Optimization of MRR, Surface Roughness and KERF Width in wire EDM Using Molybdenum Wire

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Abstract:
The wire electrical discharge machining (WEDM) is one of the latest non-traditional machining processes, based on thermoelectric energy between the work piece and wire. The performance of the process, to a large extent, depends on the tool material, work piece material &manufacturing method of the tool. A suitable selection of tool can reduce the cost of machining. The performance of WEDM is find out on the basis of Material Removal Rate (MRR), KERF Width and Surface Roughness (SR). The important machining parameters of EDM which affecting on the performance parameters are discharge current, pulse on time, pulse off time, arc gap, flushing pressure, servo voltage and wire tension. Taguchi design of experiments is used to conduct experiments by varying the parameters servo voltage, pulse on time and pulse off time. The process performance is measured in terms of Material Removal Rate (MRR), KERF Width and Surface Roughness (SR). In this research WEDM experiment using 0.25 mm diameter molybdenum wire & EN-31 tool Steel work piece has been done for optimizing MRR, KERF width, Surface finish and reducing cost of manufacturing. By using multi objective optimization technique grey relational theory, the optimal value is obtained for MRR, surface roughness and KERF width.

Keywords: *KERF width, MRR, Optimization, Grey Relation Analysis, SR, Wire Electrical Discharge Machining*

1. Introduction

Non traditional machining processes are most commonly used for machining of high strength material in industries & increase in the availability and use of difficult-to-machine materials. Wire EDM Machining (also known as Spark EDM) is an electro thermal production process in which a thin single-strand metal wire (usually brass) in conjunction with de-ionized water (used to conduct electricity) allows the wire to cut through metal by the use of heat from electrical sparks. Wire-cutting EDM is commonly used when low residual stresses are desired, because it does not require high cutting forces for removal of material [16].

Although WEDM machining is complex, the use of this machining process in industry has increased because of its capability in cutting complicated forms, especially created in hard materials. Among the various non-conventional machining methods available, EDM is the most widely used and successfully applies one for the difficult to machine materials.

2. Existing Research Efforts

Rajmohan T. et al. have studied on optimization of machining parameters in electrical discharge machining of 304 stainless steel. Author experimented that the effect of electrical discharge machining parameter such as pulse on time, pulse off time, voltage and current on material removal rate in 304 stainless steel was studied. The experiment was carried out as per design of experiments approach using L9 orthogonal array. The results were analyzed using analysis of variance and response graphs. From this study, it is found that different combination of EDM process parameters is required to achieve higher MRR for 304 stainless steel. Signal to noise ratio and analysis of variance is used to analyze the effect of parameters towards the MRR is also identified.

Vishal parashar et al. have studied Investigation and Optimization of Surface Roughness for Wire Cut Electro Discharge Machining of SS 304L using Taguchi Dynamic Experiments. Optimization of surface roughness using Taguchi's dynamic design of experiments is proposed for WEDM operations. Experimentation was planned as per Taguchi's L'32 mixed orthogonal array. Each experiment has been performed under different cutting conditions of gap voltage, pulse ON time, pulse OFF time, wire feed and dielectric flushing pressure. Stainless Steel grade 304L was selected as a work material to conduct the experiments. From experimental results, the surface roughness was determined for each machining performance criteria. Signal to noise ratio was applied to measure the performance characteristics deviating from the actual value. Finally, experimental confirmation was carried out to identify the effectiveness of this proposed method.

A.Rehman et al. have studied KERFs width analysis for wire cut electro discharge machining of SS 304L using design of experiments. Statistical and regression analysis of KERF width using design of experiments is proposed for WEDM operations. Experimentation was planned as per Taguchi's L'32 mixed orthogonal array. Each experiment has been performed under different cutting conditions of gap voltage, pulse ON time, pulse OFF time, wire feed and dielectric flushing pressure. Stainless steel grade 304L was selected as a work material conduct the experiments. From experimental results, the KERF width was determined for each machining performance criteria. Analysis of variance (ANOVA) technique was used to find out the variables affecting the KERF width. Assumptions of ANOVA were discussed and carefully examined using analysis of residuals. Variation of the KERF width with machining parameters was mathematically modelled by using the regression analysis method.

