

Effects of Process Parameters on Material Removal Rate and Surface Roughness in WEDM of P20 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 P20 Tool Steel by using Elektra Sprintcut 734 WEDM machine. Moreover the surface roughness was measured by MarSurf PS1 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;P20; 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.

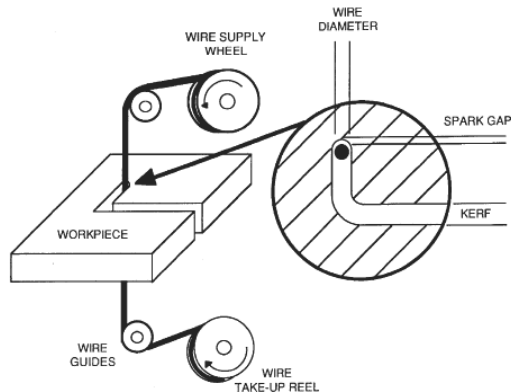


Figure 1: Wire Electric Discharge Machining

The wire is kept in tension using a mechanical tensioning device reducing the tendency of producing inaccurate

parts. 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 [1] 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 tension are 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 [2] 2013 evaluate 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 gap set voltage is significant for kerf.

Lokesh Goyat, Rajesh Dudi and Neeraj Sharma et al [3] 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 [4] 2013 evaluate 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 dielectric 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 [5] 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 [6] 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 [7] 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 [8] 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.

Miss.Swati.D.Lahane , Prof.Manik.K.Rodge and Dr. Sunil.B. Sharma et .al [9] 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 [10] 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 the optimal '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 0.324 to 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

3.1 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:

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

4 Experimental Set Up

4.1 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.

4.2 Surface Roughness

Roughness is often a good predictor of the performance of a mechanical component, since irregularities in the

Table 4.1: Spectro Analysis Test Report of P20 Material

| SPECTRO ANALYSIS TEST REPORT | |
|------------------------------|--------|
| Carbon(%) | 0.336 |
| Manganese(%) | 0.664 |
| Phosphorus(%) | 0.0179 |
| Sulphur(%) | 0.0262 |
| Silicon(%) | 0.2531 |
| Copper(%) | 0.083 |
| Nickel(%) | 0.382 |
| Chromium(%) | 1.956 |
| Vanadium(%) | 0.0622 |
| Molydeum(%) | 0.3914 |

Table 4.2: 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 4.3: S/N data of the MRR & Ra for the Material P20

| MATERIAL - P20 | | | | | | | | | | | |
|----------------|----|----|------|------|-------|----|-----|-------|-----------|--------|-----------|
| 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 | 8.505 | 18.59 | 2.599 | -8.297 |
| 2 | 8 | 7 | 120 | 120 | 50 | 40 | 170 | 6.484 | 16.24 | 2.773 | -8.858 |
| 3 | 8 | 7 | 125 | 125 | 60 | 60 | 200 | 3.984 | 12.01 | 2.754 | -8.799 |
| 4 | 8 | 8 | 115 | 115 | 40 | 40 | 170 | 7.978 | 18.04 | 3.432 | -10.71 |
| 5 | 8 | 8 | 120 | 120 | 50 | 60 | 200 | 5 | 13.98 | 2.762 | -8.826 |
| 6 | 8 | 8 | 125 | 125 | 60 | 20 | 140 | 6.552 | 16.33 | 3.275 | -10.303 |
| 7 | 8 | 9 | 115 | 115 | 50 | 20 | 200 | 6.416 | 16.15 | 3.396 | -10.62 |
| 8 | 8 | 9 | 120 | 120 | 60 | 40 | 140 | 3.73 | 11.44 | 3.59 | -11.101 |
| 9 | 8 | 9 | 125 | 125 | 40 | 60 | 170 | 11.09 | 20.9 | 3.291 | -10.346 |
| 10 | 10 | 7 | 115 | 115 | 60 | 60 | 170 | 2.06 | 6.279 | 0.846 | 1.453 |
| 11 | 10 | 7 | 120 | 120 | 40 | 20 | 200 | 12.45 | 21.9 | 4.06 | -12.17 |
| 12 | 10 | 7 | 125 | 125 | 50 | 40 | 140 | 8.867 | 18.96 | 3.371 | -10.554 |
| 13 | 10 | 8 | 115 | 115 | 50 | 60 | 140 | 3.262 | 10.27 | 1.778 | -4.999 |
| 14 | 10 | 8 | 120 | 120 | 60 | 20 | 170 | 5.146 | 14.23 | 3.013 | -9.581 |
| 15 | 10 | 8 | 125 | 125 | 40 | 40 | 200 | 17.22 | 24.72 | 3.595 | -11.114 |
| 16 | 10 | 9 | 115 | 115 | 60 | 40 | 200 | 2.9 | 9.249 | 2.001 | -6.026 |
| 17 | 10 | 9 | 120 | 120 | 40 | 60 | 140 | 8.037 | 18.1 | 1.452 | -3.239 |
| 18 | 10 | 9 | 125 | 125 | 50 | 20 | 170 | 10.67 | 20.57 | 3.823 | -11.649 |

