Evaluation of Optimal Parameters for Machining with Wire Cut EDM Using Grey-Taguchi Method

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Abstract

WEDM is one of the most extensively used non- conventional material removal processes for difficult to machine materials. It is a thermo electrical process in which material is removed from work piece by erosion effect of series of sparks between tool or work piece immersed in a dielectric liquid. There is no physical contact between tool and work piece.This is the reason, WEDM is popular in machining difficult to cut machine materials. The material selected for this investigation is HCHCR steel (D2 steel). This alloy is selected as it has high carbon content which gained dominance in the recent years where hardness and high melting are required. WEDM is one of the most suitable process to shape this alloy. For this experimentation, pulse on time (TON), wire tension setting (WT), servo feed setting (WF) have been considered as machining parameters. Material removal rate (MRR) and Surface roughness (SR) has been taken as performance measure. Taguchi's design of experiment has been employed for the present experimental investigation.

Next, the optimization of process parameters has to be done for best performance measures. Performance characteristics of WEDM maybe improved significantly by selecting optimal combinations of machining parameters. Here Taguchi grey method has been employed as a multi objective optimization technique to obtain the optimum level combination of process parameters for MRR and SR treating these performance measures as single objective separately.

Keywords

WEDM, Taguchi analysis, MRR, SR, Grey Relation Analysis (GRA)

I. Introduction

Electrical Discharge Machining (EDM), sometimes colloquially also referred to as spark machining, spark eroding, burning, die sinking, wire burning or wire erosion, is a manufacturing process whereby a desired shape is obtained using electrical discharges (sparks). Material is removed from the work piece by a series of rapidly recurring current discharges between two electrodes, separated by a dielectric liquid and subject to an electric voltage. One of the electrodes is called the tool-electrode, or simply the "tool" or "electrode", while the other is called the work piece-electrode, or "work piece". The process depends upon the tool and work piece not making actual contact.

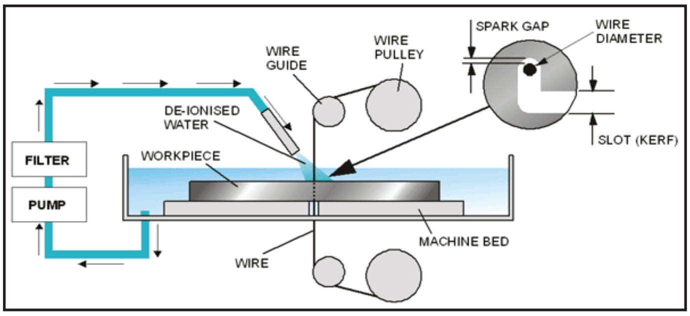

Fig. 1: Wire EDM Process

B. Main Components

1. Work-piece-all the conductive material can be worked by EDM
2. Tool Electrode-The EDM electrode is the tool that determines the shape of the cavity to be produce.
3. Dielectric fluid-The EDM setup consists of tank in which the dielectric fluid is filled. Electrode & work piece submersed into the dielectric fluid.
4. Servo system-The servo system is commanded by signals from gap voltage sensor system in the power supply and control the feed of electrode & work piece to precisely match the rate of material removal.
5. Power supply-The power supply is an important part of any EDM system. It transform the alternating current from the main utility supply into the pulse direct current (DC) required to produce the spark discharge at the machining gap.
6. The DC pulse generator- It is responsible for supplying pulses at a certain voltage and current for specific amount of time.

C. Principle of EDM

Principle of EDM Electrical Discharge Machining (EDM) is a controlled metal-removal process that is used to remove metal by means of electric spark erosion. In this process an electric spark is used as the cutting tool to cut (erode) the work piece to produce the finished part to the desired shape. The metal-removal process is performed by applying a pulsating (ON/OFF) electrical charge of high-frequency current through the electrode to the work piece. This removes (erodes) very tiny pieces of metal from the work piece at a controlled rate.

