

# **Desirability Approach Optimization in EDM for Inconel 718**

P.Sengottuvel, Manikandan G

Professor, Department of Mechatronics Engineering, Bharath University. Chennai, India

Assistant Professor, Department of Mechatronics Engineering, Bharath University. Chennai, India

**ABSTRACT:** Inconel 718 is a high nickel content super alloy possessing high strength at elevated temperature and resistance to oxidation and corrosion. The non traditional manufacturing process of Electrical Discharge machining (EDM) possesses many advantages over traditional manufacturing process during the manufacturing of Inconel 718. Experimental investigation was conducted to determine the main EDM parameters along with Tool geometry which contribute to MRR, TWR & SR in Inconel 718. It was found that current, pulse on time is directly proportional to MRR and inversely proportional to TWR, SR and rectangle profile was found best in all aspects. Experiments were conducted based on the  $L_{16}$  orthogonal array are carried out on INCONEL 718 material using copper and tungsten-copper material with kerosene as a dielectric fluid and all data's are optimized using Desirability approach technique.

**KEYWORDS:** Electrical discharge machining [EDM], Material removal rate [MRR], Tool wear rate [TWR], Surface roughness [SR].

## **I. INTRODUCTION**

The influence of EDM process parameters an MRR, TWR, SR and microstructures are discussed by many researchers [1-4] with respect to EDM parameters but only limited authors are considered the influence of Tool geometry [3-4] and applied for Taguchi optimization techniques and developed various mathematical models and also found parameters influences using ANOVA techniques. Naricies et al. [1] has studied on the influence of tool geometry and surface quality of ASIS H13 tool steel using copper electrode and parameters were optimized using Taguchi techniques. It was observed that the MRR is mainly affected by Current followed by pulse off time and SR is influenced by current. But tool geometry has no influence on MRR and SR. Due to better radial wear and square, rectangle geometry is best suited for TWR. Triangle shape tool geometry is not suitable for complex geometries, because improper wears happen in the surface material. M.S.Sohani [5] et al., investigated the effect of tool Geometry with various size factor consideration in die sink electrical discharge machining (EDM) process. The experiments were conducted as per the Central Composite Design (CCD) techniques. Based on the experimental results, the mathematical models (using response surface methodology) were developed. The developed models were further applied for ANOVA technique to verify the lack of fit and accuracy. It was concluded that, the circular tool geometry was best suitable for higher MRR and Lower TWR followed by triangular, rectangular and square cross sections. Current and pulse on time is highly significant on MRR. However limited researchers only discussed about tool geometry influence and the used single objective optimization technique. Still, there are only very few literatures are available in connection with the multi objective optimization technique on the influence of tool geometry in EDM of Inconel 718 material. So current research is essential for studying the process parameter optimization for electrical discharge machining of inconel 718 using desirability approach.

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## II. EXPERIMENTAL WORK

The 3mm thickness sheet of inconel 718 plates was cut into the required size 100X50X3 mm using wire cut EDM process. Using different tool material like Copper and tungsten copper electrode and different tool geometries like circle, square, rectangle and triangle shape. The drilling operations (through hole) were performed with different 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 work piece and electrode was blown by compressed air using air gun to ensure no debris and dielectric were present. In the present study, four level process parameters i.e. Pulse on-time [T<sub>ON</sub>=38,63,83&93 ], pulse-off-time [T<sub>OFF</sub>=2,7,8&9], current [I=4,12,14&15], Flushing pressure(2,5,7&9) and Tool geometry are considered. The rest of EDM parameters kept as constant during the experimentation.[12].

## III. DESIRABILITY APPROACH

The desirability function approach to optimize multiple equations simultaneously was originally proposed by Harrington [6]. 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<sub>i</sub>' value indicates that response value  $y_i$  is more desirable, if  $d_i = 0$  this means a completely undesired response [7].

Step 1: Calculate the individual desirability index (d<sub>i</sub>) for the corresponding responses using the formula proposed by the Derringer and Suich [8]. There are three forms of the desirability functions according to the response characteristics.

- i. Nominal - the - best

$$d_i = \begin{cases} \left( \frac{y_j - y_{\min}}{T - y_{\min}} \right)^s, & y_{\min} \leq y_j \leq T, s \geq 0 \\ \left( \frac{y_j - y_{\min}}{T - y_{\min}} \right)^t, & T \leq y_j \leq y_{\max}, s \geq 0 \\ 0 & \end{cases}$$

----- (1)

The value of  $y_j$  is required to achieve a particular target T. When the 'y' equals to T, the 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.

