Improvement of Surface Quality of INCONEL 718 in EDM Machining using MRSN and Utility Method

Sunita Singh Naik, Jaydev Rana, Prasanta Nanda

Abstract**:** ***Electro-Discharge Machining is a popular nonconventional machining process used to make dies of different shapes in any conducting materials irrespective of the hardness and strength of the workpiece materials. INCONEL 718 is a harder material used for making dies and other applications in automobile, aerospace and nuclear sectors. For long life of a die, it should have high wear resistant properties with crack free surface. In the present work, INCONEL 718 workpiece material is machined by EDM using a copper tool by varying input current, pulse on time, pulse off time and flushing pressure according to Taguchi's L_9 orthogonal array to economically carry out experimental work. Four output parameters such as: surface roughness, crackwidth, surface crack density and hardness are optimized simultaneously using two most popular multi-response optimization techniques such as: Multi-response signal to noise ratio (MRSN) and Utility method. A better optimization technique is reported based on the value of signal to noise ratio. ANOVA technique is also used to report the most effective input parameter. Finally, a confirmation test is carried out and the utility method is proved to be the better optimization technique to have minimum loss to the society. This technique can also be extended for other process optimization and helpful for industry personnel to select appropriate process parameters for making a die of long life.***

Index Terms**:** ***ANOVA, EDM, MRSN, Taguchi's L_9 orthogonal array, Utility method.***

I. INTRODUCTION

Electrical discharge machining is a non-traditional machining process used to machine harder materials by repeated electrical discharges between the tool and workpiece which are submerged in a dielectric fluid [1]. The electrical energy is converted into thermal energy and this thermal energy generates a channel of plasma between the two electrodes, at a temperature ranging from 8000 to 12000^0 C [2-4]. When the pulsed DC supply of 20,000-30,000 Hz, is switched off, the breakdown of plasma channel occurs, resulting in a sudden reduction in the temperature, allowing the circulating dielectric fluid to flush away the molten work material from the machined surface in form of microscopic debris [5]. Melting and vaporization of the work material dominates the material removal process, and therefore does not make direct contact between tool electrode and work material. This eliminates the chances of mechanical stress, chatter and vibration problems, as it is prominent in traditional machining [5]. However, due to repeated sparking of the process, thermal stress is developed on the surface of the workpiece, resulting in crack formation on the surface of the workpiece.

Bighnesh Kumar Sahu et.al [6] studied the influence of peak discharge current, pulse on duration and gap voltage on the material removal rate, surface crack density and white layer thickness while INCONEL-718 was machined in EDM. D Sudhakara et.al [7] reported that, the effective parameter was the input current. According to them, the change of current, affect severely on MRR, surface roughness, crack length and crack widths. Gangadharudu Talla et.al [8] investigated EDM, utilizing the graphite powder and its various combination of concentration. They had also varied different machining parameters to study output parameters such as: surface roughness, surface crack density, white layer thickness (WLT), microhardness, depth profile, possible phase changes and residual stress during powder mixed EDM of INCONEL 625. Hwa-teng Lee and T.Y.Tai [9] reported that, surface cracks were formed while machining on D2 and H13 tool steels in EDM. They maintained the pulse voltage of 120 V and pulse current in the range of 12-16A together with a pulse on duration of 6-9 µs and could able to avoid the formation of cracks. Munmun Bhaumik and Kalipada Maity [10] studied the machining of AISI 304 stainless steel by using tungsten carbide electrode with silicon carbide powder mixed EDM considering kerosene as dielectric. According to them, an increase in peak current and powder concentration decreased the surface crack density. Rahul et.al [11] reported the presence of different types of cracks formed in INCONEL 718 during EDM. Effects of significant process parameters on surface topography in terms of roughness average, Surface crack density, white layer thickness, etc. had been graphically represented by them. Finally, utility theory in conjugation with Taguchi's optimization philosophy had been attempted to select the most favorable process environment (parameters setting) to satisfy optimal surface roughness, Surface crack density and White layer thickness; thereby, ensuring high product quality along with its specified functional requirements in appropriate application domain.

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S. Rajendran, et.al [12] analyzed the crack formation and spherical form of resolidified layer on T90Mn2W50Cr45 tool steel surface while machined in EDM. They found that the pulse current was directly proportional with resolidified layer thickness and crack density.

