A study and investigation on kerf width in wire electrical discharge machining using molybdenum wire

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Abstract

Wire electrical discharge machining (WEDM) technology is extensively used in the field of medical, mould making, aerospace and automobile industries. Improper electrical parameters settings can affect the processing efficiency. This paper presents an investigation on the effect and optimization of machining parameters on the kerf (cutting width) in wire electrical discharge machining (WEDM) operations. In this study High Carbon High Chromium Die Steel (HCHCR) was machined using different process parameters based on L'27 orthogonal array. The experimental studies were conducted under varying pulse on time, pulse off time, flushing pressure, wire tension, servo voltage, servo feed rate. Among different process parameters Peak current (IP), Pulse peak voltage, Servo feed setting were kept constant. The settings of machining parameters were determined by using Taguchi experimental design method. The level of importance of the machining parameters on the cutting kerf width is determined by using analysis of variance Grey relational analysis (GRA).The study demonstrates that the WEDM process parameters can be adjusted so as to achieve minimum kerf width.

Index Terms – WEDM, kerf, taguchi, ANOVA, GRA

I. Introduction

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. The most important performance measures in WEDM are material removal rate (or cutting speed), workpiece surface finish and kerf (cutting width). Discharge current, discharge capacitance, pulse duration, pulse frequency, wire speed, wire tension, average working voltage and dielectric flushing conditions are the machining parameters which affect the performance measures.

Among the other performance measures, the kerf (Fig. 1), which determines the dimensional accuracy of the finished part, is of utmost importance. The internal corner radius to be produced in WEDM operations is also limited by the kerf. The wire–workpiece gap usually ranges from 0.025 to 0.075mm and is constantly maintained by a computer controlled positioning system. The kerf is calculated by summing up the wire diameter (ranges 0.05–0.4 mm) to 2 × "wire–workpiece gap distance". In WEDM operations, material removal rate (MRR) determines the economics of machining and rate of production. In setting the machining parameters, the main goal is the maximum MRR with the minimum kerf. The setting of machining parameters relies strongly on the experience of operators and machining parameter tables provided by machine tool builders. It is difficult to utilize the optimal functions of a machine owing to there being too many adjustable machining parameters.

Scott et al. [1] have presented a formulation and solution of a multi-objective optimization problem for the selection of the best parameter settings on a WEDM machine. The measures of performance for the model were MRR and surface quality. In their study, a factorial design model has been used to predict the measures of performances as a function of a variety of machining parameters. Rajurkar and Wang [2] analyzed the wire rupture phenomena with a thermal model.

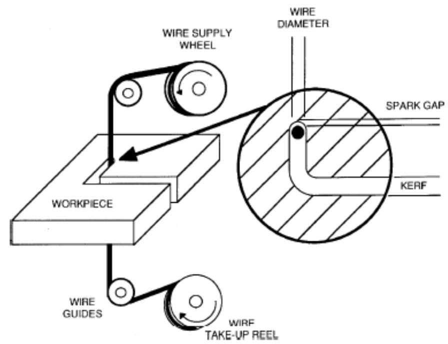

Fig.1. Detail of WEDM cutting gap [1].

An extensive experimental investigation has been carried out to determine the variation of machining performance outputs, namely MRR and surface finish, with machining parameters in the study. Tarng et al. [3] used a neural network system to determine settings of pulse duration, pulse interval, peak current, open circuit voltage, servo reference voltage, electric capacitance and table speed for the estimation of cutting speed and surface finish. Spedding and Wang [4] presented an attempt at optimization of the process parametric combination by using artificial neural networks and characterize the roughness and waviness of workpiece surface and the cutting speed. Liao et al. [5] performed an experimental study to determine the variation of the machining parameters on the MRR, gap width and surface roughness. In their work, although an attempt was made to determine the level of importance of the machining parameters on the MRR, the level of importance of gap width and surface roughness were not introduced. The variation of gap width and surface roughness with machining parameters were presented in simple graphical forms. Lok and Lee [6] compared the machining performance in terms of MRR and surface finish by the processing of two advanced ceramics under different cutting conditions using WEDM.