- ii. Larger-the better

$$d_i = \begin{cases} 0, & y_j \leq y_{\min} \\ \left( \frac{y_j - y_{\min}}{y_{\max} - y_{\min}} \right)^r, & y_{\min} \leq y_j \leq y_{\max}, r \geq 0 \\ 1, & y_j \geq y_{\max} \end{cases}$$

----- (2)

The value of 'y<sub>j</sub>' 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.[11]

- iii. smaller-the better

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 6, June 2015

$$d_i = \begin{cases} 1, & y_j \leq y_{\min} \\ \left( \frac{y_j - y_{\max}}{y_{\min} - y_{\max}} \right)^r, & y_{\min} \leq y_j \leq y_{\max}, r \geq 0 \\ 0, & y_j \geq y_{\max} \end{cases} \quad \text{----- (3)}$$

The value of ‘y<sub>j</sub>’ 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, “the smaller the better” and “the larger the better” characteristics are applied to determine the individual desirability values for maximize the MRR and minimize the TWR, SR.

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

$$d_G = \sqrt[r]{d_1^{w1} \times d_2^{w2} \times \dots \times d_i^{wi}} \quad \text{----- (4)}$$

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<sub>G</sub>), 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<sub>ij</sub>, and then the effect, E<sub>i</sub> is defined as:

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

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

$$j^* = \max_j(CDV_{ij}) \quad \text{----- (6)}$$

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 parameters. [10]

### 3.1 Steps in Desirability Approach:

Step1: The values of computed individual desirability for each quality using Equations 2 and 3. The calculated values are presented in Table 1. [8]

Step2: The composite desirability values [d<sub>G</sub>] are calculated using Equation 4. The weightage are 0.33 was considered for all parameters and the calculated results are given in Table 1.

Step 3: By using Equations 5 and 6, the main parameter effects are calculated and tabulated in Table 2. The factor effects are plotted in Figure 1 (a) for copper, (b) for tungsten copper. [7]

Step 4: From Table 2 and Figure 1, we obtain the optimal parameters and also observed that, there is one particular level for each factor for which the responses are either maximum or minimum.

STEP 5. The calculated results of ANOVA are presented in Table 3.

## IV. RESULTS AND DISCUSSIONS

Based on the experimental results, the input parameters and its individual parameters contributions are identified using ANOVA technique and the values are presented in Table.3. From Table 3, we observed that the current and pulse on time is the most influential factors followed by pulse off time and flushing pressure. When increase the discharging the heat energy at the point, where the discharge takes place and the molten metal pool is formed and its overheated. Due to overheated, the molten metal evaporates and forms the gas bubbles in the die electric media. That discharge energy will obtain the maximum level; it will take away from the molten material. The rectangular tool geometry has obtained the best results compared to other tool geometry.

### 4.1 Confirmation Test:

Based on the optimized values obtained from the desirability approach, again the EDM process was performed and the values are measured and compared with the optimized once. The comparative results are presented in Table.4. Based

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 6, June 2015

on the Table 4 results, it is confirmed that, the optimized parameters results had better performance and also confirmation experimental test results are closer values to predicted values.[9]

## V.CONCLUSIONS

Current and pulse on time is the most influential parameters than the other parameters. Rectangle tool geometry is very suitable to get maximum MRR and Lower TWR, SR for inconal 718 materials. The percentages of deviations from the experimental and optimized values are less than 10%.

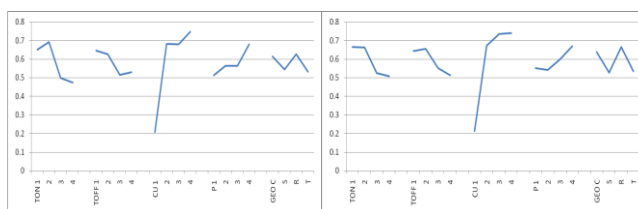
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21. Figure1: **INDIVIDUAL DESIRABILITY AND COMPOSITE DESIRABILITY**

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 6, June 2015



**(a).Copper Electrode      (b) Tungsten Copper Electrode**

**TABLE 3: ANOVA ANALYSIS**

Material	FACTOR	SS	DOF	MS	FCAL	FTAB	%CONT
Copper electrode	TON	0.142	3	0.047	5.067	9.277	13.720
	TOFF	0.052	3	0.017	1.873		5.071
	CU	0.751	3	0.250	26.841		72.673
	P	0.060	3	0.020	2.153		5.829
	GEO	0	0	0.000	0.000		
	ERROR	0.028	3	0.009			2.707
	TOTAL	1.034	15				
Tungsten Copper electrode	TON	0.088	3	0.029	0.876	9.277	8.636
	TOFF	0.059	3	0.020	0.585		5.770
	CU	0.771	3	0.257	7.678		75.730
	P	0.000	0	0.000	0.000		0.000
	GEO	0.060	3	0.020	0.594		5.859
	ERROR	0.100	3	0.033			9.864
	TOTAL	1.018	15				

