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Parametric Optimization of WEDM in Machining HSS (8X200)

Abstract:- *Nontraditional machining processes are used for machining too hard, brittle and strong conductive materials. The aim of this research is to achieve an economic and efficient machining process in machining HSS by using wire cut machine. Experimental investigations were conducted on WEDM with using different machining parameters such as (pulse duration (µs), pulse interval (µs), Servo feed and Servo voltage (V)). The experiments were designed according to DOE, which is done by using Taguchi design parameter method to investigate the optimum machining parameters, which gives the best values for MRR and CS in order to achieve an economic and efficient machining process. The results obtained from the experimental work show that the optimum values of MRR and CS are obtained with the best values of Servo voltage (V), pulse duration (µs), pulse interval (µs), Servo feed and which they are presented with (A1, B3, C2 and D3) which they are equal to (20 v, 120 µs, 35 µs, and 450 mm/min).*

Keywords- *WEDM, Taguchi orthogonal array (TOA), Material removal rate (MRR), Cutting speed (CS), SV, SF, Ton, Toff..*

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1. Introduction

Non-traditional manufacturing processes removing materials by using different types of energies such as (mechanical, thermal, electrical, chemical, or combinations of these types), without using a cutting tool. Wire Electrical Discharge Machining (EDM) is a unique type of spark erosion process that uses electricity to cut the conductive materials correctly and accurately. A metal is removed by a sequence of separate discharges between the wire electrode and the workpiece in the attendance of dielectric fluid by using a slim wire, which is good electrical conductivity such as copper or brass. The wire carries one side of an electrical charge and the workpiece carries the other side of the charge as shown in Figure 1. Wire EDM machine uses deionized water as a dielectric solution of for cooling and flushing the machining region during the machining process [1].

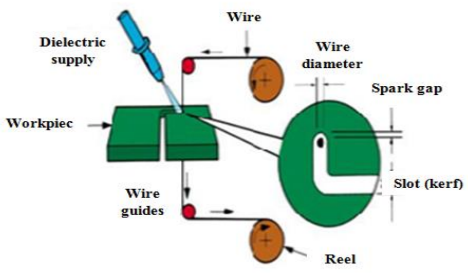

Figure1: The schematic representation of Wire Electrical Discharge Machining (WEDM).

A Titanium alloy (Ti6Al4V) had been chosen as a workpiece material is machined by wire electrical discharge machining WEDM and the study of eight cutting parameters (Ignition pulse current (A), Short pulse duration(B), Time between two pulses(C), Servo speed(D), Servo reference voltage(E), Injection pressure(F), Wire speed(G) and Wire tension(H)) is intentional by [2]. This study is aimed for reaching an optimal value of a surface roughness by using genetic algorithm (GA), the relationship between a surface roughness as a response and the eight parameters of cutting is controlled by using taguchi design as L27 (38) orthogonal array. A wire discharge electrical machining is discussed by [3], with applying taguchi design with different factors for obtaining a maximum value of MRR (Metal Removal Rate) and a minimum value of SR (Surface Roughness) with computing a predicted result from taguchi design. [4], have been improving the efficiency of machining process by considering a metal removal rate and a surface roughness as responses of experimental with applied different variables (wire tension, servo feed, servo voltage, pulse on time, pulse off time). This design done by using taguchi orthogonal array (L25) to reduce the number of experimental working. WEDM machining process is used to manufacture a Titanium Grade5(Ti-6Al-4V) with a brass wire with diameter (0.25) mm. [5]. They were machined a Titanium alloy (Ti-4.5Al-2V) in WEDM. A design method of experimental (DOE) for cutting parameters (peak current, pulse on, pulse off, taper angle, and dielectric flow rate), which have been analyzed by using the help of taguchi with minitab15 software, and determined a best optimal conditions for getting a least amount of surface roughness and a highest metal removal rate with help of ANOVA. [6], they investigated that the change of parameters in wire EDM (Servo Feed (SF), pulse off-time (TOFF), pulse on-time (TON)) as inputs affected on material removal rate and surface roughness as outputs on machining steel (AISI 1015), and The personality of cutting variables were obtained by implementing Taguchi experimental design method in this work.

