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OPTIMIZATION OF EDM PARAMETERS USING INTEGRATED APPROACH OF RSM, GRA AND ENTROPY METHOD

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Abstract- This paper presents a hybrid optimization approach for the determination of the optimal process parameters which maximize the material removal rate and minimize surface roughness & the tool wear rate. The input parameters of electrical discharge machining considered for this analysis are pulse current (Ip), pulse duration (Ton) & pulse off time (Toff). The influences of these parameters have been optimized by multi response analysis. The designed experimental results are used in the gray relational analysis & the weight of the quality characteristics are determined by the entropy measurement method. The effects of the parameters on the responses were evaluated by response surface methodology, which is based on optimization results. On the basis of optimization results it has been found that pulse current (Ip) of 5A, a pulse duration (Ton) of 60µs & pulse off time (Toff) 45µs, which are the best combination of this analysis.

Keywords- *Electrical discharge machining; EDM; Response Surface Methodology; RSM; Grey-Entropy Analysis; Material removal rate; MRR; Surface roughness; Ra. tool wear rate.*

I. INTRODUCTION

In recent years, the practice of hard and difficult to machine materials, due to its brilliant technological properties, is extensively used in various sectors in modern manufacturing industries. Owing to, its excellent properties and behavior in these applications even more challenging, its transformation and processing they present problems which limit the accuracy and rising production costs. Consequently, the machining of such material in an efficient manner is a challenge.

Electro Discharge Machining (EDM) is a brilliant solution to this problem, It is generally used to machine difficult-to-machine materials, high strength, temperature resistant alloys and manufacturing of tools and dies for machining cavities and counter shaping and cutting, As long as the Work material is conductive. It is a widely applied and very useful technique based on erosion of metal caused by the discharge occurring between the electrode and the process part. The electrical spark is generated and material removal mainly occurs due to the thermal energy of the spark. In EDM, material removal depends on mainly thermal properties of the work material rather than its strength, hardness etc. Material Removal Rate (MRR) is a vital performance characteristic in EDM process. Meanwhile, EDM researchers have used a number of methods to improve and optimize the MRR, together with a reduction in tool wear and improved surface quality. Despite a variety of different approaches, all the research work in this area shares the same objectives of attaining more efficient MRR. Among Several attempts Dvivedi et al. [1] investigated the influence of process parameters on MRR as per the relative importance are Ip, Ton, pulse offsetting, flushing pressure, and gap control setting and verified these parameters experimentally. Kao and Hocheng [2] applied GRA on investigating surface roughness and passivation strength. El-Taweel et al. [3] reveals the relationships between process parameters in electro discharge using powder metallurgy method and evaluated MRR & TWR. RSM was employed by Pradhan et al. [4] to investigate the influence of processing variables on the responses MRR & SR. kanagarajan et al. [5] study the responses MRR & SR on tungsten carbide by four variables of EDM such as electrode rotation (S), pulse on time (T), current (A), and flushing pressure (P) . Dhar et al. [6] evaluates the influence of I_p, T_{on} and (air gap voltage) V on MRR, TWR, ROC on EDM of Al–4Cu–6Si alloy–10 wt. % SiCP composites. Pradhan et al. [7] study the Elman networks which were used for prediction of MRR in EDM. Ranganathan & senthivelan [8] used TM to optimization of SR, TWR & MRR and study the effect of cutting speed, feed rate, depth of cut, and work piece temperature. Pradhan & Biswas et al. [9] have established Empirical models variables with MRR & SR. Lin B et al. [10]. Optimized the machining parameters like work piece polarity, pulse on time, duty factor, open discharge voltage, discharge current, and dielectric fluid with responses MRR, SR, and electrode wear ratio use of orthogonal array with GRA. Rao et al. [11] used GRA in entropy measurement for determination of need-YAG laser cutting process parameters. Singh et al. [12] optimizing MRR, TWR, SR, taper, radial on EDM by GRA. Pan et al. [13] to study the cutting parameters for Nd-YAG laser welding TM coupled with GRA. A. Al-Refaie et al. [14] study an approach for optimizing multiple quality responses in the Taguchi method using regression models and grey relational analysis.

