OPTIMIZATION OF MULTIPLE MACHINING CHARACTERISTIC IN WEDM OF NICKEL BASED SUPER ALLOY USING OF TAGUCHI METHOD AND GREY RELATIONAL ANALYSIS

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ABSTRACT

Wire-cut electrical discharge machining (WEDM) is one of the most emerging non conventional manufacturing processes for hard to machine materials and intricate shapes which are not possible with conventional machining methods. This paper reviews the experimental determination of the effects of the various process parameters viz. pulse on time, pulse off time, servo voltage, peak current and wire feed on the performance measures like cutting rate and surface roughness in WEDM of Nickel based super alloy by selecting the process parameters and their appropriate level using Taguchi optimization methodology and Grey relational analysis.

Keywords: Optimization, Process Parameters, Review, Wire-Cut EDM

I. INTRODUCTION

Nickel based alloys are the most widely used super-alloys, accounting for about 50% wt of materials used in the gas turbine components. They provide higher strength to weight ratio compared to steel which is denser. Other applications include marine equipment, nuclear reactors, petrochemical plants and food processing equipment. The use of nickel based alloys in such aggressive environments hinges on the fact that it maintains high resistance to corrosion, mechanical and thermal fatigue, mechanical and thermal shock, creep and erosion at elevated temperature. Nickel based alloys contains inter metallic compound Ni_3 (Al, Ta) in a matrix of nickel solid solution with chromium, tungsten and rhenium as the solid solution strengthening elements. Nickel based turbine blades can operate up to 600^0C. Generally the nominal chemical composition of nickel based alloys ranges from 38 to 70 wt% nickel, up to 27 wt% chromium (Cr) and 20 wt% cobalt (Co). They may also contain small wt% of tungsten, tantalum and molybdenum added to enhance their strength and oxidation properties.

II. AIMS AND OBJECTIVES OF WORK

The main objective of the present work is to conduct the experiments at different settings of the WEDM process parameters using one factor at a time approach. Experimental determination of the effects of the various process parameters viz. pulse on time, pulse off time, servo voltage, peak current and wire feed on the performance measures like cutting rate and surface roughness in WEDM of Nickel based superalloy. Select the process parameters and their appropriate levels. Single response Optimization using Taguchi optimization methodology. Multiple machining characteristics optimization using Grey relational analysis.

III. LITERATURE REVIEW

Lin, et al [1] optimized the multiple performance characteristics in wire electrical discharge machining by combining the orthogonal array and grey relational analysis. Machining parameters were work piece polarity, pulse on time, duty factor, open discharge voltage, discharge current, and dielectric fluid are optimized with considerations of multiple performance characteristics including material removal rate, surface roughness, and electrode wear ratio. Experimental results have shown that machining performance in the EDM process can be improved effectively through this approach.

Lin and Lin [2] investigate an efficient Ti6Al4V electrical discharge machining (EDM) process with a bundled die-sinking electrode. The feasibility of machining Ti6Al4V with a bundled electrode was studied and its effect on EDM performance was compared experimentally using a solid die-sinking electrode. The simulation results explain the high performance of the EDM process with a bundled electrode by through the use of multi-hole inner flushing to efficiently remove molten material from the inter-electrode gap and through the improved ability to apply a higher peak current. A 3-factor, 3-level experimental design was used to study the relationships between 2 machining performance parameters (material removal rate: MRR, tool wear ratio: TWR) and 3 machining parameters (fluid flow rate, peak current and pulse duration). The main effects and influences of the 2-factor interactions of these parameters on the performances of the EDM process with the bundled electrode are discussed.

Sridhar et al. [3] described the residual stress variation in titanium alloy IMI-834 as a function of depth following milling at different feeds, speeds and depths of cut was determined by a strain-gauge technique involving blind-hole drilling. The residual stresses were found to be compressive in nature and to be dependent upon the milling parameters. Heat treatment was found to relieve the residual stresses, the degree of stress relief being found to increase with increase in temperature. Optimum temperatures were determined at which significant relaxation occurred without adversely affecting the microstructure and mechanical behavior of the material.

Newman, et al [4] reviewed the vast array of research work carried out from the spin-off from the EDM process to the development of the WEDM. It reports on the WEDM research work involving the optimization of the process parameters surveying the influence of the various factors affecting the machining performance and productivity. They also highlight the adaptive monitoring and control of the process investigating the feasibility of the different control strategies of obtaining the optimal machining conditions. A wide range of WEDM industrial applications and future research work is reported.

Kim and Rumulu [5] optimize drilling feed and speed to maximize each hole quality parameter to the greatest extent possible as well as to minimize machining cost. Optimum process conditions for achieving desired whole quality and process cost were found to be a combination of low feed and low speed when using carbide drills, and high feed and low speed in drilling with HSS-Co drills in titanium alloy stacks.

