To Optimize the Process Parameters for the Improvement of Material Removal Rate and Surface Roughness using Cryogenic Treated and Untreated Wire in Wire Electrical Discharge Machining of Titanium Material

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Abstract - WEDM is popular and specialized in machining conductive metals of any hardness or that are difficult or impossible to cut with traditional methods into general, complex shapes, contours or fragile geometries. This project work focuses on finding out the effect of input parameters on output parameters in Wire-EDM for machining of Titanium. The input process parameters that are taken into consideration are wire feed rate, Pulse on time, Pulse off time, Peak current, Servo voltage and wires. Output parameters are Material removal rate (MRR) and Surface roughness (SR) is measured. Also different wire materials like Hard Brass wire and Cryogenic Treated Hard Brass wires are used in this experiment. For design of experiment Taguchi methodology of L27 orthogonal array is used. ANOVA is used for finding the percentage contribution of each parameter and found that MRR rises with rise in pulse on time and cryogenic treated wire for 4hrs gives more MRR compared to the cryogenic treated wire for 2hrs. For SR it is determined that, SR rises with rise in peak current and servo voltage and cryogenic treated wire for 2hrs gives more SR compared to the non-treated wire and cryogenic treated wire for 4hrs.

Keywords – WEDM, Titanium material, cryogenic treatment, Material removal rate, surface roughness, Taguchi approach, ANOVA.

I. Introduction

Wire electrical discharge machining (WEDM) is a widely used to manufacture components with intricate shapes and profiles. In Wire-EDM the material erodes from the job by means of a discrete runs of discharge that occur among the job and wire divided by a dielectric fluid. At present, WEDM is a widespread technique used in industry for high precision machining of all types of conductive materials. The WEDM process parameters influences the quality of processing, cutting or drilling in wire- EDM, and strength of the wire in wire-EDM can be achieved by a process termed as cryogenic treatment. In this after the treatment, there is change in the micro structure of the wire and cryogenic treatment is also wear and corrosion resistance, thus we are applying this cryogenic process in our work.

LITERATURE REVIEW-D.Sudhakara et al. introduced the promotion of the wire cut EDM machining factors for the roughness of the surface, 0.25mm diameter wire is used for machining the material named as VANADIS 4e, L27 orthogonal array was designed by the Taguchi method for performing experiments, S/N ratio was applied for finding out the rank of each parameter on surface roughness and ANOVA was used for finding the percentage involvement of each factors on response[3]. S V Subrahmanyam et al. investigated to optimize the effects of eight input process parameters on Surface Finish during the machining of EN-31 using Taguchi L36 orthogonal array and with the help of ANOVA, S/N ratio and Math model the optimal input parameter combination for the Surface Finish on the WEDM machined arrived and said that it will be useful for the people who do not have much idea of WEDM[4]. S Sivakiran et al. attempted 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 MRR[1]. U.Esme et al. studied that two of the techniques were applied as neural network and design of factorial in the prediction of surface roughness of the work piece taken as AISI 43-40 steel, ANOVA technique used for finding the significant factor and the level of factors and variation of input factors to output were modelled mathematically through nonlinear regression method and resulted that rising the factors as wire feed, pulse duration and open circuit voltage raises roughness of surface while rising in flushing pressure reduces surface roughness[13]. Navjot Singh et al. investigated cryogenically treated zinc coated diffused brass wire and cryogenically treated plain brass wire have been used as cutting tool, AISI D3 die steel has been taken work piece. Taguchi's L9 orthogonal array has been used for design of experiments. The process performance is measured in terms of optimization of material removal rate and found that the cryogenically treated zinc coated diffused brass wire gives good material removal rate as compare to cryogenically treated plain brass wire[7]. Jatinder Kapoor et al. studied the effect of Cryogenic treated brass wire electrode on the surface of an EN-31 steel machined by WEDM. Full factorial experimental design strategy is used in the experimentation. ANOVA results indicated that all the process parameters have significant effect on SR. Surface roughness is improved with cryogenic treated brass wire electrode[8].

