Investigations on the Effect of Electrical Discharge Machining Process Parameters on the Machining Behavior of Nickel-Chrome Alloy

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Abstract - *EDM is the process of electrically removing material from any conductive work-piece. This is achieved by applying high frequency pulsed, AC or DC current to the work-piece through an electrode or wire, which melts and vaporizes the work-piece material position very precisely near the work-piece. The objective of this research study is optimizing process parameter on Electric Discharge machine using fresh kerosene oil as a dielectric fluid and Inconel 601 as work-piece. The effectiveness of the EDM process with Inconel 601 is evaluated in terms of material removed rate and tool removal rate. The operating parameter selecting for this work are, current, voltage, pulse-on-time and Pulse-off-time. Better Machining performance is generally obtained with copper electrode as an anode and work-piece as a cathode. A series of experiments are conducted on the F-560 X 380 EDM machine and the fresh kerosene oil is used as a dielectric fluid to study the effects of various machining parameters of EDM process.*

Keywords: EDM, Optimization, Kerosene Oil. Inconel 601, Taguchi Method.

1. INTRODUCTION

There is a growing need for the manufacturing of precision parts in the modern industries environment. The surfaces after the machining process are becoming essential to satisfy the growing demands of complex performance of the components, their durability and reliability. A conventional machining process results in work-piece distortions such as birr, flash and protrusion. The electro discharge machining process provide greatest substitute, or some time the only substitute to machine increasing strength, corrosion and wear resistance material. Thermo Electric source of energy used to improving the Non-traditional methods impressively help in succeeding economical cutting of the very low machine-able materials and challenging to manufacture Job.

Thermal processes basically includes high amount of heat for the effective machining process and it results into high amount of heat generation. Hence, in this case, the melting of the top surface of material results in to removal of material up to a certain extent. In this case three basic requirements are amplified light, high voltage and ionized material. The common examples of this type of machining process are laser beam machining, electrical discharge machining, plasma arc machining etc.

Out of these machining processes EDM is considered as important machining process for the machining of dies and press forming tools. The machining process resulted into removal of material which is basically conductive in nature. Many times even some of the soft materials can be removed without any difficulty of distortion. Because there is not any straight contact between tool and work piece interface is there. The major problem is the poor surface finish of the processed material. Further, there is continuous increase in the demands of modification of surfaces, development of heat and corrosion resistant work surfaces [1].

The concept of EDM utilizes the heat as a result of thermal processes so that ionization of the material took place by having an intermediate material in the form of a di electric substance in the form of kerosene oil so that for the completion of the machining process. The major parameters in case of EDM are temperature and applied voltage in the form of current. The effective voltage and other machining parameters are to be controlled for the proper functioning of the EDM set up. If the required results are to be maintained then the machining parameters needs to be controlled up to a certain level for the affectivity of the machining operation. Due to high temperature instantaneously rose to an extremely high value results some metal erosion from the electrode. Thermal nature of the EDM process has been discussion by several investigators. However there are certain conflicting reports regarding the nature of discharge coloun. Some believe that the discharges are multi channeled where as other maintain that it occurs in singles channels. In order to simplify the analysis, the metal removal in case study has been analyzed as due to single channel discharge only. Electro Discharge Machining (EDM) sometimes referred to as spark machining, arc machining, or even burning [2]. William et al. [3] have attributed metal erosion in EDM with effect of electric flied which arise because of the existence of peak current density around nearest areas of the spark impingement. Authors calculated the magnitude of these forces around them to be much higher than the yield point of the work material. Authors demonstrated that the work piece erosion is closely interconnected with tensile strength. The electrode mechanical theory of Author also supports by Alden [4] and Rudoff [5] authors found that there is no sign of melting of the electrode during electric discharge machining process Other while agreeing that for very short duration pulse (<2micro sec) certain material may be removed by mechanical fracture of electrode.

