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Multiple Optimization of Wire EDM Machining Parameters Using Grey Based Taguchi Method for Material HCHCR

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Abstract: *Wire EDM is a non conventional machining process, which is used when the precision is prime importance. Multiple optimization (Grey based Taguchi) technique is used to find out the optimum machining setup for input parameter. This paper investigate the optimal set of process parameter such as Ton, Toff, Wp, Wf in wire EDM machining process to find out the variation in two output parameter such as material removal rate (MRR), and surface roughness (Ra) on material high chromium high carbon steel (HCHCr) using wire Brass/super alloy (coated).Experimentation was conducted on orthogonal array L-9 based on DOE. Analysis of experiment has been carried out using GRA. All the experimental data are fed into Minitab software, through which various tables, graphs & optimum values are obtained. The experimental result reveals that the optimum setting of input parameters significantly improves Wire EDM process.*

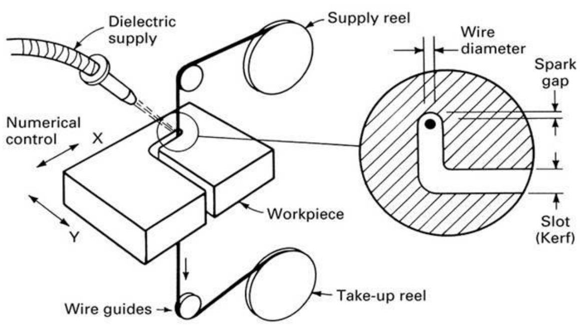
Keywords: *About five key words in alphabetical order, separated by comma.*

I. Introduction

Wire electrical discharge machining (Wire-EDM) involves a series of complex heating and cooling process. Electrical discharging happens when work piece (anode) and wire-electrode (cathode) are very close (about 5--50 μm) with a gap voltage supplied. Good static and dynamic characteristic of machine are necessary to obtain optimal machining performance. In addition, machining parameters, including pulse-on time, pulse-off time, table-feed rate, flushing pressure, wire tension, wire velocity, etc., should be chosen properly. However, selection of appropriate machining parameters for Wire-EDM is difficult, and relies heavily on operators' experience.

The Grey theory can provide a solution of a system in which the model is unsure or the information is incomplete [1]. Besides, it provides an efficient solution to the uncertainty, multi-input and discrete data problem. The relation between machining parameters and performance can be found out with the Grey relational analysis. Also, the Grey relational grade will utilize the discrete measurement method to measure the distance.

Some researches related to Wire-EDM machining-parameters setting were conducted. Kravet [2] proposed an estimating calculation method for a multi-cut Wire-EDM process. Scott, Boyina and Rajurkar [3] used a factorial design method to determine the optimal combination of control parameters in Wire-EDM. A number of 32 machining settings, which resulted in a better Metal removal rate and surface roughness, were determined from 729experiments.Tarng [4] applied neural network with simulated annealing (SA) algorithm to determine the optimal machining-parameters in Wire-EDM process. However, it cannot provide the optimal machining parameters for a desired surface roughness. Liao [5] presented an approach to determine optimal parameters setting based on the Taguchi Quality design method, analysis of variance, regression analysis and feasible direction method. Lin [6] presented the use of Grey relational grade to the machining parameters optimization of the electrical discharge machining (EDM) process. Optimal machining-parameters setting for Wire-EDM still has some difficulty: costly and time-consuming in conducting experiments, many machining parameters, and real mathematical models hard to be derived. The purpose of this paper is to present inefficient method to find the significant parameter affecting machining performance by integrating Grey relational analysis and statistical method. Also the optimal machining-parameters setting for maximum machining speed and minimum surface roughness can be obtained by applying Grey relational analysis. Furthermore, it is feasible to obtain optimal machining parameters for a desired surface roughness and maximum metal removal rate by the Grey relational analysis.



