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Wire electrode diameter effect on cutting speed, in WEDM of varying height Inconel-718

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Abstract
The wire electrical discharge machine is replacing the conventional machines at very fast rate. There is hardly any conductive and newly developed super alloy which cannot be machined by WEDM. Greater accuracy, higher cutting speed, better surface finish are fascinating features of WEDM. However enhancing cutting speed is still a challenge in difficult to cut material. In this paper a super alloy Inconel-718, is used with height variation, to evaluate effect of cutting speed by using different diameter wire electrode to get better cutting speed. Taguchi's L27, orthogonal array is used to find the effect of pulse on, pulse off, wire feed, wire diameter and work height on cutting speed. It is observed that small wire diameter gives highest cutting speed at the same operating conditions. Small wire diameter ensures better greater accuracy.
Keywords: *WEDM, cutting speed, Inconel-718.*

Introduction

In the present day advanced manufacturing scenario, the components produced must strictly adhere to the dimensional accuracy, which is greatly resolved by the use of computer numerically controlled machines. Components are of complex shape and at the same time they are difficult to cut, because of increased stiffness embedded to serve at elevated temperature and corrosive environments. Wire electrical discharge machine is highly popular among accurate machining and difficult to cut materials. Electrical discharge energy in the form of discrete sparks at regular intervals evaporates the material in small amount. The sparks are generated at the wire which is continuously fed in machining area flooded with dielectric, which breaks at regular intervals to allow the spark to generate and then flush the debris from the machining area.

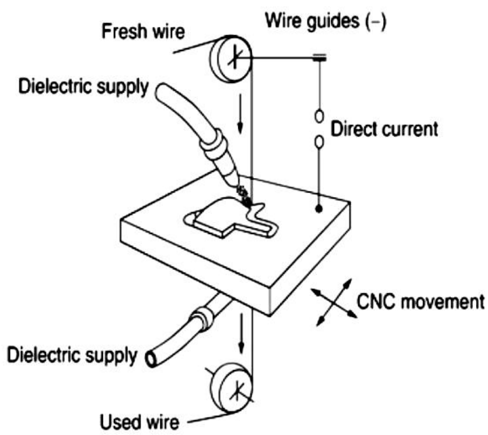

Fig 1. Schematic representation of WEDM[1] and M/c tool used

In the past, many researchers have investigated have analyzed the effect of process variables on, material removal rate (MRR) and surface roughness (SR). In such an attempt V. Aggarwal et at, used Inconel-718, and explored the effect of pulse on time, pulse off time, peak current and spark gap voltage on cutting rate and surface finish. Pulse on time was reported as the most influencing factor for both the parameters, however peak current is found to be insignificant[2]. The effect of discharge time, machining voltage, rest time and servo voltage on material removal rate[3] was studied on Inconel-718, using grey relational analysis in conjunction with Taguchi method to obtain optimal combinations of parameters. WEDM designed to be a precision machine with accuracy of over ten microns. However due to certain parametric effects its accuracy gets violated. Wire lag is proved to be major reason for inaccuracy as put forth by the work of puri and bhattacharyya[4]. The significant factors for geometrical inaccuracy due to wire lag reported were pulse on time, pulse off time, and peak current. In yet another research on effect of cutting parameters on the work piece surface roughness, it was revealed that increasing pulse duration, open circuit voltage and wire speed increases the surface roughness, whereas surface roughness was improved by increasing the dielectric fluid pressure. Vishal et al[5] used statistical and regression analysis to report pulse on time , gap voltage and pulse off time are most significant for material removal rate. The microstructure analysis is used to reveal the unidentified aspects behind the surface finish in WEDM. By the use of optical and scanning electron microscopy[6] it was reported that surface roughness primarily depends on pulse duration and open circuit voltage. With brass wire as tool electrode Nimonic 80 A, was machined with WEDM to investigate the effect of cutting speed. Cutting speed was found to increase with increase in pulse on time and peak current. [7]. The electrode constitution plays a very vital role in deciding the optimum performance. The electrical and mechanical properties along with coating embedded are chosen appropriately while selecting tool electrode for WEDM. The effect of electrode material was investigated by prohaszka[8], cutting efficiency of magnesium electrode was greater than zinc electrode. Also an electrode with sharp edges like triangular, rectangular, cutting speed increases. Three different types of electrodes brass, zinc coated and diffused were used to evaluate the nature of cutting speed. It was reported that for lower pulse on time and pulse off time cutting speed of zinc coated brass wire is better than diffused and brass wire[9]. Material thickness is important aspect to be considered for WEDM. As thickness increased the cutting speed decreases as the amount of material to be removed increases. Different heights of die steel work pieces are used to analyze effect of cutting speed[10]. Constant area feeding mode gives good results as compared to constant feed mode. Influence of work piece orientation, wire diameter on cutting speed was evaluated by Kashif Ishfaq [11]. Higher values of pulse on time results into high cutting speed whereas increase in wire diameter lower down the cutting rate. Cutting speed was also affected by the overall thickness of work piece. Higher work piece thickness results into low cutting speed. Effect of wire diameter on WEDM performance measures such as cutting speed was investigated on Inconel-706[12]. It was revealed that small diameter wire improves the cutting speed as well as surface finish. The only problem reported with small wire diameter is the wire breakage and pulse on time and servo voltage was found to be major factors significantly contributing towards the wire rupture.