Huang et al. [7] investigated experimentally the effect of machining parameters on the gap width, the surface roughness and the depth of white layer on the machined workpiece surface. Rozenek et al. [8] used a metal matrix composite as workpiece material and investigated the variation of machining feed rate and surface roughness with machining parameters. Tosun and Cogun [9] investigated the effect of machining parameters on wire wear ratio based on the weight loss of wire in WEDM. Tosun et al. [10] introduced a statistical approach to determine the optimal machining parameters for minimum size of wire craters in WEDM.
The survey of literature indicates that there are publishedworks on the effect of machining parameters on MRR, surface roughness, cutting speed, wire rupture and wire craters. To the best of the knowledge of the authors of this work, there is no published work studying the effect of machining parameters on kerf statistically in WEDM. The variation of kerf and MRR with machining parameters and optimization of machining settings for minimum kerf and maximum MRR should be investigated experimentally and the obtained results should be interpreted and modeled statistically to understand closely the behavior of machining rate and accuracy in WEDM.

In this study, the effect of the machining parameters and their level of significance on the kerf width. Experiments were conducted under different machining parameters, namely, pulse on time, pulse off time, flushing pressure, wire tension, servo voltage, servo feed rate. The settings of machining parameters were determined by using Taguchi experimental design method.

II. Experiments

1.1. Materials, test conditions and measurement

The experimental studies were performed on a machine used for experiments is electronic Sprintcut Wire cut EDM,Model-ELPULS-40 A DLX WEDM machine tool. Different settings of Different settings of Pulse On Time (µs), Pulse Off Time (µs), Flushing pressure (kgf/cm^2), Wire Tension (gms), Servo Voltage (volt), Wire Feed Rate (m/min) used in experiments. (Table 1).
Molybdeneum was cut with 0.25 mm diameter stratified wire with vertical configuration was used and discarded once used. As workpiece material is High Carbon High Chromium Die Steel (HCHCR) used. The kerf was measured using the Nikon profile projector model 6C.

Table No: 1 Input Variables with Levels value

Sr. No.	Machining process parameter	Level 1	Level 2	Level 3
1	Pulse On Time (µs)	110	115	120
2	Pulse Off Time (µs)	40	45	50
3	Flushing pressure (kgf/cm^2)	8	10	12
4	Wire Tension (gms)	550	750	950
5	Servo Voltage (volt)	15	20	25
6	Wire Feed Rate (m/min)	6	8	10

1.2. Design of experiment based on Taguchi method

Taguchi proposed to acquire the characteristic data by using orthogonal arrays, and to analyze the performance measure from the data to decide the optimal process parameters [11, 12]. This method uses a special design of orthogonal arrays to study the entire parameter space with small number of experiments only. In this study, six machining parameters were used as control factors and each parameter was designed to have three levels, denoted 1, 2 and 3 (Table 1). According to the Taguchi quality design concept, a *L*27 orthogonal arrays table with 27 rows (corresponding to the number of experiments) waschosen for the experiments (Table 2).

Table.2. Experimental design using *L*18 orthogonal array

Sr.No	Ton (μs)	Toff (μs)	Fp (Kgf/cm^2)	Wt (gms)	SV (volts)	Wf (m/min)	KW (mm)
1	110	40	8	550	15	6	0.2645
2	110	40	8	550	20	8	0.2540
3	110	40	8	550	25	10	0.2532
4	110	45	10	750	15	6	0.2732
5	110	45	10	750	20	8	0.2722
6	110	45	10	750	25	10	0.2667
7	110	50	12	950	15	6	0.2832
8	110	50	12	950	20	8	0.2865
9	110	50	12	950	25	10	0.2678
10	115	40	10	950	15	8	0.2690
11	115	40	10	950	20	10	0.2597
12	115	40	10	950	25	6	0.2566
13	115	45	12	550	15	8	0.2645
14	115	45	12	550	20	10	0.2611
15	115	45	12	550	25	6	0.2588
16	115	50	8	750	15	8	0.2690
17	115	50	8	750	20	10	0.2712
18	115	50	8	750	25	6	0.2759
19	120	40	12	750	15	10	0.2618
20	120	40	12	750	20	6	0.2644
21	120	40	12	750	25	8	0.2633
22	120	45	8	950	15	10	0.2714
23	120	45	8	950	20	6	0.2769
24	120	45	8	950	25	8	0.2812
25	120	50	10	550	15	10	0.2911
26	120	50	10	550	20	6	0.2878
27	120	50	10	550	25	8	0.2898

III. Multi-objective optimization

In this part of the study an effort has been spent to find the machining settings for the objective of "minimum kerf". This is the case of the optimal search for machining parameters for a multi-objective optimization problem (MOP) with multi-performance characteristics. The optimization problem for the minimum kerf problem can be formulated as a multi-objective, multi-variable, nonlinear optimization problem with multi-constraints.

