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Metal Removal Rate Optimization in Electric Discharge Machining Process

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ABSTRACT: Electrical discharging machining (EDM) has become an outstanding approach in the field of metal cutting especially for conductive metals. It's very difficult to cut the conducting metals with the aid of traditional machining. The main object of the present work has to investigate the effects of various EDM input parameters like pulse on time (T_{on}) pulse off time (T_{OFF}) as well as the influence of different tool geometry on Material Removal Rate (MRR) Electrode tool geometry (ETG) peak current (A), flushing and pressure (P). Five basic input parameters were planned according to different levels as per the L_{16} orthogonal array. Multi-objective optimization technique of desirability approach and the significance of each parameter was analyzed by Analysis Of Variance (ANOVA).Fuzzy Logic Model (FLM) also used to better understand the input and output responses. It was found that rectangular tool geometry for cooper electrode emerged successful to get optimize results for MRR. Desirability approach and ANOVA for the comparison showed that current is the most influencing factor followed by pulse on time pulse off time.FLM tests were carried out to show closer relationship with experimental results.

Keywords: Electrical Discharge Machining; Metal Removal Rate, Desirability Approach Technique; Analysis of Variance; Fuzzy Logic Model.

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1 INTRODUCTION

Electrical Discharge Machining (EDM) is a controlled metal-removal process that is used to remove metal by means of electric spark erosion. In this process an electric spark is used as the cutting tool to cut (erode) the work piece to produce the finished part to the desired shape. The metal-removal process is performed by applying a pulsating (ON/OFF) electrical charge of high-frequency current through the electrode to the work piece. This removes (erodes) very tiny pieces of metal from the work-piece at a controlled rate. The main goal of EDM manufactures and users are to achieve better stability and higher productivity in EDM process. As new materials are developed and more exotic and complex shape are presented so limitation to the use of traditional machining process put up extreme accelerate demand for the machining of such complex shapes and materials.

2 LITERATURE REVIEW

Zimmermann H. J [23]: developed Fuzzy Programming and Linear Programming with Several Objective Functions. This paper presents the application of fuzzy linear programming approaches to the linear vector maximum problem. It also shows that solutions obtained by fuzzy linear programming are always efficient solutions. It also shows that consequences of using different ways of combining individual objective functions in order to determine an optimal compromise solution. Joopelli, V [24] tried to model and formulate the Electric Discharge Machining process with the optimization of objective functions related to moving trajectories of machine tool electrode. Gradient based methods have been used to optimize the single objective function variable. A moving frame reference has also been used to locate the tool electrode at any instant along its traversed trajectories. Jain V. K. [25] formulated the generalized Electro Discharge Machining method with the limited constraints related to Pulse interval time and pulse duration. Many operating variables are considered as parameters with fixed working values over a given erosion depth and erosion rate on the work piece. The formulated problem has been analyzed by using a simple optimization algorithm by keeping other objective functions unaffected and the results are concluded to give the suitable operating variable value selection on the basis of output obtained.

Kahng, C. H [26] stated that operating working voltage and the pulse interval plays an important role in obtaining the required surface finish. The flow movement of the dielectric fluid controls the homogeneous surface characteristics in the entire EDM controlled region. The spark gap control has also been explained to obtain the desired level of surface roughness for a given set of operating variables. Fluttering of the edges in the EDM region has been investigated for the variation in the controlling parameters. Kee. P. [27] specified an integrated approach for jointly solving process selection, machining parameter selection, and tolerance design problems to avoid inconsistent and infeasible decision. The integrated problem is formulated as bi-criterion model to handle both tangible and intangible costs. The model is solved using a modified chebyshev goal programming method to achieve a preferred compromise between the two conflicting and non-commensurable criteria. L.C. Lim, H.H. Lu [28] specified the basic thumb rules for the analysis of surface features of Electro discharge machining process. This paper is mainly meant for skilled workmanship towards achieving the desired surface characteristics in minimum time and with safety. The saving of the production cost is justified for the EDM process carried out. Common measures and precautions which are helpful in carrying out the EDM process for efficient operation are also been suggested. This paper is recommended for peer mainly.