So in the present work the effect of wire diameter and work material thickness on cutting speed is investigated for Inconel-718.

Experimental Procedure

i. **Work material:** Inconel-718, blocks of 8, 10 and 12 mm thickness are used as work material.
ii. **Machining Parameters:** Thee machining parameters Pulse on, Pulse off, wire feed and one tool electrode parameter wire di-

ameter and one wok material parameter work material thickness is taken.Table.1

Table 1: Input Process parameters and their levels

Sr. No	Parameter	Level 1	Level 2	Level 3
1	Wire Diameter mm	0.150	0.200	0.250
2	Pulse On µ sec	114	117	120
3	Pulse Off µ sec	58	55	52
4	Wire Feed m/min	6	8	10
5	Work Material thickness mm	8	10	12

iii. **Performance Characteristics:** Cutting Speed is directly obtained from the machine display in mm/min

iv. **Experimental design:** Taguchi's methodology is an important tool for experiments which offers a good approach to optimize design for performance[13]. The plan of experiments consists of recording the data, executing these experiments and analyzing this data, in order to obtain information about the behavior of a given process.

Results and Discussion

1. **Signal-to-noise (S/N) ratio**: Tool used in Taguchi's design, which measures quality with emphasis on variation and by applying this methodology you can reduce the time and cost of experimental investigation and can easily determine which factor is most influential. To find the optimal settings and factor levels. S/N ratio is the ratio of signal to noise where signal represents the desirable value, and noise represents the undesirable value. It is denoted by 'η' with a unit of dB. Regardless of the category of performance characteristics, a greater η value corresponds to a better performance. Therefore optimal level of machining parameters is the level with greatest η value. The S/N ratio values for each experiment were calculated. According to Quality Engineering, the characteristic that higher observed value represents better machining performance, as in case of cutting speed, is known as "higher is better". The S/N ratio can be calculated as a logarithmic transformation of the loss function as shown in Eq. (1). The S/N ratio values are calculated for the experiments conducted on the Inconel-718 and, the obtained values are tabulated in Table: 2.

Larger the Better:

$$\frac{S}{N} = -10\log\left(\frac{1}{n}\right)\sum_{i=1}^{n}\left(\frac{1}{y2}\right) \quad \ldots\ldots.(1)$$

where n = number of replication,

Y = observed response variable value

Table 2. Results of cutting speed and values of signal to noise ratios

Expt No.	Wire Diameter	Pulse On	Pulse Off	Wire Feed	Work Material thickness	Cutting Rate 1	Cutting Rate 2	Signal/Noise ratio db
1	0.15	114	58	6	8	0.81	0.82	-1.77734
2	0.15	114	55	8	10	0.71	0.68	-3.16637
3	0.15	114	52	10	12	0.59	0.62	-4.37290
4	0.15	117	58	8	12	0.50	0.50	-6.02060
5	0.15	117	55	10	8	1.07	1.09	0.66736
6	0.15	117	52	6	10	1.06	1.07	0.54670
7	0.15	120	58	10	10	0.88	0.88	-1.11035
8	0.15	120	55	6	12	0.70	0.69	-3.16098
9	0.15	120	52	8	8	1.57	1.86	4.59203
10	0.20	114	58	6	8	0.97	1.06	0.10370
11	0.20	114	55	8	10	0.92	0.98	-0.45852
12	0.20	114	52	10	12	0.73	0.88	-1.99734
13	0.20	117	58	8	12	0.65	0.76	-3.11560
14	0.20	117	55	10	8	1.40	1.45	3.07229
15	0.20	117	52	6	10	1.29	1.38	2.49482
16	0.20	120	58	10	10	1.13	1.19	1.28044
17	0.20	120	55	6	12	0.88	1.06	-0.37689
18	0.20	120	52	8	8	1.95	2.01	**5.93031**
19	0.25	114	58	6	8	0.77	0.82	-2.00554
20	0.25	114	55	8	10	0.70	0.75	-2.80874
21	0.25	114	52	10	12	0.65	0.66	-3.67593
22	0.25	117	58	8	12	0.53	0.59	-5.07365
23	0.25	117	55	10	8	1.09	0.98	0.26200
24	0.25	117	52	6	10	1.05	0.93	-0.13518
25	0.25	120	58	10	10	0.94	0.83	-1.11149
26	0.25	120	55	6	12	0.68	0.70	-3.22575
27	0.25	120	52	8	8	1.42	1.48	3.22178