The basic process steps for multi-response optimization are given below.

(a) Normalization of experimental results for all performance characteristics.

(b) Calculation of grey relational coefficient (GRC).

(c) Calculation of grey relational grade (GRG) using weighing factor for performance characteristics.

(d) Analysis of experimental results using GRG.

(e) Selection of optimal levels of process parameters.

(f) Conducting confirmation experiment to verify optimal process parameter settings.

3.1Grey relational coefficient and grey relational grade

Following data pre-processing, a grey relational coefficient is calculated to express the relationship between the ideal and actual normalized experimental results. The Grey relation coefficient [13] can be express as follows.

$$\zeta_i(k) = \frac{\Delta min + \psi \Delta max}{\Delta_{0i}(k) + \psi \Delta max} \quad \text{……..…… (4.1)}$$

Where $\Delta_{0i}(k)$ is the deviation sequence of the reference sequence $xi(k)$ and the comparability sequence.

$$\Delta_{0i} = \left| x_0(k) - x_i(k) \right| \quad \text{…………… (4.2)}$$

$$\Delta min = \min_{i \in I} \min_{k} \left| x_0(k) - x_i(k) \right| \quad \text{……………… (4.3)}$$

$$\Delta max = \max_{i \in I} \max_{k} \left| X_0(k) - X_i(k) \right| \quad \text{……………… (4.4)}$$

The Grey relation grade [13] is defined as follows:

$$\gamma_i = \frac{1}{n} \sum_{k=1}^{n} \zeta i(k) \quad \text{……………… (4.5)}$$

However, since in real application the effect of each factor on the system is not exactly same, Eq.6.8 can be modified as:

$$\gamma_i = \frac{1}{n} \sum_{k=1}^{n} W_k \zeta i(k) \quad \text{…………….. (4.6)}$$

Where, W_k represents the normalized weighting value of factor k.

ζ is distinguishing or identification coefficient: $\zeta \in [0,1]$, is generally used. After obtaining the Grey relation coefficient, its average is calculated to obtain the Grey relation grade.

The distinguishing coefficient can be substituted for the grey relational coefficient in Eq4.3 If all the process parameter has equal weighting, ζ is 1. Table 6.4 lists the grey relational coefficient and grade for each experiment of the L_{27} orthogonal array by applying Eqs.4.3, 4.5 and 4.6.

Table3. Calculation of Grey relational coefficient & Grey relational grade

Exp No:	Grey Relation Co-efficient	Grey Relational Grade	Orders
1	0.6264	1.9180	4
2	0.9595	2.2605	2
3	1.0000	2.3902	1
4	0.4865	1.4929	18
5	0.4993	1.4749	19

6	0.5840	1.6191	11
7	0.3871	1.4005	20
8	0.3627	1.3575	22
9	0.5648	1.5246	16
10	0.5453	1.8496	5
11	0.7446	1.8162	6
12	0.8479	1.8013	7
13	0.6264	1.5288	15
14	0.7058	1.5617	14
15	0.7719	1.5684	13
16	0.5453	1.3083	23
17	0.5129	1.2687	25
18	0.4550	1.2019	27
19	0.6878	2.0333	3
20	0.6285	1.7963	8
21	0.6523	1.7747	9
22	0.5101	1.6601	10
23	0.4443	1.5755	12
24	0.4036	1.5012	17
25	0.3333	1.3797	21
26	0.3539	1.2849	24
27	0.3411	1.2532	26

According to performed experiment design, it is clearly observed from Table 3 that the 'wire cut EDM process parameters' setting of experiment no. 03 has the highest grey relation grade. Thus, the third experiment gives the best multi-performance characteristics among the 27 experiments. To find out the optimum level of WEDM parameters, calculate the average grey relational grade for each factor level.