Madhu, P., Jain, V. K [29] developed the governing equations for the analysis of Electro Discharge machining process under a controlled environment. A computer program has also been developed in the form of subroutines for the calculation of electrode wear rate. Metal removal rate and dielectric material effect on the EDM process. The results obtained by the formulation used with the help of quadratic elements have shown a good convergence with those obtained by the commercial packages. Masstoshi, S., and Ryo, Kubota [30] studied the imprecise or fuzzy nature of the data in real-world problems, job shop scheduling with fuzzy processing time and fuzzy due date is introduced. On the basis of the agreement index of fuzzy due date and fuzzy completion time, multi-objective fuzzy job shop scheduling problems are formulated as three-objective ones which not only maximize the minimum agreement index but also maximize the avg. agreement index and minimize the maximum fuzzy completion time. Pandit, S. M [31] stated the critical factors affecting the performance of the Electro Discharge machining process when the work piece material is Cemented carbide. A suitable hard alloy material is selected as electrode tool material. And the dielectric fluid is given turbulent flow in and around the EDM region. The operating variables like Pulse duration, Discharge Current, Operating voltage, Pulse Interval time and heat dissipation rate differ in operating ranges considerably as compared to electro discharge machining of Steel alloys. However, it has been claimed that consistency and repeatability of the machine towards maintaining the minimum deviation in the operating conditions helps a lot in the Machining accuracy in the process. Pandit, S. M [32] considered the theoretical aspects of the Electro Discharge machining Process. The energy parameters and the Metal removal rate relationships have been developed for the given set of operating voltages and the dielectric pressure. The relationships obtained have been used to plot graphs for the variation in the operating controlling parameters and their effects on the consequents such as metal removal rate, surface roughness and the power consumption by the machine etc. These graphs can be directly used for the selection of given constrained condition of operating variables for the desired objectives.

Rajurkar, K.P., Zhu, D [33] elaborated a number of alternatives for the improvement in the electrochemical machining process by changing the sensitivity parameters and have stated that in comparison to other operating variables, the trajectory of the electrode movement plays a vital role in improving the surface characteristics of the ECM process. Spedding, T.A [34] used the concept of conformal transformation of the operating characteristic variables. The variables are parameterized and the parametric representation of the metal removal rate, surface roughness has been mapped onto parametric surface. The surface characteristics of the wire-Cut EDM process have been analyzed for the sensitivity of the operating variables. The dependencies of the decision variable on each other are represented and a computation algorithm has been proposed to evaluate the mapped point for specified surface characteristics onto parametric plane. Spedding, T.A. and Wang, Z.Q [35] considered the theoretical aspects of the modeling of the wire-Cut EDM process. A user friendly approach has been adopted for the definition of process parameters and these parameters are compared to other various ranges of operating variables. The interpretation of output variables variations has been carried out for the wire Cut EDM process and the suggested ranges of the input variables are given for a desired set of output variables in terms of metal removal rate and power consumption etc.

Smyers, S. Guha, A. [36] stated a practical approach for Machining the Beryllium Copper alloys as work piece by Electro Discharge Machining process. Methods have been suggested for obtaining the desired level of surface characteristics by using this EDM method. Safety precautions and the indicative measures are suggested for the fruitful implementation of the process. A brief note is also given for specifying the operating characteristics and safety precautions for the EDM process to be carried out. Wang W.M. [37] stated that spark gap and the controlling parameters for a sensitive EDM process layout can be controlled in number of ways. A feedback system with real time stability analysis and process monitoring through digital modern sensors and transducers can give an efficient responding mechanism for the EDM process control. The author also states that transducers, circuitry, encoders etc. can be selected to give influence of simultaneous variation of operating variables and their response data storage facility. The author has developed an artificial neural network for the entire Electro Discharge Machining process. The relationships between the operating intermediate processes along with decision variables have been framed. The performance index evaluation for the EDM process for a given specified crisp sets of the operating variables helps in understanding the efficiency of the process to be carried out. The performance Index evaluated by using this method helps in analyzing the adverse and positive gradient effects of the variation in the Metal removal rate, the surface roughness and the power consumption by the machine. Zhang, B [38] calculated the effect of motion and turbulence level in the dielectric material during various stages of the electro-discharge machining process. The results are tabulated and graphs have been recommended for use for the machining of steel materials. The effect of the selection of dielectric fluid has also been analyzed for a given set of electrode tool and material combination. Zhang C [39] developed tolerances for the different machining parameters, the results have recommended for the machining parameters.

3 EDM PROCESS

EDM spark erosion is the same as having an electrical short that burns a small hole in a piece of metal In EDM both the work-piece material and the electrode material must be conductors of electricity. The EDM process can be used in two different ways: A reshaped or formed electrode (tool), usually made from graphite or copper, is shaped to the form of the cavity it is to reproduce. The formed electrode is fed vertically down and the reverse shape of the electrode is eroded (burned) into the solid work piece. A continuous-travelling vertical-wire electrode, the diameter of a small needle or less, is controlled by the computer to follow a programmed path to erode or cut a narrow slot through the work piece to produce the required shape.