Santosh kumar sahu and Saurav Datta [13] reported that, the performance characteristics of INCONEL 718 was improved by adding the powder in dielectric. Soni Kumari et.al [14] analysed the surface roughness, surface crack density, white layer thickness and microhardness of INCONEL-825 super alloy. Various metallurgical characteristics of EDMed surface were studied by them. Tzu-Yao Tai et.al [15] investigated and correlated between the surface crack of seven engineering steels (JIS SKS93, SNCM439, SCM440, SKS2, SK2, SKH51, and SKD11 with the pulse current and the pulse-on duration. They found that by increasing the pulse current or shortening the pulse-on duration, the surface cracking could be reduced. It is observed from the stated past research works that a few works have been reported on the improvement of surface quality of INCONEL 718. In the present work, extensive experimental work has been carried out on INCONEL 718 to achieve minimum possible surface crack density, minimum crack width, higher surface finish and highest achievable hardness, using two most popular multi-response optimization techniques (i.e MRSN and Utility methods). It will be highly helpful for the industry personnel to decide judiciously the input parameters for best surface quality with long life assurance for popularly used die material INCONEL 718.

II. EXPERIMENTAL WORK

The experiment was conducted on an Electro-Discharge Machine with Model ECOWIN MIC-432CS CNC EDM as shown in Fig.1. The workpiece INCONEL 718 with compositions as shown in Tab.I was machined with 10mm copper tool. Four input parameters were varied such as: input current, pulse on time, pulse off time and flushing pressure with their ranges presented in Tab.II. All the input parameters are arranged as per L_9 orthogonal array [16] in Tab.III. According to the L_9 orthogonal array, the output parameters such as surface roughness (SR), crackwidth (CW), surface crack density (SCD) and hardness are experimented and values are measured. These output parameters values are shown in Tab.IV. The hardness of the unmachined surface of INCONEL 718 is measured and recorded as 359Hv by a micro-hardness testing machine.

Fig.1 ECOWIN MIC-432CS CNC EDM

Table-I: The composition of workpiece (INCONEL 718):

Element	Weight%
C	0.20
Al	0.36
Si	0.12
P	0.06
S	0.04
Ti	0.95
Cr	17.51
Mn	0.14
Fe	19.17
Co	0.25
Ni	54.51
Nb	4.31
Mo	2.38

Table-II: Input parameters and their ranges

Input parameters	Value at Low level (1)	Value at Medium level (2)	Value at High level (3)
Input current (A)-amp	10	20	30
Pulse on time(B)-µs	200	500	1000
Pulse off time(C)-µs	100	175	250
Flushing pressure(D)-$\frac{\mathbf{kgf}}{\mathbf{cm^2}}$	0.15	0.25	0.5

Table-III: Arrangement of input parameters in L_9 orthogonal array

Expt.No.	Input current (A)-amp	Pulse on time(B)-µs	Pulse off time(C)-µs	Flushing pressure(D)-$\frac{\mathbf{kgf}}{\mathbf{cm^2}}$
1	10	200	100	0.15
2	10	500	175	0.25
3	10	1000	250	0.5
4	20	200	175	0.5
5	20	500	250	0.15
6	20	1000	100	0.25
7	30	200	250	0.25
8	30	500	100	0.5
9	30	1000	175	0.15

Table-IV: Experimental values of output parameters

Expt.No.	SR in µm	C.W in µm	SCD in µm	Hardness in Hv
1	1.98	1.615	0.006259	419
2	2.54	1.654	0.006798	965
3	2.69	1.889	0.008356	492
4	2.25	1.72	0.007655	9180
5	2.73	1.6431	0.017019	435
6	2.85	1.6856	0.007087	385

7	2.96	2.013	0.004661	786
8	3.05	2.4933	0.006039	879
9	3.09	2.54	0.003609	984

III. OPTIMIZATION OF EXPERIMENTAL RESULTS USING MRSN TECHNIQUE AND UTILITY TECHNIQUE

Here we have applied two optimization techniques i.e, multi-response signal-to noise ratio (MRSN) and Utility technique. These techniques are used to optimize the output parameters simultaneously and get the best level of input parameters with minimum loss to the society. From these two optimization techniques, utility method is proved to be the best and it has high values of signal-to-noise ratio than the MRSN technique.

A. MRSN Technique:

This is a multi-response signal to noise ratio method [17] used to optimize various process parameters simultaneously to get the optimum level of input parameters. The steps followed in this technique (to determine the optimum level combination), is stated in the following.