The theory on the development of discharge channel in electro erosion was proposed by Drabkina [6] Studied in ignition from ionization effect in the gap through high field strength between the electrodes and found that it was difficult to clearly see the difference between the spark and arc. Kruthj P et al. [7] explains that the electro discharge machine surface has comparatively excess micro hardness because of evacuation of carbon from the dielectric fluid to the work piece for combing iron carbide in the white layer on recast layer. Soni J.S. et al. [8] Show that significant volume of material transfers from tool to work-piece and vice versa. The migration of tool electrode to work-piece is more in blind holes than through hole machining if the debris of the steel is alloys with tool material and the surface hardness of the work piece increase significantly. Further Abuzeid O. A. [9] Show that white layer exerts great influence on the surface properties of the work piece. The presence of micro crack due to high tensile strength on the electrode surface caused due to high temperature gradient. Marafona J. et al. [10] the describe the optimization of EDM process using Taguchi method studying the influence of carbon which has transfer from the dielectric fluid to Cu-W electrode. Their work lead to the development of double phases of the process which give better MRR for given TWR. Author found the current intensity and pulse duration are the most critical parameters. MRR increases with the current intensity whereas with increasing pulse duration TWR decreases. Lee S.H et al [11] Studied the effect of operating parameter on machining characteristics and use graphite, copper, copper tungsten electrode and found that the MRR in decreasing order is with graphite, Cu-W Copper. Moreover MRR increase with peak current, Cu-W exhibits lowest relative wear ration at all stages of peak current. The negative tool polarity produces constant wear ration (RWR) and MRR decrease with increase in open circuit voltage. Puertas I.et al. [12] Authors focus on surface quality and dimensional precision conditions of the process as well as economical aspects. The Authors observed that intensity of current most important factor, that influence on the surface roughness. Moreover, there is solid interaction between current intensity and pulse on time factor. Further Puertas I. et al. [13] in 2004 have study the EDM of different conductive ceramics. In this author observe that surface roughness increases with increases current intensity. Further Noordin M.Y et al. [14] experimentally investigated the performance of multilayer tungsten carbide tool using RSM when Turing AISI 1045 steel. Luis C.J. et al. [15] worked on MRR and EWR on die sinking EDM. The found that the case of MRR, current and voltage are the only influential factors and with regards to EW the descending order of important are the current and pulse time. Luis C.J. et al. [16] carried out the study of influence of the factor over technology characteristics and found that the technique of experiments combine with technique of liner deterioration can be effectively apply to the molding of the function, that depends upon the several variables. George P.M. et al. [17] determine the optimal setting of parameters on EDM, during machining carbon caron composites using Taguchi techniques. It was found that TWR reduces substantially within the region when the input parameter are set on lowest values, while the input parameters are set on maximum value increases the MRR significantly. Shashikant, Apurba Kumar Roy and Kaushik Kumar. [18] The experimental analyzed EDM parameters that give finest dimensional accuracy. EDM parameter are taken as machining parameters for blind hole operation on EN 19 steel. Niraj Kumar Ohdar at al. [19] the experiment analyses that for effective MRR and TWR and authors found the most significant factor low TWR and High

Many researchers have been reported their valuable work in the electric discharge machining of different materials like SS316L nickel, *EN19* magnesium alloy, titanium super alloy, stainless steel etc using different input parameters like current, pulse-on -time, pulse-off- time voltage, spark gap, polarity of electrode, etc. The main objective of this experimental study is to find out the impact of important parameters viz. applied current (I), pulse time (T_{on}), pulse off time (T_{off}) and voltage (V) on the material removal rate, tool wear rate and dimensional accuracy during electric discharge machining of Inconel 601 work material with commercially available copper electrode and kerosene oil as a dielectric medium.

2. MATERIALS AND METHODS

In this study, commercially available Inconel 601 sheet of the size 90 mm X 50 mm X 10 mm (procured from the market) was selected as work-piece material. The chemical composition of Inconel-601 is shown in Table 1. The inconel601 exhibits and melting point This alloy exhibits high temperature corrosion and oxidation resistances, excellent resistance to various corrosive media both organic and inorganic and good mechanical properties with combination of high strength and good workability. This material is extensively used in many engineering application such as furnace muffles in oxidizing atmosphere, high temperature springs, heat exchanger tubes, chemical and food processing equipment, nuclear parts viz. feed values, combustion chambers etc.

The pure copper tool (purity of 99.8%) in form of cylindrical in shape with 12 mm diameter and 25 mm height was chosen as tool material. The Inconel 601 exhibits density of 8.11 kg/m^3 and melting point around 1320-1370^{o}C while that of copper electrode exhibits density 8.9 kg.m^3 and melting point 1083^{o}C.