D. Applications

1. Prototype production
2. Small hole drilling
3. Metal disintegration machining
4. Closed loop manufacturing

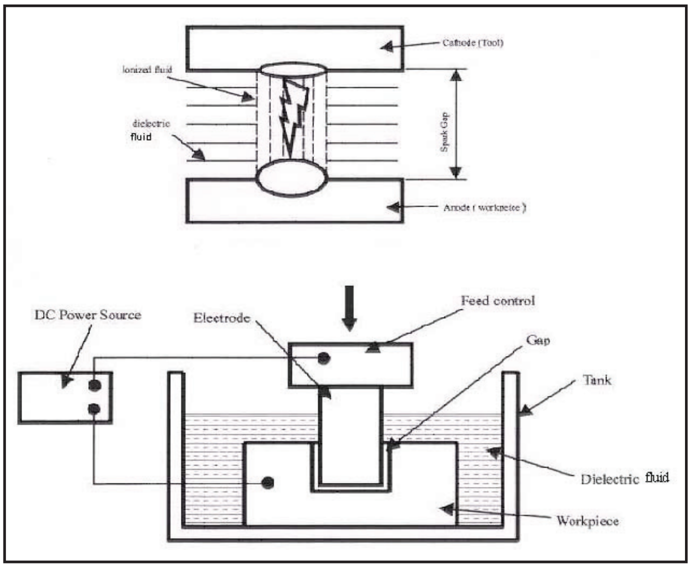

Fig. 2: Spark Erosion in a Wire EDM

II. Literature Survey

A. AISI D2 Tool Steel

Total steel refers to a variety of carbon and alloy steels, their distinctive hardness, resistance to abrasion and deformation and their ability to hold a cutting edge at elevated temperatures. As a result tool steels are suited for their use in the shaping of other materials.

With carbon content between 0.5% and 1.5%, tool steels are manufactured under carefully controlled conditions to produce the required quality. The presence of carbides in their matrix plays the dominant role in the qualities of tool steel. The four major alloying elements in tool steel that form carbides are: tungsten, chromium, vanadium and molybdenum.

Tool steels are used for cutting, pressing, extruding, and coining of metals and other materials. Their use, such as the production of injection moulds, is essential, due to their resistance to abrasion, which is an important criterion for a mould that will be used to produce hundreds of thousands of mouldings of a product or part.

B. Research Trends in EDM

WEDM is a thermo electric process in which material is removed from work piece by erosion effect of series of sparks between tool and work piece immersed in a dielectric liquid. This process is widely used in aerospace, nuclear and automotive industries in order to satisfy safety production and quality requirements.

C. Material Removal Rate and Surface Roughness

In WEDM process, MRR and SR determine the economics of machining and rate of production. During 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. Earlier researches conducted experiments for MRR on EDM processes for the following reasons. To improve MRR and SR for hard and difficult to machine materials, to prepare technological data tables in machining in various tables. The findings of various researches in EDM and WEDM processes on MRR are presented here.

D Scott (1991) optimized EDM process parameters while machining of aluminium composites. The process parameters considered were pulse current, gap voltage and pulse on time whereas the responses are MRR and SR. L8 orthogonal array was selected. It has been found that optimum conditions are different for these responses. It has been proved that the optimum setting of parameters showed considerable enhancement in the responses which has been conformed experimentally.

Y.S.Tarng (1995) studied WEDM by Grey Taguchi method. This method was used to study the effect of each machining parameter on the performance measure and to determine optimum level of each parameter such as peak current, gap current, duty cycle and pulse on time. An L9 orthogonal array was adopted. It has been proved that these parameters have a considerable effect on MRR, SR. It has been observed that peak current effects MRR and pulse on time effects SR considerably.

Marafona et al (2000) optimized MRR while EDM using fractional factorial method developed by taguchi when copper tungsten electrodes were employed. The input parameters were selected as ram speed, current intensity, pulse duration, gap compression and cycle time. MRR and SR were the output parameters considered for optimization. It has been found that this method is successfully used to optimize the output parameters.

B.Nagaraju (2006) optimized EDM process parameters while machining of titanium. Taguchi method was employed with multi performance characteristics. The input parameters such as powder concentration, peak current, pulse duration and pulse on time are optimized for the output parameters like MRR, SR and TWR. An L9 orthogonal array was selected. It has been observed that peak current and pulse on time or the most significant factors. The predicted optimum values of output parameters are verified experimentally.

