

Research Article

Effects of Process Parameters on Material Removal Rate and Surface Roughness in WEDM of H13 Tool Steel

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Abstract

The objective of the present work is to investigate the effects of the various WEDM process parameters on the machining quality and to obtain the optimal sets of process parameters so that the quality of machined parts can be optimized. In this work the effects of various process parameters of WEDM like pulse on time (TON), pulse off time (TOFF), Servo voltage (SV), peak current (IP), Wire feed (WF) and Wire tension (WT) have been investigated to reveal their impact on material removal rate of H13 Hot Work Tool Steel by using Elektra Sprintcut 734 WEDM machine. Moreover the surface roughness was measured by MarSurf PSI surface-roughness measuring instrument. The experiments were designed by Taguchi methodology. L18 Orthogonal Array was used and Results of the experimentation were analyzed by MINITAB software analytically as well as graphically.

Keywords: WEDM; H13; TON; TOFF; WT; WF; SV; IP; MRR; Ra

1. Introduction

Wire electrical discharge machining (WEDM) is a widely accepted non-traditional material removal process used to manufacture components with intricate shapes and profiles. It is considered as a unique adaptation of the conventional EDM process, which uses an electrode to initialize the sparking process. However, WEDM in fig.1 utilizes a continuously traveling wire electrode made of thin copper, brass or tungsten of diameter 0.05-0.3 mm, which is capable of achieving very small corner radii. The wire is kept in tension using a mechanical tensioning device reducing the tendency of producing inaccurate parts.

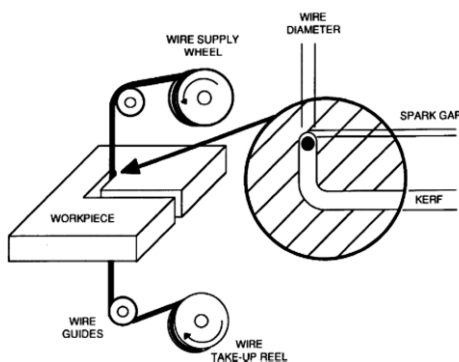


Figure 1: Wire Electric Discharge Machining

During the WEDM process, the material is eroded ahead of the wire and there is no direct contact between the work piece and the wire, eliminating the mechanical stresses during machining. In addition, the WEDM process is able to machine exotic and High strength and temperature resistive (HSTR) materials and eliminate the geometrical changes occurring in the machining of heat-treated steels.

The material removal mechanism of WEDM is very similar to the conventional EDM Process involving the erosion effect of produced by the electrical discharge (sparks). In WEDM, material is eroded from the work piece by a series of discrete sparks occurring between the work piece and the wire separated by a stream of dielectric fluid, which is continuously fed to the machining zone. The present application of WEDM process includes automotive, aerospace, mould, tool and die making industries. WEDM applications can also be found in the medical, optical, dental, jewellery industries, and in the automotive and aerospace R & D areas.

2 Literature Review

H. Singh and R. Garg et al. 2009 evaluates the effects of various process parameters of WEDM like pulse on time (TON), pulse off time (TOFF), gap voltage (SV), peak current (IP), wire feed (WF) and wire tension (WT) have been investigated to reveal their impact on material removal rate of **Hot die steel (H-11)** using one variable at a time approach. The optimal set of process parameters has also been predicted to maximize the material removal rate & finally concluded that the wire feed and wire

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ensionare neutral input parameters. The material removal rate (MRR) directly increases with increase in pulse on time (TON) and peak current (IP) while decreases with increase in pulse off time (TOFF) and servo voltage (SV).

S. B. Prajapati and N. S. Patel et .al, 2013 evaluates the effect of process parameter like Pulse ON time, Pulse OFF time, Voltage, Wire Feed and Wire Tension on MRR, SR, Kerf and Gap current is studied by conducting an experiment. Response surface methodology is used to analyze the data for optimization and performance. The **AISI A2 tool steel** is used as work piece material in the form of square bar. & finally concluded that for cutting rate and surface roughness, the pulse ON and pulse OFF time is most significant. The spark gape set voltage is significant for kerf.

Lokesh Goyat , Rajesh Dudi and Neeraj Sharma et .al, 2013 have discuss and investigate the significant process parameters along with the percentage contribution of each parameter. ANOVA is used to find the percentage contribution of significant process parameters. Response surface methodology is used for the planning of experiments and **D-2 tool steel** is used as a work-piece. D-2 tool steel used in tools, punches and die industries. The analysis of results indicates that pulse on servo voltage have the maximum effect in single parameter compared to pulse off time and peak current during the investigation of cutting rate on WEDM for D-2 tool steel.