Table 1: Composition of the Inconel 601

Element	C	Ni	Cr	Fe	Si	Mn	S	Cu
Maximum	0.11	63	25.1	10	0.51	1	0.014	1

The experiments are conducted on the F-560 X 380 EDM machine into the fresh commercial grade kerosene oil as a dielectric fluid. The properties of the kerosene oil are listed in table 2. This study has undertaken with an aim to find out the impacts of important parameters viz. applied current (I), voltage (V) pulse on time (T_{on}), and pulse off time (T_{off}), on the material removal rate (MRR) tool wear rate (TWR) and Overcut (OC).

Table 2: Properties of Kerosene Oil

S. No.	Property	Value
1	Physical state at 15°C at 1 atm	Liquid
2	Surface tension (N/m) at 20°C	0.028
3	Boiling point (°C)	200-260
4	Specific gravity at 15°C at 1 atm	0.8
5	Freezing Point (°C)	-45.6

Each parameter has different effect on the electric discharge machining performance. So it is necessary to identify which process parameter has considerable effect on the EDM machine output. Therefore this is the aim of investigation to identify and to achieve an optional setting for various response characteristics and the important process parameter among the various parameters using design of experiment to examine the influence of input parameters on output parameters of Inconel 601. Four parameters viz. applied current (I), pulse time (T_{on}), pulse off time (T_{off}), and applied voltage (V) required were selected to study influence of each parameter on MRR and TWR and Overcut. The input parameters and their levels are shown in table 3

Table 3: Process Parameters and Levels

S. No.	Factors (Units)	Parameter Designation	Level 1	Level 2	Level 3
1	Current (A)	A	2	5	8
2	Voltage (V)	B	50	75	100

3	T_{on} (µs)	C	60	100	140
4	T_{off} (µs)	D	30	60	90

Figure 1: Photograph of the work-piece after Machining

The response variables selected for this experimental refer to the speed of the EDM process. The effectiveness of a machining process is termed in form of material removing capacity and dimensional accuracy along with minimum tool wear. So material removal rate (MRR), tool wear rate (TWR) and Overcut (OC) were chosen as the response variables.

The MRR and TWR were evaluated in the form of volume removed per unit time. For this, the weight of the workpiece samples and copper electrodes was measured before and after each run using high precision electronic weight measuring machine and time for each run is recorded with the help of electronic stop watch. The material removal rate tool wear rate was calculated by using equation 1 equation 2 respectively.

$$MRR = \frac{W_{wb} - W_{wa}}{\rho_w * t} \quad mm^3/min \qquad (1)$$

$$TWR = \frac{W_{tb} - W_{ta}}{\rho_t * t} \quad mm^3/min \qquad (2)$$

Where W_w and W_t represent the weight of the workpiece and copper tool before and after the machining, ρ represents density and t *is* the period of each run. The dimensional accuracy in form of overcut is measured using profile projector.

To improve the efficiency the process parameters are optimized. The process parameters are further optimized by using Design of Experiments (Taguchi Method).

Table 4: Control log of experiments as per Taguchi's L_{27} orthogonal array.

Trial Number	Current (A)	Voltage (V)	Pulse on Time (µs)	Pulse off Time (µs)
1	2	50	60	30
2	2	50	100	60
3	2	50	140	90
4	2	75	60	60
5	2	75	100	90
6	2	75	140	30
7	2	100	60	90
8	2	100	100	30
9	2	100	140	60
10	5	50	60	30
11	5	50	100	60
12	5	50	140	90
13	5	75	60	60
14	5	75	100	90
15	5	75	140	30
16	5	100	60	90
17	5	100	100	30
18	5	100	140	60
19	8	50	60	30
20	8	50	100	60
21	8	50	140	90
22	8	75	60	60
23	8	75	100	90
24	8	75	140	30
25	8	100	60	90