Step-1: Calculation of the loss function of the output parameters:

Based on the requirement of output parameters, the following two different formulae are used.

For higher the better (HTB) case,

$$L_{pq} = \frac{1}{{y_{pq}}^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

For lower the better (LTB) case,

$$L_{pq} = {y_{pq}}^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

Where, L_{pq}=quality loss function of output parameter at p^{th} rows at q^{th} columns

y_{pq}= The measured value of the output parameter.

According to the properties of output parameters, lower the better formula (i.e. Eq.2) is used in surface roughness, crackwidth, surface crack density and higher the better formula (i.e Eq.1) is used for the hardness. All the loss values of output parameters are shown in Tab.V.

Step-2: Calculation of normalized values of output parameters:

When the units of output parameters are different, these are normalised first. It is calculated using the following formula as stated in Eq.3

$$N_{pq} = \frac{L_{pq}}{\overline{L}_q} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3)}$$

Where, N_{pq} =Normalized value of output parameter at p^{th} rows at q^{th} columns.

$\overline{L}_q$=average values of loss function of output parameter at q^{th} columns.

In this way, the normalized values are calculated and these are presented in Tab.VI.

Step-3: Calculation of total loss function of output parameters:

The total loss function of all the output parameters can be calculated using Eq.4.

$$TL_p = \sum_{q=1}^{n} w_q \times N_{pq} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4)}$$

Where, TL_p=Total loss function at p^{th} row.

n= no.of columns or output parameters.

w_q= weightage of each output parameters.

The weightage of each output parameters can be calculated by Analytical Hierarchy Process (AHP) [18]. From this method, the weightages of surface roughness, crack width, surface crack density and hardness are w_1 =0.56, w_2 =0.26, w_3=0.12, w_4=0.06 respectively. The total loss function of the output parameters are shown in Tab.VII.

Step-4: Calculation of MRSN value of output parameters:

The multi-response signal to noise ratio (MRSN) value can be calculated using Eq.5.

$$\text{MRSN}=\eta_p=-10\times \log_{10}(TL_p)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(5)}$$

The MRSN values of all the output parameters are calculated. According to the highest value of MRSN, the rank is obtained and are shown in Tab.VII.

Table-V: Loss function of the output parameters

Expt. No.	LTB-SR	LTB-CW	LTB-SCD	HTB-Hardness
1	3.9204	2.608225	3.91751E-05	5.69603E-06
2	6.4516	2.735716	4.62128E-05	1.07385E-06
3	7.2361	3.568321	6.98227E-05	4.13114E-06
4	5.0625	2.9584	5.86042E-05	1.18663E-08
5	7.4529	2.699778	0.000289643	5.28471E-06
6	8.1225	2.841247	5.02201E-05	6.7465E-06
7	8.7616	4.052169	2.17247E-05	1.61866E-06
8	9.3025	6.216545	3.64687E-05	1.29426E-06
9	9.5481	6.4516	1.30243E-05	1.03278E-06

Table-VI: Normalization of the output parameters

Expt. No.	N_{pq}-SR	N_{pq}-CW	N_{pq}-SCD	N_{pq}-Hardness
1	0.535751	0.687742	0.564215	1.906456
2	0.881658	0.72136	0.665576	0.359418
3	0.988865	0.940903	1.005615	1.38269
4	0.691827	0.780077	0.844042	0.003972
5	1.018493	0.711883	4.171555	1.76879
6	1.109998	0.749186	0.72329	2.258049
7	1.197336	1.068485	0.312888	0.541764
8	1.271254	1.639192	0.525237	0.433189
9	1.304817	1.701172	0.187582	0.345672

Table-VII: Calculation of total loss function and MRSN value

Expt. No.	TL_p	MRSN	RANK
1	0.660927	1.798466	1
2	0.782716	1.063958	3
3	1.002035	-0.00883	4
4	0.691767	1.600403	2

5	1.36216	-1.34228	9
6	1.038665	-0.16476	6
7	1.018367	-0.07904	5
8	1.227112	-0.88884	8
9	1.216252	-0.85024	7

From the Tab.VII, Expt. No1 is having the highest MRSN value. In the expt. No-1, the combination of input parameters is $\mathbf{A_1 B_1 C_1 D_1}$. Here A_1 means 10amp of input current, B_1 means 200 µs of pulse on time, C_1 means 100 µs of pulse off time and D_1 means 0.15 $\frac{\mathbf{kgf}}{\mathbf{cm^2}}$ of flushing pressure. Then a graph is plotted between the experiment numbers with the MRSN values. This is shown in Fig.2. The different expt. no. corresponds to different combination of input parameters as stated in Tab.III.

