the basis of four input parameters such as pulse on time, pulse off time, peak current and servo voltage for the machining of NIMONIC-75 by WEDM. But it is possible to consider more input parameters like flushing pressure, wire speed and feed, wire tension and dielectric conductivity etc.

- The effects of such input parameters can be investigated on other output parameters like kerf width, surface integrity etc.
- In future the methodology used in this study can also be changed. Instead of using Taguchi's design of experiments, other methods can also be used.
- More experiments can may be conducted by widening the limits of factors like pulse on time, pulse off time, peak current, servo voltage.
- Different materials can also be investigated taking different wire electrodes and the combination of different input parameters.
- The effect of process parameter such as conductivity of dielectric, wire diameter, work piece thickness etc. may also be investigated.

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