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OPTIMAL CONTROL PARAMETERS OF MACHINING USING IN CNC WIRE-CUT EDM FOR TITANIUM

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ABSTRACT:

The objective of this project is to study the effect of machining parameters of wire electrical discharge machining (WEDM) on TITANIUM, which are now widely used in many medical, aerospace applications due to their high technical benefits. Conventional method of machining the material will damages the work piece due to chipping, presence of burrs and cracking. Wire cut Electrical discharge machining (WEDM) techniques have been already tried with other materials, which is difficult to cut to prove the feasibility of machining the titanium. Hence as steps a head wire electrical discharge machining process is to be used to machine the material (titanium) and the effect of various control parameters on the response parameters were studied. As a part of the project, titanium is machined in wire cut EDM machine and the optimal combination of control parameters were found to get higher metal removal rate and surface finish using Taguchi method.

Keywords: Signal-to Noise ratio, response time, Orthogonal Arrays, Dielectric pressure, L9 Arrays

INTRODUCTION

Wire Electric Discharge Machining (WEDM) is one of the greatest innovations in the tooling and machining industry. This process has brought dramatic improvements in accuracy, quality, productivity and earnings. Before wire EDM, costly processes were often used to produce finished parts. Now with the aid of computer and wire EDM machines, extremely complicated shapes can be cut automatically, precisely and economically even in materials as hard as carbide. As more design engineers incorporate new designs into the drawings, therefore it becomes important for contract shops to understand wire EDM as today's drawings are calling for tighter tolerances and shapes that can be efficiently machined only with wire EDM. Hence WEDM plays a significant role in the industries to attain better surface finish of the components.

The selection of optimum machining parameters in WEDM is an important step. Improperly selected parameters may result in serious problems like short-circuiting of wire, wire breakage and work surface damage which is imposing certain limits on the production schedule and also reducing productivity. As Material Removal Rate (MRR) and Surface Roughness (Ra) are the most important responses in WEDM, various investigations have been carried out by several researchers. However, the problem of selection of machining parameters is not fully depending on machine controls rather material dependent. The main objective of this study is to investigate the multi-response optimization of WEDM process for machining of titanium using Taguchi method to achieve higher Material Removal Rate (MRR) and lower surface roughness (Ra).

Electrical discharge machining is one of the non-conventional techniques. It is a controlled metal-removal process that is used to remove metal by means of electric spark erosion between the tool and work. 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. Wire EDM machining (Electrical Discharge Machining) is an electro thermal production process in which a thin single-strand metal wire 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.

Due to the inherent properties of the process, wire EDM can easily machine complex parts and precision components out of hard conductive materials.

EXPERIMENTAL SET-UP AND WORKING

In wire electrical discharge machining (WEDM), a thin single-strand metal wire, usually brass, is fed through the work piece, submerged in a tank of dielectric fluid, typically deionized water. Wire-cut EDM is typically used to cut plates as thick as 300mm and to make punches, tools, and dies from hard metals that are difficult to machine with other methods.

The wire, which is constantly fed from a spool, is held between upper and lower diamond guides. The guides usually CNC-controlled, move in the x–y plane. On most machines, the upper guide can also move independently in the z–u–v axis, giving rise to the ability to cut tapered and transitioning shapes (circle on the bottom square at the top for example). This allows the wire-cut EDM to be programmed to cut very intricate and delicate shapes.

CONSTRUCTION OF WEDM

The upper and lower diamond guides are usually accurate to 0.004mm, and can have a cutting path or kerf as small as 0.12mm using Ø 0.1mm wire, though the average cutting kerf that achieves the best economic cost and machining time is 0.335mm using Ø 0.25mm brass wire. The reason that the cutting width is greater than the width of the wire is because sparking occurs from the sides of the wire to the work piece, causing erosion. Spools of wire are long—an 8 kg spool of 0.25mm wire is just over 19 kilometers in length. Wire diameter can be as small as 20µm and the geometry precision is not far from +/- 1µm.

COMPONENTS IN WEDM

1. Dielectric Fluid
2. Electrode Material
3. Power Supply Unit

Working of WEDM

Wire EDM machining (also known as "spark EDM") works by creating an electrical discharge between the wire or electrode and the workpiece. As the spark jumps across the gap, material is removed from both the workpiece and the electrode.

To stop the sparking process from shorting out, a non-conductive fluid or dielectric is also applied. The waste material is removed by the dielectric, and the process continues.

The wire-cut process uses de-ionized water as its dielectric fluid, controlling its resistivity and other electrical properties with filters and de-ionizerunits. The water flushes the cut debris away from the cutting zone. Flushing is an important factor in determining the maximum feed rate for a given material thickness.