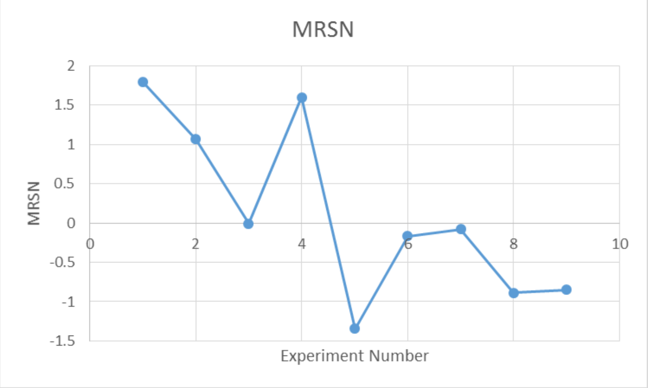

Fig-2: Experiment number with MRSN

Step-5 Average response of the MRSN value:

The experimental design is a orthogonal array design in which the effect of each machining parameter on the MRSN at different levels can be determined. The mean of the MRSN for the input current at levels 1, 2 and 3 can be calculated by averaging the MRSN for the experiments 1 to 3, 4 to 6 and 7 to 9 respectively. The mean of the MRSN for each level of the other machining parameters can be calculated in similar manner. The average responses of MRSN are presented in Tab.VIII.

Table-VIII: Average response table for MRSN values

Input parameters	LEVEL-1	LEVEL-2	LEVEL-3
Input current-A	**0.951199**	0.031122	-0.60604
Pulse on time-B	**1.106609**	-0.38905	-0.34127
Pulse off time-C	0.248289	**0.604708**	-0.47672
Flushing pressure D	-0.13135	**0.273387**	0.234245

From Tab.VIII, we get the Optimum level combination of input parameter is $\mathbf{A_1 B_1 C_2 D_2}$ i.e 10 amp of input current, 200 µs of pulse on time, 175 µs of pulse off time and 0.25 $\frac{\mathbf{kgf}}{\mathbf{cm^2}}$ of flushing pressure. Then a graph is plotted between the average response of MRSN and the level of input parameters as shown in Fig.3.

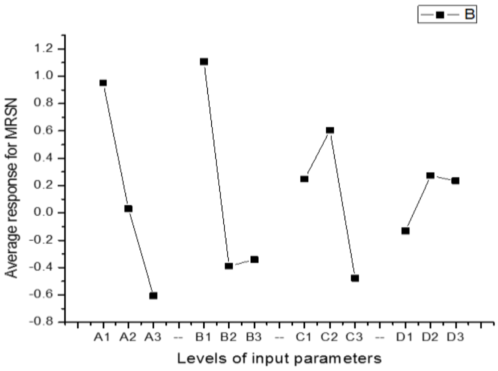

Fig 3. Average response of MRSN with different levels of input parameters

The highest value of MRSN for current, pulse on time, pulse off time and flushing pressure is taken as the optimum level because at this level of input parameters if anyone will perform experiment will get the best result with minimum loss to the society.

B. Utility method:

Utility can be determined by the satisfaction of the customers irrespective of the level of expectations or input parameters. So that the summation of utilizes of each objective indicates the overall utility of a product. It is used for multi-response optimization [19].

The steps followed in this optimization technique are stated in the following.

Step-1: Calculation of constant A:

The value of constant A can be calculated using the following equation (Eq.6)

$$A=\frac{9}{\log_{10}\left(\frac{Y^*}{Y^-}\right)} \text{........................} (6)$$

Where, Y^*=maximum value of the each output parameter

Y^-=minimum value of each output parameter

Step-2: Calculation of individual utility:

The individual utility(u_{pq}) is represented as:

$$u_{pq}=A\times\log_{10}\frac{y_{pq}}{Y^-} \text{............................}(7)$$

Where, u_{pq}=individual utility at p^th rows at q^th column.

y_{pq}=response variable at p^th rows at q^th column. First of all, the constant (A) for all the output can be calculated using Eq.6 and after that, the individual utility value can be calculated by using Eq.7. The calculated values are shown in Tab.IX.