S. Sivakiran et al. studied of Effect of Process Parameters on MRR in Wire Electrical Discharge Machining of En31 Steel. To study the influence of various machining parameters Pulse on, Pulse off, Bed speed and Current on metal removal Rate (MRR). The relationship between control parameters and Output parameter (MRR) is developed by means of linear regression. Taguchi's L16 (4*4) Orthogonal Array (OA) designs have been used on EN-31 tool steel to achieve maximum metal removal rate.

Singaram Lakshmanan et al. have studied, Optimization of Surface Roughness using Response Surface Methodology for EN31 Tool Steel EDM Machining. The work piece material was EN31 tool steel. The pulse on time, pulse off time, pulse current and voltage were the control parameters of EDM. RSM method was used to design.

Brajesh Kumar Lodhi and Sanjay Agarwal studied Optimization of machining parameters in WEDM of AISI D3 Steel using Taguchi Technique. In this work, an attempt has been made to optimize the machining conditions for surface roughness based on (L9 Orthogonal Array) Taguchi methodology. Experiments were carried out under varying pulse-on-time, pulse-off time, peak current, and wire feed. An orthogonal array, the signal-to-noise (S/N) ratio, and the analysis of variance (ANOVA) were employed to the study the surface roughness in the WEDM of AISI D3 Steel.

Gaurav Raghav et al. studied Optimization of Material Removal Rate in Electric Discharge Machining Using Mild Steel. In the present work, relationships have been developed between the input decision variables and the desired goals by applying the statistical regression analysis of investigations obtained by Electro Discharge machining process for a considerable variation in the crisp sets of variables. The objectives functions were maximized or minimized by using the generalized Genetic Algorithms and the data are stored for a given set of objectives.

Amit Kohli et al. studied Optimization of Material Removal Rate in Electrical Discharge Machining Using Fuzzy Logic. The objective of present work is to stimulate the machining of material by electrical discharge machining (EDM) to give effect of input parameters like discharge current (Ip), pulse on time (Ton), pulse off time (Toff) which can bring about changes in the output parameter, i.e. material removal rate. Experimental data was gathered from die sinking EDM process using copper electrode and Medium Carbon Steel (AISI 1040) as work-piece. It was found that proposed fuzzy model is in close agreement with the experimental results. By Intelligent, model based design and control of EDM process parameters in this study will help to enable dramatically decreased product and process development cycle times.

Zahid A. Khan et al. studied Multi response optimization of Wire electrical discharge machining process parameters using Taguchi based Grey Relational Analysis. This paper presents a study that investigates the effect of the WEDM process parameters on the surface roughness average and the KERF width of the stainless steel (SS 304). Nine experimental runs based on an orthogonal array of Taguchi method are performed and grey relational analysis method is subsequently applied to determine an optimal WEDM parameter setting. Surface roughness and KERF width are selected as the quality targets. An optimal parameter combination of the WEDM process is obtained using Grey relational analysis. By analyzing the Grey relational grade matrix, the degree of influence for each controllable process factor onto individual quality targets can be found. The pulse ON time is found to be the most influential factor for both the surface roughness and the KERF width. The results of the analysis of variance (ANOVA) reveals that the pulse ON time is the most significant controlled factor for affecting the multiple responses in the WEDM according to the weighted sum grade of the surface roughness and the KERF width.

Harpreet Singh and Amandeep Singh studied Effect of Pulse On/Pulse off Time on Machining of AISI D3 Die Steel Using Copper and Brass Electrode in EDM. Electric discharge machining is non conventional machining process. EDM is generally used for machining for those materials which are cannot processed by conventional machining process. In this article we compared the material removal rate achieved using different tool materials. Work piece used is AISI D3 and tool materials used copper and brass electrode with pulse on/pulse off as parameter. The electrolyte used is kerosene oil.

S. A. Sonawane & M.L. Kulkarni studied effect of WEDM machining parameters on output characteristics. Wire Electrical discharge machining [WEDM] is an electro-thermal machining process. It can machine any material irrespective of its hardness, brittleness or toughness with utmost accuracy. As there is no contact between wire and the work piece mechanical stresses are not induced during machining. In WEDM many machining parameters are involved. A small change in the control parameters affects the process performance namely material removal rate, surface finish, cutting speed, dimensional deviation and geometrical accuracy. In this paper an investigation of the effect of machining parameters namely pulse-on time, pulse-off time, peak current, wire feed rate, wire tension and servo voltage on cutting rate and surface finish is presented. Experimental results showed that with increase in the pulse-on time, peak current and wire feed rate, cutting rate increases and surface finish decreases. Also, the empirical model developed for cutting rate and surface finish is validated and has showed good agreement with experimental results.