Wire-cutting EDM is commonly used when low residual stresses are desired, because it does not require high cutting forces for removal of material. If the energy/power per pulse is relatively low (as in finishing operations), little change in the mechanical properties of a material is expected due to these low residual stresses, although material

WORKPIECE MATERIAL

Titanium

Titanium is a high quality, high tensile, alloy steel with high tensile strength, shock resistance, good ductility and resistance to wear. Titanium is renowned for its wear resistance properties and also were high strength properties are required. Table 4.1 illustrates the chemical composition of Titanium.

ELEMENTS	WEIGHT %
C	0.08
N	0.03
H	0.015
O	0.18
Pd	0.08-0.14
Fe	0.20

Ti	99.67

Table 1: Illustrates the mechanical properties of Titanium.

Mechanical Properties	
Density (×1000 kg/m^3)	4.51
Poisson's Ratio	0.27-0.30
Elastic Modulus (GPa)	72-120
Tensile Strength (MPa)	240
Yield Strength (MPa)	170
Elongation (%)	24
Hardness (HB)	80

Table 2: Mechanical Properties of Titanium.

METHODOLOGIES

TAGUCHI METHOD

Genichi Taguchi, an international consultant in the field of total quality control and assurance formulated both a philosophy and a methodology for the process of quality improvement that depends on statistical concepts, especially statistically designed experiments. Taguchi defined quality as the loss imparted to the society from the time a product is shipped to the market.

The primary goals of the taguchi methodology can be described as:

a) A reduction in the variation of a product design to improve quality and lower the loss imparted to society.

b) A proper product or process implementation strategy which can further reduce the level of variation.

Signal - to - Noise Ratio

Traditionally a designed experiment can be used to estimate or test the significance of certain factors on the basis of a measurable response over a set of experimental conditions. Taguchi emphasized that in addition to this, the variation of the experimental data needs to be studied. In order to facilitate this study he used the concept of a signal-to-noise ratio. The simplest form of signal-to-noise ratio (S/N) is the ratio of the mean (signal) to the standard deviation (noise).

Type 1: $S/N_{LB} = -10 \log_{10}[\sum Y_{ij}^2 / n]$ (5.1)

Type 2: $S/N_{HB} = -10 \log_{10}[(1/n) (\sum 1/ Y_{ij}^2)]$ (5.2)

Where

Y_{ij} is the value of the response ‘j’ in the ith experiment condition, with i=1, 2, 3,…n; j = 1,2…k.

Orthogonal Arrays

Orthogonal arrays are highly fractional orthogonal designs proposed by Dr. Genichi Taguchi, a Japanese industrialist. These designs can be used to not only applicable to two level factorial experiments, but also can investigate main effects when factors have more than two levels. Designs are also available to investigate main effects for certain mixed level experiments where the factors included do not have the same number of levels.

DESIGN OF EXPERIMENTS

The experiments to be conducted are based on varying the process parameters which affect the machining process to obtain the required quality characteristics. Quality characteristics are the response values or output values expected out of the experiments. There is 64 such quality characteristics.The most commonly used are:

- Larger the better
- Smaller the better
- Nominal the best
- Classified attribute
- Signed target

As the objective is to obtain the best surface finish and high material removal rate (MRR), it is concerned with obtaining the least value of surface roughness and large value for MRR. Hence, the required quality characteristic is smaller the better, which states that the output must be as low as possible, tending to zero for surface roughness and larger the better, which states that the output must be as large as possible for high MRR. The process parameters are known as factors which influence the nature of these response variables.

The factors and levels can be tabulated as shown in Table 3

Symbol	Control factors	Level 1	Level 2
A	Dielectric pressure	Low	High
B	Wire feed rate (m/min)	8	7
C	Wire tension (g)	900	1000
D	Pulse on time (μs)	4	5
E	Pulse off time (μs)	6	5
F	Table feed	6	5
G	Gap voltage (V)	6	7

Table 3: Factors and Levels

The values over which these process parameters vary are known as levels. Dielectric pressure can be made high or low, which means it has two levels ie. Dielectric pressure is a two level factor. The other factors namely pulse on time, pulse off time, wire tension, wire feed rate, and gap voltage and average gap current vary in three range of value.

Selection of Orthogonal Array

Orthogonal array is the tabulation which considers various factors involved in any experiment and it estimates the effect of those factors independently over the others. There are many such standard orthogonal arrays from which required one can be selected based on various conditions.

An orthogonal array is represented in the skeletal form

$$L_R V^F \quad (5.3)$$

Where L – Latin square

R – Number of rows (number of experiments to be conducted)

V – The level of chosen factors

F – Number of factors under study

Such an orthogonal array is used if all the factors possess the same number of levels. In some cases where factors may have different levels, mixed orthogonal arrays are used, of the form

$$L_R\,(V1^{F1} * V2^{F2}) \quad (5.4)$$

Where V1 factors vary with F1 levels,

V2 factors vary with F2 levels

Degree of freedom:

Degree of freedom is the number of fair comparisons that can be made with the available data. This forms the basis in selecting the required orthogonal array.