M.DILIPKUMAR et al. [15] optimized 4 nutrients viz. Yeast extract, MnSO4.7H2O, K2HPO4 and Corn using RSM, in which steep liquor were found to be most significant nutrient components. Reddy Sreenivasulu et al. [16] (review paper) obtain the optimal levels of process parameters that yield the burr size and hole quality in drilling of Aluminum 6061 alloy & enhance the effectiveness of the drilling process using design of experiments based grey relational analysis. Li Shichang et al. [17] optimize the fermentation medium of high-yielding L-lactic acid strains using Response surface method. Song & Shepperd [18] study for optimization of software effort prediction, outlier detection, and feature subset selection at an early stage of a software development process by using Grey Relational Analysis. Saurav Datta et al. [19] study the effect of parametric influence of wire EDM on MRR, SR and width of cut to establish mathematical models & simulation. Kamal Jangra et al. [20] study the optimization of four machining characteristics in WEDM of WC-5.3%Co composite using GRA coupled with entropy measurement method. Amit Sharma & Vinod Yadava [21] present a hybrid approach of RSM & TM for modeling and TM, GRA coupled with entropy measurement method for optimization of cut quality during pulsed Nd:YAG laser cutting of thin Al-alloy sheet for straight profile. Though, several researches have been done to increase the MRR, accuracy and surface quality, using various traditional and hybrid techniques. But, optimization of responses using the integration of RSM, GRA and entropy measurement methods is tied very rarely. Thus, in this study an attempt has been made to identify the effect of the EDM parameters and to find the optimal parametric combination. The RSM is used to conduct the experiments, secondly, GRA is used to obtain a gray relational grade through normalization, gray relational co-efficient. Eventually, the entropy analysis is used to compute the percentage weighting of the gray relational coefficients and gray relational grades has been calculated. The flow chart of the detail steps for obtaining the optimal setting is illustrated in Fig.1. This work will help the researcher and EDM operators to find the optimal combination of the parameters to obtain maximum MRR, without losing the precision, accuracy and surface quality.

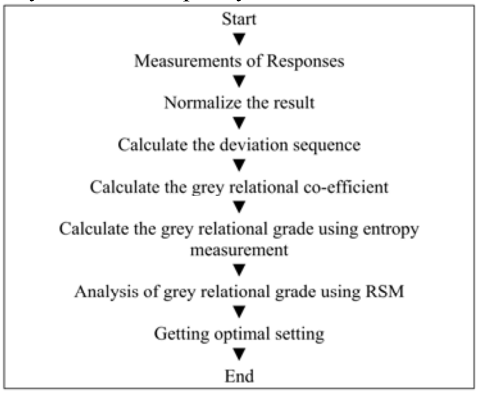

FIG.1 – FLOW CHART

II. EXPERIMENTAL PROCEDURE

Experiments were conducted to study the effects of various machining parameters; such as Ip, Ton & Toff on MRR, TWR and SR on die sinking electro discharge machine. The arrangement to conduct with three variables, having a total of 20 runs in three blocks. The different levels of factor considered for this study are shown in Table 1. The machining time for all experiments was kept constant at 15 min, and the various responses are measured and tabulated in Table 2.

III. MEASUREMENT OF RESPONSE

III.I- MATERIAL REMOVAL RATE

MRR is calculated by using the volume loss from the work
piece divided by the time of machining. The calculated weight loss is converted to volumetric loss in mm3/min as per equation -I

$$MRR = \frac{\Delta V_w}{t} = \frac{\Delta W_w}{\rho_w t} \text{ ....I}$$

Where ΔV_w = volume loss from the work piece

ΔW_w = the weight loss from the work piece

t = the duration of the machining process

ρ_w = 7700kg/m^3 the density of the work piece.