II. Grey Relational Analyses (GRA)

2.1 Data Preprocessing

In a Grey relational analysis, experimental data, i.e., measured features of the quality characteristics, are first normalized, ranging from zero to one. This process is known as Grey relational generation. Next, based on normalized experimental data, the Grey relational coefficient is calculated to represent the correlation between the desired and the actual experimental data. Then overall Grey relational grade is determined by averaging the Grey relational coefficient corresponding to selected responses 9. The overall performance characteristic of the multiple response process depends on the calculated Grey relational grade. This approach converts multiple-response process-optimization problem into a single-response optimization situation with the objective function of the overall Grey relational grade. The optimal parametric combination is then evaluated, which would result in the highest Grey relational grade. The optimal factor setting for maximizing the overall Rey relational grade can be performed using the Taguchi method.

In Grey relational generation, the normalized MRR and Ra corresponding to the smaller-the-better (SB) criterion which can be expressed as:

$$x_i(k) = \frac{\max y_i(k) - y_i(k)}{\max y_i(k) - \min y_i(k)} \qquad (1)$$

MRR should follow the larger-the-better (LB) criterion, which can be expressed as:

$$x_j(k) = \frac{y_j(k) - \min y_j(k)}{\max y_j(k) - \min y_j(k)} \qquad (2)$$

Where $x_i(k)$ and $x_j(k)$ are the value after the Grey relational generation for the SB and LB criteria, respectively. Min yi(k) is the smallest value of yi(k) and for the kth response, and max yi(k) is the largest value of yi(k) for the kth response 9. An ideal sequence is x0(k) (k=1, 2… m) for the responses. The definition of the Grey relational grade in the course of the Grey relational analysis is to reveal the degree of relation between the 9 sequences [x0(k) and xi(k), k = 1,2,…,m and i =1,2,…,9]. The Grey relational coefficient $\xi_i(k)$ can be calculated as:

$$\xi_i(k) = \frac{\Delta_{min} - \Delta_{max}}{\Delta_{0i}(k) + \psi \Delta_{max}} \qquad (3)$$

where Δ_{0i}= ‖ $x_0(k) - x_i(k)$ ‖ is the difference of the absolute value x0(k) and xi(k); ψ is the distinguishing coefficient $0 \leq \psi \leq 1$;Δ_{min}(k) =∀j^{min}∈i∀k^{min}‖ $x_0(k) - x_j(k)$ ‖ is the smallest value of Δ_{0i}; andΔ_{max}(k) = ∀j^{max} ∈ i∀k^{max}‖ $x_0(k) - x_j(k)$ ‖ is the largest value of Δ_{0i}. After averaging the Grey relational coefficients, the Grey relational gradeγ_i can be computed as:

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} \xi_i(k) \qquad (4)$$

Where n is the number of process responses. The higher value of the Grey relational grade corresponds to an intense relational degree between the reference sequencex0 (k) and the given sequence xi (k).The reference sequence x0(k) represents the best process sequence; therefore, a higher Grey relational grade means that the corresponding parameter combination is closer to the optimal. The mean response for the Grey relational grade with its grand mean and the main effect plot of the Grey relational grade are very important because the optimal process condition can be evaluated from this plot.

III. Experimental Procedures And Test Results

3.1 Experimental Details

The cutting experiments were carried out on an electronica 4-axes wire EDM using wire brass (super alloy coated) on material high chromium high carbon steel (HCHCr). The mechanical properties and percent of contains are shown in table 1

3.1.1Surface roughness (SR):-

A Phynix TR-100 model surface-roughness tester was used to measure the surface roughness of the machined samples. No of reading was taken for getting average value of surface roughness. The multi-criteria optimization technique was chosen to find the optimum value.

3.1.2 Material removal rate (MRR):-

MRR (mm^3 /min) was calculated using Eq. (5)

$$\textbf{MRR} = \frac{Wi - Wf}{\rho * t} \qquad (5)$$

Where Wi=initial weight, Wf=final weight ρ=density of material (HCHCr) & t =time taken for machining.

3.2 Process Parameters and Test Results.

In full factorial design, the number of experimental runs exponentially increases as the number of factors, as well as their level increases. This results in a huge experimentation cost and considerable time periods. So, in order to compromise these two adverse factors and to search for the optimal process condition through a limited number of experimental runs Taguchi's L9 orthogonal array consisting of 9 sets of data was selected to optimize the multiple performance characteristics of the Wire EDM process.

