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PARAMETRIC OPTIMIZATION OF WEDM USING GREY RELATIONAL ANALYSIS WITH TAGUCHI METHOD

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ABSTRACT

Wire EDM is one of the latest advanced micro-machining techniques, where a thin wire (Ǿ= 0.25 mm) of tool electrode is fed on the work piece which gradually shears off the material during the machining process. This micro-machining process may help overcome the limitations and restriction faced during conventional mechanical machining process. This paper is based on wire-EDM machining of a particular ISO standard Aluminium material. The varying input parameters are identified as Servo Voltage (V), Pulse on Time (T_{on}), Pulse off Time (T_{off}) and wire tension and the outputs response is measured and analyzed in terms of Surface Roughness (R_a). Taguchi's method has been utilized for design of experiment followed by parametric optimization of wire EDM using GRA.

KEYWORDS: Wire-EDM, TAGUCHI'S Method, GRA

INTRODUCTION

Wire Electrical discharge machining (WEDM) is a nontraditional, thermoelectric process which erodes material from the work piece by a series of discrete sparks between a work and tool electrode immersed in a liquid dielectric medium [1]. These electrical discharges melt and vaporize small amounts of the work material, which are then flushed away by the Dielectric. Wire electrical discharge machining (WEDM) is a specialized thermal machining process capable of accurately machining parts with varying hardness or complex shapes, very difficult to be machined by the other machining processes. Wire-cut EDM (WEDM) is one of the most favorable variants owing to its ability to machine conductive, exotic and high strength and temperature resistive (HSTR) materials with the scope of generating intricate shapes and profiles [2]. It uses a thin continuously traveling wire feeding through the workpiece by a micro-processor eliminating the need for elaborate reshaped electrodes, which are required in the EDM. The Wire-Cut EDM process uses a thin copper wire of diameter about 0.1 to 0.3 mm as the electrode and the workpiece is mounted on a CNC controlled worktable, enabling complex two dimensional shapes can be cut on the work piece by controlled the movement of the X-Y worktable [3]. Wire EDM process is widely applied not only in tool and die-making industry, but also in the fields of medicine, electronics and the automotive industry [4].

Wire Cut EDM Applications

Because of its versatility, it can be used for the different purposes by manufacturers for a number of applications. Since the process can cut very small pieces, it is often an ideal choice for the production of small, highly detailed items that would normally be too delicate for other machining options [5]. Additionally, the process is cost effective for low quantity projects, and can prove to be beneficial in prototype manufacturing. It is important to remember that the wire in the process is constantly moving, and should not be reused. As a result, the copper, brass or other metallic wire can be kilometers long, adding to the cost. And, while the process uses no force and thus does not cause burrs and can be used on delicate items, the possibility of thermal stress is certainly present [6].

Working Principle of WEDM

A model of WEDM is shown in figure 1. The electric discharge is caused to occur erratically in a pulse-like manner between an electrode wire and a work piece through a processing liquid so as to fuse-cutting the work piece in a desired configuration. A pulse voltage is applied between the wire electrode and work piece in the processing fluid to melt the surface of the work piece by the thermal energy of an arc discharge, while at the same time removing machining dust through a vaporizing explosion and recirculation of the processing fluid. The residue resulting from the melting of a small volume of the surface of both the work piece and the EDM wire electrode is contained in gaseous envelope. The plasma eventually collapses under the pressure of the dielectric fluid. The liquid and the vapor phases created by the melting are quenched by the dielectric fluid to form solid debris. This process is repeated at nanosecond interval along the length of the wire in cutting zone [7].

The fishbone diagram showing varying input parameters and process performance of WEDM is shown in figure 2.

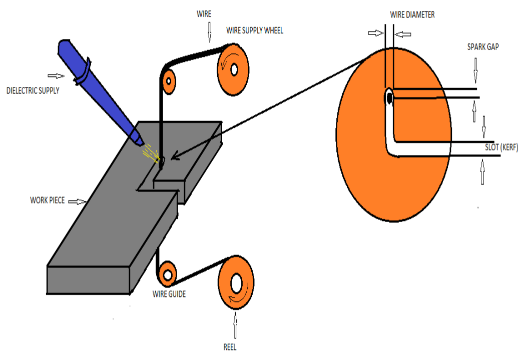


Figure 1: WEDM Set-up

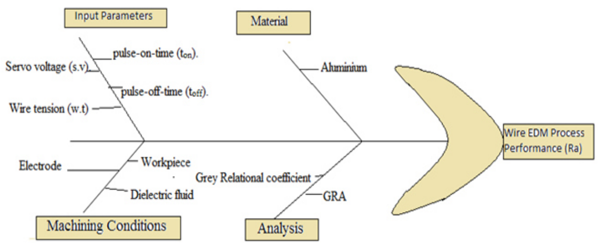


Figure 2: Fishbone Diagram of WEDM [7]

METHODOLOGY OF EXPERIMENT AND DATA COLLECTION

The input process parameters are indentified as:

- Pulse duration or pulse-on-time (t_{on}).
- Pulse interval or pulse-off-time (t_{off}).
- Servo voltage (s.v).
- Wire tension (w.t).