Bharati et al (2010) investigated EDM characteristics of Inconel 718. Experiments were carried out to study the effects of shape factor, pulse on time, discharge current, gap voltage, flushing pressure and electrode lift time on MRR, SR and TWR. Taguchi method was employed. Experiments were conducted as per the L36 orthogonal array. Discharge current and pulse on time have been found the most influential factors influencing factors affecting the MRR, SR and TWR.

III. Design of Experiment

Based on literature survey and preliminary investigations, the process parameters chosen as inputs are 1) pulse on time 2) wire tension setting 3) servo feed setting. The working range of input parameters and the levels taken are shown in the table 3.1.

The performance measures taken in this work are material removal rate (MRRmm^3/min) surface roughness SR (μm).

Table 3.1: Machining Parameters and their levels for Experimentation

Parameter	Units	Level1	Level 2
Pulse on time	Seconds	6	7
Wire tension setting	Kg-f	3	4
Servo feed setting	m/min	5	6

In this work L_4 orthogonal array has been used to carry out the experiment. The OA is shown in the Table 3.2. Experimental analysis has been performed after conducting the experiments as per L_4 mixed OA in the subsequent chapters.

Table 3.2. Mixed orthogonal array L_4 for experimentation

Experiment	P1	P2	P3
1	1	1	1
2	1	2	2
3	2	1	2
4	2	2	1

A. Experimental Setup

Wire electrical discharge machining (WEDM) is a nontraditional thermo electric process which erodes material from the work piece by a series of discrete sparks between a work piece and a wire electrode separated by a thin film of dielectric medium. The parameter settings employed for machining the material determines the surface roughness and MRR.

1. Work Piece Material

The material used in wire EDM process is High Carbon, High Chromium (HCHCR) steel which is the most highly alloyed steels. According to AISI standard, this type of steel is D2 steel. D2 Die steel is an air hardening steel. It has high wear and abrasion resistant properties. It is heat treatable and will offer hardness in the range 55-62 HRC, and is machinable in the annealed condition.

Table 3.3. D2 Steel Material Chemical Composition

Material	C	Si	Cr	Mo	V
% composition	1.50	0.30	12.00	0.80	0.90

2. Tool Electrode Material

Brass wire is used as electrode material in wire EDM. It is used for good conductivity and tensile strength as shown in Table 3.4. 0.25 mm diameter wire is used as the electrode material, with a diameter of less than 0.1 mm is commonly made of tungsten or molybdenum, whereas the larger wire diameter made of brass.

Table 3.4. Properties of Wire Electrode Material Brass

Wire electrode	Tensile strength (MPa)	Elongation	Electrical conductivity (%)
Brass	1080	2.1	22

3. Machine Tool Identification

All the experiments are conducted on Spin cut Electronic machine as show in fig. 3. In this machine, a series of electric pulses are applied between the work piece and travelling wire electrode. In the event of spark discharge, there is a flow of current across the wire electrode and work piece gap. The energy contained in a tiny spark discharge removes a fraction of work piece material. Large number of such time spaced discharges between the work piece and wire electrode causes the electro erosion of the work piece material.

Fig. 3: Spin Cut Electronic Machine

4. Machine Tool

The machine tool comprises of main work table (X-Y table), an auxiliary table (U-V table) and a wire drive mechanism. The work piece is mounted and clamped on the main work table. The main work table moves along X and Y axes by means of servo motor. A travelling wire which is commonly fed from wire feed is caused to travel through the work piece and goes finally top the waste wire box. Along its travelling path, the wire is supported under tension, between a pair of wire guides which are disposed on both sides of the work piece. Lower wire guide is stationary, where the upper wire guide is supported by the U-V table.

As the material removal or machining proceeds, the work table carrying the work piece is displaced transversely along a predetermined path which is stored in the controller. The path specifications can be supplied to the controller through controller key board. The path information of X-Y table and U-V table is given to the controller in terms of linear and circular elements as a NC program. The profile geometry is defined in terms of various geometrical definitions of point, line and circle as a wire tool path elements on graphical screen, by using a totally menu driven software. After the profile is fed to the computer, all the numerical information about the is calculated automatically

5. Power Supply Unit

The power supply unit comprises of iso-frequent pulse generator with a maximum operating current of 30A, motor driver units for X-Y, U-V axes and controller. Pulse generator for generating electric pulses and drive units for movement of tables along X, Y, U and V axes.