Table 1, shows the chemical composition of material high chromium high carbon steel (HCHCr).
Table 2 shows the selected design matrix based on the Taguchi L9 orthogonal array consisting of 9 sets of coded conditions and the experimental results for the responses of, SR and MRR. All these data were utilized for the analysis and evaluation of the optimal parameter combination required to achieve the desired quality within the experimental domain.
Table 3 shows Ton Toff, Wf, Wp input parameter settings and its related output parameter values i.e. MRR & SR.
Table 4 shows the material removal rate MRR & Surface roughness SR.
Table 5 represents the calculation of Δ0i (K), which is based upon the formula, Δ0i (K) =|x0 (K)-Xi (K)|
This helps to find out the value of Δ min & Δ max after calculation of Δ0i (K) we calculate the value of grey relation coefficient with the help of equation no 4. Table no 6 shows the calculation of Grey Relational Coefficient.
Table 7 shows the value grey relation grade calculation with the help of equation no 4.

Table no 1 show the chemical composition of HCHCr steels.

Element	Content (%)
C	2.00-2.35
Mn	0.6
Si	0.6
Cr	11.00–13.50
Ni	0.3
W	1
V	1
P	0.03
S	0.03
Cu	0.25

Table no 2 Orthogonal Array **L9**

EXPERIMENTS	P1	P2	P3	P4
1	1	1	1	1
2	1	2	2	2
3	1		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

Table no 3 Experimental results

Runs	Ton (μ sec)	To ff (μ sec)	Wf (mm/sec)	Wp (mm3/min)	MRR(mm^3/min)	SR (μ-sec)
1	120	63	5	5	3.71	3.325
2	120	58	10	7	3.89	8.935
3	120	53	15	10	2.22	8.511
4	122	63	10	10	4.08	9.822
5	122	58	15	5	4.26	5.321
6	122	53	5	7	4.267	7.588
7	123	63	15	7	3.89	10.427
8	123	58	5	10	3.71	9.172
9	123	53	10	5	4.267	3.932
MAX					4.267	10.427
MIN					2.22	3.325

Table no 4 shows the Normalization value

NORMALIZATION	
NOR_MRR	NORM Ra
0.728	1.000
0.816	0.210
0.000	0.270
0.909	0.085
0.997	0.719
1.000	0.400
0.816	0.000
0.728	0.177
1.000	0.915

Table no 5: Calculation of ∆0i (K)

∆0i (K) =|x0 (K)-Xi (K)|

MRR	SR
1	1
0.272	0.000
0.184	0.790
1.000	0.730
0.091	0.915
0.003	0.281
0.000	0.600
0.184	1.000
0.272	0.823
0.000	0.085

Table 6. Grey Relational Coefficient: (ψ = 0.33) COEFFICEINT FOR MRR & SR

MRR	SR
1	1
0.548	1.000
0.642	0.295
0.248	0.311
0.783	0.265
0.990	0.540
1.000	0.355
0.642	0.248
0.548	0.286
1.000	0.794

Table 7 Grey relational grades. Grades

0.774	*0.191*	*0.03647*
0.468	*-0.115*	*0.013186*
0.280	*-0.303*	*0.092038*
0.524	*-0.059*	*0.003472*
0.765	*0.182*	*0.033064*
0.677	*0.094*	*0.008893*
0.445	*-0.138*	*0.019072*
0.417	*-0.166*	*0.027542*
0.897	*0.314*	*0.098644*

A graphical representation of the S/N ratio for the overall grey relational grade is shown in figure. Figure 2 the center line is the value of total mean ratio.