III.II- TOOL WEAR RATE

TWR is expressed as the volumetric loss of tool per unit
time, expressed as

$$TWR = \frac{\Delta V_t}{T} = \frac{\Delta W_t}{\rho_t g T} \text{ ....II}$$

Where ΔV_t = the volume loss from the electrode

ΔW_t = the weight loss from the electrode

T= the duration of the machining process

ρ_t = 8960kg/m3 the density of the electrode.

III.III- SURFACE ROUGHNESS

Surface roughness is a measure of the technological quality of a product, which mostly influence the manufacturing cost of the product. Roughness measurement was carried out using a portable stylus type profilometer, Talysurf. It is defined as the arithmetic value of the profile from the centerline along the length, expressed as

$$SR = \frac{1}{L}\int_0^L [y(x)]dx \text{ ....III}$$

Where L= sampling length

Y= profile curve

X= profile direction.

IV. METHODOLOGY

IV.I- RESPONSE SURFACE METHOD

In statistics, Response surface methodology (RSM) investigates the interaction between several illustrative variables and one or more response variables. Box and Draper [22] were introducing RSM in 1951.The most important proposal of RSM is to use a series of designed experiments to attain an optimal response. A second-degree polynomial model is use in RSM. These models are only an approximation, but use it because such a model is easy to estimate and apply, even when little is known about the process. This model is known as quadratic model, which is as follows:-

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum_{i=1}^{k} \beta_{ii} X_i^2 + \sum_{i,j=1,\ i\neq j}^{k} \beta_{ij} X_i X_j + \varepsilon \quad \text{.....IV}$$

where ε is the noise or error observed in the response Y. X_i is the linear input variables, X^2_{ii} and X_iX_j are the squares and interaction terms, respectively, of these input variables. The unknown second order regression coefficients are β_o, β_i, β_{ij} and β_{ii}, which should be determined in the second-order model, are obtained by the least square method.

The process of RSM includes designing of a series of experiments for sufficient and reliable measurement of the response and developing a mathematical model of the second order response surface with the best fittings. Obtaining the optimal set of experimental parameters, thus produce a maximum or minimum value of the response. The Minitab Software was used to analyze the data [23].

IV.II- GREY RELATIONAL ANALYSIS

Initiator of the Grey system theory (1982) was Deng [24]. In grey system theory includes three types of systems first black which shows no information in this system, second white which shows all information in this system & third grey system which shows imperfect information. The grey system theory is a efficient technique, which requires a limited information to estimate the behavior of an uncertainty system & discrete data problem.

If the sequences range is large, in GRA, the factors are effaceable. Although, if the measured factors are discrete, then wrong results may be produce by GRA. So, for evade this influence, must perform data per-processing of original experimental data. The range of data processing is zero to one (0-1). Normalizing involves transforming the original sequence to comparable sequence. This is known as grey relational generating. In this study, normalization of the experimental results attained for MRR, TWR & SR.

There are three conditions of normalization-

1) - lower is better
2) - higher is better
3) - nominal the best

But in this study only two conditions are required, lower is better & higher is better.
The normalization is taken by the following equations

Higher is better

$$X_i^*(k) = \frac{X_i(k) - \min X_i(k)}{\max X_i(k) - \min X_i(k)} \quad \text{.....V}$$

Lower is better

$$X_i^*(k) = \frac{\max X_i(k) - X_i(k)}{\max X_i(k) - \min X_i(k)} \quad \text{.....VI}$$

Nominal the best

$$X_i^*(k) = \frac{1 - |X_i(k) - X_0 b(k)|}{\max X_i(k) - X_0 b(k)} \quad \text{......VII}$$

where I = 1, 2n, k = 1, 2, y, p; X^*_i (k) is the normalized value of the k^{th} element in the i^{th} sequence, X_0b (k) is desired value of the k^{th} quality characteristic, max X*i (k) is the largest value of $X_i(k)$, and min X^*_i (k) is the smallest value of $X_i(k)$, n is the number of experiments and p is the number of quality characteristics.