Kuriachen Basil, Dr. Josephkunju Paul and Dr. Jeoju M.Issac et .al, 2013 evaluates the effect of voltage, dielectric pressure, pulse on-time and pulse off-time on spark gap of **Ti6AL4V alloy**.

It is found that the pulse on time , pulse off time , the interaction of dielctric pressure and pulse off time, and interaction of pulse on time and pulse off time are significant parameters which affect the spark gap of WEDM. Minimum spark gap can be obtained by adopting a low value of pulse on time (20 μ s) , a high value of dielectric pressure (15 kgf/cm²), high value of pulse off time(50 μ s) and voltage of 50V . Improper setting of pulse on time and pulse off time can lead to wire breakage which in turn lead to increase in machining time. The developed model agrees with the conformation results by less than 6%.

C.D. Shah, J.R.Mevada and B.C.Khatri et .al, 2013 the study has been made to optimize the process parameters during machining of **Inconel-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.

Atul J Patel and Prof.Satyam P Patel et .al, 2013 have investigate the effects of the various WEDM process parameters on the machining quality of **AISI 304 stainless steel** and to obtain the optimal sets of process parameters so that the quality of machined parts can be optimized. The working ranges and levels of the WEDM process parameters are found using one factor at a time approach. The Taguchi technique has been used to investigate the effects of the WEDM Three levels of each of the factors will be taken and experiments is designed by Taguchi methodology. L9 Orthogonal Array are used and experiment will be performed as designed by Taguchi method. It can be concluded that Pulse on time, Input power, pulse off time and wire tension significantly effects on surface roughness. Pulse off time is found to have effect on surface roughness. Increase in pulse off time value of surface roughness is decrease. Pulse on time, Input power, pulse off time and wire tension significantly effects on MRR. Increase in Pulse on time, value of material removal rate is increase.

Gaurav Sachdeva, Ravinder Khanna, Parveen Yadav, Amit Nara and Narender Singh et .al, 2013 Present investigation is to optimize the process parameters for single response optimization using Taguchi's L18 orthogonal array. Experiments were carried out on **H-21 die tool steel** as work piece electrode and zinc coated brass wire as a tool electrode. Response parameters are cutting speed, surface roughness and die width. The feature which makes optimization most powerful in comparison to other methods is its ability to handle multiple performance parameters in the form of constraints. The experimental results are then transformed into a signal to noise ratio(S/N) ratio. The S/N ratio can be used to measure the deviation of the performance characteristics from the desired value. The optimal level of the process parameter is the level with the highest S/N ratio. A statistical analysis of variance (ANOVA) is performed to identify the process parameters that are statistically significant.

Vijayant Maan and Abhishake Chaudhary et .al, 2013 discuss the effect of four controllable variables on the material removal rate(MRR).The work piece material is **D-2 tool steel** and the four process variables are pulse on time,pulse off time,peak current and servo voltage.These parameters are varied to study their effect on the MRR of D-2 steel. The response surface methodology (RSM) in conjunction with central composite design has been used to develop the empirical models for response characteristics. Desirability functions have been used for simultaneous optimization of performance measures.It was found that the material removal rate (MRR) directly increases with increase in pulse on time and peak current

while decreases with increase in pulse off time and servo voltage

Swati. D. Lahane, Prof.Manik.K.Rodge and Dr. Sunil.B. Sharma et .al, 2012 discuss the effect of process parameters on **High Speed Steel (HSS)** In this paper, weighted principal component (WPC) method is used to optimize the multiple responses of WEDM processes . finally it concluded that Wire electrical discharge machining (WEDM) processes require optimization of multiple performance characteristics (responses). The multiple responses of a WEDM process can be efficiently optimized using the weighted principal component (WPC) analysis method. Most importantly, there is no need for any input from the engineer(s) during analysis of the experimental data in the WPC method. The proposed WPC method reduces the uncertainty & complexity of engineers judgment associated with taguchi method. Result shows that it can offer significantly better overall quality.

