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Efficiency Optimization during Electric Discharge Machining of H-13 Steel Based on Grey Relation Analysis

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Abstract— Optimization of multi-performance characteristics is more complex compared to optimization of single-performance characteristics. Grey relation analysis is a new technique for decision making, relational analysis, and performing prediction in different areas. In this paper, the use of grey relational analysis for optimizing the machining efficiency during electric discharge machining of H-13 tool steel is introduced. The machining parameters selected for the study are polarity, electrode type, peek current, pulse on time, duty cycle, gap voltage, retract distance and flushing pressure. Machining performance is evaluated in the form of material removal rate, tool wear rate and wear ratio. An L36 (2^1X3^7) orthogonal array based on the Taguchi method has been adopted to conduct series of experiments and to measure the machining performance parameters. A grey relation grade is obtained from the grey relation analysis which represents the aggregate of different selected machining parameters. By this approach a multi-objective parametric optimization is converted into optimization of a single grey relational grade.

Index Terms— Electrical discharge machining, grey relation analysis, material removal rate, tool wear rate, wear ratio, orthogonal array.

1 Introduction

Electrical discharge machining (EDM) is a very complex phenomenon and several parameters are involved in its theory. It is the process of material removal by controlled erosion through a series of electric sparks between the tool and the work-piece. Material is removed both from the work-piece and the electrode because of the intense heat generated in the sparking zone this heat melts and evaporates the material [1].

Marafona and Wykes [2] performed experimental investigations to optimize material removal rate (MRR) during EDM with copper-tungsten electrodes using Taguchi L18 orthogonal array and achieved improvement of MRR for a given tool wear ratio. Tsai et al. [3] performed blending of copper powders containing resin with chromium powders to form EDM electrode. The machined surface showed fewer cracks and good corrosion resistance. Moro et al. [4] applied the technology of electrical discharge coating and reported improvement in working life of the die by three to seven times. Beri et al. [5] made an attempt to correlate the usefulness of powder metallurgy (PM) electrodes in electrical discharge machining (EDM). It was found that copper tungsten electrode made through powder metallurgy gives better multi-objective performance than conventional copper electrode. Kumar et al. [6] performed experimental investigations during EDM of OHNS die steel with Inconel electrode under machining conditions favoring high electrode wear. Ashokan and Senthilkumaar [7] illustrated a new approach of selecting machining parameters during turning of Inconel 718 using the multi-objective optimization coupled with multiple attribute decision-making method. Garg R.K. et al. [8] reported that hard composite materials can be machined by many non-traditional methods like water jet and laser cutting but these processes are limited to linear cutting only. Electrical discharge machining (EDM) shows higher capability for cutting difficult to machine shapes with high precision for these materials. Beri et al. [9] performed experimentation on electric discharge machining of AISID2 steel in kerosene with copper tungsten electrode made through PM technique and conventional Cu electrode and recommended to use conventional Cu electrode for higher MRR and CuW electrode made through PM for higher surface finish. Beri et al. [10] evaluated surface quality measured in terms of surface roughness (Ra value) during electric discharge machining using orthogonal array L36 (21X 37) based on Taguchi methodology. Experimental data was statistically analyzed (ANOVA) and optimum condition was achieved for evaluation criteria. It was concluded minimum Ra is obtained with CuW2080 electrode at minimum current and negative polarity and polarity, electrode type, peek current, have significant effect on surface quality of the machined surface. Beri N. et al. [11] explained the usefulness of powder metallurgy (PM) electrodes in electrical discharge machining (EDM) with the

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help of experimentation on AISI D2 steel in kerosene with CuW (25% Cu and 75% W) PM electrode.