2. The experimental work

I. the experimental setup

This section involves the specification of machine, wire and a workpiece. The wire electrical discharge machining process is done by using 4-axis (ELEKTRA DEM 400 A) EL PULSE 5 wire cut machine which exist in workshop of University of Technology-Iraq. The specifications of this machine are listed in a Table1 below:

Table 1: Specification of WEDM machine

Maximum workpiece dimensions.	Maximum workpiece weight	Table travel in (X,Y,Z)	U and V axis travel	Maximum table feed rate	Wire diameter range	Wire tension	tolerance
(350*440*300) mm	300 Kg	(250*350*210)mm	30*30mm	180 mm/min	0.1-0.33 mm	2-10 Kgf	0.001 mm
Guide of wire	Work fluid	Maximum current	Supply voltage	power	Power needed	Soft ware	
steel	Distill water	12 A	400 V	DC power	4.5 KVA	CAD/CAM	

The variables of a machine fixed are:
1. Metal sort of a workpiece is a high speed steel.
2. A wire cutting is made of brass with a diameter of 0.25 mm.
3. A wire tension is equal to (6) kgf .
4. The dielectric that used in a machining is pure (distilled) water.
5. A voltage is fixed at 11 volt (V) and the current is fixed at 12 ampere (A).

The parameters that are changed their values in this work:

1-Pulse on time (TON): is a period of time when the voltage is useful across the gap, with maximum values of (TON) will produce a large amount of metal removal rate with a small value of surface roughness [7]. Pulse on time is called also pulse duration, which expressed it in microsecond unit [8].

2-Pulse off time (POFF): is a period of time when the voltage is absent across the gap. In this time, the flush will be removed by the dielectric prior to the next discharge. Lowest value of pulse off time will increase the cutting speed, and this time expressed it in microsecond unit [8].

3-Servo feed (SF): The feed rate of the table during the machining process is called servo feed, this factor may be specified automatically with respect of servo voltage or manually. In this work, the value of (SF) is set manually [7].

4. Servo voltage (SV): The advance and retract of a wire is controlled by a servo voltage. The wire will advance if the mean voltage of a machining is upper than a servo voltage set level, and it will be retract if the mean voltage of a machining is lower [7].

A material removal rate and cutting speed are the responses variables in this work, which are defined as:

1) 1.Material Removal Rate (MRR):

The efficiency and the cost of the machining process are intensively affected by a material removal rate in the wire EDM process [7]. It means the removed.

Material volume per machining time, which expressed by a unit (mm3/min) [6], and measured by the relationships as follow:

$$MRR = Vc * b * H \quad (1)$$

$$b = d\ wire + 2 * S \quad (2)$$

MRR = Material Removal Rate (mm3/min).
Vc = cutting speed in (mm/min).
b = cutting width in (mm).
H = workpiece thickness in (mm).
d wire = wire diameter in (mm).
S = spark gab in (mm).

2) The cutting speed:

The efficiency of the machining process is affected with (CS) as well as (MRR). A cutting speed can be calculated by division the travel length of a wire on the total time, and expressed on it (mm/min) [9]. In addition, it is different from material to another in WEDM process depending on the conductivity and the melting properties of a material. A rod of HSS (8X200) with dimensions (8*8*200) mm and the chemical composite of this rod is measured in Midland Refineries Company according to standard and codes ASME SEC.II P.A, which listed in Table 2.

Table 2: Chemical composition of the workpiece

material	C	Si	Mn	C	Mo	Ti	V
weight	1.1	1.28	0.4	1.0	0.08	0.007	0.0

This workpiece is cut by using a soft brass wire with diameter (0.25) mm in WEDM machine according to a design of taguchi to nine pieces with thickness equal to (3) mm. Figure 2, shows the workpiece (a) before machining, (b) front view of workpiece after machining and (c) side view of workpiece after machiuning .