Zhang et al [6] focused on using ultrasonic to improve the efficiency in electrical discharge machining (EDM) in gas medium. The new method is referred to as ultrasonic-assisted electrical discharge machining (UEDM). In the process of UEDM in gas, the tool electrode is a thin-walled pipe, the high-pressure gas medium is applied from inside, and the ultrasonic actuation is applied onto the work piece. In their experiments, the work piece material was AISI 1045 steel and the electrode material was copper. The experiment results indicate that (a) the Material Removal Rate (MRR) is increased with respect to the increase of the open voltage, the pulse duration, the amplitude of ultrasonic actuation, the discharge current, and the decrease of the wall thickness of electrode pipe; and (b) the surface roughness is increased with respect to the increase of the open voltage, the pulse duration, and the discharge current. Based on experimental results, theoretical models to estimate the MRR and the surface roughness are developed.

Mahapatra and Patnaik [7] described the optimization of WEDM process parameters using Taguchi method. In this paper author optimized metal removal rate (MRR), surface finish and cutting width for a rough cut. Taguchi's L_{27} is used to optimize the individual response characteristic. Finally, genetic algorithm, a popular revolutionary approach, is employed to optimize the wire electric discharge machining process with multiple objectives. The study demonstrates that the WEDM process parameters can be adjusted to achieve better metal removal rate, surface finish and cutting width simultaneously. The confirmation experiments are carried out that shows the error associated with MRR, SR and kerf is less than 5 percent.

Singh et al [8] described the Taguchi's approach and utility concept to optimize the multi-machining characteristics simultaneously. They discussed a case study on En24 steel turned parts using titanium carbide coated tungsten carbide inserts. They had chosen the three process parameters as, cutting speed, feed and depth of cut. After optimization they found a single optimal condition to get near optimal value of all the response characteristics simultaneously. The response characteristics optimizes were MRR, tool wear rate, power consumption and surface finish. Kanagurajan et al [9] studied the influence of operating parameters of EDM such as pulse current, pulse on time, electrode rotation and flushing pressure on material removal rate and surface roughness with tungsten carbide and cobalt.

Jatinder Kumar et al [10] investigated the tool wear rate during the Ultrasonic machining of pure titanium. Tool material, abrasive material, slurry concentration, abrasive grit size and power rating of the Ultrasonic machine were included as input factors in this investigation. The optimal setting of these parameters were determined through experiments planned, conducted and analyzed using the Taguchi method.

IV. METHODOLOGY

A scientific approach to plan the experiments is a necessity for efficient conduct of experiments. By the statistical design of experiments the process of planning the experiment is carried out, so that appropriate data will be collected and analyzed by statistical methods resulting in valid and objective conclusions. When the problem involves data that are subjected to experimental error, statistical methodology is the only objective approach to analysis. Thus, there are two aspects of an experimental problem: the design of the experiments and the statistical analysis of the data. These two points are closely related since the method of analysis depends directly on the design of experiments employed.

V. RESULTS AND DISCUSSIONS

For this experimental work the five process parameters, one at two and four at three levels have been taken to reflect the true behavior of output parameters of study. The process parameters and their level is shown in Table 1

Table 1: The Process Parameters and their Level

Symbol	Process Parameters	Level 1	Level 2	Level 3
A	Servo Voltage (SV)	20	30	---
B	Pulse off Time(µs)Toff	35	40	45
C	Pulse-on time (µs)Ton	106	112	118
D	Peak Current (Amp) Ip	100	130	160
E	Wire Tension	6	8	10

In order to predict the optimal values of the machining characteristics, only significant parameters are considered. Significant parameters are those whose effect is great on the machining characteristics. These significant parameters were found using Analysis of Variance (ANOVA) on S/N data of machining characteristics.

Table 2: Analysis of Variance for Mean Cutting Speed

Source	DF	Seq SS	Adj SS	Adj MS	F	P
SV	1	1.05609	1.05609	1.05609	73.49	0.000
Toff	2	0.17943	0.17943	0.08972	6.41	0.022
Ton	2	1.80390	1.80390	0.90195	64.48	0.000
Ip	2	0.02643	0.02643	0.01322	0.94	0.428
WT	2	0.05063	0.05063	0.02532	1.81	0.225
Error	8	0.11191	0.11191	0.01399		
Total	17	3.22840				
S = 0.118275		R-Sq = 96.53%		R-Sq(adj) = 92.63%		

Table 3: Analysis of Variance for Mean Surface Roughness

Source	DF	Seq SS	Adj SS	Adj MS	F	P
SV	1	0.01076	0.01076	0.01076	0.31	0.592
Toff	2	0.16914	0.16914	0.08457	2.44	0.148
Ton	2	5.53098	5.53098	2.76549	79.91	0.000
Ip	2	0.02314	0.02314	0.01157	0.33	0.725
WT	2	0.13724	0.13724	0.06862	1.98	0.200
Error	8	0.27684	0.27684	0.03461		
Total	17	6.14811				
S = 0.186026		R-Sq = 95.50%		R-Sq(adj) = 90.43%		

In order to validate the results obtained, two confirmation experiments were conducted for each of the machining characteristics (CS and SR) at optimal levels of the process variables.

