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Research Article

Optimization of Process Parameter of WEDM on C-45 Steel

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Abstract

Wire-cut Electrical Discharge Machining (WEDM) is extensively used in machining of conductive materials producing intricate shapes with high accuracy. This study exhibits that WEDM process parameters can be altered to achieve betterment of Material removal rate (MRR), Surface Roughness (SR). The main goals of WEDM manufacturers and users are to achieve a better stability and higher productivity of the WEDM process, i.e., higher machining rate with desired accuracy and minimum surface damage. However, due to a large number of variables and the stochastic nature of the process, even a highly skilled operator working with a state-of-the-art WEDM is unable to achieve the optimal performance and avoid wire rupture and surface damage as the machining progresses.

Keywords: *Ton, Toff, IP, MRR, SR, C-45 steel and orthogonal array, WEDM.*

Introduction

Electrical Discharge Machining, EDM is one of the most accurate manufacturing processes available for creating complex or simple shapes and geometries within parts and assemblies.EDM works by eroding material in the path of electrical discharges that form an arc between an electrode tool and the work piece. EDM manufacturing is quite affordable and a very desirable manufacturing process when low counts or high accuracy is required. Turnaround time can be fast and depends on manufacturer back log. The EDM system consists of a shaped tool or wire electrode, and the part. The part is connected to a power supply. Sometimes to create a potential difference between the workpiece and tool, the work piece is immersed in a dielectric (electrically non conducting) fluid which is circulated to flush away debris. The cutting pattern is usually CNC controlled. Many EDM machine electrodes can rotate about two-three axis allowing for cutting of internal cavities. This makes EDM a highly capable manufacturing process.

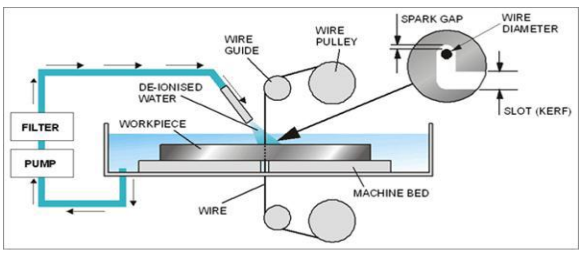

Fig. 1.1 Schematic Diagram of WEDM System [Amar pattnaik *et al*, 2006]

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Electrical discharge wire cutting, more commonly known as wire electrical discharge machining (WEDM), is a spark erosion process used to produce complex two- and three-dimensional shapes through electrically conductive workpieces by using wire electrode. The sparks will be generated between the workpiece and a wire electrode flushed with or immersed in a dielectric fluid. The degree of accuracy of workpiece dimensions obtainable and the fine surface finishes make WEDM particularly valuable for applications involving manufacture of stamping dies, extrusion dies and prototype parts. Without WEDM the fabrication of precision workpieces requires many hours of manual grinding and polishing. Wire electrical discharge machining (WEDM) has been improved significantly to meet the requirements in various manufacturing fields, especially in the precision die industry. WEDM is a thermo electrical process in which material is eroded from the workpiece by a series of discrete sparks between the workpiece and the wire electrode (tool) separated by a thin film of dielectric fluid (deionized water) that is continuously fed to the machining zone to flush away the eroded particles. The movement of wire is controlled numerically to achieve the desired three-dimensional shape and accuracy of the workpiece.

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high accuracy is required. Turnaround time can be fast and depends on manufacturer back log. The EDM system consists of a shaped tool or wire electrode, and the part. The part is connected to a power supply. Sometimes to create a potential difference between the workpiece and tool, the work piece is immersed in a dielectric (electrically non conducting) fluid which is circulated to flush away debris. The cutting pattern is usually CNC controlled. Many EDM machine electrodes can rotate about two-three axis allowing for cutting of internal cavities. This makes EDM a highly capable manufacturing process. [Ahmet Hascalık *et al*, 2007]

The WEDM process consists of three operations, a roughing operation, a finishing operation, and a surface finishing operation. The performance of various types of cutting operations is judged by different measures. In rough cutting operation both metal removal rate and surface finish are of primary importance. In finish cutting operation, the surface finish is of primary importance. Dimensional accuracy is highly dependent on cutting width. This means that the rough cutting operation is more challenging because three goals must be satisfied simultaneously. Hence, the rough cutting phase is investigated in the present approach considering three performance goals like MRR, SF.