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

4.3 Work Piece Material

In this work P20 Tool Steel is used for the experimentation. P20 Tool Steel used in tooling applications in the plastic mould industry, these steels are also suited for use in applications where a high tensile strength is the prime requirement. These steels are supplied in the hardened and tempered condition with a tensile strength of 950-1100MPa. The presence of chromium and nickel enhances the toughness and hardness of P20 steels. These steels are capable of being machined into complex and large dies and molds. P20 tool steels are used for low temperature applications that include injection molds and die casting dies. And also used in high tensile applications such as heavy duty shafts, gears, axles, etc. In this work the P20 tool steel of plate size of 134.5mm x 88.5mm x 19.56mm is used for experimentation.

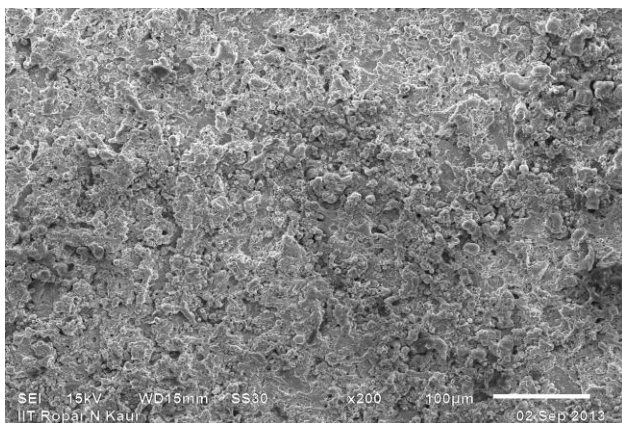


Figure 4: Micro Structure of P20 Material

4.4 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 P20 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 and their Ranges are shown in table 4.2.

5 Data Analysis

5.1 Analysis of Material Removal Rate Values For P20 Tool Steel

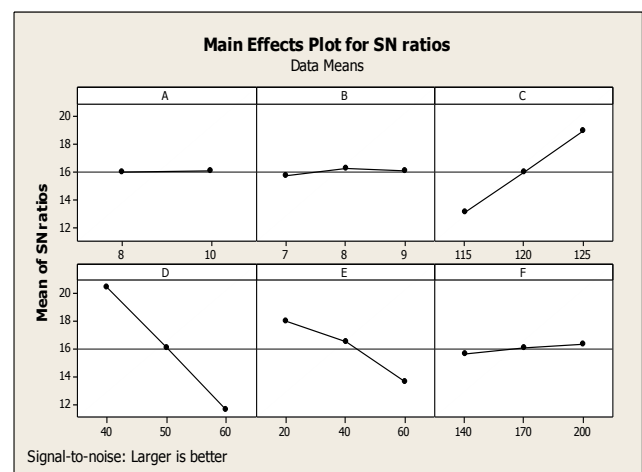


Figure 5: Effects of Process Parameters on MRR for P20 Tool Steel (S/N Data)

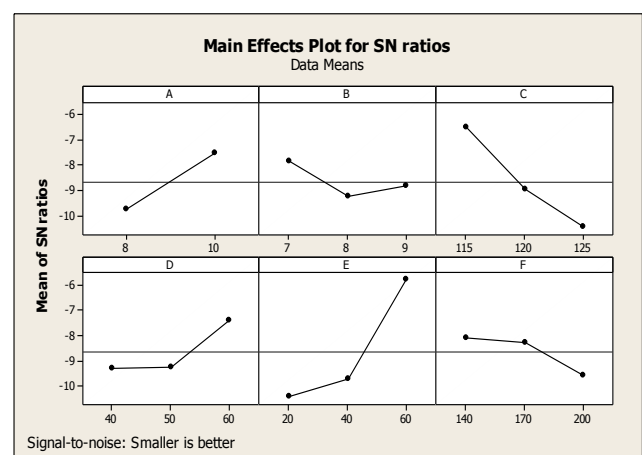


Figure 6: Effects of Process Parameters on Surface Roughness for P20 Tool Steel (S/N Data)

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) Pluse ON Time the MRR also increases & by increasing the value of parameter Pluse Off Time & Servo Voltage the MRR decreases.

5.2 Analysis of Surface Roughness Values for P20 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 (C) Pulse ON Time & (F) Peak current the value of Ra decreases.

6 Conclusions

The following conclusions are drawn from the experimental study:

6.1 Conclusion for MRR

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

6.2 Conclusion for Surface Roughness

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

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