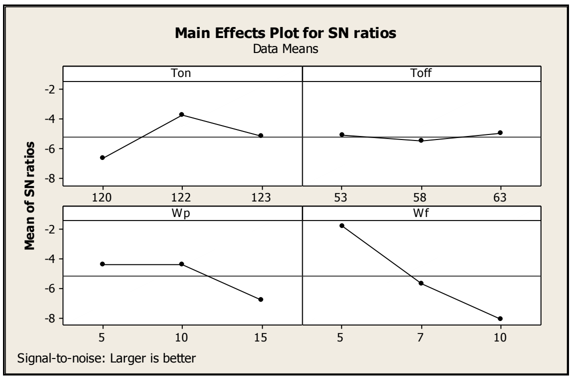


Figure 2. Main effects plot for SN ratios

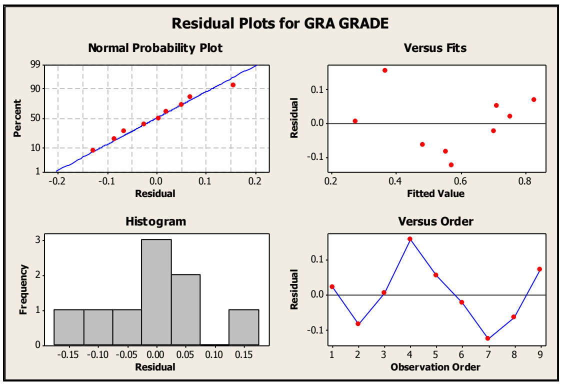


Figure 3.Residual plots for GRA Grade

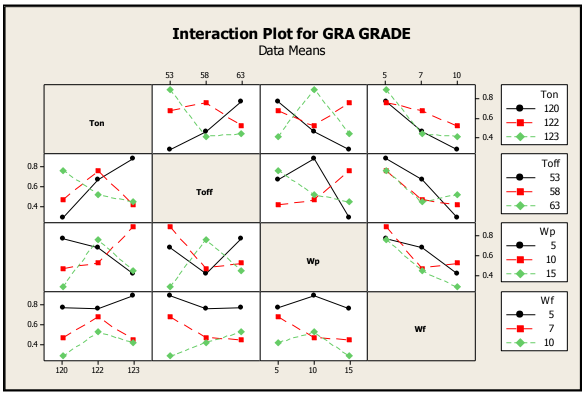


Figure 4.Interaction plot for GRA Grade

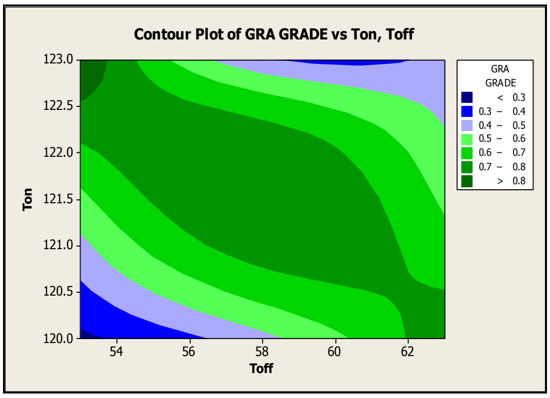
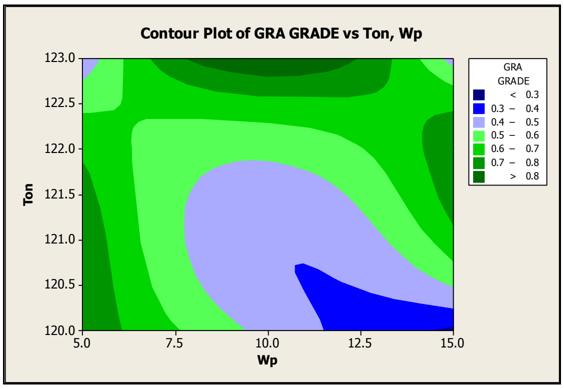