In order to achieve the economic objective of this process, optimal machining conditions have to be determined and so there is a need to established mathematical models. In recent years, the Taguchi method has become a powerful tool for improving process performance. Most of the experimental investigations using Taguchi method are concerned with a single quality characteristic. As the original Taguchi method was designed to optimize a single performance characteristic. Handling multiple performance characteristics by the Taguchi method requires further research efforts [12,13]. For the EDM process, material removal rate is a higher-the-better characteristic. As a result, an improvement of one performance characteristic may require a degradation of another performance characteristic. Hence, optimization of the multiple performance characteristics is much more complicated than optimization of a single performance characteristic. In such complex and multivariate system it is difficult to understand the relationship between factors and to analyze the process using the classical statistical procedure. Grey relation theory is capable of handling such type of problems efficiently.

This theory was first proposed by Deng [14] and thereafter it was applied in different fields of science and engineering. Lin and Lin [15] used this theory for optimizing EDM process response characteristics viz. MRR, electrode wear ratio and surface roughness in relation to the different input parameters such as open discharge voltage, discharge current, polarity, duty factor, pulse on time, and type of dielectric fluid. Huang and Liao [16] applied grey relation theory to obtained optimal parametric setting in wire EDM for minimum SR and maximum MRR. Panda [17] used grey relational theory to establish the significance of the EDM process parameters based on Fisher test of grey relational coefficients as the observations of crater morphology was unable to provide detailed information regarding the effect of parameters. Kumar et al. [18] optimized process parameters of silicon mixed EDM on tool steel using grey relation theory. Beri et al. [9] studied the effect of current, duty cycle and flushing pressure using powder metallurgy processed electrode having 75% tungsten. Performance was evaluated in terms of MRR, SR and surface hardness during EDM of AISI D2 steel in kerosene keeping all other parameters constant. An L18 orthogonal array was used for the experimentation and multiple performances characteristic was studied using the grey relation analysis. Beri et al. [19] performed multi-objective parametric optimization during electrical discharge machining (EDM) of Inconel 718 using the Taguchi method with grey relation analysis.

From the above reviewed literature it is observed that the analysis based upon grey relation theory has found wide application for determining the optimum parameters in different machining processes. In this paper, the use of orthogonal array with the grey relational analysis for optimizing the machining efficiency during electric discharge machining of H-13 tool steel is introduced. The machining parameters selected for the study are polarity, electrode type, peek current, pulse on time, duty cycle, flushing pressure, retract distance and gap voltage. Machining performance is evaluated in the form of material removal rate (MRR), tool wear rate (TWR) and wear ratio (WR).

2 Experimantation and Determination of Optimal Machining Parameters

2.1 Experimental planning, procedures and parameters

Experiments were carried out on Electronica make EDM machine; model SMART ZNC (S50). H-13 steel was used as the work piece material and EDM oil as the dielectric medium. Cylindrical Cu electrodes and PM processed CuCr9010 (Cu90%Cr10%) and CuCr8515 (Cu85%Cr15%) electrodes were used for the experimentation. MRR and TWR were obtained using weight loss method.

The ranges of the parameters were selected on the basis of trial experimentation and reviewed literature. The machining parameters and their levels selected for the study are tabulated in Table 1 and all other parameters were kept constant. To obtain optimal machining performance, the maximum MRR, minimum TWR and the maximum WR are desired. Therefore, the criterion selected for the experiments with the Minitab 15.1.1 (software) is higher-the-better MRR and WR and lower-the-better TWR. A mixed orthogonal array L36 (2^1X3^7) experimental design has been used for experimentation. Two set of 36 experiments were performed as per standard L36 (2^1X3^7) Taguchi design and average values were taken for the analysis.

2.2 Grey Relation Analysis for the Experimental Results

Following steps are involved in the gray relation theory based optimization of the machining efficiency:

a) Normalizing the experimental results of MRR, TWR and WR for all the trials.
b) Performing the Grey relational generating and calculating the Grey relational coefficient.
c) Calculating the Grey relational grade by averaging the Grey relational coefficient.
d) Performing statistical analysis of variance (ANOVA) for the input parameters with the Grey relational grade so as to find which parameter significantly affects the process.
e) Selecting the optimal levels of process parameters.
f) Conduct confirmation experiment and verify the optimal process parameters setting.