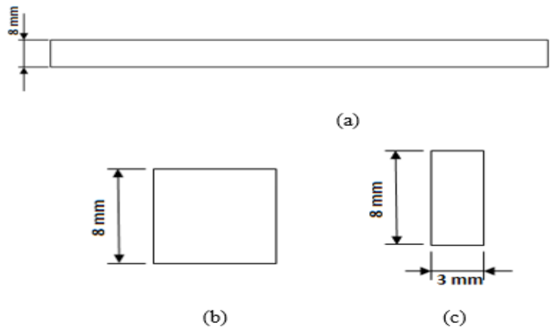

Figure 2: The workpiece (a) before machining, (b) and (c) after machining

II. The experimental design

The experimental works involve machining according to taguchi design with MINITAB 17 for reducing the number of experimental to the minimum number. Taguchi technique is a developing method for designing the experimental to study the effected of different parameters on the mean and signal to noise ratio, reducing the cost of production and achieving time [10]. In this work four parameters (servo voltage, servo feed, pulse on time, and pulse off time) are used with three levels as shown in Table 3.

So the design is appeared in a worksheet as in Figure 3 below:

Table 4 explains the four parameters with three levels, machining the nine experiments (Taguchi orthogonal array design).

Table 3: The parameters of machining with its levels

parameters	First level	Second level	Third level
Servo voltage (SV)	A1=20	A2=21	A3=22
Pulse on time (µs) (PON)	B1=110	B2=115	B3=120
Pulse off time (µs) (POff)	C1=30	C2=35	C3=40
Servo feed mm/min	D1=350	D2=400	D3=400

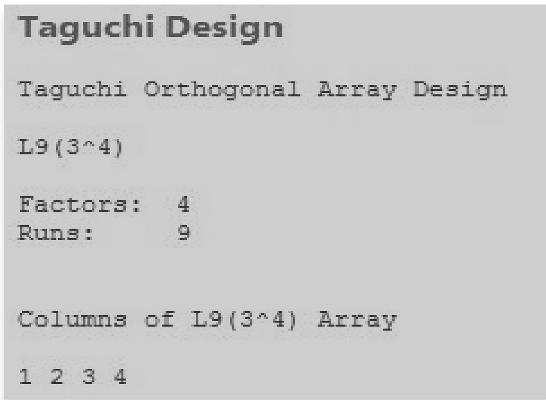

Figure 3: Taguchi design worksheet

Table 4: Taguchi Orthogonal Array Design

No.	Servo voltage (V)	Pulse duration (µs)	Pulse interval (µs)	Servo feed (mm /min)
1	A1	B1	C1	D1
2	A1	B2	C2	D2
3	A1	B3	C3	D3
4	A2	B1	C2	D3
5	A2	B2	C3	D1
6	A2	B3	C1	D2
7	A3	B1	C3	D2
8	A3	B2	C1	D3
9	A3	B3	C2	D1

3. The result and discussion:

I. An analysis of the results and discussion for cutting speed as a response factor:

After machining the nine processes in WEDM machine the cutting speed and material removal rate are studied as responses factors. At first the cutting speed factor will be studied and analyzed. After the machining processes are done on wire cut machine, the values of cutting speed were obtained from WEDM machine, and the analysis of cutting speed (S/N) ratio and mean with respect to the four variables are shown in Table 5. The S/N ratio is quoted in decibel (db) [11].

Table 5: Design of experiments factors with a cutting speed as a response factor

No.	Servo voltage (V)	Pulse duration (μs)	Pulse interval (μs)	Servo feed (mm/min)	Cutting speed (mm/min)	S/N ratio (decibel)	Mean (mm/min)
1	20	110	30	350	1.227	1.77689	1.227
2	20	115	35	400	1.700	4.60898	1.700
3	20	120	40	450	1.855	5.36688	1.855
4	21	110	35	450	1.382	2.81016	1.382
5	21	115	40	350	1.172	1.37855	1.172
6	21	120	30	400	1.276	2.11701	1.276
7	22	110	40	400	1.433	3.12492	1.433
8	22	115	30	450	1.361	2.67716	1.361
9	22	120	35	350	1.596	4.06066	1.596
average						3.1023567	1.44467

The study of four parameters (servo voltage, time on, time off, and servo feed) with respect to cutting speed (CS) in separate graph for each interaction are noticed in Figure 4.