Figure 5.Contour plot of GRA Grade Vs Ton, Toff



6. Contour plot of GRA Grade Vs Ton, Wp

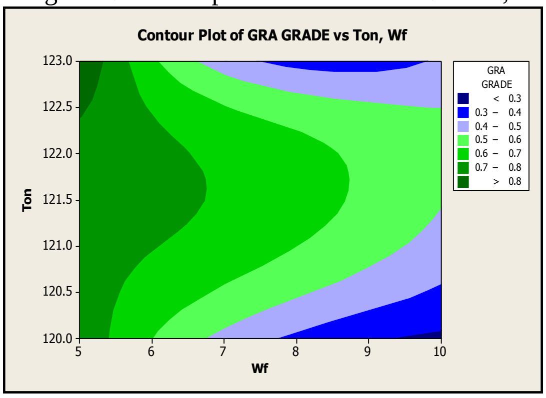


Figure 7.Contour plot of GRA Grade Vs Ton, Wf

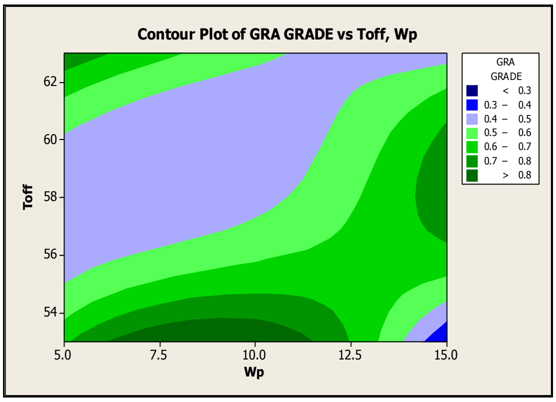


Figure 8.Contour plot of GRA Grade Vs Toff, Wp

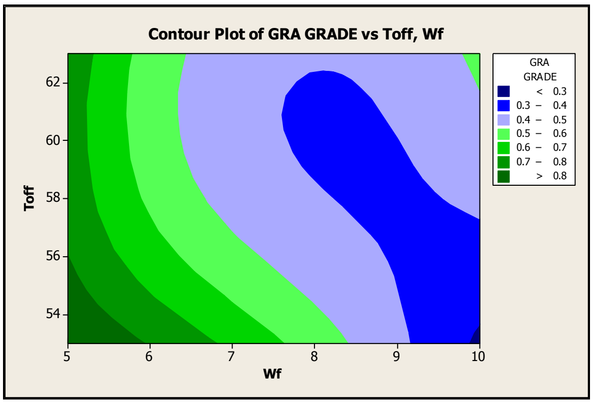


Figure 9.Contour plot of GRA Grade Vs Ton, Wf

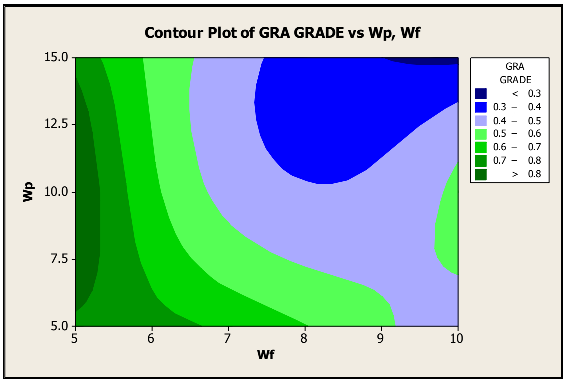


Figure 10.Contour plot of GRA Grade Vs Wp, Wf

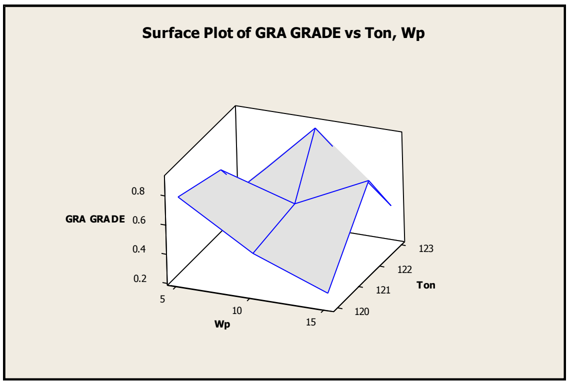


Figure11.Surface Plot of GRA Grade Vs Ton,Wp

IV. Result and discussion

As indicated in Figure 2 the optimal condition for Wire EDM process for the parameter Ton 2,Toff 1,Wp 2, & Wf 1.As per the experiment performed on machine by taking the optimum values it is observed that machine performed effectively. The percent contributions of the input parameters on the material-removal rate, and the surface roughness are shown in Figure 2. The Main effects plot for SN ratios. Figure 3 shows the Residual plots for GRA Grades, It contain normal probability chart, versus fits, histogram, versus order. Figure 4 shows the Residual plots for GRA Grades i.e. interaction graph for GRA grades for the input parameter Ton.Toff,Wf, and Wp. Figure 5,6,7,8,9 Shows the Contour plot of GRA Grade simultaneously Vs (Ton, Toff),(Ton, Wp),(Ton, Wf),(Toff, Wp) and (Ton, Wf).

V. Analysis of Variance (ANOVA)

The purpose of the analysis of variance (ANOVA) is to investigate which turning parameters significantly affect the performance characteristics 8–10. This is accomplished by separating the total variability of the grey relational grades, which is measured by the sum of the squared deviations from the total mean of the grey relational grade, into contributions from each of the turning parameters and the error 9. Thus;

$$SS_T = SS_F + SS_E \quad (7)$$

$$SS_T = \sum_{j=1}^{p} (\Upsilon_j - \Upsilon_m)^2 \quad (8)$$

SST – Total sum of the squared deviations about the mean Υj – Mean response for the *j*th experiment Υm – Grand mean of the response

p – Number of experiments in the orthogonal array *SSF* – Sum of the squared deviations due to each factor *SSe* – Sum of the squared deviations due to error In addition, the *F* test was used to determine which input parameters have a significant effect on the per performance characteristic. Usually, the change of the input parameter has a significant effect on the performance characteristics when the *F* value is large. According to this analysis, the most effective parameters with respect to the material-removal rate and the surface roughness are the Ton, Toff, Wf, Wp. The percentage contribution indicates the relative power of a factor to reduce the variation. For a factor with a high percentage contribution, there is a great influence on the performance.