After the normalization, calculated grey relational co-efficient, which shows the interaction between optimal & actual normalized experimental results. GRC can be presented-

$$\gamma_i(k) = \gamma(x_0(k)) = \frac{\Delta \min + \zeta \Delta \max}{\Delta_{0,i}(k) + \zeta \Delta \max} \quad \text{...... .....VIII}$$

I=1; . . . ; n; k= 1; . . . ; p

where $\Delta_{0,i}(k) = |x_0(k) - x_i(k)|$ is the difference of the absolute value called deviation sequence of the reference sequence $x_0(k)$ and comparability $x_i(k)$. The ξ is the distinguishing coefficient or identification coefficient $0 \le \zeta \le 1$. In general, it is set to 0.5. The GRG is a weighting-sum of the grey relational coefficients and it is defined as-

$$\gamma(x_{0,} x_i) = \sum_{n}^{k=1} \beta_k (x_{0,} x_i) \quad \text{........IX}$$

where β_k represents the weighting value of the k[th] performance characteristic, and $\sum_{n}^{k=1} \beta_k = 1$.

IV.III- ENTROPY MEASUREMENT METHOD

This is an objective weighting method. In GRA, determine the weights of each quality characteristics. Suggested by wen et al. [25] discrete type of entropy is used in grey entropy measurement for properly conduct weighting analysis. Entropy method is used for calculating gray relational grade. There are seven steps for calculations of weights of each characteristic-

1- Compute the summation of each attribute's value for all sequences, D_k-

$$D_k = \sum_{i=1}^{m} x_i(k) \quad \text{.......X}$$

2- Compute the normalization coefficient K-

$$K = \frac{1}{(e^{0.5} - 1)n} \quad \text{.......XI}$$

where n represents the number of attributes.

3- Find the entropy for the specific attribute, e_k-

$$e_k = \frac{1}{K} \sum_{i=1}^{n} f\left(\frac{x_i(k)}{D_k}\right. \quad \text{.......XII}$$

4- Compute the total entropy value E-

$$E = \sum_{k=1}^{n} e_k \quad \text{.........XIII}$$

5- Determine the relative weighting factor λ_k -

$$\lambda_k = \frac{(1 - e_k)}{n - E} \quad \text{.......XIV}$$

6-The normalized weight of each attribute can be calculated as-

$$\beta_k = \frac{\lambda_k}{\sum_{k=1}^{n} \lambda_i} \quad \text{.....XV}$$

For calculation of GRG, grey relational co-efficient multiplying with corresponding weight of quality characteristics.

V-RESULT & DISCUSSION

The experimental values are obtained from experiments conducted as per plan presented in Table no. 2. Normally, higher value of MRR and lower value of TWR & surface roughness are desired. Thus, the normalized equation no. (V) used for higher the better (MRR) and lower the better for TWR & SR is used equation no. (VI). In normalization, the original sequence must be normalized in the range of zero to one. The normalized value & deviation sequence are presented in table no. 3, calculation of grey relational co-efficient, grey relational grade & rank are given in table no. 4. The grey relational co-efficient was calculated from equation no. (VIII). Before calculating GRG, must be find wattage of each characteristic used by entropy measurement method. GRG calculated by equation no. (IX). Statistical analysis of GRG was performed by using Minitab software, and the main effect of process parameters on GRG are shown in figure no. 2 & effect of process parameters on MRR, TWR & SR are shown in figure no. 3,4 & 5.