II. DESIGN OF EXPERIMENTS

Increasing productivity and improving quality are important goal in any business. The method for determining how to increase productivity and improving quality are evolving. The design of experiments (DOE) is an efficient procedure for planning experiments so that the obtained data can be analyzed to yield valid and objective conclusions. DOE begins with determining the objectives of an experiment and selecting the process factors for the study.

A. Taguchi Technique

Dr. Taguchi has developed a method predicated on "ORTHOGONAL ARRAY" experiments which gives much reduced "variance" for the experiment with "optimum settings" of control parameters. Thus with optimization of control parameters to obtain best results is achieved in the Taguchi Method. "Orthogonal Arrays" (OA) provide a set of well balanced (minimum) experiments and Dr. Taguchi's Signal-to-Noise ratios (S/N), which are log functions of desired output, accommodate as objective functions for optimization, avail in data analysis and presage of optimum results. Taguchi techniques concentrates on the actual application of the design plans somewhat than Advanced Statistics. As per the method of Taguchi, the S/N ratio is the proportion between signal and noise where the signal signifies the appropriate value and undesirable value is signified by noise. The software Minitab supports to analyze the S/N ratio on the basis of requested responses and make available table of analysis of variance and graph of the response to choose significant factor and to discover the involvement of percentage for each factor. Moreover the Minitab allots rank on the basis of values of delta; rank 1 for the maximum value delta, rank 2 for the second maximum and so forth. Ranks shows the specific importance of each parameter for the responses. Three levels for each control parameter will be used. Based on number of control parameter and their levels, L27 orthogonal array (OA) was selected. Table 1 represents Control parameters with their level value.

Table 1 Control parameters with level value

Serial No.	Machining Process Variables	Level 1	Level 2	Level 3
1	Wire Feed Rate(m/min)	6	7	8
2	Pulse On Time(µs)	110	115	120
3	Pulse Off Time(µs)	50	55	60
4	Peak Current(Amp)	120	140	160
5	Servo Voltage(Volt)	15	20	25
6	Types Of Wire	A	B	C

B. Cryogenic Treatment

Cryogenic processing has a technique to make cool the tool or the work-piece in the elimination of the material of the procedures. Liquid Nitrogen which is liquefied to -196°C through cooling, generally used as coolant. Liquid Nitrogen is non-corrosive, safe and non-flammable. In this work cryogenic treatment of three spool of hard brass wire of weight 1kg, one thermocol box and liquid nitrogen were taken. From the three spool of wire, two wire spool were treated by liquid nitrogen at (-196˚ C) for 2hrs and 4hrs and one spool was untreated. Fig 1 shows the cryogenic treatment of the wire spools.

Fig 1 cryogenic treatment of wire spools

III. Experiment and Result

For this work, the wire taken is Hard Brass Wire of 0.25 mm and the experiments performed is done in sprint-cut wire-EDM (ELEKTRA SPRINT-CUT 734) on Titanium material through changing the parameters of Processing. The size of the titanium material taken is (250mm x 50mm x 6mm).The output parameters Material Removal Rate is found based on the volume method, the work piece to be machined is the volume of the material removal rate per minute. The equation-1 is used for finding out MRR values. The values of surface roughness of the finished products work pieces were calculated by Mitutoyo surface roughness tester, SJ-201 by means of a correct method. Table 2 shows the final measured results where in table A stands for non treated wire, B stands for cryo treated wire for 2hrs and C stands for cryo treated wire for 4hrs.