Shubhra Paliwal et al. studied parameter optimization of wire electrical discharge machining for minimum surface roughness and KERF width using taguchi method. The cutting of SS302 material using Wire electro discharge machining (EDM) with Molybdenum electrode by using Taguchi methodology has been reported. The Taguchi method is used to formulate the experimental layout and to analyze the effect of each parameter on the machining characteristics. Optimum level of process parameters like current, pulse-on time and pulse-off time that would yield optimum response of surface roughness and KERF width are determined. Percentage contribution of the process parameters is calculated using ANOVA. It is found that pulse off time is significant factor for surface roughness, while pulse on time is significant factor for KERF width.

M. Durairaj et al. studied Analysis of Process Parameters in Wire EDM with Stainless Steel using Single Objective Taguchi Method and Multi Objective Grey Relational Grade. This paper summarizes the Grey relational theory and Taguchi optimization technique, in order to optimize the cutting parameters in Wire EDM for SS304. The objective of optimization is to attain the minimum KERF width and the best surface quality simultaneously and separately. In this present study stainless steel 304 is used as a work piece, brass wire of 0.25mm diameter used as a tool and distilled water is used as a dielectric fluid. For experimentation taguchi's L16, orthogonal array has been used. The input parameters selected for optimization are gap voltage, wire feed, pulse on time, and pulse off time. Dielectric fluid pressure, wire speed, wire tension, resistance and cutting length are taken as fixed parameters. For each experiment surface roughness and KERF width was determined by using contact type surf coder and video measuring system respectively. By using multi objective optimization technique grey relational theory, the optimal value is obtained for surface roughness and KERF width and by using Taguchi optimization technique, optimized value is obtained separately..

S. S. Mahapatra et al. studied Optimization of wire electrical discharge machining (WEDM) process parameters using Taguchi method. Wire electrical discharge machining (WEDM) is extensively used in machining of conductive materials when precision is of prime importance. Rough cutting operation in WEDM is treated as a challenging one because improvement of more than one machining performance measures viz. metal removal rate (MRR), surface finish (SF) and cutting width (KERF) are sought to obtain a precision work. Using Taguchi's parameter design, significant machining parameters affecting the performance measures are identified as discharge current, pulse duration, pulse frequency, wire speed, wire tension, and dielectric flow. It has been observed that a combination of factors for optimization of each performance measure is different. In this study, the relationship between control factors and responses like MRR, SF and KERF are established by means of nonlinear regression analysis, resulting in a valid mathematical model. Finally, genetic algorithm, a popular revolutionary approach, is employed to optimize the wire electrical discharge machining process with multiple objectives.

3. Design of Experiment

DOE is a technique of defining and investigating all possible combinations in an experiment involving multiple factors and to identify the best combination. In this, different factors and their levels are identified. Design of experiments is also useful to combine the factors at appropriate levels each within the respective acceptable range, to produce the best results and yet exhibit minimum variation around the optimum results. The design of experiment is used to develop a layout of the different conditions to be studied. And experiment design must satisfy two objectives: first, the number of trials musty be determined; second, the conditions for each trial must be specified.

The L9 Orthogonal Array methodology has been used to plan the experiments. Three factors are chosen the design becomes a 3 level 3 factorial Taguchi design. The version 17 of the MINITAB software was used to develop the experimental plan for L9 Orthogonal Array.

Table 1: Factors with Levels

Parameters	Level-1	Level-2	Level-3
Pulse on time(μs)	110	120	130
Pulse off time(μs)	40	50	60
Servo voltage(V)	20	30	40

4. Experiment Setup

The machine used for experiments is electronica sprint cut Wire cut EDM, Model-ELPULS-40 A DLX, incorporated with molybdenum wire technology which is installed at Darshan Wire Cut, Odhav, G.I.D.C., Ahmadabad, Gujarat as shown in Figure.

Fig. 1: Sprint cut Wire Cut EDM

Work piece material to be used- EN-31 tool steel. Typical applications in stamping dies, metal cutting tools or any other industries because of its high strength and heavy weight.