TABLE NO. 1– INPUT PARAMETERS AND THEIR LEVELS

Parameters	Units	Level 1	Level 2	LEVEL 3
Discharge current (Ip)	A	2	5	7
Pulse on Time (Ton)	μs	20	40	60
Pulse off Time (Toff)	μs	15	30	45

TABLE NO. 2- EXPERIMENTAL RESULTS FOR THREE VARIABLES IN CODED UNITS

Sr. no.	Ip	Ton	Toff	MRR	TWR	SR
1	5	20	15	4.31	4.38	4.25
2	5	20	45	17.59	4.67	7.99
3	5	60	45	6.42	4.47	1.01
4	5	40	30	13.434	4.36	6.446
5	5	60	15	43.1	7.14	6.66
6	5	40	30	12.826	4.831	6.864
7	5	40	30	12.943	4.846	6.372
8	5	60	15	5.98	4.64	1.07
9	5	60	45	43.45	6.89	6.65
10	5	20	15	17.39	4.75	7.95
11	5	40	30	13.48	4.633	6.52
12	5	20	45	4.75	3.19	4.27
13	5	40	30	30.62	5.74	7.92
14	5	60	30	18.08	5.59	2.02
15	5	40	30	13.54	4.926	7.783
16	5	20	30	9.02	4.32	7.85
17	5	40	45	13.55	4.96	6.58
18	5	40	30	5.59	3.83	2.64
19	5	40	30	13.55	4.96	6.58
20	5	40	15	13.168	4.673	7.744

TABLE NO. 3-NORMALIZATION & DEVIATION SEQUENCE OF OUTPUT

NORMAL VALUES			DEVIATION SEQUENCE		
MRR	TWR	SR	MRR	TWR	SR

0.000	0.699	0.536	1.000	0.301	0.464
0.339	0.625	0.000	0.661	0.375	1.000
0.054	0.676	1.000	0.946	0.324	0.000
0.233	0.704	0.221	0.767	0.296	0.779
0.991	0.000	0.191	0.009	1.000	0.809
0.218	0.585	0.161	0.782	0.415	0.839
0.221	0.581	0.232	0.779	0.419	0.768
0.043	0.633	0.991	0.957	0.367	0.009
1.000	0.063	0.192	0.000	0.937	0.808
0.334	0.605	0.006	0.666	0.395	0.994
0.234	0.635	0.211	0.766	0.365	0.789
0.011	1.000	0.533	0.989	0.000	0.467
0.672	0.354	0.010	0.328	0.646	0.990
0.352	0.392	0.855	0.648	0.608	0.145
0.236	0.561	0.030	0.764	0.439	0.970
0.120	0.714	0.020	0.880	0.286	0.980
0.236	0.552	0.202	0.764	0.448	0.798
0.033	0.838	0.766	0.967	0.162	0.234
0.236	0.552	0.202	0.764	0.448	0.798
0.226	0.625	0.035	0.774	0.375	0.965

TABLE 4- GREY RELATIONAL CO-EFFICIENT, GREY RELATIONAL GRADE AND RANK

GRC MRR	GRC TWR	GRC SR	GRG	RANK
0.333	0.624	0.519	0.487	8
0.431	0.572	0.333	0.441	13
0.346	0.607	1.000	0.644	1
0.395	0.628	0.391	0.467	9
0.982	0.333	0.382	0.560	6
0.390	0.546	0.374	0.432	16
0.391	0.544	0.394	0.439	14
0.343	0.577	0.983	0.628	2
1.000	0.348	0.382	0.571	5
0.429	0.559	0.335	0.436	15
0.395	0.578	0.388	0.449	11
0.336	1.000	0.517	0.611	3
0.604	0.436	0.336	0.454	10
0.435	0.451	0.776	0.549	7
0.396	0.532	0.340	0.418	20
0.362	0.636	0.338	0.441	12
0.396	0.527	0.385	0.432	18
0.341	0.755	0.682	0.587	4
0.396	0.527	0.385	0.432	17
0.393	0.571	0.341	0.431	19