1. At first the values of (CS) are decreased with increasing the values of servo voltage and at a middle of curve the (CS) is improved with raise the servo voltage values that caused a greater amount of ions and electron collisions
2. The (CS) values are increased continually with growing the pulse on time values because the time of discharge will remain for longer time.
3. With adding the pulse off time the number of discharge will be decreased, lead to a lower value of cutting speed (CS).
4. Finally its clear that the (CS) value is increasing with rising the value of servo feed.

The results of the analysis for cutting speed with respect to a mean response are listed in Table 6. The higher is the best of cutting speed with respect to servo voltage, pulse on time, pulse off time and servo feed are given the optimum values of input factor (A1, B3, C2, D3) respectively. The predicated mean value of cutting speed (CS) can be computed from the higher value from the Table 6 [12]:

$$The\ predicated\ mean\ of\ (CS) = A1 + B3 + C2 + D3 - 3 * (average\ mean) \quad (3)\ [12]$$

= (1.594+1.576+1.559+1.533)-3*(1.44467)
= 6.262-4.334
= 1.928 mm/min

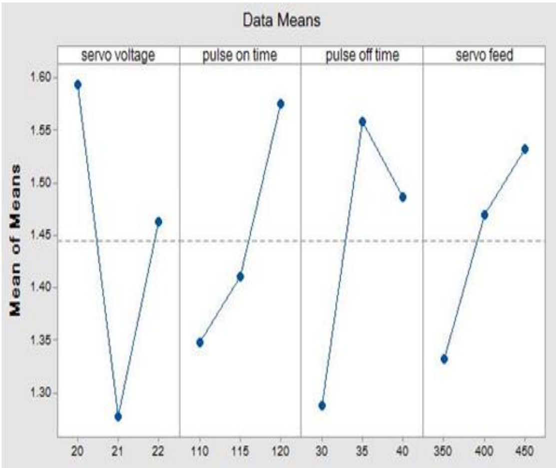

Figure 4: Mean response graph for cutting speed.

Table 6: Response values of cutting speed for the mean (the higher better)

Level	Servo voltage (A)	Pulse on time (B)	Pulse off time (C)	Servo feed (D)
1	1.594	1.347	1.288	1.332
2	1.277	1.411	1.559	1.470
3	1.463	1.576	1.487	1.533
Delta	0.317	0.228	0.271	0.201
Rank	1	3	2	4

The main effects of the four variables as a signal to noise ratio (S/N) on cutting speed (CS) are explained in Figure 5.

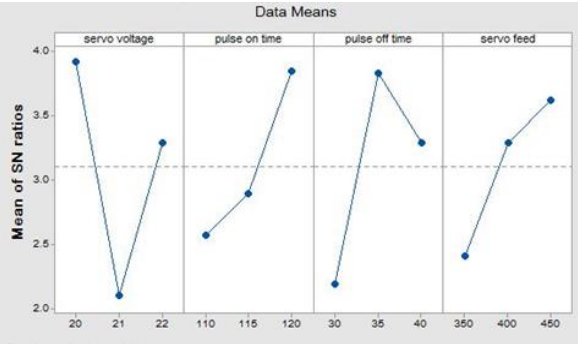

Figure 5: Signal to noise ratio response for cutting speed.