Table 4. Response table for grey relational grade

Machining parameters	Average grey relational grade by factor level		
	Level 1	Level 2	Level 3
Pulse On Time, A	1.7153*	1.4098	1.3605
Pulse Off Time, B	1.5450*	1.2750	1.2400
Wire Feed Rate, C	1.5843*	1.1002	1.1845
Wire Tension, D	1.6828*	1.5522	1.6096
Servo Voltage, E	0.1870*	0.1725	0.1788
Flushing pressure, F	0.0208*	0.0192	0.0199

From this table, one has concluded optimum parameter levels which are indicated by "*". In this table, higher grey relational grade from each level of factor indicates the optimum level. From this table it is concluded that the optimum parameter level for Pulse on time, Pulse off time, Flushing pressure, Wire tension, Servo voltage, Wire feed rate is (110 μs), (120 μs), (8 kgf/cm^2), (550gms),(15volts), and (6 m/min) respectively.

IV. Analysis and discussion of experimental results

The Grey relational grade graph (Figure 2) which shows the change in the response when the factors go from one level to other that the WEDM parameters setting of experiment no. 3 has highest grey relation grade. Thus, the tenth experiment gives the best multi-performance characteristics of the WEDM process among the 27 experiments.

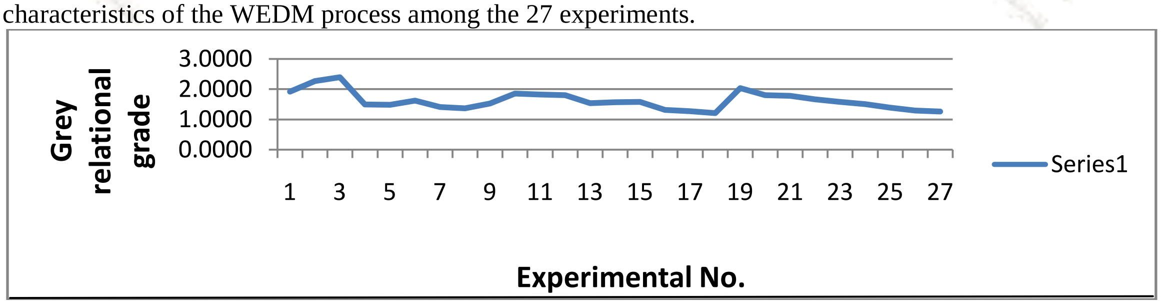

Fig 2. Graph of Grey relational grades

V. Confirmation test

The final step in the experiment is to do confirmation test. The purpose of the confirmation runs is to validate the conclusion drawn during the analysis phases. In addition, the confirmation tests need to be carried out in order to ensure that the theoretical predicted parameter combination for optimum results using the software is acceptable or not. The parameters used in the confirmation test are suggested by grey relational analysis. The confirmation test with optimal process parameters is performed for Wire cut EDM of HCHCR at levels A1 (110 µs Pulse on time), B1 (120 µs Pulse off time), C1 (8 kgf/cm^2 Flushing pressure), D1 (550gms Wire tension), E1(15volts Servo voltage) , F1(6 m/min Wire feed rate) and it gives kerf width of 0.4393 mm with the error in error in kerf width is 7 %.

VI. Conclusion

This paper has presented an investigation on the optimization and the effect of machining parameters on the kerf in WEDM operations. The level of importance of the machining parameters on the kerf is determined by using ANOVA and GRA.The analysis shows the percentage contribution of individual process input parameters of WEDM on HCHCR for kerf width. The percentage contribution of Pulse on time is 19.32506%, Pulse off time is 55.98105%, Flushing pressure is 6.50978%, Wire tension is 2.41095%, Servo voltage is 2.16174%, Wire feed rate is 4.24691% and error is 9.36448%. This error is due to machine vibration.The confirmation tests indicated that it is possible to decrease kerf and increase MRR significantly by using the proposed statistical technique. The experimental results confirmed the validity of the used Taguchi method for enhancing the machining performance and optimizing the machining parameters in WEDM operations.

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