3.1 Conventional EDM

In the EDM process an electric spark is used to cut the work piece, which takes the shape opposite to that of the cutting tool or electrode. The electrode and the work piece are both submerged in a dielectric fluid, which is generally light lubricating oil. A servomechanism maintains a space of about the thickness of a human hair between the electrode and the work, preventing them from contacting each other. In EDM ram or sinker machining, a relatively soft graphite or metallic electrode can be used to cut hardened steel, or even carbide. The EDM process produces a cavity slightly larger than the electrode because of the overcut.

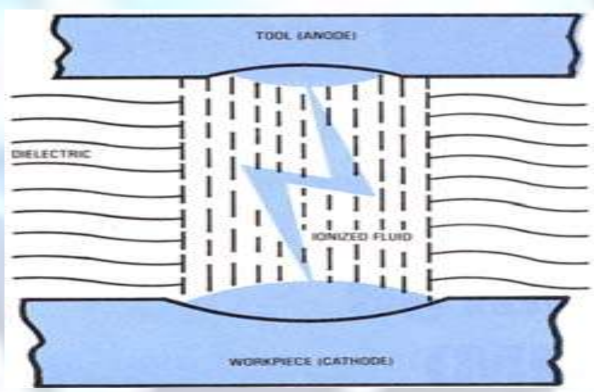

Figure 1: EDM Principle

4 EXPERIMENTAL DETAILS

4.1 Experimental Work

The 3mm thickness sheet of Inconel 718 plates was cut into the required size 100*50*3 mm using wire cut EDM process and machined by using copper electrode with different tool geometries like circle, square, rectangle and triangle shape. The drilling operations were performed with copper electrode tool material with different tool geometries using die sinking EDM machine. The weight of the workpiece and electrodes were measured using precise electronic balance machine before and after the machining process over. After completion of each machining operations, the workpiece and electrode was blown by compressed air using air gun to ensure no debries and dielectric were present. In the present study, four level process parameters i.e. TON=38,63,83&93μs, TOFF=2,7,8&9μs, A=4,12,14&15Amp, P=2,5,7&9 kgf/cm2 and Geo=C,S,R&T are considered. The rest of EDM parameters kept as constant during the experimentation.

4.2 Desirability Approach

The desirability function approach to optimize multiple equations simultaneously was originally proposed by Harrington [19].Essentially, the approach is to translate the functions to a common scale [0, 1], combine them using the geometric mean and optimize the overall metric. The desirability approach involves transforming each estimated response, y_i, into a unit less utility bounded by $0<d_i<1$, where a higher 'd_i' value indicates that response value y_i is more desirable, if $d_i=0$ this means a completely undesired response [20].

Step 1: Calculate the individual desirability index (d_i) for the corresponding responses using the formula proposed by the Derringer and Suich [21]. There are three forms of the desirability functions according to the response characteristics; Nominal - the best.

$$d_i = \begin{cases} \left(\frac{y_j - y_{min}}{T - y_{min}}\right)^s, y_{min} \le y_j \le T, S \ge 0 \\ \left(\frac{y_j - y_{min}}{T - y_{min}}\right)^t, T \le y_j \le y_{max}, S \ge 0 \\ 0 \end{cases} \quad (1)$$

Desirability value equals to 1; if the departure of 'y' exceeds a particular range from the target, the desirability value equals to 0, and such situation represents the worst case.

i. **Larger-the better**

$$d_i = \begin{cases} 0, \; y_j \le y_{min} \\ \left(\frac{y_j - y_{min}}{y_{max} - y_{min}}\right)^r, y_{min} \le y_j \le y_{max}, r \ge 0 \\ 1, y_j \ge y_{min} \end{cases} \quad (2)$$

The value of 'y_j' is expected to be the larger the better. When the 'y' exceeds a particular criteria value, which can be viewed as the requirement, the desirability value equals to 1; if the 'y' is less than a particular criteria value, which is unacceptable, the desirability value equals to 0.

ii. **Smaller-the better**

$$d_i = \begin{cases} 1, \; y_j \le y_{min} \\ \left(\frac{y_j - y_{min}}{y_{max} - y_{min}}\right)^r, y_{min} \le y_j \le y_{max}, r \ge 0 \\ 0, y_j \ge y_{min} \end{cases} \quad (3)$$

The value of y_j is expected to be the smaller the better. When the 'y' is less than a particular criteria value, the desirability value equals to 1; if the 'y' exceeds a particular criteria value, the desirability value equals to 0.In this study, " smaller the better" and " larger the better" characteristics are applied to determine the individual desirability values for minimize the TWR ,SR and maximize the MRR.