Table-IX: The individual utility of output parameters

Expt. No.	u_{pq} **-SR**	u_{pq} **-CW**	u_{pq} **-SCD**	u_{pq} **- hardness**

1	9	9	5.804791	0.240151
2	3.963525	8.525749	5.325415	2.607555
3	2.803283	5.885329	4.127952	0.695914
4	6.415037	7.748084	4.63616	9
5	2.504808	8.657161	0	0.346496
6	1.634938	8.149614	5.084129	0
7	0.86915	4.621702	7.515493	2.025332
8	0.263474	0.36882	6.012502	2.342671
9	0	0	9	2.662885

The overall utility can be calculated by using the formula

$$u_p=\sum_{q=1}^{n} w_q \times u_{pq} \text{..............................(8)}$$

Where, w_q=weightage of each output parameter.

From Analytical Hierarchy Process (AHP), w_1 =0.56, w_2 =0.26, w_3 =0.12 and w_4 =0.06 are the weightage of surface roughness, crack width, surface crack density and hardness respectively. The calculated overall utility values are shown in Tab.X.

Signal-to-noise ratio of overall utility can be calculated using following formula (Eq.9) and these values are shown in Tab.X.

$$\text{S/N-}u_p=-10\text{x}\log_{10}\frac{1}{{u_p}^2} \text{..............................(9)}$$

Table-X: Overall utility and signal-to-noise ratio:

Expt. No.	I_p in amp	T_{on} in µs	T_{off} in µs	F_p in $\frac{kgf}{cm^2}$	Overall u_p utility	S/N-u_p	Rank
1	10	200	100	0.15	8.090984	18.16003	1
2	10	500	175	0.25	5.231772	14.37298	3
3	10	1000	250	0.5	3.637133	11.21518	6
4	20	200	175	0.5	6.703262	16.52572	2
5	20	500	250	0.15	3.674344	11.3036	4
6	20	1000	100	0.25	3.64456	11.2329	5
7	30	200	250	0.25	2.711746	8.66498	7
8	30	500	100	0.5	1.105499	0.871169	9
9	30	1000	175	0.15	1.239773	1.866844	8

				AVG= 4.004341			

From the Tab.X, the Expt. No.1 shows the highest value of signal-to-noise ratio of overall utility. The corresponding level combination of input parameter is $A_1 B_1 C_1 D_1$. i.e 10amp of input current, 200 µs of pulse on time, 100 µs of pulse off time and 0.15 $\frac{kgf}{cm^2}$ of flushing pressure. Then a graph is plotted in between experiment number with overall utility and is presented in Fig.4.

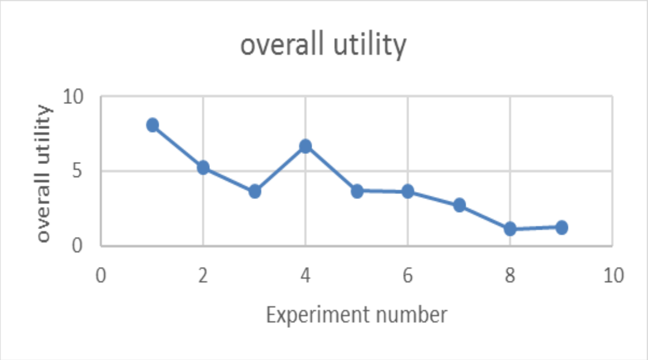

Fig-4: Experiment number with overall utility

The average response of overall utility can be calculated in the same way as followed for the MRSN technique. These are presented in Tab.XI.

Table-XI: Average response of overall utility

Machining parameters	LEVEL-1	LEVEL-2	LEVEL-3
Input current-A	5.653296	4.674055	1.685673
Pulse on time-B	5.835331	3.337205	2.840489
Pulse off time-C	4.280348	4.391602	3.341074
Flushing pressure-D	4.335034	3.862693	3.815298

From the average response of overall utility (Tab.XI) the optimum level is $A_1 B_1 C_2 D_1$. Here 10 amp of input current, 200 µs of pulse on time, 175 µs of pulse off time and 0.15 $\frac{kgf}{cm^2}$ of flushing pressure. Then a graph is plotted between the average response of overall utility and the level of input parameters as shown in Fig.5.