**TABLE 4: OPTIMIZED RESULTS:**

MATERIAL	T <sub>ON</sub>	T <sub>OFF</sub>	V	P	MRR (mg/min)	TWER (mg/min)	SR (micron)
COPPER	63	2	15	9	0.181	0.004	2.74
TUNGSTEN COPPER	63	5	14	8	0.183	0.0014	2.593

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 6, June 2015

**TABLE 1: INDIVIDUAL DESIRABILITY AND COMPOSITE DESIRABILITY:**

LEVELS <span style="font-size: 2em;">➔</span>		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
PARAMETERS	T <sub>ON</sub>	38	38	38	38	63	63	63	63	83	83	83	83	93	93	93	93
	T <sub>OFF</sub>	2	7	8	9	2	7	8	9	2	7	8	9	2	7	8	9
	Current	4	12	14	15	12	4	15	14	14	15	4	12	15	14	12	4
	Pressure	5	7	8	9	8	9	5	7	9	8	7	5	7	5	9	8
	Geometry	c	s	R	T	T	R	s	C	s	C	T	R	R	T	C	s
COPPER ELECTRODE	MRR	0.04	0.25	0.15	0.19	0.23	0.11	0.24	0.20	0.21	0.22	0.01	0.12	0.18	0.09	0.11	0.01
	TWR	0.00	0.02	0.03	0.03	0.02	0.01	0.02	0.02	0.02	0.02	0.00	0.01	0.02	0.01	0.01	0.12
	SR	2.98	4.46	3.66	5.44	4.87	2.76	3.49	5.11	4.56	4.17	4.64	4.26	4.87	2.78	4.69	1.55
INDIVIDUAL DESIRABILITY	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	0.00
	TWR	0.13	0.50	0.63	0.60	0.57	0.39	0.52	0.50	0.47	0.52	0.00	0.24	0.49	0.39	0.40	1.00
	SR	0.52	0.84	0.68	1.00	0.91	0.46	0.65	0.95	0.86	0.79	0.87	0.80	0.91	0.46	0.88	0.00
COMPOSITE DESIRABILITY (d <sub>G</sub> )			0.31	0.75	0.72	0.82	0.80	0.52	0.70	0.76	0.73	0.73	0.00	0.53	0.74	0.51	0.65
TUNGSTEN COPPER ELECTRODE	MRR	0.04	0.25	0.15	0.19	0.23	0.11	0.24	0.20	0.21	0.22	0.01	0.12	0.18	0.09	0.11	0.01
	TWR	0.00	0.02	0.03	0.03	0.02	0.01	0.02	0.02	0.02	0.02	0.00	0.01	0.02	0.01	0.01	0.12
	SR	3.87	3.64	6.6	4.14	4.03	2.63	3.2	4.35	4.72	5.45	1.57	5.07	4.78	4.52	5.38	2.15
INDIVIDUAL DESIRABILITY	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	0.00
	TWR	0.13	0.50	0.63	0.60	0.57	0.39	0.52	0.50	0.47	0.52	0.00	0.24	0.49	0.39	0.40	1.00
	SR	0.73	0.68	1.15	0.78	0.76	0.42	0.58	0.82	0.89	1.00	0.01	0.94	0.90	0.85	0.99	0.26
COMPOSITE DESIRABILITY (d <sub>G</sub> )			0.35	0.70	0.85	0.76	0.75	0.50	0.67	0.73	0.74	0.79	0.00	0.56	0.74	0.62	0.68

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 6, June 2015

TABLE 2: MAIN FACTORS EFFECT ON DESIRABILITY

PARAMETRS/LEVELS	COPPER ELECTRODE							TUNGSTEN COPPER ELECTRODE						
	1	2	3	4	DIIFERENCE ( $E_i$ )	RANK	OPTIMUM LECVEL( $j^*$ )	1	2	3	4	DIIFERENCE ( $E_i$ )	RAN K	OPTIMUM LECVEL( $j^*$ )
$T_{ON}$	0.6	0.6	0.5	0.4	0.22	2	2	0.6	0.6	0.5	0.5	0.16	2	1
$T_{OFF}$	0.6	0.6	0.5	0.5	0.13	4	1	0.6	0.6	0.5	0.5	0.16	2	1
CURRENT	0.2	0.6	0.6	0.7	0.54	1	4	0.6	0.6	0.5	0.5	0.16	2	1
FLUSHING PRESSURE	0.5 1	0.5 6	0.5 6	0.6 8	0.17	3	4	0.6 7	0.6 6	0.5 2	0.5 1	0.16	2	1
TOOL GEOMETRY	0.6 2	0.5 4	0.6 3	0.5 3	0.09	5	3	0.6 7	0.6 6	0.5 2	0.5 1	0.16	2	1