If the levels are denoted by V,

Degree of freedom associated with levels = V-1

Total d.o.f of factors and levels = No. of factors * (V-1)

According to this experiment,

No. of two level factors = 1

Degree of freedom of two level factors

= 1*(2-1) = 1

No. of three level factors = 7

Degree of freedom of three level factors

= 7*(3-1) = 14

Total degree of freedom of factors and levels

= 1+14 = 15

In general if there are 'n' experiments from an orthogonal array,

Degree of freedom of orthogonal array = n-1.

RESULTS AND DISCUSSIONS

Experiments were conducted as per the L_{18} (2^1*3^7) orthogonal array, assigning various values of the levels to the process parameters. After individual experiments for a set of values were conducted on Titanium for a size of 150×100×2 mm^3, square profiles were cut and their surface roughness values were measured in surface roughness tester to determine the surface finish and MRR was calculated using the standard formula. The responses are given in the Table 6.1.

Sample Calculation of MRR for Experiment No.1

v_f= 3.7 mm/min

h = 2 mm

b = 0.271 mm

MRR = v_f *h* b

=3.7 x 0.271 x 2

= 1.9512 mm^3 /min.

EX.NO	CONTROL FACTORS							RESPONSES	
	A	B	C	D	E	F	G	MRR (g/min)	Ra (µm)
1	1	1	1	1	1	1	1	0.499	2.453
2	1	1	2	2	2	2	2	0.729	2.201
3	1	1	3	3	3	3	3	0.580	2.433
4	1	2	1	1	2	2	3	0.702	2.861
5	1	2	2	2	3	3	1	0.823	2.770
6	1	2	3	3	1	1	2	0.526	1.851
7	1	3	1	2	1	3	3	0.526	2.111
8	1	3	2	3	2	1	1	0.742	2.845
9	2	3	3	1	3	2	2	0.715	2.366
10	2	1	1	3	3	2	1	0.499	2.313
11	2	1	2	1	1	3	2	0.540	3.337
12	2	1	3	2	2	1	3	0.729	3.622
13	2	2	1	2	3	1	2	0.850	2.975
14	2	2	2	3	1	2	3	0.513	1.687
15	2	2	3	1	2	3	1	0.688	2.416
16	2	3	1	3	2	3	2	0.702	2.761
17	2	3	2	1	3	1	3	0.715	2.817
18	2	3	3	2	1	2	1	0.769	3.011

Table 4: L_{18} (2^1*3^7) Orthogonal Array with Responses

OPTIMIZATION STEPS USING TAGUCHI METHOD

In this step, the original response values are transformed into S/N ratio values. Further analysis iscarried out based on these S/N ratio values. The material removal rate is a higher-the-better performance characteristic, since the maximization of the quality characteristic of interest is sought and can be expressed as

S/N_{HB} = -10 $\log_{10}[(1/n)\ (\sum 1/\ Y_{ij}^{2})]$ (6.1)

Where

n = number of replications and y_{ij} = observed response value

Where

i=1, 2... ....n; j = 1, 2...k.

The surface roughness is the lower-the-better performance characteristic and the loss function for the same can be expressed as

S/N_{LB} = -10 $\log_{10}[\sum Y_{ij}^{2}/n]$ (6.2)

The S/N ratio values for the experimental results were calculated.

EX. NO	CONTROL FACTORS							S/N RATIO	
	A	B	C	D	E	F	G	MRR (db)	Ra (db)
1	1	1	1	1	1	1	1	6.044	-7.793
2	1	1	2	2	2	2	2	9.327	-6.852
3	1	1	3	3	3	3	3	7.349	-7.722
4	1	2	1	1	2	2	3	9.000	-9.130
5	1	2	2	2	3	3	1	10.38	-8.849
6	1	2	3	3	1	1	2	6.501	-5.348
7	1	3	1	2	1	3	3	6.501	-6.489
8	1	3	2	3	2	1	1	9.487	-9.081
9	2	3	3	1	3	2	2	9.165	-7.480
10	2	1	1	3	3	2	1	6.044	-7.283
11	2	1	2	1	1	3	2	6.721	-10.467
12	2	1	3	2	2	1	3	9.327	-11.178
13	2	2	1	2	3	1	2	10.66	-9.478
14	2	2	2	3	1	2	3	6.275	-4.542
15	2	2	3	1	2	3	1	8.831	-7.661
16	2	3	1	3	2	3	2	9.000	-8.821
17	2	3	2	1	3	1	3	9.165	-8.995
18	2	3	3	2	1	2	1	9.797	-9.574