Table 2: Chemical composition of En-31 tool Steel

Material	C	Cr	Mn	P	S	Si
EN-31 tool steel	1.020	1.450	0.660	0.025	0.021	0.180

Electrode to be used- Molybdenum wire with 0.25 mm diameter. Technical reason for selecting molybdenum wire It has High melting point Compare To copper wire. It is used for cutting high strength material. It has less tool wear.

5. Experiment Results

The effect of process parameters on the machining parameter is recorded in the table. The nine experiments done on the electro discharge machine based on the Taguchi method and summarized in the following table.

Surface roughness values of finished work pieces were measured by Mitutoyo Surface Roughness Tester SJ – 201 by a proper procedure. KERF width has been measured using Nikon profile projector. MRR measured based on KERF width base method.

MRR = KW*T*CS*D

Density=0.00786 g/mm^3

Table 3: Design Layout and Experimental Results

Sr. No.	Ton (µs)	Toff (µs)	SV (volts)	MRR (g/min)	KW (mm)	SR (µm)
1	110	40	20	0.0390	0.2561	3.3433
2	110	50	30	0.0325	0.2769	3.0710
3	110	60	40	0.0164	0.2730	2.3967
4	120	40	30	0.0613	0.2531	3.2255
5	120	50	40	0.0409	0.2820	3.0883
6	120	60	20	0.0256	0.2598	3.2650
7	130	40	40	0.0465	0.2611	2.6817
8	130	50	20	0.0494	0.2907	3.4817
9	130	60	30	0.0492	0.3182	3.2767

6. Grey Relational Analysis

Grey Relational Analyses are applied to determine the suitable selection of machining parameters for Electrical Discharge Machining (EDM) process. The Grey theory can provide a solution of a system in which the model is unsure or the information is incomplete. Besides, it provides an efficient solution to the uncertainty, multi-input and discrete data problem. In this work, Grey Relational Analysis (GRA) has been used to convert the multi-response optimization model into a single response grey relational grade.

The following steps to be followed while applying grey relational analysis to find the Grey relational coefficients and the grey relational grade:

(a) In grey relational analysis, the data is normalized using equation 1 for larger the better

$$x_i(k) = \frac{y_i(k) - \min y_i(k)}{\max y_i(k) - \min y_i(k)} \quad \text{......... (1)}$$

(b) When lower the better, the data is normalized using equation 2,

$$x_i(k) = \frac{\max y_i(k) - y_i(k)}{\max y_i(k) - \min y_i(k)} \quad \text{........... (2)}$$

Here $X_{i\,(k)}$ is the value after grey relational generation, min $y_{i\,(k)}$ is the smallest value of $y_{i\,(k)}$ for the k^{th} response, and max $y_{i(k)}$ is the largest value of $y_{i\,(k)}$ for the k^{th} response. 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 [16] can be express as follows.

$$\zeta_i(k) = \frac{\Delta\min + \psi\Delta\max}{\Delta_{0i}(k) + \psi\Delta\max} \quad \text{............ (3)}$$

Where, Δ is the deviation sequence of the reference sequence $xi(k)$ and the comparability sequence.

$$\Delta_{0i} = \left| x_0(k) - x_i(k) \right| \quad \text{......... (4)}$$

$$\Delta\min = \min_{i\in} \min \left| x_0(k) - x_i(k) \right| \quad \text{........... (5)}$$

$$\Delta max = \max_{i\in} \max |x_0(k) - x_i(k)| \quad \text{......... (6)}$$

Where, 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 Grey relation grade is defined as follows:

$$\gamma_i = \frac{1}{n} \sum_{k=1} \quad \text{.......... (7)}$$

Table 4: Grey relational coefficient and grey relational grade for MRR, KERF width and SR

Data Pre Normalization			The Deviation Sequence			Grey Relation Co-efficient			Grade
MRR	KW	SR	MRR	KW	SR	MRR	KW	SR	
0.5041	0.9539	0.1276	0.4959	0.0461	0.8724	0.5021	0.9156	0.3643	0.5940
0.3576	0.6344	0.3785	0.6424	0.3656	0.6215	0.4377	0.5776	0.4458	0.4871
0.0000	0.6943	1.0000	1.0000	0.3057	0.0000	0.3333	0.6206	1.0000	0.6513
1.0000	1.0000	0.2361	0.0000	0.0000	0.7639	1.0000	1.0000	0.3956	0.7985
0.5455	0.5561	0.3626	0.4545	0.4439	0.6374	0.5238	0.5297	0.4396	0.4977
0.2039	0.8971	0.1997	0.7961	0.1029	0.8003	0.3858	0.8293	0.3845	0.5332
0.6697	0.8771	0.7373	0.3303	0.1229	0.2627	0.6022	0.8027	0.6556	0.6868
0.7349	0.4224	0.0000	0.2651	0.5776	1.0000	0.6535	0.4640	0.3333	0.4836
0.7303	0.0000	0.1889	0.2697	1.0000	0.8111	0.6496	0.3333	0.3814	0.4548