The output response is taken as:

- Surface Roughness (R_a)

Machining Conditions

Table 1: Machining Conditions

Conditions	Descriptions
Workpiece (+)	Alumunium.
Electrode (–)	Brass 0.25mm diameter.
Dielectric fluid	Kerosene.
Pulse-on-time (µs)	15-25
Pulse-off-time (µs)	50-60
Servo voltage (v)	40-60
Wire tension (gram)	5-7

Experimental Matrix and Results for the WEDM Performance Characteristics

Table 2: Design of Experimental Matrix

Expt No.	Process Parameters			
	Pulse-on-Time (t_{on}) (µs)	Pulse-off-Time (t_{off}) (µs)	Servo Voltage (s.v) (v)	Wire Tension (w.t) (Gram)
1	15	50	40	5
2	15	55	50	6
3	15	60	60	7
4	20	50	50	7
5	20	55	60	5
6	20	60	40	6
7	25	50	60	6
8	25	55	40	7
9	25	60	50	5

Process Parameters and their Levels

Table 3 Shows the Process Parameters and Their Levels and Table 4 Shows Process Parameters and Their Coded Levels.

Table 3: Design Scheme of Process Parameters and their Levels

Factor Symbol	Parameter	Levels		
		Low (1)	Medium(2)	High (3)
A	Pulse on time, T_{on} (µs)	15	20	25
B	Pulse-off-time (µs)	50	55	60
C	Servo voltage (V)	40	50	60
D	Wire tension (gram)	5	6	7

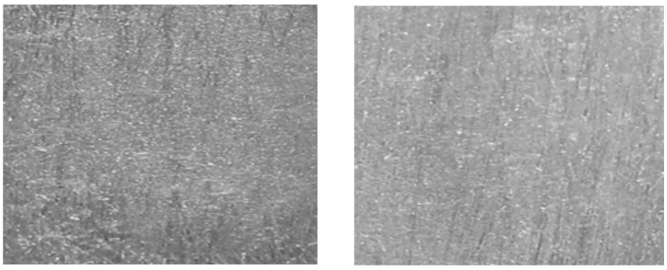
Table 4: Experimental Matrix with Process Parameters and their Coded Levels

Expt No.	Process Parameters			
	Pulse-on-Time (t_{on}) (µs)	Pulse-off-Time (t_{off}) (µs)	Servo Voltage (s.v) (V)	Wire Tension (w.t) (Gram)
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Observed Values of Output Responses

Table 5: Observed Values of Output Responses

Expt No.	R_a(µm)		
	I	II	Average
1	2.123	1.445	1.784
2	2.246	1.492	1.869
3	2.321	1.736	2.0285
4	1.997	1.658	1.8275
5	2.523	1.176	1.8495
6	1.993	1.139	1.566
7	2.056	1.655	1.856
8	2.547	1.690	2.118
9	2.182	1.347	1.7645



(a) (b)

Figure 3: (a) Surface Finish of Raw Al Alloy
(b) Super Finished Surface of Al Alloy with Emery Paper

GREY RELATIONAL ANALYSIS

The grey relational analysis (GRA) is one of the powerful and effective soft-tool to analyze various processes having multiple performance characteristics. In actual practice, the situation comes in a state which is neither perfectly black (with no information) nor perfectly white (with complete information), the condition described as being grey. Generally, GRA is carried out for solving complicated problems which have interrelationships among the designated performance characteristics.

Normalization of the Experimental Results in GRA

Normalization is the process in which transformation of input data takes place to an evenly distributed data in a scale range between 0 and 1. The experimental results for the responses i.e. Ra are normalized using equations where x_{ij} is the normalized value of y_{ij} [8-9]

Since the response Ra is of smaller-the-better type, then normalized value x_{ij} is expressed as,

$$x_{ij} = \left(\max\left(y_{ij}\right) - y_{ij}\right) / \left(\max\left(y_{ij}\right) - \min\left(y_{ij}\right)\right) \quad (1)$$

The normalized values of output response is shown in table 6.