26	8	100	100	30
27	8	100	140	60

3. RESULTS AND DISCUSSION

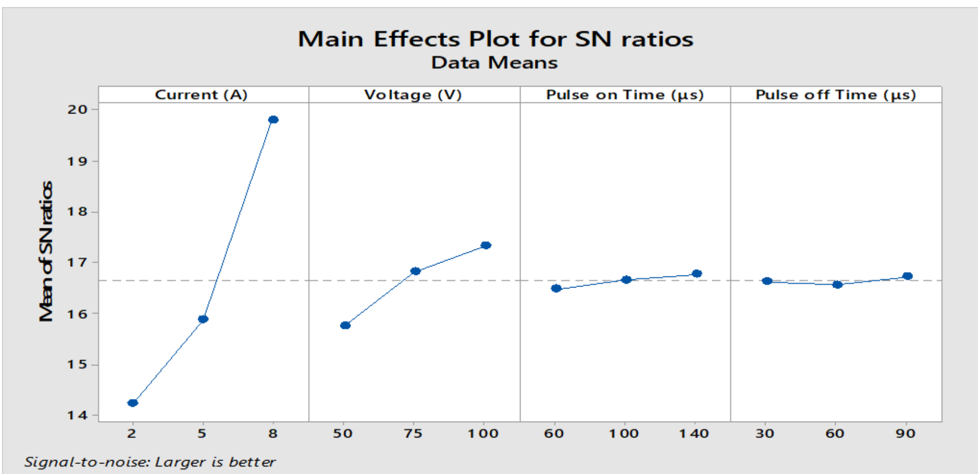
In this research, the use of the method has been adopted so as to reduce the repetition of experiments for optimization and require machining parameters are reported thus results after experimentation are studied using the S/N ratio and ANOVA analyses. And after that Based on the results of the S/N ratio and ANOVA analysis, and by controlling the machining parameters MRR, TWR and Overcut are recorded and verified. The machining time or cycle of operation was taken 1 minute for each experiment.

The main effects of process parameters on the response characteristics are plotted accordingly. The response curves for MRR, TWR and Overcut are the average S/N values versus levels of process parameters. The response curves are used as an aid to visualize the parametric effects on the selected quality characteristics. The ANOVA identifies the significant parameters and quantifies their effect on the selected of optimal levels of process parameters for individual quality characteristics.

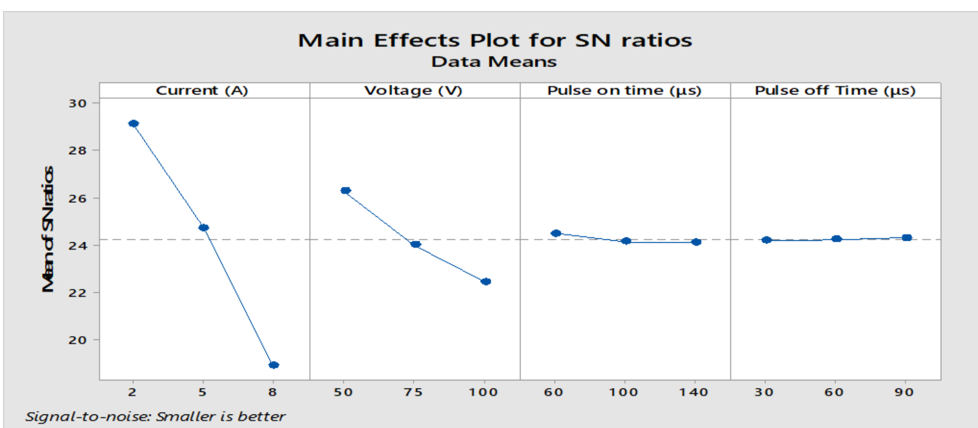
Table 5: Result of the analysis of variance of MRR, TWR and Over-cut

Material removal rate						
Source	DF	Seq SS	Adj MS	F	P	% Contribution
Current (A)	2	148.307	74.1535	1478.96	0.000	86.75
Voltage (V)	2	11.561	5.7803	115.29	0.000	6.76
Pulse on time (µs)	2	0.394	0.197	3.93	0.081	0.23
Pulse off Time (µs)	2	0.111	0.0557	1.11	0.388	0.06
Current *Voltage	4	10.02	2.5049	49.96	0.000	5.86
Current * Pulse on time	4	0.189	0.0472	0.94	0.500	0.11
Current* Pulse off Time	4	0.082	0.0205	0.41	0.797	0.05
Residual Error	6	0.301	0.0501			0.17
Total	26	170.964				
Tool wear rate						
Source	DF	Seq SS	Adj MS	F	P	% Contribution
Current (A)	2	467.253	233.626	6469.8	0.000	77.17
Voltage (V)	2	66.18	33.09	916.35	0.000	10.93
Pulse on time (µs)	2	0.769	0.384	10.64	0.011	0.13
Pulse off Time (µs)	2	0.062	0.031	0.86	0.471	0.01
Current *Voltage	4	70.72	17.68	489.61	0.000	11.68
Current * Pulse on time	4	0.153	0.038	1.06	0.450	0.03
Current* Pulse off Time	4	0.103	0.026	0.71	0.613	0.02
Residual Error	6	0.217	0.036			0.04
Total	26	605.456				
Overcut						