MRR = Cutting Speed(mm/min) * Thickness of w/p(mm)………………. (1)

Table 2 final measured results

Serial no	Wire feed rate (m/min)	Pulse on time (µs)	Pulse off time (µs)	Peak current (Amp)	Servo voltage (V)	Types of wire	MRR (mm²/min)	SR (µm)
1	6	110	50	120	15	A	21.30	2.17
2	6	110	50	120	20	B	19.44	2.50
3	6	110	50	120	25	C	18.24	2.12
4	6	115	55	140	15	A	26.88	2.45
5	6	115	55	140	20	B	25.32	2.58
6	6	115	55	140	25	C	23.22	2.44
7	6	120	60	160	15	A	26.88	3.08
8	6	120	60	160	20	B	25.26	2.50
9	6	120	60	160	25	C	23.88	2.65
10	7	110	55	160	15	B	13.14	1.97
11	7	110	55	160	20	C	12.06	2.39
12	7	110	55	160	25	A	11.64	2.05
13	7	115	60	120	15	B	20.88	2.36
14	7	115	60	120	20	C	20.52	2.71
15	7	115	60	120	25	A	19.98	2.37
16	7	120	50	140	15	B	25.87	2.54
17	7	120	50	140	20	C	40.03	2.85
18	7	120	50	140	25	A	34.00	2.96
19	8	110	60	140	15	C	12.24	2.47
20	8	110	60	140	20	A	12.66	2.28
21	8	110	60	140	25	B	11.22	2.14
22	8	115	50	160	15	C	26.27	2.23
23	8	115	50	160	20	A	26.04	2.58
24	8	115	50	160	25	B	23.52	2.63
25	8	120	55	120	15	C	33.54	3.07
26	8	120	55	120	20	A	31.80	2.79
27	8	120	55	120	25	B	34.20	2.89

Signal-to-Noise Ratio (S/N Ratio)

The material removal rate is "larger the better" performance features and the surface roughness is "smaller the better", characteristics of performance and can be stated as. The S/N ratio for MRR and SR is measured by using equation 3 and 2. Table 3 and 4 displays the response table Wire for MRR and SR. The S/N ratio graph for input parameters versus MRR and SR is shown in fig 2 and 3.

$$SNi = -10\log\left(\sum_{u=1}^{Ni} \frac{y_u^2}{N_i}\right) \quad (2)$$

$$SNi = -10\log\left[\frac{1}{N_i}\sum_{u=1}^{Ni} \frac{1}{y_u^2}\right] \quad (3)$$

Table 3 S/N ratio for MRR

Level	Wire feed rate	Pulse on time	Pulse off time	Peak current	Servo voltage	wire
1	27.30	23.08	28.14	27.49	26.79	26.96
2	26.16	27.44	26.73	26.69	26.97	26.39
3	26.70	29.65	25.29	25.98	26.41	26.81
Delta	1.15	6.58	2.85	1.52	0.56	0.56
rank	4	1	2	3	6	5