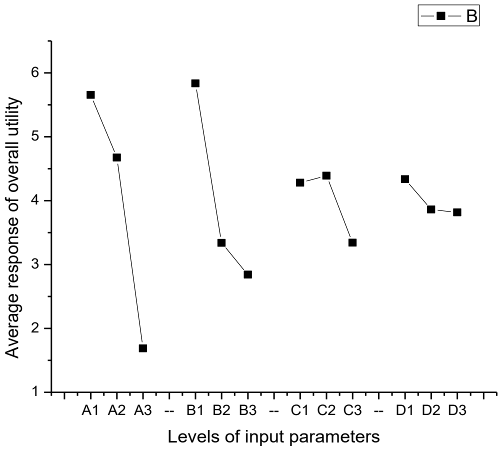

Fig 5. Average response of overall utility with different levels of input parameters

It is observed from fig.5 that, the optimum level combination in this case is different from the MRSN technique.

IV. ANALYSIS OF VARIANCE (ANOVA) FOR MRSN AND UTILITY TECHNIQUE

The main aim of the analysis of variance is to find out the importance of the input parameters. The machining parameters significantly affect the performance characteristics that can be determined. This is accomplished by separating the total variability of the optimization technique (MRSN and Utility), which is measured by the sum of the squared deviations from the total mean of the MRSN or Utility, into contributions by each machining parameter and the error.

For MRSN technique,

First, the total sum of the squared deviations SS_T is determined.
Sum of squared deviation of total

$SS_T=\sum_{p=1}^{m}(\eta_p-\eta_g)^2$ ……………………… (10)

Sum of squared deviation of first input parameter of A

$SS_A=\sum_{k}^{l}(\eta_k-\eta_g)^2$ ……………………………..(11)

Where, η_g=total mean of the MRSN value

η_k=the mean value of the MRSN in the corresponding input parameter at different level.
m= number of experiments.
k= (1, 2, 3,…………..l), l= number of levels
Similarly, sum of squared deviation for other input parameters are calculated using Eq.11.
Sum of squared deviation of error,
SSE=SST-(SSA+SSB+SSC+SSD+…..) ……..........(12)

Once the sums of squared deviation of all are calculated, the mean square can be calculated as follows:

Mean square of the input current (A)

$MS_A=\frac{SS_A}{DOF}$ ……………………………………… …..(13)

Where, DOF =Degrees of freedom of the input parameters. It is calculated as: levels of input parameter-1

Fo is the fisher's test and the value can be calculated as $\frac{MS_A}{MS_{Error}}$ ……..................(14)

Percentage of input current (A) =

$\frac{SS_A}{SS_T}\times100$ ……………………………………………….. (15)

Similarly, ANOVA for utility method can be calculated using Eq.10 to Eq.15.

The ANOVA table for both MRSN and Utility technique are presented in Tab.XII and Tab.XIII respectively.

Table-XII: Analysis of variance (ANOVA) for MRSN

Machining parameter	Error parameter	DOF	SS	MS	FO	% Contribution
Input current-A		2	3.68	1.84	12.30	36.29
Pulse on time-B		2	4.34	2.17	14.50	42.78
Pulse off time-C		2	1.82	0.91	6.09	17.98
Flushing pressure-D	ERROR	2	0.30	0.15	1	2.95
ERROR		0	0			
TOTAL		8	10.13	1.27		100

Table-XIII: Analysis of variance (ANOVA) for Utility Method

Machining parameter	Error parameter	DOF	SS	MS	FO	% Contribution
Input current-A		2	25.63	12.81	51.73	58.81
Pulse on time-B		2	15.46	7.73	31.20	35.47
Pulse off time-C		2	2.0	1.00	4.03	4.59

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Flushing pressure-D	ERROR	2	0.50	0.25	1	1.14
ERROR		0	0	0		
TOTAL		8	43.58	5.45		100

V. CONFIRMATION TEST:

Once the optimal level of each machining parameters is determined, the final step is to predict and verify the improvement of the performance characteristics using this optimal level of the machining parameters.

The estimated value for MRSN technique using the optimal level of the machining parameters can be calculated as:

$$\eta=\eta_g+\sum_h^d(\eta_h-\eta_g) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots16$$

Where, η_h= the highest mean of MRSN at levels of each input parameter.

h= (1, 2, 3,…………..d), d= no of input parameters.

Similarly, the estimated value of overall utility for Utility technique is calculated using the same formula used in the MRSN technique (i.e Eq.16).