Source	DF	Seq SS	Adj MS	F	P	% Contribution
Current	2	277.9	138.95	213.41	0.000	40.16
Voltage	2	218.04	109.02	167.44	0.000	31.51
Pulse on Time	2	41.086	20.543	31.55	0.001	5.94
Pulse off Time	2	4.147	2.074	3.18	0.114	0.6
Current *Voltage	4	11.464	2.866	4.4	0.053	1.66
Current *Pulse on Time	4	1.303	0.326	0.5	0.738	0.19
Current *Pulse off Time	4	134.117	33.529	51.5	0.000	19.38
Residual Error	6	3.907	0.651			0.56
Total	26	691.964				



(a)



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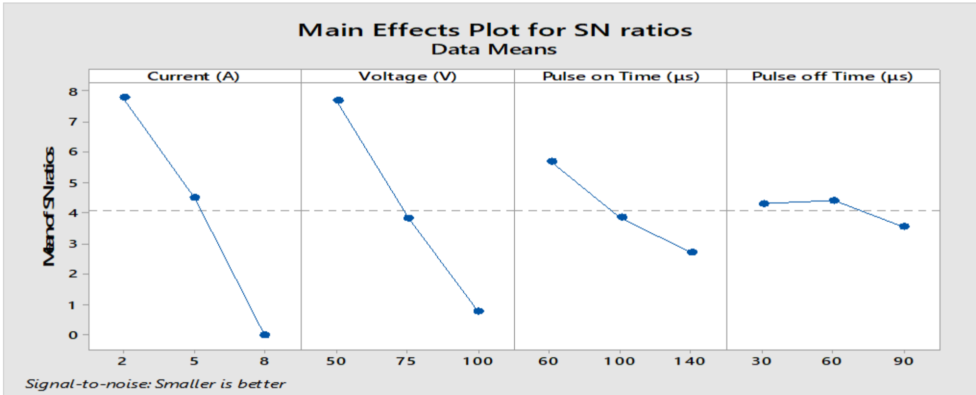
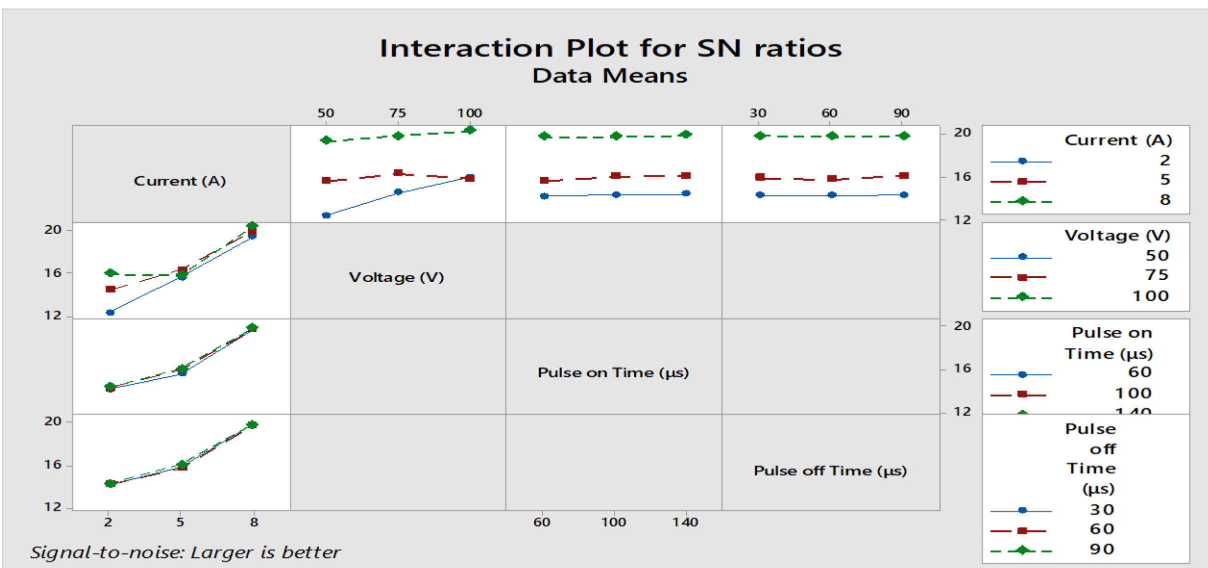