Literature Review

R.Nagaraja *et al*, (2015) presents an investigation on the optimization of machining parameters in WEDM of bronze-alumina MMC. The main objective is to find the optimum cutting parameters to achieve a low value of Surface roughness and high value of material removal rate (MRR). The cutting parameters considered in this experimental study are, pulse on time (Ton), pulse off time (Toff) and wire feed rate. The settings of cutting parameters were determined by using Taguchi experimental design method. An L9 orthogonal array was chosen. Signal to Noise ratio (S/N) and analysis of variance (ANOVA) was used to analyze the effect of the parameters on surface roughness and to identify the optimum cutting parameters. The contribution of each cutting parameters towards the surface roughness and MRR is also identified. The study shows that the Taguchi method is suitable to solve the stated problem with minimum number of trails as compared with a full factorial design.

R.Pandithurai, *et al*, (2014) lustrates that WEDM involves complex physical and chemical process including heating and cooling. The electrical discharge energy affected by the spark plasma intensity and the discharging time will determine the crater size, which in turn will influence the machining efficiency and surface quality. This paper presents an effective approach to optimize process parameters for Wire electro discharge machining (WEDM).WEDM is extensively used in tool and die industries. Precision and intricate machining are the strengths. While machining time and surface quality still remains as major challenges. The main objective of this study is to obtain higher material removal rate (MRR) and lower surface roughness (SR). Ton, T off, Gap voltage and wire feed rate are the four control factors taken each at various levels. The genetic algorithm optimization tool is used to find the factors level that create a low surface roughness in WEDM.

P. Abinesh *et al*, (2014) Kumar study exhibits that WEDM process parameters can be altered to achieve betterment of Material removal rate (MRR), Surface Roughness (SR) and Electrode Wear. The objective of our project is to investigate and optimize the potential process parameters influencing the MRR, SR and Electrode Wear while machining of Titanium alloys using WEDM process. This work involves study of the relation between the various input process parameters like Pulse-on time (Ton), Pulseoff time (Toff), Pulse Peak Current(IP), Wire material and Work piece material and process variables. Based on the chosen input parameters and performance measures L-16 orthogonal array is selected to optimize the best suited values for machining for Titanium alloys by WEDM.

J. T. Huang *et al*, (2013) experimented optimization of machining parameters of Wire-EDM based on Grey relational and statistical analyses it is concluded that table feedrate and Ton have the main influence in MRR, and Ton has a significant influence on G and Ra.

Navjot Singh, *et al* (2013) studied for material removal rate by using two different wires as electrodes in a WEDM machine. The effects of input parameters were evaluated using ANOVA for S/N ratios. In addition, main effects plots for S/N ratios has been developed and analyzed.

Harshad kumar *et al* (2012) found Process parameters affect different response in different ways MRR increase by increasing Pulse on Time, flushing pressure and reduces with increasing Pulse OFF Time. Increasing Pulse ON Time also increase Surface Roughness. Material Thickness has little effect on MRR but it has significant effect over surface finish. Increasing Thickness reduces Surface Roughness and increase surface finish. Little interaction effect found for Surface Roughness between wire tension and flushing pressure.

S.R.Nithin *et al*, (2012) found five optimal control parameters input voltage, current, speed, pulseon/off time to maximize metal removal rate (MRR) and minimize surface roughness (SR) on wire edm (electrical discharge machining). For the purpose to get a best solution to maximize MRR and reduce SR, he optimize parameters using taguchi method. Also hecompares experimental reading with taguchi optimum result to know the optimal solution.

Amoljit Singh Gill (2012) conducted on deep cryogenic treated OHNS die steel by WEDM Cryogenic treatment of the workpiece significantly improves the surface finish of machined surface. Analysis of various process parameters.