The estimated value of MRSN is 2.559622. It matches with MRSN value from Tab.VII. is 1.798466. Then the experiment was conducted on the optimum level combination in EDM machine and the values of all the output parameters are measured and that is shown Tab.XIV.
The estimated value of overall utility is 8.202238. It matches with overall utility value from Tab.X is 8.090984.Then one experiment was conducted on the optimum level combination in EDM machine and the values of SR, CW, SCD and hardness are evaluated. These values are shown in Tab.XV.

Table-XIV: Experimental values of optimum level combination and initial level combination (For MRSN)

Optimum level (Experiment.)	Initial machining
Level=$A_1B_1C_2D_2$	**Level=$A_1B_1C_1D_1$**
MRSN=1.927175	MRSN=1.798466
SR=2.14	SR=1.98
CW=1.5786	CW=1.615
SCD=0.006549	SCD=0.006259
Hardness=954	Hardness=419

It is clearly obvious from this table (Tab.XIV) that, the MRSN value corresponding to the optimum level combination of input parameter is higher compared to the maximum possible MRSN value of initial machining i.e optimum level combination is justified.

Table-XV: Experimental values of optimum level combination and initial level combination (For Utility method)

Optimum level (Experiment.)	Initial machining
Level=$A_1B_1C_2D_1$	**Level=$A_1B_1C_1D_1$**
Overall utility=8.101487	Overall utility =8.090984
S/N- Overall utility=18.17129	S/N- Overall utility=18.16003
SR=2	SR=1.98
CW=1.526	CW=1.615
SCD=0.006235	SCD=0.006259
Hardness=856	Hardness=419

It is clearly obvious from this table (Tab.XV) that, the overall utility value corresponding to the optimum level combination of input parameter is higher compared to the maximum possible overall utility value of initial machining i.e optimum level combination is justified.

VI. SUMMARY OF THE OPTIMIZATION RESULTS:

A. Multi-response signal-to-noise ratio optimization technique

a. From the multi-response signal-to-noise ratio (Tab.VII), the experiment no.1 (**Level combination= $A_1B_1C_1D_1$ i.e, $I_p=10$ amp, T_{on}=200μs, T_{off}=100μs, F_p=0.15$\frac{kgf}{cm^2}$**) has the highest multi-response signal-to-noise ratio. The value of MRSN=**1.798466.**

b. From Tab.VIII, The optimum **Level combination= $A_1B_1C_2D_2$ ($I_p=10$ amp, T_{on}=200μs, T_{off}=175μs, F_p=0.25$\frac{kgf}{cm^2}$),** where the MRSN value=1.927175.

c. From the ANOVA (Tab.XII), the most effective input parameter is **pulse on time** which has **42.78%** contribution.

B. Utility optimization technique:

a. From the overall utility (Tab.X), the experiment no.1 (Level combination= **$A_1B_1C_1D_1$ i.e, $I_p=10$ amp, T_{on}=200μs, T_{off}=100μs, F_p=0.15$\frac{kgf}{cm^2}$)** has highest overall utility. The value of overall utility is **8.090984.**

b. The signal-to-noise ratio for overall utility is **18.16003.**

c. From Tab.XI, the optimum Level combination is **$A_1B_1C_2D_1$ ($I_p=10$ amp, T_{on} =200μs, T_{off}=175μs, F_p=0.15$\frac{kgf}{cm^2}$)** and the corresponding S/N ratio is 18.1719.

d. From the ANOVA (Tab.XIII), the most effective input parameter is **input current** which has **58.81%** contribution.

VII. CONCLUSION

- From the summary of results of two optimization techniques, Utility method is a better method for multi-response optimization because, it has higher signal-to noise ratio representing minimum loss to the society.
- From the summary of results of two optimization techniques, the utility method gives the optimum level combination of $A_1 B_1 C_2 D_1$ **i.e** 10 amp of input current, 200µs of pulse on time, 175µs of pulse of time, 0.15 $\frac{kgf}{cm_2}$ of flushing pressure are the appropriate input parameters for obtaining better quality surface for INCONEL 718.
- From the above experimental study the most effective input parameter is input current. It has 58.81% contribution.
- The hardness of unmachined surface of workpiece is measured as 359Hv. The highest achievable hardness is 856Hv. That means there is tremendous (2.38 times) improvement of hardness of machined surface as noticed from the utility method.

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