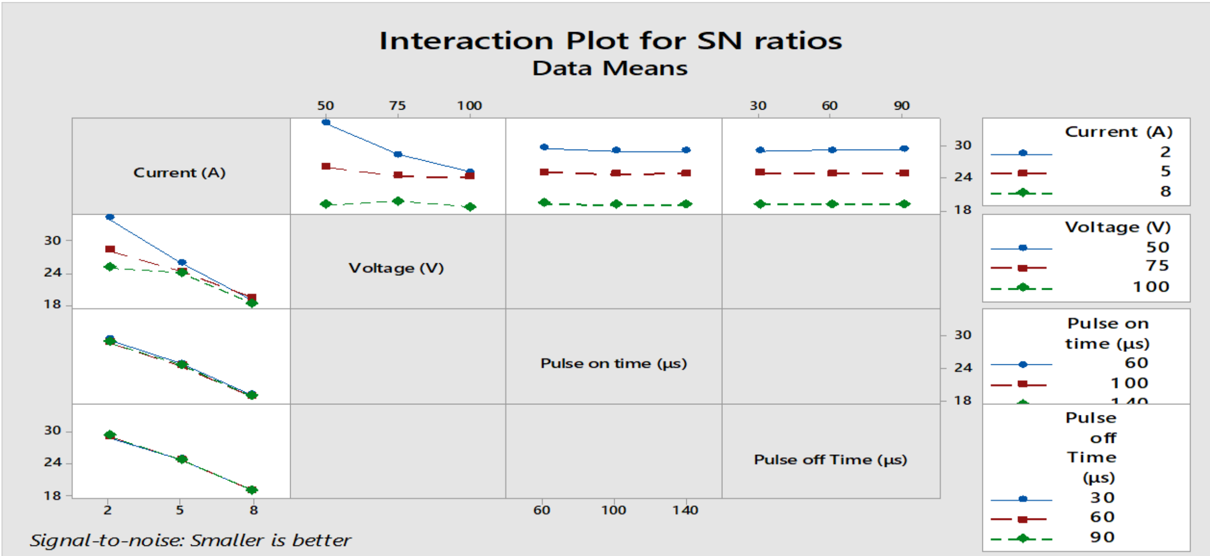
(c)

Figure 2 Main Effects plots for S/N Ratio for: a) MRR, b) TWR and c) Overcut

Fig 2 shows the influence of current, voltage, pulse on time and pulse on off Time on MRR, TWR and overcut. At high Current and Voltage the discharge intensity increases which result in high MRR, TWR and Overcut. With increase in pulse on time, spark time increases which increases MRR and TWR, when pulse-on-time decreases then the spark time decreases so that MRR and TWR also decrease. The pulse off time does not have significant effect in this experiment.



(a)



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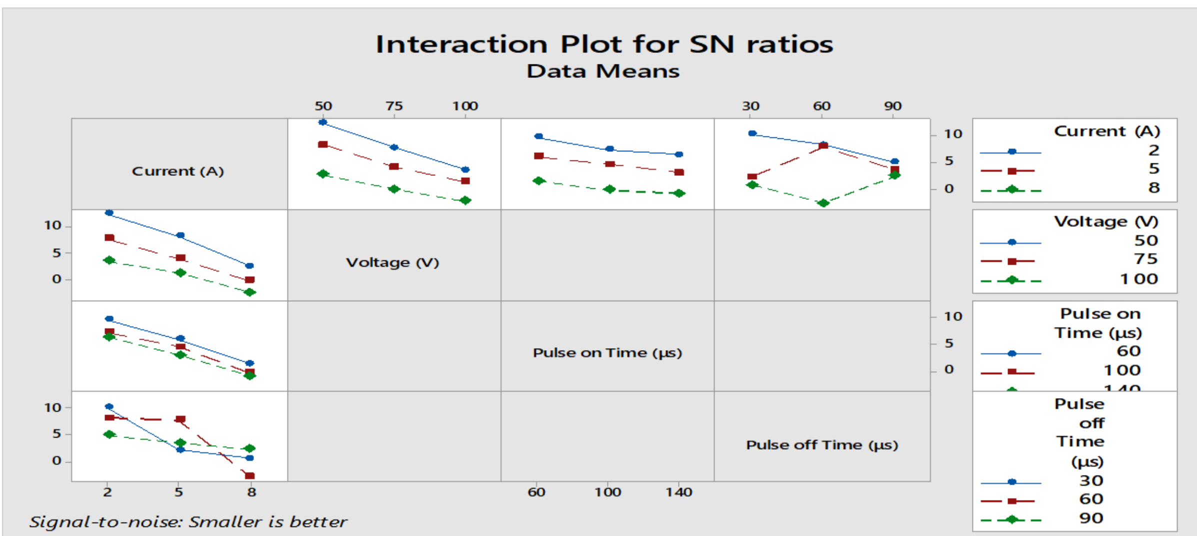