Step 2: Compute the composite desirability (d_G). The individual desirability index of all the responses can be combined to form a single value called composite desirability (d_G) by the following Equation (4).

$$d_G = \sqrt[w]{d1^{w1} \times d2^{w2} \ldots\ldots\ldots\ldots\ldots. di^{wi}} \quad (4)$$

Step 3: Determine the optimal parameter and its level combination. The higher composite desirability value implies better product quality. Therefore, on the basis of the composite desirability (d_G), the parameter effect and the optimum level for each controllable parameter are estimated. For examples, to estimate the effect of factor 'i', we calculate the composite desirability values (CDV) for each level 'j', denoted as CDV_{ij}, and then the effect, E_i is defined as:

$$E_i = \max(CDV_{ij}) - \min(CDV_{ij}) \quad (5)$$

If the factor i is controllable, the best level j*, is determined by

$$j^* = \max_j (CDVij) \quad (6)$$

Step 4: Perform ANOVA for identifying the significant parameters. ANOVA establishes the relative Significance of parameters. The calculated total sum of square values is used to measure the relative influence of the parameters.

Step 5: Calculate the predicted optimum condition. Once the optimal level of the design parameters has been selected, the final step is to predict and verify the quality characteristics using the optimal level of the design.

5 FUZZY LOGIC MODEL

Due to the complex and non-linear relationship between the input parameters and output performance measures, it is quite difficult to develop a process model for EDM. Unfortunately, no efficient, generalized approach to model ,the EDM process has been reported for studying and predicting MRR, TWR and SR. In this work, an attempt was ,made to develop a comprehensive intelligent approach to model the die-sinking EDM process using fuzzy logic. A fuzzy set is a set without a crisp boundary. The fuzzy inference system or fuzzy model is a computing framework based on fuzzy set theory, fuzzy if-then rules and fuzzy reasoning. The fuzzy inference system consists of three components, namely rule base, data base and reasoning mechanism. A fuzzy logic unit consists of a fuzzifier, membership functions, a fuzzy rule base, an inference engine, and a defuzzifier [21]. The input and output values are fuzzified using membership functions. The fuzzy reasoning works on fuzzy rules to generate a fuzzy value to be used by inference engine. Finally, fuzzy value is converted into a crisp output by defuzzifier. Generally, defuzzification is done according to the Centre of Area (COA) method. MAT Lab R2011b fuzzy logic tool box was used to build the FLM of EDM process.

The first step in generating a fuzzy logic is to identify the ranges of input and output variables. Then, the range of each process variable is divided into groups of fuzzy subsets. Each fuzzy subset is given a proper name and assigned a membership function. The membership function is assigned without depending on the results of the experiments. In general, membership functions are classified into trapezoidal, triangular and square or their combinations. Based on the number of trials, Gaussian membership functions were selected for this study. The notations used in fuzzy subsets were as follows: EL - Extreme Low, L - Low, LM - Low Medium, M - Medium, LA - Low Average, A - Average, LH - Low High, H - High, EH - Extreme High. For all inputs, four input functions were considered, namely low, medium, average and high, represented by L, M, A, H, respectively. Similarly, for output variables, nine different functions were considered, namely extreme low, low, low medium, medium, low average, average, low high, high and extreme high, represented by EL, L, LM, M, LA, A, LH, H, EH, respectively. The relationship between input and output in a fuzzy system is characterized by a set of linguistic statements. There are no systematic tools for forming the rule base of the FLM. The fuzzy control rules can be derived from experience and knowledge of control engineering [22]. One experiment results in one fuzzy rule. If all the fuzzy rules are saved in a data base, a fuzzy rule base is established. The number of fuzzy rules in a fuzzy system is related to the number of fuzzy sets for each input variable. In this study, 16 fuzzy rules were established as shown in Table 1.