7. Result Analysis and Discussion

The grey relational grade represents the level of correlation between the reference sequence and the comparability sequence, the greater value of the grey relational grade means that the comparability sequence has a stronger correlation to the reference sequence.

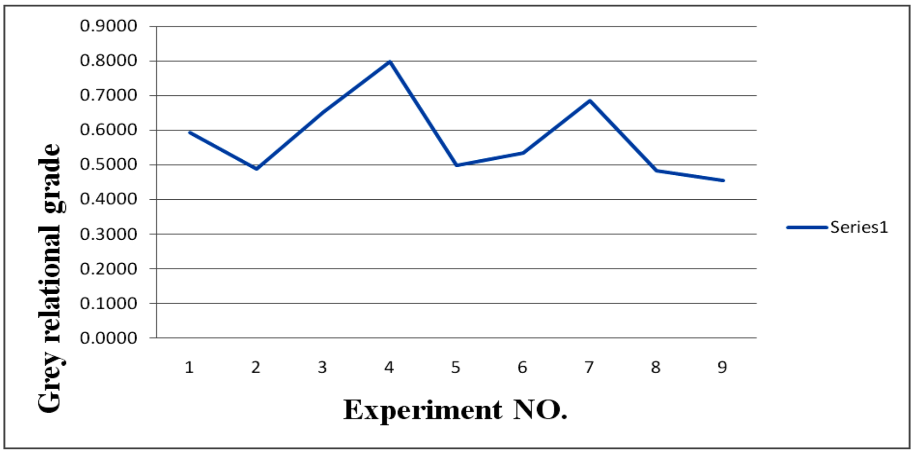

Fig. 2: Graph of Grey relational grades

Based on grey relational grade value were given by average response in table. In this table, higher grey relational grade from each level of factor indicates the optimum level. Pulse on time (120 µs), Pulse off time (40 µs) and Servo voltage (40 volts) respectively.

Table 5: 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	1.7323	1.8294*	1.6252
Pulse Off Time, B	2.0793*	1.4684	1.6392
Servo Voltage, C	1.6108	1.7403	1.8358*

8. Conclusion

In the presented work, experiments are carried out for material removal rate, surface roughness and KERF width with variables as pulse on time, pulse off time and servo voltage. There are 9 experimental readings taken for all variables to conduct the parametric study.
Finally it can be concluded that:

Grey relational analysis is done to find out optimal parameter levels. After grey relational analysis, it is found that pulse on time at level 3 (130 µs), pulse off time at level 3 (60 µs), servo voltage at level 2 (30volts) are the best process parameter for the MRR, KERF width and Surface roughness. Process parameters do not have some little effect for every response. Significant parameters and its percentage contribution changes as per the behaviour of the parameter with objective response.

Increase of Pulse on time generates more spark energy as the length of time that electricity supply increases. MRR, KERF width and SR all response increasing with pulse on time. Pulse on time found most significant parameter in all response. Surface roughness also increases with increase of pulse on time because the increases of pulse on time produce crater with broader and deeper characteristic.
Pulse off time has opposite effect to pulse on time.MRR decrease with increase of pulse off time, while surface roughness reduces. During off time removed material flushed away. More the off time better the flushing. Servo voltage has little effect on SR and KERF width but it has more effect over MRR. Surface roughness reduces with increase of servo voltage.

9. Future Scope

It would be interesting to take more input parameters like, wire feed, wire tension and flushing pressure etc.

The work was done using Molybdenum as wire electrode material. It would be interesting to compare with other wire electrode materials. Graphite, Copper-Graphite, Tungsten Copper are some of the most promising ones. It would be interesting to take different work piece material as Inconel, Hastalloy, carbides, and titanium alloys etc. for research work.

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