(c)

Figure 3 Interaction Plots for SN Ratios for: a) MRR, b) TWR and c) Overcut

Table 6: Response table for response parameters

Material removal rate				
Level	Current (A)	Voltage (V)	Pulse on Time (µs)	Pulse off Time (µs)
1	14.22	15.76	16.48	16.62
2	15.87	16.83	16.66	16.56
3	19.81	17.32	16.77	16.72
Delta	5.59	1.57	0.29	0.16
Rank	1	2	3	4

Tool wear rate				
1	29.08	26.26	24.48	24.19
2	24.72	24.01	24.13	24.23
3	18.93	22.45	24.12	24.31
Delta	10.16	3.81	0.36	0.12
Rank	1	2	3	4
Overcut				
1	7.8051	7.69582	5.70676	4.31287
2	4.4939	3.83108	3.85711	4.42218
3	-0.0224	0.74968	2.7127	3.54152
Delta	7.8276	6.94614	2.99406	0.88065
Rank	1	2	3	4

Table 7: Obtained results from experiment for response parameters

Material Removal Rate			
	Initial Machining Parameters	**Optimal response Parameters**	
		Prediction	**Experimented value**
Best settings	A2B2C2D2	A3B3C3D3	A3B3C3D3
MRR (mm3/min)	6.8765	11.028	10.624
S/N Ratio (dB)	16.747	20.85	20.36
Improvement of S/N ratio		3.611	
Tool Wear Rate			
Best settings	A2B2C2D2	A1B1C1D1	A1B1C1D1
TWR (mm^3/min)	0.05843	0.027	0.02
S/N ratio (dB)	24.667	31.372	34.125
Improvement of S/N ratio		9.45	
Overcut			
Best settings	A2B2C2D2	A1B1C1D1	A1B1C1D1
TWR (mm^3/min)	0.5313	0.21	0.141

S/N ratio (dB)	5.4932	13.556	17.156
Improvement of S/N ratio		11.52	

Table 7 gives the results of the MRR TWR and Overcut and good agreements between the predicted machining performance and actual machining results. Based on the obtained result MRR increase 1.73 Times also TWR and Overcut decreased by 1.65 and 1.73 times respectively

4. CONCULSIONS

In current study investigate the effect of the EDM process like peak current, applied voltage, pulse on time and pulse off time on various responses including material removal rate, tool wear rate and Overcut. Inconel 601 was chosen as work-piece material. The experiments were performed as per Taguchi's L_{27} orthogonal array. To establish the relevant significance of the individual parameter, ANOVA has been performed on S/N Ratio suggested by Taguchi. The percentage contribution of parameters affecting mean value of MRR, TWR and OC is studied. On the basis result obtained, the following conclusion can be made:

- The results demonstrate that the current, voltage, and interaction among them are significant factor to achieve maximum MRR. The current, voltage, pulse on time and interaction between current and voltage are significant factor for TWR and current, voltage, pulse on time and interaction between current and pulse off time are significant factor for overcut during EDM of Inconel 601 work Material
- The percentage contributions of current, applied voltage, Pulse on time is 86.75%, 6.76%, and 0.23%, and 0.06% respectively for MRR, 77.17%, 10.93%, 0.13%, 0.01%, respectively for TWR and 40.16%, 31.51%, 5.94%, 0.60%, respectively for overcut
- The optimal parametric conditions are discharge current 8A, voltage 100V, pulse-on-time 140µs and pulse-off-time 90µs for MRR, TWR and overcut
- Confirmation tests are conducted as per obtained set of cutting condition and it has been observed that MRR increases by 1.65 time and TWR and overcut reduces by 1.65 and 1.73 respectively from the initial to the optimal machining parameter

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