Muthu Kumar , Suresh Babu , Venkatasamy and Raajenthiren et .al , 2010 work demonstrates optimization of Wire Electrical Discharge Machining process parameters of **Incoloy800 super alloy** with multiple performance characteristics such as Material Removal Rate (MRR) ,surface roughness and Kerf based on the Grey-Taguchi Method. The process parameters considered in this research work are Gap Voltage, Pulse On-time, Pulse Off-time and Wire Feed. Taguchi's L9 Orthogonal Array was used to conduct experiments. It concluded that theoptimal 'process parameters' based on Grey Relational Analysis for the Wire-Cut EDM of Incoloy 800 include a 50 V Gap Voltage, 10 μ s pulse on-time, 6 μ s pulse off-time and 8 mm/minute Wire Feed rate. While applying the Grey-Taguchi method, The Material Removal Rate shows an increased value of 0.05351 g/min to 0.05765 g/min, the Surface Roughness shows a reduced value of 3.31 μ m to 3.10 μ m and the Kerf width shows an reduced value of 0.324to 0.296 mm respectively, which are positive indicators of efficiency in the machining process. Thus, it can be concluded that the Grey-Taguchi Method, is most ideal and suitable for the parametric optimization of the Wire-Cut EDM process, when using the multiple performance characteristics such as MRR (Material Removal Rate), Surface Roughness and kerf width, for machining the Incoloy 800

3 Experimental Methodologies

Taguchi design approach

Taguchi's comprehensive system of quality engineering is one of the greatest engineering achievements of the 20th century. His methods focus on the effective application of engineering strategies rather than advanced statistical. The original response values are transformed into S/N ratio values. Further analysis is carried out based on these S/N ratio values. The material removal rate is a higher performance characteristics, since the maximization of the quality characteristic of interest is sought and can be expressed as:

$$S/N(\text{MRR}) = -10 \text{ Log } \frac{1}{R} \left[\sum_{j=1}^R \frac{1}{y_j^2} \right]$$

The surface roughness is the lower-the performance characteristic and the loss function for the same can be expressed as:

$$S/N(\text{Ra}) = -10 \text{ Log } \frac{1}{R} \left[\sum_{j=1}^R y_j^2 \right]$$

Experimental Set Up

Machine Tool

The experiments were carried out on a wire-cut EDM machine (fig 2) (ELEKTRA SPRINTCUT 734) of Electronica Machine Tools Ltd. installed at Micro Precision (A Sensible Solution) 15,MW, Industrial Area , Phase-1,chandigarh India.



Figure 2: Elektra Sprintcut 734

The electrode material used was a 0.25 mm diameter brass wire. A small gap of 0.025 mm to 0.05 mm is maintained in between the wire and work-piece. Various input parameters varied during the experimentation are pulse on time (TON), pulse off time (TOFF), servo voltage (SV), peak current (IP), wire feed (WF) and wire tension (WT). The effects of these input parameters are studied on material removal rate and Surface Roughness.

Surface Roughness

Roughness is often a good predictor of the performance of a mechanical component, since irregularities in the surface may form nucleation sites for cracks or corrosion. Roughness is a measure of the texture of a surface. It is quantified by the vertical deviations of a real surface from its ideal form. If these deviations are large, the surface is rough; if small, the surface is smooth. Roughness is typically considered to be the high frequency, short wavelength component of a measured surface. The parameter mostly used for general surface roughness is Ra. It measures average roughness by comparing all the peaks and valleys to the mean line, and then averaging them all over the entire cut-off length. Cut-off length is the length that the stylus is dragged across the surface; a longer cut-off length will give a more average value, and a shorter

cut-off length might give a less accurate result over a shorter stretch of surface.

In this work the surface roughness was measured by MarSurf PS1 (fig.3). The MarSurf PS1 is a shop-floor type surface-roughness measuring instrument, which traces the surface of various machine parts and calculates the surface roughness based on roughness standards, and displays the results in μm . The work piece is attached to the detector unit of the MarSurf PS1 which traces the minute irregularities of the work piece surface. The vertical stylus displacement during the trace is processed and digitally displayed on the liquid crystal display of the Mar Surf PS1.