6. Dielectric Fluid

When machining is continued, the machining zone is continuously flushed with water passing through nozzles on both sides of the work piece. The spark discharge across the work piece and wire electrode causes ionization of the water which is used as a dielectric medium. The dielectric fluid used in this work is de-ionized water. Functions of dielectric fluid is to flush away the eroded particles , acts as an insulator of the wire and work piece gap and also it acts as a coolant of wire and work piece.

The detailed technical specifications of the machine tool used are given as below:

Work table dimensions X * Y: 300x400mm
Max. Work piece height : 200 mm
Max. Table size : 440 x 650 mm
Max. Cutting speed : 160 mm^2 / min
Max. Job weight : 300 kg
Max. Electrode weight : 100 kg
Dielectric capacity : 400 litres
Feed motor for servo system: DC servo
Power supply : 3 Phase, AC 415V, 50Hz
Best surface finish : 0.8 μ Ra

B. Experimental Procedure

The experimental runs were performed based on the basis of mixed orthogonal array L(2×3). The process parameters and their levels are shown in table. The trial runs were carried out to select the parameters was carried out to select the parameters and their respective levels. Three parameters were taken each of two levels. By using a brass wire, which is of 0.25 mm diameter, a 15 mm opening of square and 25 mm depth of four samples were made as shown in fig. 4.

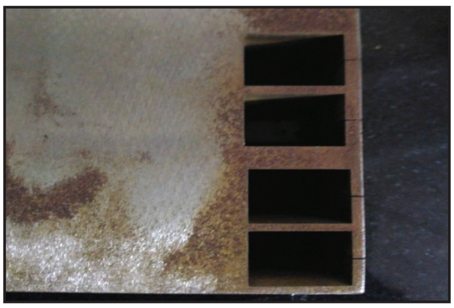

Fig. 4: Cutting of Four Parts

C. Performance Characteristics

1. Material Removal Rate (MRR)

For the calculation of material removal rate, the cutting speed values which are displayed on the monitor of the machine tool are taken for various settings of the experiment. From this data by using equation (4.1) the MRR can be calculated
MRR = Cutting speed ×Width of cut x Height

2. Surface Roughness

Surface integrity is the sum of all elements that describe all the conditions existing on or at the surface of a piece of finished hardware. Surface integrity has two aspects. The first is surface topography which describes the roughness, lay or texture of the outmost layer of the work piece that is its interface with the environment. Roughness is a measure of texture of the surface, which is quantified by the height of the closely spaced irregularities over a short length. This is called as the cut –off length. The second is the surface metallurgy which describes the nature of altered layers below the surface with respect to the base or matrix material. After the machining, responses for the surface roughness are displayed on the monitor and calculate further.

IV. Experimental Investigation

When the input process parameters are given for machining, we get different responses for four experiments. The MRR and surface roughness responses are displayed or calculated for each experimental run. The main objective is to optimize these parameters for wire cut EDM process. So for studying these parameters, we have a analysis named taguchi analysis.

A. Taguchi Analysis

As per taguchi the predicted data provided by the mathematical models can be transformed into a signal-to-noise (S/N) ratio. The characteristic that higher value represents better machining performance, such as MRR higher-the-better, HB ; and inversely, the characteristic that lower value represents better machining performance, such as surface roughness is called lower-the-better, LB. Therefore, HB for the MRR, LB for the SF has been selected for obtaining optimum machining performance characteristics. The S/N ratio can be calculated as a logarithmic transformation of the loss function as shown below. The optimal setting would be the one which could achieve highest S/N ratio.
S/N ratio for MRR = -10log 10(LHB)
S/N ratio for SF = -10log 10 (LLB)

B. Signal to Noise Ratio (S/N Ratio)

The signal to noise ratio for parameters MRR and surface roughness in each experimental run is given below Table 4.1. The material removal rate (MRR), signal to noise ratios which are varied in two levels for four experiments are positive as shown because of the higher the better machining performance. The surface roughness, signal to ratios which are varied in two levels for four experiments are negative as shown because of the lower the better machining performance.