Bijendra Diwakar (2012) researched the work, through the Taguchi methodology found the optimum process parameters for CNC wire electric discharge machining (WEDM). The research is to optimize the MRR and Surface Roughness of work piece high chromium high carbon (HCHC) die steel tool. This methodology based on Taguchi's, analysis of variance (ANOVA) and signal to noise ratio (S/N Ratio) to optimize the CNC WEDM process parameter. The design of experiment for machining process control parameter are Voltage(A), Discharge current(B), Pulse duration(C), Pulse frequency(D) and Wire Tension(E) L27 (3*5) standard orthogonal array design of experiment three level and five parameter A,B,C,D and E respectively for each combination we have conducted one experiment.

Jatinder Kapoor (2011) studied the results of the effect of Cryogenic treated brass wire electrode on the surface of an EN-31 steel machined by WEDM. Full factorial experimental design strategy is used in the experimentation. Three process parameters, namely type of wire electrode (untreated and cryogenic treated brass wire electrodes), Pulse width, and wire tension have been considered. The process performance is measured in terms of surface roughness (SR). Type of wire, pulse width and wire tension significantly affect the SR in WEDM ANOVA results indicated that all the process parameters have significant effect on SR.

Controlled parameters	Levels				Observed Values
	L_1	L_2	L_3	L_4	
Wire Speed	10	20	30	40	1. Material Removal Rate (mm^3/min) 2. Surface Roughness (R_a)
Flushing Pressure	120	140	160	180	
Gap Voltage	70	80	90	100	
Current	40	60	80	100	

Experimentation

The ELPULS 12 Wire EDM (WEDM) was used to carry out the experiments. The WEDM experiments were conducted in ELPULS 12 machine using 0.25 mm brass wire as the tool electrode.

Fig. 2 Pictorial View of WEDM

C-45 Material

C45 steel is one mainly of medium carbon steel. C45 is for general engineering purposes. C45 is a medium carbon steel is used when greater strength and hardness is desired than in the as rolled condition. Extreme size accuracy, straightness and concentricity combine to minimize wear in high speed applications. Turned ground and polished.

Fig 3: - C-45 Steel

Input Parameters

As per the Taguchi quality design concept L16 orthogonal array table.

1. Three control factors were chosen each at 4 levels
a) Wire Speed
b) Flushing Pressure
c) Gap Voltage
d) Current
2. Two response parameters will measure:-
a) MRR(mm3/min) (Metal removal rate)
b) Surface Roughness (Ra)

Process Parameters and Design

The experimental layout for the machining parameters using the L9 orthogonal array was used in this study. This array consists of four control parameters and four level, as shown in table 3.3 In the Taguchi method, most all of the observed values are calculated based on 'the Larger the better'. Thus in this study the observed values of MRR.

Table 1 Control Factors and their Levels

Controlled parameters	Levels				Observed Values
	L_1	L_2	L_3	L_4	
Wire Speed	10	20	30	40	1. Material Removal Rate (mm^3/min) 2. Surface Roughness (R_a)
Flushing Pressure	120	140	160	180	
Gap Voltage	70	80	90	100	
Current	40	60	80	100	

Conduct of Experiment

Selecting the input parameters and performance measures has to be determined before performing the experiments. In this work, the behaviors of three control factors were studied. These parameters with their levels are listed in Table 2.

Table 2 Taguchi L16 Orthogonal Array

Experiment No.	Wire Speed	Flushing Pressure	Gap Voltage	Current
1	10	120	70	40
2	10	140	80	60
3	10	160	90	80
4	10	180	100	100
5	20	120	70	40
6	20	140	80	60
7	20	160	90	80
8	20	180	100	100
9	30	120	70	40
10	30	140	80	60
11	30	160	90	80
12	30	180	100	100
13	40	120	70	40
14	40	140	80	60
15	40	160	90	80
16	40	180	100	100