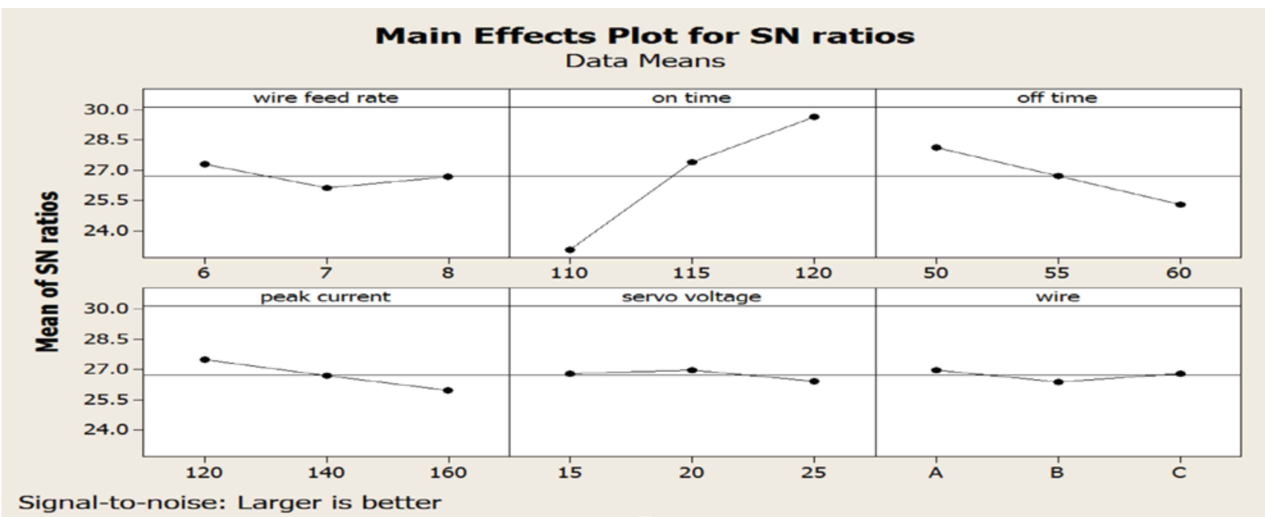

Fig 2 graph of input parameters versus MRR

Table 4 S/N ratio for SR

Level	Wire feed rate	Pulse on time	Pulse off time	Peak current	Servo voltage	wire
1	-7.908	-6.948	-7.937	-8.078	-7.810	-7.971
2	-7.769	-7.886	-7.925	-8.000	-8.197	-7.758
3	-8.121	-8.965	-7.936	-7.721	-7.791	-8.070

Delta	0.352	2.018	0.011	0.357	0.406	0.312
Rank	4	1	6	3	2	5

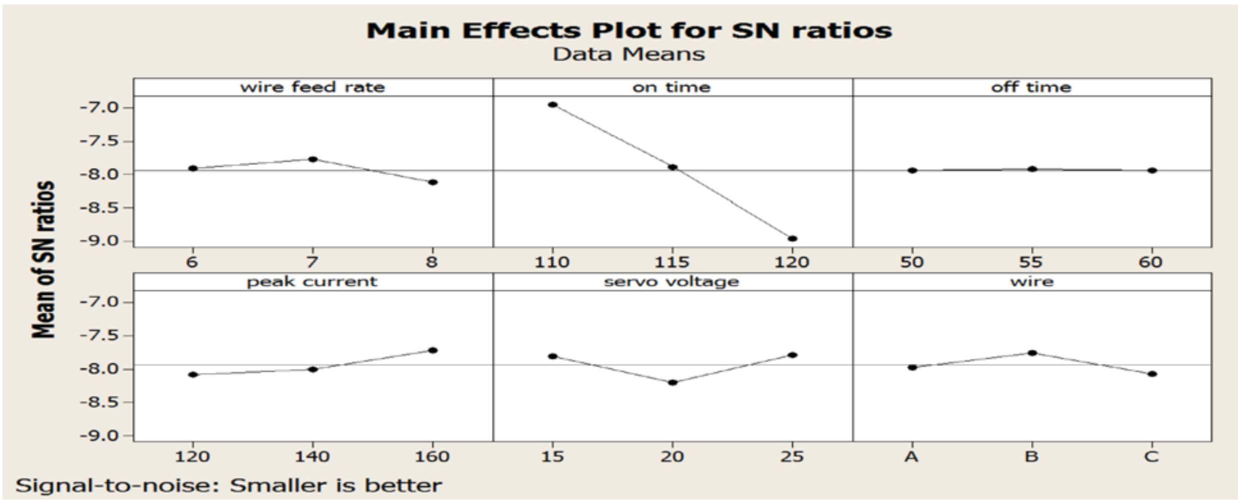

Fig 3 graph of input parameters versus SR

Analysis Of Variance (ANOVA)