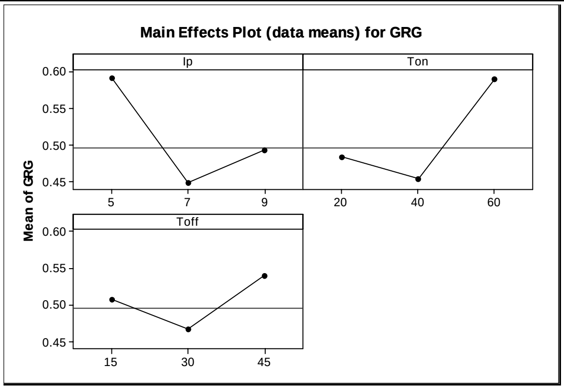

FIGURE 2- EFFECT OF PROCESS PARAMETERS ON GRG

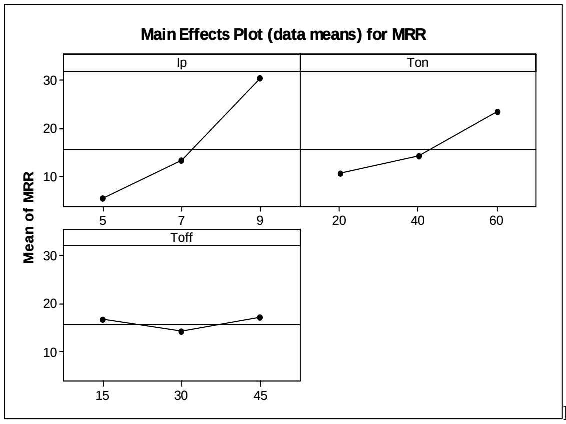

FIGURE 3- EFFECT OF PROCESS PARAMETERS ON MRR

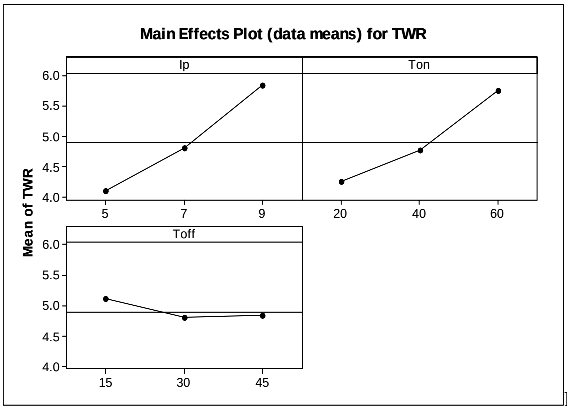

FIGURE 4- EFFECT OF PROCESS PARAMETERS ON TWR

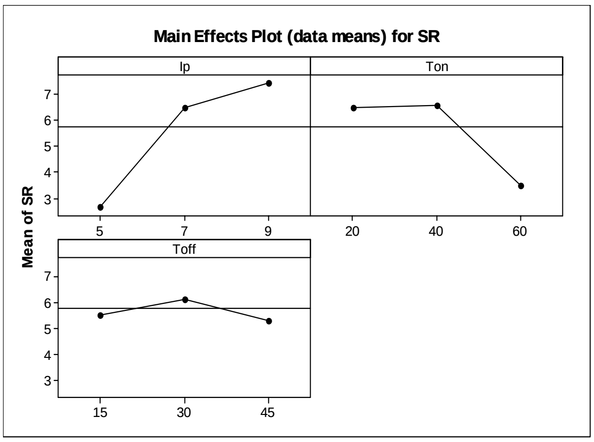

FIGURE 5- EFFECT OF PROCESS PARAMETERS ON SR

VI. CONCLUSION

In this study, the machining parameters of EDM process have optimized by gray relational analysis combine with entropy measurement method. The influence of various process parameters is calculated and found that a pulse current 5A, pulse duration 60µs & pulse off time 45µs are the best parametric combination. This analysis shows that the RSM, GRA and entropy analysis can be successfully implemented to find the best parametric combination. Further it can be used to other manufacturing process.

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