According to SN ratio's higher value (5.93031) is obtained for 0.200 diameter wire, indicating small diameter wire gives better cutting speed.[12]

The effects of process parameters are plotted in the main effects plots for cutting speed. Figure. 2. It shows that as wire diameter increases the cutting speed increases however it decreases as further wire diameter is increased under the same operating condition. The cutting speed also increases with increase of pulse on time and decrease of pulse off time. Higher cutting speed is obtained with wire feed of 8 mm/min. As work material thickness is increased from 8 mm to 10 mm cutting speed decreases as the amount of material to be cut is substantially an increase.

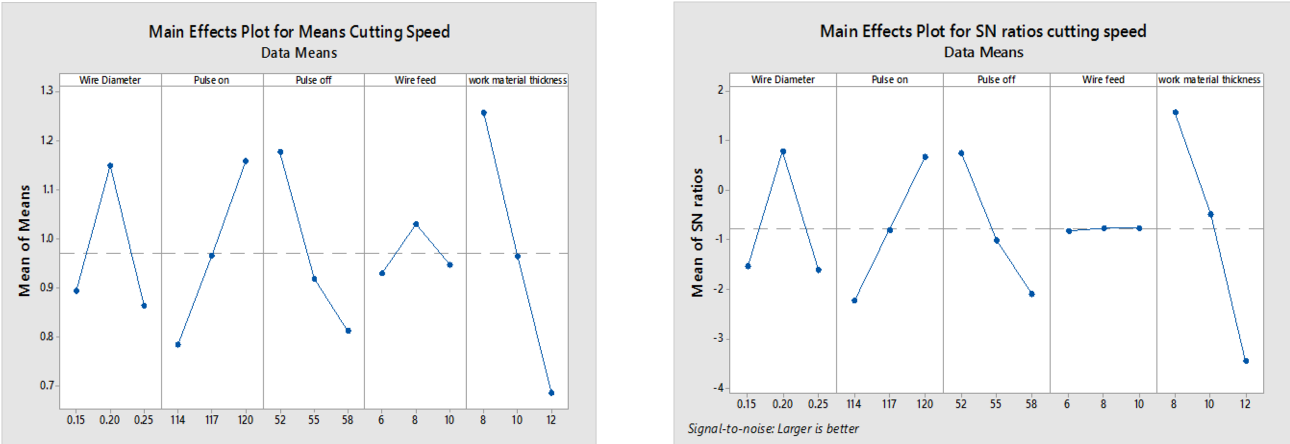

Fig 2. Main effects plots for cutting speed

Four two way interactions between wire diameter and pulse on, pulse off, wire feed and work material thickness were taken. Interaction of wire diameter with pulse on and work material thickness is significant.

Fig 3 Interaction plot for cutting speed

2 ANOVA: The purpose of ANOVA experimentation is to reduce and control the variation of a process; subsequently, decisions can be made concerning which parameters affect the performance of the process. ANOVA is the statistical method used to interpret experimental data to make the necessary decisions[13]. Through ANOVA, the parameters can be categorized into significant and insignificant machining parameters. In the present study all the designs, plots and analysis have been carried out using Minitab17 software. The analysis of variance was performed at 95 % confidence level. The associated P-value for the model is lower than 0.05 (i.e. =0.05), indicating that the model is statistically significant. It is used to establish statistically significant process parameter. Statistically, Larger F-value indicates that the variation of the process parameter makes a big change on the performance characteristics. According N.Tosun[14] higher value of F-ratio shows that any small variation of the process parameter can make a significant influence on the performance characteristics. The results of ANOVA for the performance measure are presented in