Table 4.1: S/N ratios for MRR and Surface Roughness

S no	TON	WT	WF	MRR	RA
1	1	1	1	9.75186	1.3371
2	1	2	2	10.5748	1.2349
3	2	1	2	11.00836	1.14321
4	2	2	1	11.2124	0.8751

So from these values taguchi analysis cannot optimize single objective function.

V. Multi Optimization Techniques

A. Grey Relation Analysis (GRA)

The process involves Grey relational analysis, Grey modeling, prediction and decision making of the system for which model is unsure. In grey relational analysis, the first step is to normalize experimental data ranging from zero to one. The process is known as grey relational generation. Based on normalized experimental data, calculation of grey relational coefficient, to represent the correlation between the desired and actual experimental data, is the second step. Then, final step is determination of overall grey relational grade which is done by averaging the grey relational coefficient corresponding to selected responses. By this approach a multiple response process optimization problem is converted into a single response optimization problem with overall grey relation grade being the objective function. In grey relational generation, the normalized data i.e. Ra surface finish corresponding to lower-the-better (LB) criterion can be expressed as:

$$x_i(k) = \frac{max\,y_i(k) - y_i(k)}{max\,y_i(k) - min\,y_i(k)}$$

For MRR should follow higher-the-better criterion (HB), which can be expressed as:

$$x_i(k) = \frac{y_i(k) - min\,y_i(k)}{max\,y_i(k) - min\,y_i(k)}$$

where x_i (k) is the value after grey relational generation, min y_i(k) is the smallest value of y_i (k) for the kth response, and max y_i (k) is the largest value of y_i (k) for the k^{th} response. The normal ideal sequence for the responses is x0 (k) (where k=1, 2, 3... 27). The grey relational coefficient ξ_i (k) can be expressed as follows

$$\xi_i(k) = \frac{\Delta_{min} - \psi\Delta_{max}}{\Delta_{0i} - \psi\Delta_{max}}$$

Where Δ0i= difference of absolute value x_0(k) and x_i (k); ψ is the distinguishing coefficient 0 ≤ψ ≤1; usually taken as 0.5 Δmin = the smallest value of $\Delta 0_i$; Δmax = the largest value of $\Delta 0_i$. After averaging the grey relational coefficients, the grey relational grade γ_i can be computed as:

$$\gamma_i(k) = \frac{1}{n}\xi_i(k)$$

Where γ_i is the grey relational grade and n is the number of performance characteristics. The best process sequence is taken as reference sequence x_0(k).The intense relational degree between the reference sequence x_0(k) and the given sequence x_i (k) corresponds to the higher value of grey relational grade. Hence, higher grey relational grade means that the corresponding parameter combination is closer to the optimal.

B. Analysis of Parameters

Table 5.1: Normalized S/N Data

Experiment	MRR	RA
1	0	1
2	0.5201	0.7878
3	0.8389	0.6969
4	1	0

Table 5.2: Evaluation of Δ_{0i}

Experiment	MRR	RA
1	1	0
2	0.4799	0.2122
3	0.1611	0.3031
4	0	1

Table 5.3: Grey Relational Grade for Performance Characteristics

Experiment	MRR	RA	Grey Relational Grade
1	0.125	0.25	0.1875
2	0.16893	0.20623	0.18958
3	0.21531	0.19185	0.20358
4	0.25	0.125	0.1875

VI. Conclusion

We studied the machining of HCHCR steel (D2 steel) for two levels in four experiments using wire cut EDM process. For optimization of input parameters we studied the taguchi and grey relational analysis. The grey analysis shows the optimization of input process parameters.

From Table5.3 for HCHCR by Wire Cut EDM shows the highest grey relational grade, indicating the optimal process parameter set of TON2, WT1, and WF2. It has the best multiple performance characteristics among the four experiments, which can be compared with results of confirmation experiment for validation of results.

Highest Grey relational grade = 0.20358

Input Process Parameters:

Pulse on time (TON) = 7 seconds

Wire tension (WT) = 3 kgf

Wire feed setting (WF) = 7 m/min

At these values of input parameters given to Wire Cut EDM, we obtained the optimal values of Material Removal Rate (MRR) and Surface Roughness (RA).

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