Figure 3: MarSurf PS1

Work Piece Material

In this work H13 Hot Work Tool Steel is used for the experimentation. H13 Hot Work Tool Steel have high hot tensile strength, hot wear-resistance and toughness. Good thermal conductivity and insensitiveness to hot cracking. H13 type grade offers a good resistance to softening, up to 600°C, combined with good stability in hardening and high toughness, making it suitable not only for hot die applications but also plastic moulds. It have many application for making Hot punches and dies for blanking, bending, swaging and forging, hot extrusion dies for aluminium, cores, ejector pins, inserts and nozzles for aluminium, tin and lead die casting. In this work H13 tool steel plate of 123.6mm x 86.9mm x 19.74mm is used for Experimentation.

Table 1: Spectro Analysis Test Report of H13 Material

Spectro Analysis Test Report	
Carbon	0.316(%)
Manganese	0.338(%)
Phosphorus	0.0125(%)
Sulphur	0.0134(%)
Silicon	0.8025(%)
Chromium	4.956(%)
Vanadium	1.09(%)
Molydeum	1.285(%)

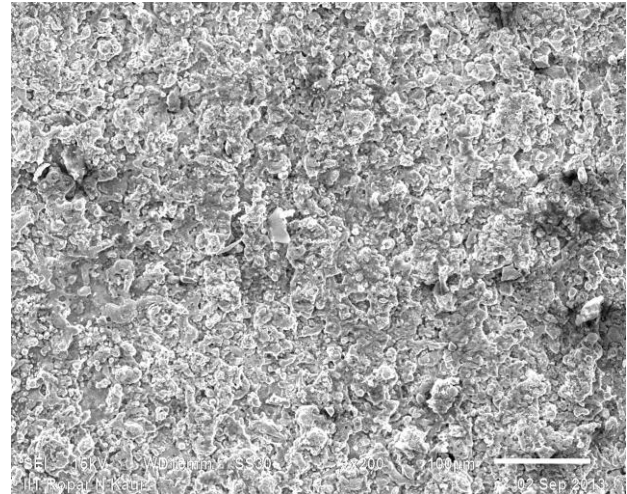


Figure 4: Micro Structure of H13 Material

Experimental Procedure

The experiments were carried out on a wire-cut EDM machine (ELEKTRA SPRINTCUT 734) of Electronica Machine Tools Ltd. installed at Micro Precision (A Sensible Solution) 15,MW, Industrial Area , Phase 1, Chandigarh India. A pure brass wire with a diameter 0.25mm was used as an electrode to erode a work piece of H13 Tool Steel (flat plate). The gap between work piece and the wire was flooded with a moving dielectric fluid (distilled water). Machining Experiments for determining the performance of WEDM machining for enhancing the MRR were carried out by using distilled water as a dielectric fluid. The process parameters are shown in table 4.2.

4. Data Analysis

4.1 Analysis of Material Removal Rate Values For H13 Tool Steel

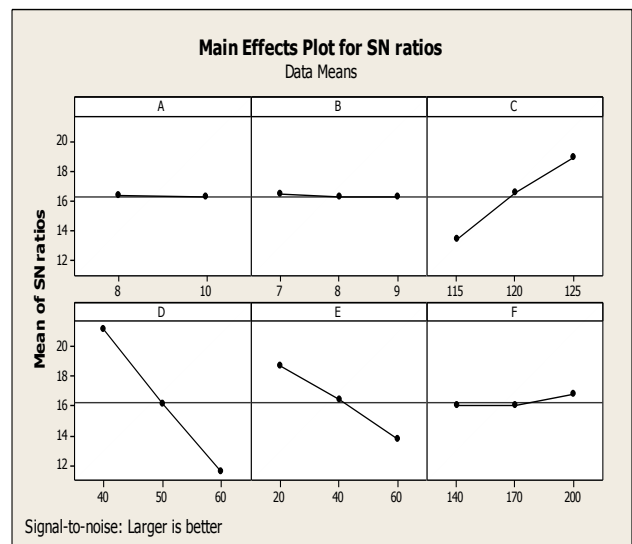


Figure 5: Effects of Process Parameters on MRR for H13 Tool Steel (S/N Data)

Table 2: Process Parameters and their Ranges

Process Parameters	Symbols	Process Designation	Level 1	Level 2	Level 3
Wire Tension	WT	A	8	10	-
Wire Feed	WF	B	7	8	9
Pulse-on Time	T on	C	115	120	125
Pulse-off Time	T off	D	40	50	60
Servo voltage	SV	E	20	40	60
Peak current	IP	F	140	170	200