Table 3 The L9 Orthogonal Array with Performance

Experiment No.	Wire Speed	Flushing Pressure	Gap Voltage	Current	MRR	S/N Ratio	R_a	S/N Ratio
1	10	120	70	40	6.002	15.5659	5.321	-14.5199
2	10	140	80	60	8.95	19.0365	4.112	-12.2811
3	10	160	90	80	8.05	18.1159	5.8	-15.2686
4	10	180	100	100	8.22	18.2974	4.46	-12.9867
5	20	120	70	40	8.746	18.8362	6.02	-15.5919
6	20	140	80	60	7.49	17.4896	3.03	-9.6289
7	20	160	90	80	7.96	18.0183	4.395	-12.8592
8	20	180	100	100	8.492	18.5802	4.1	-12.2557
9	30	120	70	40	7.04	16.9515	6.678	-16.4929
10	30	140	80	60	8.99	19.0752	5.445	-14.72
11	30	160	90	80	8.47	18.5577	5.408	-14.6607
12	30	180	100	100	7.97	18.0292	5.945	-15.483
13	40	120	70	40	7.81	17.853	4.95	-13.8921
14	40	140	80	60	6.561	16.3394	4.58	-13.2173
15	40	160	90	80	7.99	18.0509	5.1	-14.1514
16	40	180	100	100	7.14	17.074	5.2	-14.3201

Analysis of Machining Variables

The present analysis includes Taguchi's method based on parametric optimization technique to quantitatively determine the effects of various machining parameters on the quality characteristics of EDM process and to find the optimum parametric condition for obtaining optimum machining criteria. In this analysis, the performed parametric design of experiment is based on the selection of an appropriate standard orthogonal array. The analysis of signal-to-noise (S/N) ratio and ANOVA were carried out to study the relative influence of the machining parameters on the MRR of the Wire cut EDM machined material.

The tables 3.8 include ranks based on delta statistics, which compares the relative magnitude of effects. The delta statistic is the highest average minus the lowest average for each factor. Minitab assigns ranks based on delta values in descending order; the highest delta value has rank. 1 and rank 2 is assigned to the second highest, and so on. The ranks indicate the relative importance of each factor to the response.

Analysis of variance (ANOVA) is performed and signal-to-noise (S/N) ratio will be determined to know the level of importance of the machining parameters. To obtain the optimal machining performance the higher the better quality characteristics for MRR. As can be seen from Table 6, the MRR is most significantly influenced by the Current followed by the Gap Voltage, Wire Speed and Flushing Pressure. The respective values of these parameters are 1.52, 1.32, 0.90 and 0.88. After finding all the observation as given in Table 6 & 7 , S/N ratio are calculated and graph for analysis is drawn by using Minitab 16 software. The S/N ratio for MRR is calculated on Minitab 16 Software using Taguchi Method.

Table 4 Analysis of variance (ANOVA) for S/N Ratio w.r.t MRR

Source	DF	Seq SS	Adj SS	Adj MS	F	P	%Contribution
Wire Speed	3	1.6055	1.6055	0.53517	14.44	0.027	15.01
Flushing Pressure	3	1.22493	1.22493	0.40831	11.02	0.04	11.45
Gap Voltage	3	3.60676	3.60676	1.20225	32.45	0.009	33.72
Current	3	4.14672	4.14672	1.38224	37.3	0.007	38.77
Error	3	0.11116	0.11116	0.03705			1.04
Total	15	10.69507					

Table 5 Analysis of variance (ANOVA) for S/N Ratio w.r.t SR

Source	DF	Seq SS	Adj SS	Adj MS	F	P	%Contribution
Wire Speed	3	4.5397	4.5397	1.5132	49.07	0.005	37.2
Flushing Pressure	3	4.337	4.337	1.4457	46.88	0.005	35.54
Gap Voltage	3	1.0746	1.0746	0.3582	11.62	0.037	8.81
Current	3	2.1603	2.1603	0.7201	23.35	0.014	17.7
Error	3	0.0925	0.0925	0.0308			0.76
Total	15	12.2041					

Table 6 Response Table for Signal to Noise Ratio Larger is better

Level	Wire Speed	Flushing Pressure	Gap Voltage	Current
1	17.75	17.3	17.17	16.99
2	18.23	17.99	18.49	18.51
3	18.15	18.19	17.5	18.28
4	17.33	18	18.31	17.7
Delta	0.9	0.88	1.32	1.52
Rank	3	4	2	1

Table 7 Response Table for Signal to Noise Ratio Smaller is better

Level	Wire Speed	Flushing Pressure	Gap Voltage	Current
1	-13.76	-15.12	-13.28	-14.02
2	-12.58	-12.46	-14.38	-13.27
3	-15.34	-14.23	-14.31	-14.98
4	-13.9	-13.76	-13.61	-13.31
Delta	2.76	2.66	1.09	1.7
Rank	1	2	4	3

To obtain the optimal machining performance the higher the better quality characteristics for R_a. As can be seen from Table, the R_a is most significantly influenced by the Wire Speed followed by the Flushing Pressure, Current and Gap Voltage. The respective values of these parameters are 2.76, 2.66, 1.70 and 1.09.