Table 4: Confirmatory Results of Cutting Speed and Surface Roughness

Performance characteristics	Optimal combination of process parameters	Predicted Mean	Confirmatory value
Cutting speed	$A_1B_1C_3D_1E_1$	2.527 mm/min.	2.47 mm/min.
Surface roughness	$A_1B_3C_1D_3E_2$	1.23µm	1.17 µm

Basically, the larger the grey relational grade, the better is the multiple performance characteristics. The main effects of each process parameter on grey relational grade were calculated using Taguchi methodology. Thus, the optimum input parameter level corresponds to maximum average grey relational grade is **A1 B3 C1 D3 E2 .**

Table5: Response Table for Mean GRG

Level	A	B	C	D	E
1	0.6348	0.5809	0.6297	0.5647	0.5888
2	0.5251	0.5669	0.5340	0.5651	0.5947
3	---	0.5921	0.5762	0.6101	0.5564

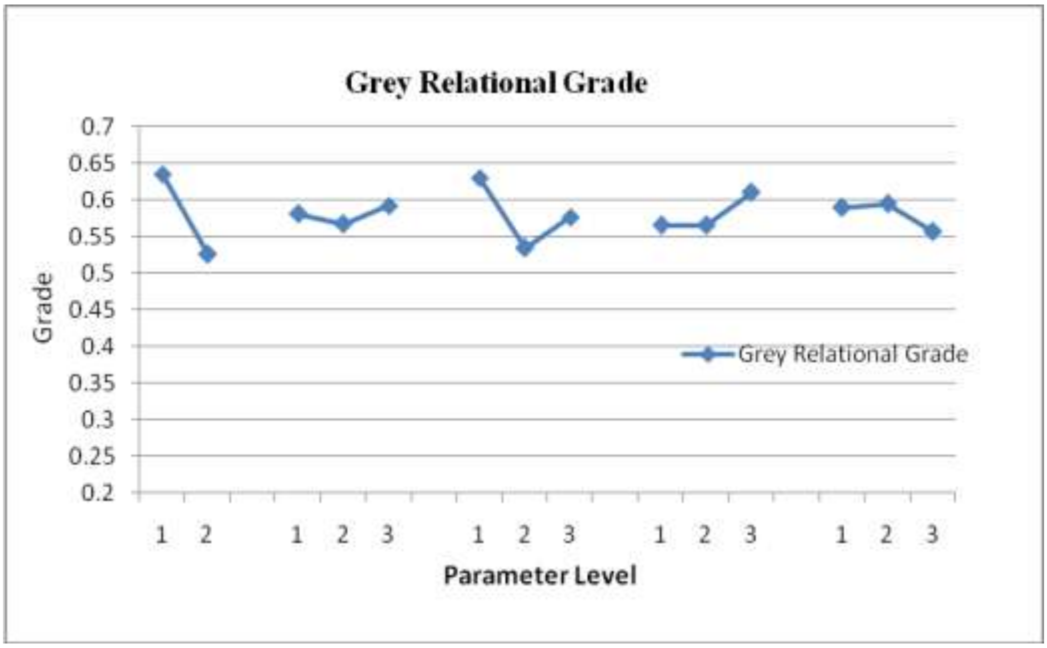

Fig.1: Response Graph for Grey Relational Grade

Finally, confirmation experiments were conducted using the optimal process parameters (A_1, B_3, C_1, D_3, E_2). The measured mean value at optimal parameters for CS and SR is 1.70 mm/min., 1.15 µm.

Table6: Summarizes the Predicted and Experimental Results

Machining characteristics	Experimental value
Optimal parameter	$A_1 B_3 C_1 D_3 E_2$
CS (mm/min.)	1.70
SR (µm)	1.15

VI. CONCLUSION

In present work, wire electrical discharge machining (WEDM) for Monel-K500, a Nickel based super alloy, has been studied. Grey relational analysis (GRA), along with Taguchi method were used to optimize the cutting speed (CS) and surface roughness (SR), simultaneously. Based on the results and discussions, the following conclusions are made:

- Taguchi design of methodology have been utilised to optimize the single performance characteristic. Thus the orthogonal array is selected for above mention five process parameters and $_{L18}$ is chosen as orthogonal array for present experimentation. Using Taguchi method, CS and SR were optimized individually.
- The optimal setting of process parameters were obtained as **A1 B1 C3 D1 E1** for cutting speed and **A1 B3 C1 D3 E2** for surface roughness. Optimal predicted values for cutting speed and surface roughness are 2.527 mm/min and 1.23µm respectively.
- ANOVA has been applied to find the significant process parameters. Using ANOVA, three process parameters namely Servo voltage (A), pulse off time (B) and pulse on time (C) were found the most significant affecting the Cutting speed while SR was affected mostly by Ton only under 95% confidence level.
- By Grey relational analysis, the optimal machining parameters setting can be obtained for considering maximum metal removal rate and minimum surface roughness simultaneously. Highest grey relational grade correspond to first level of A(20V), third level of B(45µs), first level of C(106µs), third level of D(160 ampere) and second level of E(8N) is the optimal parameter combination for multi-machining characteristics. Thus, the optimum input parameter level corresponds to maximum average grey relational grade is **A1 B3 C1 D3 E2**.

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