VI. Confirmation Test

After evaluating the optimal parameter settings, the next step is to predict and verify the enhancement of the quality characteristics using the optimal parametric combination 9. The estimated Grey relational grade ϒ using the optimal level of the design parameters can be calculated as:

$$\Upsilon = \Upsilon_m + \sum_{i=1}^{o} (\Upsilon_j - \Upsilon_m) \quad (9)$$

Where ϒ *m* is the total mean Grey relational grade, ϒ *i* is the mean Grey relational grade at the optimal level, and *o* is the number of the main design parameters that affect the quality characteristics 9. Table 11 indicates the comparison of the predicted values of input parameter. Good agreement between the actual and the predicted results has been observed (the improvement in the overall Grey relational grade was found to be as 0.90). it shows the accuracy and effectiveness of the experiment

In the Taguchi method, the only performance feature is the overall Grey relational grade and the aim should be to search for a parameter setting that can achieve the highest overall Grey relational grade 9. The Grey relational grade is a representative of all the individual performance characteristics. In the present study, the objective functions were selected in relation to the parameters of the material-removal rate, and surface roughness. The importance weights of the material-removal rate, and the surface roughness were equally adjusted to be 0.33. The results show that using the optimal parameter setting (*Ton 2, Toff1, Wp2, Wf1*) causes lower surface roughness with a higher material removal rate and hence a better surface finish.

VII. Conclusions

In this study, the Grey-based Taguchi method was applied for the multiple performance characteristics of Wire EDM operations. A grey relational analysis of the material-removal rate, and the surface roughness obtained from the Taguchi method reduced from the multiple performance characteristics to a single performance characteristic which is called the grey relational grade. Therefore, the optimization of the complicated multiple performance characteristics of the processes can be greatly simplified using the Grey-based Taguchi method. As per the experimental result and graph it is clear that all the optimize values have significant effect on output parameter i.e. SR and MRR.Optimize values for a particular material to be machined is advantageous for the operator .As the repetition of the experiment causes delay in production and increases machining time. This paper will help to take input paramer for the material HCHCr. It is also shown that the performance characteristics of Wire WEDM operations, such as the material removal rate, and the surface roughness are greatly enhanced by using this method.

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