Table 1: Fuzzy expressions of input and output parameters for copper electrode

Rules		IF							THEN		
	T_{ON}	CON	T_{OFF}	CON	A	CON	P	CON	GEO	CON	MRR
1	L	And	L	and	L	And	L	and	L	and	EL
2	L	And	M	and	M	And	M	and	H	and	EH
3	L	And	A	and	A	And	A	and	M	and	LA
4	L	And	H	and	H	And	H	and	A	and	LH
5	H	And	L	and	H	And	M	and	M	and	A
6	H	And	M	and	A	And	L	and	A	and	LM
7	H	And	A	and	M	and	H	and	L	and	LA
8	H	And	H	and	L	and	A	and	H	and	EL

The output responses of the fuzzy process can be viewed only in fuzzy values and they need to be defuzzified. In this study, the centric defuzzification method was chosen, as it could produce the centre of area of the possible distribution of the inference output FLM and the outputs are noted. The outputs of experimental results and FLM are compared and it shows the FLM output parameters have closer agreement with the experimental results. Thus the FLM is validated with 5% error which is due to errors in machining, measurement and modeling.

6 RESULTS AND DISCUSSIONS

6.1 Steps in Desirability approach and ANOVA

Step1: The values of computed individual desirability for each quality using Equations 2 and 3. The calculated values are presented in Table 2.

Step2: The composite desirability values [DG] are calculated using Equation 4.The equal weight age of 0.33 was considered for all parameters and the calculated results are given in Table 2.

Table 2: Individual desirability and composite desirability of copper electrode

Desirability Descriptions	**Desirability Values for 15 Experiments**														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Individual desirability of MRR	0.43	1.00	0.85	0.92	0.98	0.76	0.99	0.93	0.95	0.96	0.04	0.78	0.90	0.71	0.77

Step 3: By using Equations 5 and 6, the main parameter effects are calculated and tabulated in Table 3.

Table 3: Main effect on desirability factor

Parameters / levels	**1**	**2**	**3**	**4**	**DIFFERENCE (E_I)**	**RANK**	**OPTIMUM LEVEL**
T_{ON}	0.65	0.70	0.75	0.50	0.25	2	3
T_{OFF}	0.70	0.65	0.63	0.60	0.10	4	1
A	0.20	0.67	0.70	0.67	0.47	1	4
P	0.68	0.58	0.59	0.51	0.17	3	2

Step 4: From Table 3, the optimal parameters are obtained and also observed that, there is one particular level for each factor for which the responses are either maximum or minimum. To test the optimum output values of desirability approach, experiments are conducted in EDM by using the input parameters (TON=63µs, TOFF=5µs, A=15, P=9kgf/cm2 and Geo=R) are obtained through desirability approach as shown in Table 2. The outputs values of MRR, TWR & SR are 0.254g/min,0.0085g/min & 0.459µm respectively. When comparing these values with individual optimum responses obtained in the L16 array of experiments, the desirability approach gives optimum result for all responses in one set of input.

Step 5: The calculated results of ANOVA are presented in Table 4.

Table 4: ANOVA analysis of copper electrode

Factor	**S.S**	**DOF**	**MS**	F_{CAL}	F_{TAB}	$\%CONT.$
T_{ON}	0.14	3	0.045	5.07		13.72
T_{OFF}	0.05	3	0.016	1.87	9.27	5.07
A	0.75	3	0.26	26.84		72.6
P	0.06	3	0.020	2.15		5.83
GEO	0.0	0.0	0.00			
ERROR	0.027	3	0.009			
TOTAL	1.034	15				

CONCLUSION

The present study investigated the machining responses (MRR, TWR and SR) using copper electrode of Inconel 718 workpiece. The multi-objective optimization desirability approach was employed for simultaneous optimization of response characteristics. The optimal sets of process parameters for the selected performance measures were identified. The results of multi-objective optimization desirability tests were pulse on time 63 µs, pulse off time 5 µs, peak current 15 A, flushing pressure 9 kgf/cm2, and rectangular tool geometry. From the above, higher current (15A) and flushing pressure (9kgf/cm2) was preferred. Medium pulse on time (63 µs) was suitable for copper electrode. Rectangular tool geometry was best for copper electrode.

The significance and contribution of each parameter was analyzed using ANOVA. From this, the contribution of peak current (72.67%) was high followed by pulse on time (13.07%). Tool geometry was not the most significant factor to affect the performance measures. The proposed fuzzy model provides a more precise and easy selection of EDM input parameters for the required MRR, TWR and SR, thereby to optimize machining conditions and reduce costs. The fuzzy model was shown to be able to predict the experimental results with accuracy of 95%. The validation of fuzzy results with experimental findings proved the high accuracy of the model.

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