Table 3: S/N data of the MRR & Ra for the Material H13

Material - H13												
Experiment	WT	WF	T on	T on	T off	SV	IP					
	A	B	C	C	D	E	F	MRR	S/N ratio	Ra(μm)	S/N ratio	
1	8	7	115	115	40	20	140	10.85	20.71	1.661	-4.407	
2	8	7	120	120	50	40	170	6.504	16.26	2.918	-9.301	
3	8	7	125	125	60	60	200	4.195	12.45	1.864	-5.407	
4	8	8	115	115	40	40	170	8.162	18.24	4.058	-12.166	
5	8	8	120	120	50	60	200	5.31	14.5	2.475	-7.872	
6	8	8	125	125	60	20	140	6.534	16.3	2.748	-8.779	
7	8	9	115	115	50	20	200	6.504	16.26	4.173	-12.409	
8	8	9	120	120	60	40	140	3.731	11.44	1.844	-5.317	
9	8	9	125	125	40	60	170	11.08	20.89	3.936	-11.902	
10	10	7	115	115	60	60	170	1.984	5.95	1.611	-4.144	
11	10	7	120	120	40	20	200	15.94	24.05	3.526	-10.945	
12	10	7	125	125	50	40	140	8.745	18.84	1.638	-4.285	
13	10	8	115	115	50	60	140	3.208	10.12	1.528	-3.681	
14	10	8	120	120	60	20	170	5.044	14.06	3.061	-9.717	
15	10	8	125	125	40	40	200	16.27	24.23	3.729	-11.431	
16	10	9	115	115	60	40	200	2.872	9.164	1.911	-5.624	
17	10	9	120	120	40	60	140	8.498	18.59	2.835	-9.05	
18	10	9	125	125	50	20	170	10.81	20.68	4.979	-13.942	

The Fig 5 concluded that Parameters (A) Wire Tension,(B) Wire Feed & (F) not highly contribute in MRR whereas by increasing the value of parameter (C) Pulse ON Time the MRR also increases & by increasing the value of parameter Pulse Off Time & Servo Voltage the MRR decreases.

4. 2 Analysis of Surface Roughness Values for H13 Tool Steel

The Fig. 6 concluded that by increasing the parameters (A) wire Tension ,(D) Pulse off time & (E) Servo voltage the value of Ra also increases whereas by increasing the Value of Parameters (B) Wire Feed,(C) Pulse ON Time the value of Ra decreases & for parameter (F) Peak current the value of Ra first decreases and then there is some increase in the value

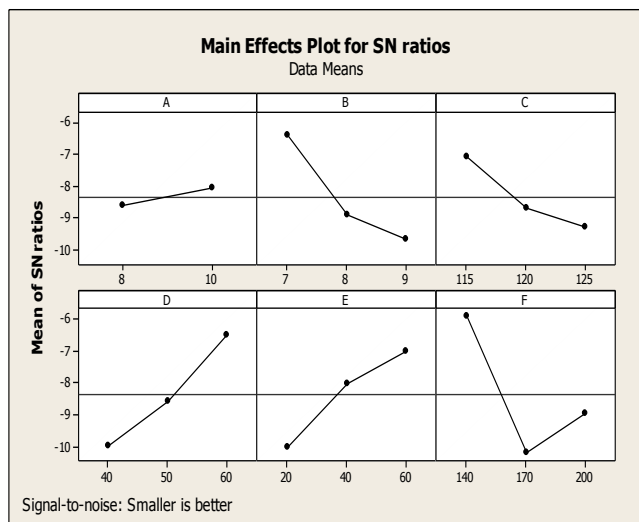


Figure 6: Effects of Process Parameters on Surface Roughness for H13 Tool Steel (S/N Data)

Conclusions

The following conclusions are drawn from the experimental study:

Conclusion for MRR

1. The parameter wire tension has small effect on the material removal rate.
2. Wire feed has minimum effect on the material removal rate
3. When pulse on time is increased the material removal rate also increased.
4. The material removal rate increased when the peak current is increased.
5. When the pulse off time in increased the material removal rate decreased.
6. When servo voltage is increased material removal rate decreased.

Conclusion for Surface Roughness

1. When wire tension is increased, the surface roughness decreased.
2. The surface roughness is increased when wire feed increases.
3. When parameter pulse on time increased the value of surface roughness increased.
4. When the pulse off time increased the value of surface roughness decreased.
5. By increasing servo voltage the value of surface roughness decreased.
6. When Peak current is increased, the surface roughness increases.

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