ANOVA is an authentic statistical method to take the practical results. It can be used for estimating the percentage involvement of the different process factors selected for the functional characteristics. The study of ANOVA table for a specified investigation allows you to decide which parameters needs control and which does not need. ANOVA is to examine the parameters of the project and to specify which are the parameters that will considerably affect the output factors. The variance and sum of squares are measured in the investigation. A F-test value at a sureness level of 95% is taken for determining the major parameters that influence the process. Greater F- value specifiesthe variant of the factors of the process makes a large variation on performance. ANOVA investigation is performed in Minitab 16 software. If the value of p identified as possibility value which is smaller than 0.05, displays that all factors are significant. The ANOVA table for material removal rate and surface roughness are displayed under, the percentage of each factor is found by using equation 4 displayed below.

$$\% = \frac{Seq\ SS}{Total\ Seq\ SS} * 100 \qquad \text{……………………………………(4)}$$

Table 5 Analysis Of Variance for MRR

Source	DF	Seq SS	Adj SS	Adj MS	F	P	%
Wire feed rate	2	12.81	12.81	6.40	0.83	0.457	**0.81**
Pulse on time	2	1150.91	1150.91	575.45	74.52	0.000	**73.60**
Pulse off time	2	215.46	215.46	107.73	13.95	0.000	**13.77**
Peak current	2	55.96	55.96	27.98	3.62	0.054	**3.57**
Servo voltage	2	9.79	9.79	4.90	0.63	0.545	**0.62**
Wire	2	10.67	10.67	5.33	0.69	0.518	**0.68**
Error	14	108.11	108.11	7.72			**6.95**

Total	26	1563.69					**100**

Table 6 Analysis Of Variance for SR

Source	DF	Seq SS	Adj SS	Adj MS	F	P	%
Wire feed rate	2	0.04469	0.04469	0.02234	0.49	0.625	**1.88**
Pulse on time	2	1.53502	1.53502	0.76751	16.70	0.000	**64.76**
Pulse off time	2	0.00029	0.00029	0.00014	0.00	0.997	**0.01**
Peak current	2	0.04740	0.04740	0.02370	0.52	0.608	**2.00**
Servo voltage	2	0.05847	0.05847	0.02923	0.64	0.544	**2.46**
Wire	2	0.04062	0.04062	0.02031	0.44	0.651	**1.71**
Error	14	0.64351	0.64351	0.04597			**27.18**
Total	26	2.37000					**100**

IV.CONCLUSION

MRR rises with rise in pulse on time and is significant and comparative essential factor related to the other factors for MRR. This is because the discharge energy increases with pulse on time and the number of discharges within a given period becomes more. Wire feed rate shows minor effect on MRR and Wire C (cryogenic treated wire for 4hrs) gives more MRR compared to the wire B (cryogenic treated wire for 2hrs).

On greater pulse off time, a smaller amount of quantity of sparks is passed for the period of processing, gives lesser MRR. Because of which minor holes are generated on the exterior gives minor SR, raising in servo voltage reduces the sparks through the wire-electrode gives lesser MRR.

For SR it is determined that, SR rises with rise in peak current and servo voltage, wire feed rate shows minor effect on SR. The purpose for raising of SR in peak current, is the quantity of energy for each spark rests on the value of the peak current, higher is the current value extra energy is released, results in greater SR. Here also pulse on time is significant and comparative essential factor related to the other factors for SR. Wire B (cryogenic treated wire for 2hrs) gives more SR compared to the wire A (non-treated wire) and C (cryogenic treated wire for 4hrs).

The percentage contribution of Wire feed rate is 0.81%, Pulse on time is 73.60%, Pulse off time is 13.77%, Peak current is 3.57%, Servo voltage is 0.62%, wires is 0.68% and error is 6.95% for MRR.

The percentage contribution of Wire feed rate is 1.88%, Pulse on time is 64.76%, Pulse off time is 0.01%, Peak current is 2.00%, Servo voltage is 2.46%, wires is 1.71% and error is 27.18% for SR.

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