Table 3 Results of ANOVA for cutting speed

Factor	DF	Adj SS	Adj MS	F-value	P-Value
Wire dia	2	0.88080	0.44040	101.46	0.000
Pulse on	2	1.25847	0.62924	144.96	0.000
Pulse Off	2	1.27007	0.63504	146.30	0.000
Wire feed	2	0.10490	0.05245	12.08	0.000
WM thickness	2	2.91898	1.45949	336.23	0.000
Wire Dia * Pulse on	4	0.04295	0.01074	2.47	0.068
Wire Dia *Pulse off	4	0.03539	0.00885	2.04	0.117
Wire Dia *Wire Feed	4	0.00592	0.00148	0.34	0.848
Wire Dia *WM thickness	4	0.05971	0.01493	3.44	0.021
Error	27	0.11720	0.00434		
Total	53	6.69439			
Model Summery	S 0.0658843		R-sq 98.25%	R-sq(adj) 96.56%	R-sq(pred) 93.00%

From the ANOVA of cutting speed the work material thickness is observed to be most significant and most influential among all parameters. The next significant is pulse on and pulse off. Figure 4. Shows the residuals almost fall on straight line indicating residuals are normally distributed and the normality assumption is valid.

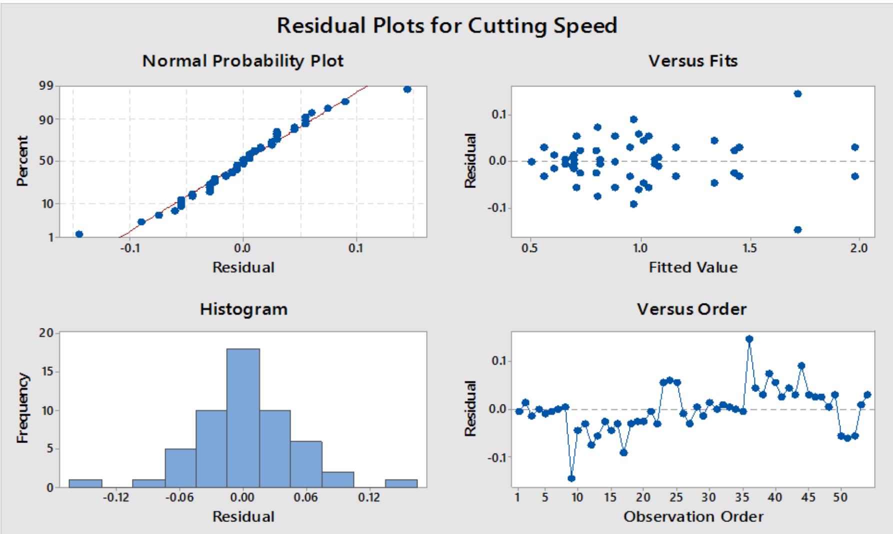

Fig 4 Residual plots for cutting speed

3. Interpretations of the results obtained

a. *Effect of pulse on time on cutting speed:* With the increase in pulse on time, electric spark duration prolongs which leads to increase in the amount of discharge energy produced. This increase in discharge tends to generate more heat for longer period of time which enhances vaporization rate and resulting increase in cutting speed.

b. *Effect of wire diameter on cutting speed:* With the increase in diameter of wire the exposed surface are of the wire to the work piece also increases therefore a wider area of the work piece is to ve vaporized which not only require more heat but also consumes more time. This is turn reduces the wire feed in the work piece compared to small diameter wire. Thus cutting speed reduces with the increase in wire diameter. Also with small wire diameter the wire transport speed was relatively higher, which improves the wire feed compared with large diameter wire. Therefore more amount of molten metal splashed through the machining zone and hence leading to higher cutting speed.

c. *Effect of work material thickness on cutting speed:* With the increase of work material thickness, the overall material to be cut in front of the wire is increased. As the material to be cut is increased with the same parametric input the time of cutting increases which reduces the cutting speed.

Conclusions

Using Taguchi's methodology experimentation is done and following conclusions can be drawn.

1) Highest cutting speed is obtained with small wire diameter of 0.200 mm diameter, opening curtain for research in small wire diameters.
2) Higher values of pulse on time results into high cutting speed
3) Cutting speed decreases with increase in work material thickness. Higher thickness of work piece results into low cutting speed.

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