The grey relation grade obtained for each experimental set up is shown in Table 2. The high value of grey relation grade represents that the corresponding experimental result is very closer to the ideally normalized value. Experimental conditions

TABLE 1
MACHINING PARAMETERS LEVELS

Parameter	Symbol	Units	Level 1	Level 2	Level 3
Polarity	A	-	+ve	-ve	
Electrode type	B	-	Copper (Cu)	Copper Chromium (CuCr9010) (Cu 90%Cr10%)	Copper Chromium (CuCr8515) (Cu 85%Cr15%)
Peek current	C	(Amp.)	6.0	10.0	14.0
Duty cycle	D	-	0.7	0.8	0.9
Gap voltage	E	(Volts)	40	50	60
Retract distance	F	(mm)	1	2	3

TABLE 2
MACHINING PARAMETERS LEVELS

Exp No.	Polarity	Electrode type	Peak Current (Ampere)	Duty Cycle	Gap Voltage (Volt)	Retract Distance (mm)	Grey Relation Grade
1	Positive	Copper	6	.7	40	1	0.652174
2	Positive	CuCr-1	10	.8	50	2	0.602672
3	Positive	CuCr-2	14	.9	60	3	0.665494
4	Positive	Copper	6	.7	40	2	0.627394
5	Positive	CuCr-1	10	.8	50	3	0.594123
6	Positive	CuCr-2	14	.9	60	1	0.833336
7	Positive	Copper	6	.8	60	1	0.797657
8	Positive	CuCr-1	10	.9	40	2	0.595919
9	Positive	CuCr-2	14	.7	50	3	0.691542
10	Positive	Copper	6	.9	50	1	0.624393
11	Positive	CuCr-1	10	.7	60	2	0.643705
12	Positive	CuCr-2	14	.8	40	3	0.635834
13	Positive	Copper	10	.9	40	3	0.598416
14	Positive	CuCr-1	14	.7	50	1	0.610884
15	Positive	CuCr-2	6	.8	60	2	0.582955
16	Positive	Copper	10	.9	50	1	0.593923
17	Positive	CuCr-1	14	.7	60	2	0.639606
18	Positive	CuCr-2	6	.8	40	3	0.570496
19	Negative	Copper	10	.7	60	3	0.557149
20	Negative	CuCr-1	14	.8	40	1	0.563482
21	Negative	CuCr-2	6	.9	50	2	0.423982
22	Negative	Copper	10	.8	60	3	0.333608
23	Negative	CuCr-1	14	.9	40	1	0.559917
24	Negative	CuCr-2	6	.7	50	2	0.408815
25	Negative	Copper	14	.8	40	2	0.556277
26	Negative	CuCr-1	6	.9	50	3	0.423450
27	Negative	CuCr-2	10	.7	60	1	0.408888
28	Negative	Copper	14	.8	50	2	0.556411
29	Negative	CuCr-1	6	.9	60	3	0.486202
30	Negative	CuCr-2	10	.7	40	1	0.374846
31	Negative	Copper	14	.9	60	2	0.556106
32	Negative	CuCr-1	6	.7	40	3	0.410775
33	Negative	CuCr-2	10	.8	50	1	0.430936
34	Negative	Copper	14	.7	50	3	0.556092
35	Negative	CuCr-1	6	.8	60	1	0.555885
36	Negative	CuCr-2	10	.9	40	2	0.556068

for experiment no. 6 has the best multiple performance characteristics among 36 experiments because it has the highest grey relation grade (0.833336) as shown in Table 2. In other words, optimization of the complicated multiple performance characteristics i.e machining efficiency can be converted into optimization of single grey relation grade.

Since the experimental design is orthogonal type, it is then possible to separate out the effect of each input parameter on the grey relation grade at different levels. The mean of the grey relation grade for each level of the input parameters is calculated and the total mean of the grey relation grades for all the 36 experiments is calculated and is shown in Table 3. Since the grey relation grades represents the levels of correlation between the reference and the comparability sequences, the larger grey relation grade means the comparability sequence exhibits a stronger correlation with the reference sequence. Therefore, the comparability sequence has a larger value of grey relation grade for MRR, TWR and WR. Based on this premise, this study selects the level that provides the largest average response.