The results of analysis for cutting speed with respect to the S/N ratio response are listed in a Table 7. The higher is the best of cutting speed computed according to the follow equation:

$$\frac{S}{N} ratio\ of\ cutting\ speed = \ -10 * \log 10 \sum (\frac{\frac{1}{y2}}{n}) \quad (4)\ [from\ program]$$

Where:
Y= the measuring value of cutting speed.
N =the number of noise factor.
with respect to servo voltage, pulse on time, pulse off time and servo feed are (A1, B3, C2, D3) respectively. The predicated signal to noise ratio (S/N) value of cutting speed (CS) can be computed from the bigger value from the Table 7.

$$The\ predicated\ \left(\frac{S}{N}\right) ratio\ of\ (CS) = A1 + B3 + C2 + D3 - 3 * (average\ S/n) \ldots (5)[12]$$

= (3.918+ 3.848+3.827+3.618)-3*(3.1023567)
= 15.211- 9.3070701= 5.9039299 mm/min

Table 7: Response values of cutting speed for (S/N) ratio (the higher is the better)

Level	Servo voltage (A)	Pulse on time (B)	Pulse off time (C)	Servo feed (D)
1	3.918	2.571	2.190	2.405
2	2.102	2.888	3.827	3.284
3	3.288	3.848	3.290	3.618
Delta	1.816	1.278	1.636	1.213
Rank	1	3	2	4

II. An analysis of the results and discussion for material removal rate as a response factor:
The values of material removal rate are computed from equations (1) and (2) with (d = 0.25 mm, S = 0.2 mm and h = 10 mm), and they are listed in Table 8.
The values of signal to noise ratio (S/N) for material removal rate (the bigger is the best) are computed from equation (6) and listed in Table 8.

$$\frac{S}{N} ratio\ of\ material\ removal\ rate\ (MRR) = -10 * \log 10 \sum (\frac{\frac{1}{y2}}{n}) \quad (6)[from\ program]$$

Where:
Y= the measuring value of cutting speed.
N =the number of noise factor.
From analyze taguchi design the relationships between material removal rate with respect to each factor are noticed in Figure 6, in signal to noise ratio, and in Figure 7, in mean.

Table 8: Design of experiments factors with a MRR as a response factor

No.	Servo voltage (V)	Pulse duration (μs)	Pulse interval (μs)	Servo feed (mm/min)	MRR (mm^3/min)	S/N ratio (decibel)	Mean (mm/min)
1	20	110	30	350	7.9755	18.0352	7.9755
2	20	115	35	400	11.0500	20.8672	11.0500
3	20	120	40	450	12.0575	21.6251	12.0575
4	21	110	35	450	8.9830	19-0684	8.9830
5	21	115	40	350	7.6180	17.6368	7.6180
6	21	120	30	400	8.2940	18.3753	8.2940
7	22	110	40	400	9.3145	19.3832	9.3145
8	22	115	30	450	8.8465	18.9354	8.8465
9	22	120	35	350	10.3740	20.3189	10.3740
average						19.36061	9.39033

The study of four parameters (servo voltage, time on, time off, and servo feed) with respect to material removal rate (MRR) in separate graph for each interaction are noticed in Figure 8 and 9.

1. At first the values of (MRR) are reduced with increasing the values of servo voltage and at a middle of curve, the (MRR) is increased with raising the servo voltage values, which results in a greater amount of ions and electron collisions.
2. A (MRR) values are enhanced continually with increasing the pulse on time values, which lead to increases the number of discharge for longer time.
3. (MRR) values have been increased at first and lessen with raise the values of pulse off time because the number of discharge will be decreased.
4. Finally it is clear from the graph that the (MRR) values are increasing with adding the values of servo feed because high amount of metal will be melting with higher temperature.

Where:
A: Servo voltage (V).
B: Pulse duration (μs).
C: Pulse interval (μs).
D: Servo feed (mm/min).