Grey Relational Coefficient

The grey relational coefficient is calculated to determine the closeness of x_{ij} to x_{0j}. Higher value of grey relational coefficient means x_{ij} is closer to x_{0j} [9-10]. Grey relational coefficient is calculated based on equation (2).

$$\gamma\left(x_{0j}, x_{ij}\right) = \left(\Delta_{min} + \xi\Delta_{max}\right) / \left(\Delta_{ij} + \xi\Delta_{max}\right)$$

for i = 1, 2, 3, ….., m and j = 1, 2, 3, …., n …… (2)

where,

$$\Delta_{ij} = \left| x_{0j} - x_{ij} \right|$$

ξ = distinguishing coefficient, $i \in (0,1)$

$$\Delta_{min} = \min\{\Delta_{ij}, i = 1,2,3,....,m, \quad j = 1,2,3,....,n\}$$

$$\Delta_{max} = \max\{\Delta_{ij}, i = 1,2,3,....,m, \quad j = 1,2,3,....,n\}$$

The normalized values of each of the responses for all 9 experiments are used to calculate the grey relational coefficient using equation (2). The distinguishing coefficient ξ is taken as 1.

Grey Relational Grades

Grey relational grade is the weighted sum of the grey relational coefficients for a particular experiment and it is calculated using equation (3) [10-11].

$$\Gamma\left(X_0, X_i\right) = \sum_{j=1}^{n} wj \cdot \gamma\left(x_{0j}, x_{ij}\right)$$

for i = 1, 2, 3,..., m and j = 1, 2, 3, …., n ……… (3)

where, $\Gamma_{(X0, Xi)}$ is grey relational grade between comparability sequence

X_i and reference sequence X_0 and

$$\sum_{j=1}^{n} w_{ij} = 1$$

The grey relational grades of output response is shown in table 8.

Table 6: Normalization Values of Results

Expt. No	R_a(µm) X_{ij}
1	0.6050725
2	0.4510869
3	0.1621377
4	0.5262682
5	0.4864131
6	1
7	0.4746377
8	0
9	0.6403986

Table 7: Deviation from Ideal Sequence of Ideal Solution

Expt. No	Deviation of Ra (1-X_{ij})
1	0.3949275
2	0.5489131
3	0.8378623
4	0.4737318
5	0.5135869
6	0
7	0.5253623
8	1
9	0.3596014

Table 8: Grey Relational Grades

Expt No.	R_a(µm)	Coeff of R_a(µm)	Grey Relational Grades	Order
1	0.3949275	0.7168832	1.3949274	7
2	0.5489131	0.6456141	1.5489129	3
3	0.8378623	0.5441104	1.8378623	2
4	0.4737318	0.6785495	1.4737318	6
5	0.5135869	0.6606823	1.5135867	5
6	0	1	1	9
7	0.5253623	0.6555819	1.5253624	4
8	1	0.5	2	1
9	0.3596014	0.7355097	1.3596014	8

Table 9: Average and Range of Grey Relational Grade

Parameters	Average Grey Relational Grade			Max-Min (Range)
	Level 1	Level 2	Level 3	
Pulse on time, T_{on} (µsec)	1.59390086	1.32910616	1.62832126	0.2992151
Pulse-off-time (µsec.)	1.46467387	1.68749987	1.39915457	0.2883453
Servo voltage (v)	1.4649758	1.4607487	1.6256038	0.1648551

Table 9: Contd.,

Wire tension (gram)	1.42270517	1.35809177	1.77053137	0.4124396
Mean Value of the Grey Relational Grade = 0.291213775				

RESULTS AND DISCUSSIONS

By using GRA, it was found that the experiment number 8 has the maximum value of grey relational coefficient, which is the best run as shown in Table 8. The optimized process parameters are 25µs/55µs /40v/7g/. respectively. Wire tension 'WT' was found to be the most influencing factor since it has the maximum value of range of average grey relational grades as shown in Table 9, followed by pulse-on time 't_{on}' and then 't_{off}' and finally the least influencing factor servo voltage SV.

WT > t_{on} > t_{off} > SV

It was observed that with increase in pulse-on-time t_{on} and servo voltage SV, the surface roughness R_a also increases. R_a was also found to increase with increase in wire tension WT. It was also observed that with increase in pulse-off-time $t_{off,}$ R_a increased to a certain limit and then decreased.

CONCLUSIONS

- The experiment number 8 which has highest grey relational grade is said to be best choice of all the runs. The optimized process parameters are found to be 25µs/55µs /40v/7g/.
- WT was found to be the most influencing factor in WEDM process followed by $t_{on,}$ and then $t_{off,}$ and finally the least influencing factor SV.
- With increase in pulse-on-time $t_{on,}$ and wire tension WT, the surface roughness R_a also increases.
- It is also concluded that with increase in pulse-off-time t_{off} R_a also increased to a certain limit and then decreased.

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