From Table 3, it is clear that A1, B1, C3, D3, E3 and F1 have the largest values of grey relation grades for the respective factors. Therefore, A1, B1, C3, D3, E3 and F1 are the condition for the optimum parameter combination of the EDM process.

TABLE 3
RESPONSE TABLE FOR THE GREY RELATION GRADE

Machine Parameters	Grey relation grade			
	Level 1	Level 2	Level 3	Max – Min
Polarity (A)	0.642251	0.484383		0.157868
Electrode type (B)	0.584133	0.557218	0.548599	0.035534
Peek current (C)	0.547015	0.524188	0.618748	0.094560
Duty cycle (D)	0.548489	0.565028	0.576434	0.027945
Gap voltage (E)	0.558466	0.543102	0.588383	0.045281
Retract distance (F)	0.583860	0.562492	0.543598	0.040262
Total Mean Value of the Grey Relation Grade = 0.5633				

TABLE 4
RESULTS OF MACHINING PERFORMANCE USING INITIAL AND OPTIMAL MACHINING PARAMETERS

EDM Response Parameters	Initial Machining Parameters	Optimal Machining Parameters	
		Predicted	Experimental
	A1, B3,C3,D1,E2,F2	A1, B1,C3,D3,E3,F1	A1, B1,C3,D3,E3,F1
Material removal rate (g/min)	0.12364	------	0.13548
Tool wear rate (gm/min)	0.00174	------	0.01137
Wear Ratio (WR)	71.09072	------	611.10221
Grey relation grade	0.691542	0.777225	0.766039
Improvement in grey relation grade =(0.766039-0.691542)=0.074497 i.e 7.45%			

From the last column of Table 3 it is observed that the difference between the maximum and minimum value of the grey relation grade for all factor in decreasing order are polarity, peak current, gap voltage, retract distance, electrode type and duty cycle respectively. This indicates that polarity, peak current and gap voltage have more effect on the multiple-performance characteristics then other machining parameters.

2.3 Confirmation Test

Once the optimum levels of the selected machining parameters are selected, the final step is to predict and verify the improvement of performance characteristic using optimal level of the machining parameters. The estimated grey relational grade using optimal level of the machining parameters can be calculated as:

$$\alpha = \alpha_m + \sum_{i=1}^{q} \overline{\alpha}_i - \alpha_m \qquad (2)$$

where α_m is the total mean of the grey relation grade, α_i is the mean of the grey relation grade at optimum level, and q is the number of the machining parameters that significantly affects the multiple performance characteristics.

Based on this equation, the estimated grey relational grade using optimum machining parameters can then be obtained. Table 4 shows results of confirmation experiments using optimum experimental conditions. As shown in Table 4, MRR is improved from 0.12364 g/min to 0.13548 g/min, TWR is reduced from 0.00174 g/min to 0.01137 g/min and WR is improved from 71.09072 to 611.10221. It is clearly shown that multiple performance characteristics in EDM process are greatly improved through grey relation technique. The improvement in grey relation grade is 7.45%.

3 Conclusion

From the present experimental investigation following conclusions can be drawn:

1. A grey relation analysis was applied on the experimental results of MRR, TWR and WR to obtain grey relation grade, hence, the optimization of the multi-objective performance was converted into a single objective grey relation grade. As a result, optimization of machining efficiency during EDM of H-13 steel is simplified.
2. A significant improvement of the grey relation grade is obtained for the machining efficiency using the optimum machining parameters and the grey relation grade is improved by 7.45%.
3. The optimum machining parameter combination for better machining efficiency during electric discharge machining of H-13 steel as suggested by the present study is EDM process. A1, B1, C3, D3, E3 and F1.

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