The S/N response graph for Material Removal rate is shown in Fig 3.3. The greater average S/N ratio corresponds to the max MRR. From the S/N response graph Fig 3.3, it is concluded that the optimum parametric combination is Wire Speed (20), Flushing Pressure (160), Gap Voltage (80) and Current (60). In other words, it is this combination of parameters that gives the max MRR for the machined material.

The S/N response graph for Surface Roughness is shown in Fig 3.4. The greater average S/N ratio corresponds to the min R_a. From the S/N response graph Fig 3.4, it is concluded that the optimum parametric combination is Wire Speed (30), Flushing Pressure (120), Gap Voltage (80) and Current (80). In other words, it is this combination of parameters that gives the min R_a for the machined material.

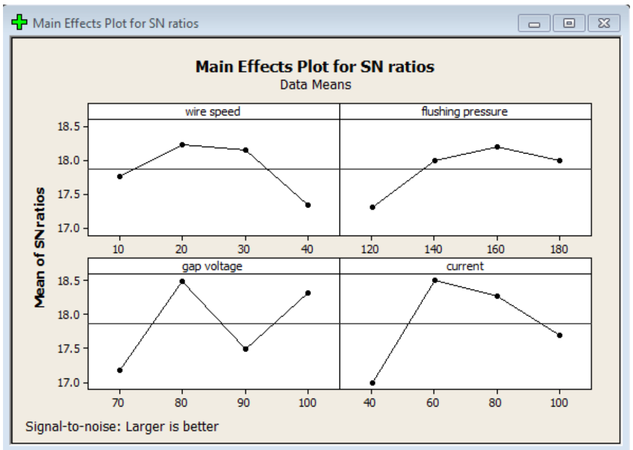

Fig. 4 S/N Ratio for MRR

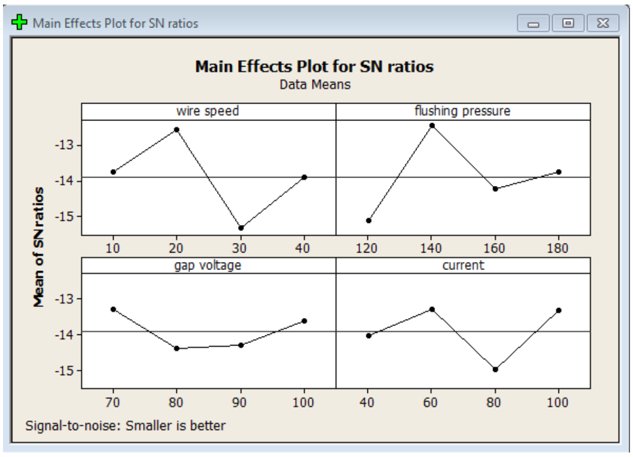

Fig.5 S/N Ratio for SR

Conclusion

From the experimental results, S/N ratio and ANOVA analysis and predicted optimum machining parameters, the following conclusions are drawn:-

1. From ANOVA Table 3.6 and Response table for Signal to Noise, based on the ranking it shows MRR is most significantly influenced by the Current followed by the Gap Voltage, Wire Speed and Flushing Pressure.
2. From ANOVA Table 3.6 and Response table for Signal to Noise, based on the ranking it shows the R_a is most significantly influenced by the Wire Speed followed by the Flushing Pressure, Current and Gap Voltage.
3. The optimum parametric combination is Wire Speed (20), Flushing Pressure (160), Gap Voltage (80) and Current (60).
4. The optimum parametric combination is Wire Speed (30), Flushing Pressure (120), Gap Voltage (80) and Current (80).
5. The validation experiment confirmed that the error was less than 1.04 % between equation and actual value for MRR.
6. The validation experiment confirmed that the error was less than 0.76 % between equation and actual value for SR.

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