The analysis results for material removal rate (MRR) with respect to a signal to noise ratio as a bigger is the best are listed in a Table 9. The shadow cells in a Tables 9, are explained the optimum value of each factor (servo voltage, pulse on time, pulse off time and servo feed), which they are presented in cells (A1, B3, C2, D3) respectively. The predicated signal to noise ratio(S/N) value of material removal rate (MRR) can be computed as follow:

$$The\ predicated\ \left(\frac{S}{N}\right) ratio\ of\ (MRR) = A1 + B3 + C2 + D3 - 3 * (average\ S/n)\ .\ (7)[12]$$

= (20.18+ 20.11+20.08+19.88)-3*(19.36061)
= 80.25- 58.08183
= 22.16817 mm^3/min

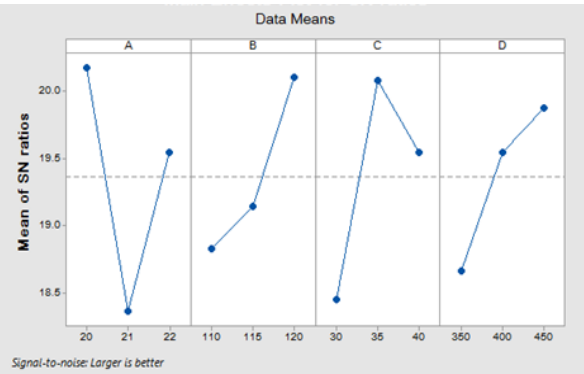

Figure 6: Signal to noise ratio response for material removal rate.

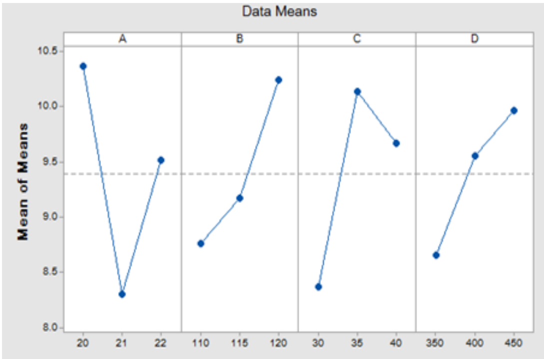

Figure 7: mean response for material removal rate.

Table 9: Response values of cutting speed for (S/N) ratio (the higher is the better)

Level	Servo voltage (A)	Pulse on time (B)	Pulse off time (C)	Servo feed (D)
1	20.18	18.83	18.45	18.66
2	18.36	19.15	20.08	19.54
3	19.55	20.11	19.55	19.88
Delta	1.816	1.28	1.64	1.21
Rank	1	3	2	4

Analysis results for material removal rate (MRR) with respect to means are listed in a Table 10. The shadow cells in a Tables 10, are represent the optimum value of each factor (servo voltage, pulse on time, pulse off time and servo feed), which are presented in cells (A1, B3, C2, D3) respectively. The predicated means value of material removal rate (MRR) can be computed as follow:

$$the\ predicated\ means\ of\ (MRR) = A1 + B3 + C2 + D3 - 3 * (average\ mean) \quad (8)\ [12]$$

= (10.361+ 10.242+10.136+9.962)-3*(9.39033)
= 40.701 - 28.17099
= 12.53001mm^3/min

Table 10: Response values of material removal rate for means

Level	Servo voltage (A)	Pulse on time (B)	Pulse off time (C)	Servo feed (D)
1	10.361	8.758	8.372	8.656
2	8.298	9.172	10.136	9.553
3	9.512	10.242	9.663	9.962
Delta	2.063	1.484	1.764	1.306
Rank	1	3	2	4

4. The Conclusion

1. The (CS) and (MRR) values are increasing with raising the values of (servo voltage, pulse on time and servo feed), and reducing with increase the values of (pulse off time).

2. The best values of servo voltage equal to (20) voltage, pulse on time equal to (120) µs, pulse off time (35) µs, and servo feed (450) mm/min.
3. The optimum value means of cutting speed is (1.928 mm/min), with optimum values of (servo voltage, pulse on time, pulse off time, and servo feed). In addition, the optimum value (S/N) of cutting speed is equal to (5.90392299 mm/min).
4. The optimum value (S/N) of material removal rate is equal to (22.16817 mm^3/min). Moreover, the optimum value means of material removal rate is (1.928 mm/min.

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