Table 5: S/N Ratios

ANALYSIS OF VARIANCE (ANOVA)

The results obtained from the experiments were analyzed using Analysis of Variance to find the significance of each input factor on the measures of process performances, Material Removal Rate and surface roughness. ANOVA is formulated for identifying the significant factors. The influences of various parameters on MRRand surface roughness are presented in Table 6

Parameters	Sum Of Squares	Variance	D of	F Test Values	Contribution %
DIELECTRIC PRESSURE	4.268	4.268	1	0.553	0.593
WIRE FEED	118.08	59.04	2	7.662	16.42
WIRE TENSION	30.821	15.41	2	2	4.285
PULSE ON TIME	197.1	98.55	2	12.79	27.41
PULSE OFF TIME	262.2	131.13	2	17.018	36.46
TABLE FEED	8.947	4.47	2	0.580	1.244
GAP VOLTAGE	66.849	33.42	2	4.337	9.295
ERROR	30.821	7.70	4		4.285
TOTAL	719.158				

Table 6: The Influence of Various Parameters on MRR

The results of the ANOVA are represented in graphical form and from the graphical representation it is clear that average pulse off time is the major influencing factor contributing 36.46% to MRR, followed by pulse-on time contributing 27.41%, Wire tension contributing 4.285% and Wire Feed contributing 16.42%, Dielectric pressure contributing 0.593%, table feed contributing 1.244% and gap voltage contributing 9.295%.

The Figure 1 shows the percentage of contribution of control machining parameters on Material Removal Rate (MRR).

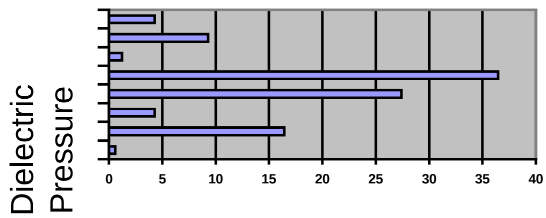

Figure 1: Percentage of contribution of Control Parameters on MRR

The results of the ANOVA are represented in graphical form and from the graphical representation it is clear that average gap voltage is the major influencing factor contributing 31.829% to Ra, followed by pulse-on time contributing 21.859%, pulse-off time contributing 14.46% and Wire Feed contributing 8.9%, Dielectric pressure contributing 11%, Wire tension contributing 0.009% and gap voltage contributing 31.829 %.

The Figure 2 shows the Percentage of contribution of control machining parameters on surface roughness

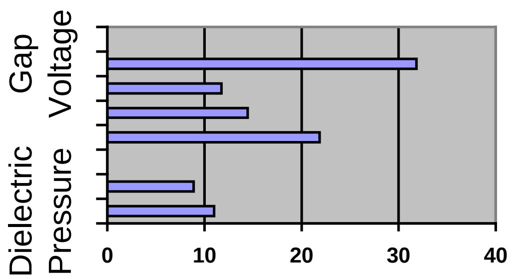

Figure 2: Percentage of contribution of control parameters on surface roughness

CONFIRMATION EXPERIMENT

The confirmation test for the optimal parameter setting with its selected levels was conducted to evaluate the quality characteristics for WEDM of Titanium. Table 6.5 shows the experimental results using the initial (A2B2C1D2E3F1G2) WEDM parameters on Titanium. The response values obtained from the confirmation experiment are MRR = 0.850 g/min and Ra = 1.687 µm. The Material Removal Rate shows a value of 0.823 g/min and the Surface Roughness shows a value of 1.687 µm respectively.

Process parameters	Orthogonal Array
Level	A2B2C1D2E3F1G2
MRR(g/min)	0.823
Ra (µm)	1.687

Table 7: Optimization Results of OA L_{18} (2^1*3^7)

CONCLUSION

In this project, an application of combined Taguchi Method is to improve the multi-response characteristics of MRR (Material Removal Rate) and Surface roughness in the Wire-Cut EDM of Titanium has been reported. As a result, this method greatly simplifies the optimization of complicated multiple performance characteristics and since it does not involve complicated mathematical computations, this can be easily utilized by the stakeholders of the Manufacturing world.

While applying the Taguchi method, The Material Removal Rate shows an increased value of 0.513g/min to 0.823 g/min and the Surface Roughness shows a reduced value of 3.789µm to1.687 µm respectively, which are positive indicators of efficiency in the machining process.

Thus, it can be concluded that the Taguchi Method, is most ideal and suitable for the parametric optimization of the Wire-Cut EDM process, when using the multiple performance characteristics such as MRR (Material Removal Rate) and Surface Roughness for machining the Titanium.

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