ANALYSIS OF PROCESS PARAMETERS IN WIRE EDM WITH STAINLESS STEEL 410 USING TOPSIS METHOD

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Abstract : ***Wire Electrical Discharge Machining is an extremely important machining process among newly developed non-traditional machining techniques for "difficult to machine" conducting materials such as, ceramics, nemonic alloys, heat treated tool steels, composites, carbides, super alloys, heat resistant steels etc. In wire EDM, the material removal is achieved through high frequency sparks between the wire and the workpiece immersed into the dielectric. The Material Removal Rate (MRR) and Surface Roughness (SR) are some of the important performance measures characteristics of wire EDM process. The objective of wire EDM is to get maximum MRR along with achieving reasonably good surface quality of machined component. Important machining parameters like Peak current, Pulse on time, wire feed are considered for investigation. The optimum condition of wire EDM is determined by using technique for order preference by similarity to ideal solution (TOPSIS) method. After TOPSIS analysis, it is found that optimal parameter levels are Peak Current level 3 (210 A), pulse on time at level 1 (110 μs), wire feed level 2 (3 m/min). Optimum response characteristic relative closeness is improved with 6.92% by employing TOPSIS method.***

IndexTerms - Electrical Discharge Machining (EDM), Material Removal Rate (MRR), Surface Roughness (SR), TOPSIS.

I. INTRODUCTION

Recent developments in the mechanical industry have fueled the demand for materials having high toughness, hardness and impact resistance. These materials are difficult to machine with traditional methods. The search for new, lightweight material with greater strength and toughness has led to the development of new generation of materials. Sometimes their properties may create major challenges during machining operations [1]. The manufacturing industry is becoming more time conscious and quality oriented with the advancement of the global economy. This becomes necessary to use non-conventional machining processes such as Laser Machining, Electric Discharge Machining (EDM), Chemical Machining, Abrasive Water Jet Machining, etc. Wire EDM is a method to cut conductive materials with a thin electrode that follows a defined path. It is necessary to drill a hole for machining the workpiece or start from the edge. Machining is always through the entire workpiece. On the machining area, each discharge creates a crater in the workpiece and an impact on the wire electrode. The dielectric fluid acts as an insulator, coolant and debris removal. Since no cutting forces are present, wire EDM is ideal for complex parts [2]. In recent years, the wire EDM technology significantly improved to meet the requirements in various manufacturing industries, especially in the die industries and precision mould industry. The wire EDM process has improved in terms of accuracy, quality, precision and productivity; this immensely helped the tooling and manufacturing industry. Most workpieces come off from the machine as a finished part, without the need for any secondary operations i.e. as a one step machining process.

II. LITERATURE REVIEW

Sharma et al. [3] conducted experiments for multi quality characteristics of wire EDM process parameters with RSM. They concluded that as pulse on time and peak current increases; MRR and SR also increases. The wire tension had insignificant effect on MRR and SR. Pulse off time, servo voltage, peak current and interaction of pulse off time and peak current, servo voltage and peak current, pulse on time and pulse off time, pulse on time and servo voltage were the significant factor for surface roughness.

Basil et al. [4] evaluates the effect of voltage, dielectric pressure, pulse on time and pulse off time on spark gap of Ti6Al4V alloy. It was found that the pulse on time, pulse off time, the interaction of dielectric pressure and pulse off time, interaction of pulse on time and pulse off time are significant parameters which affect the spark gap of wire EDM. Based on grey relational analysis, the best combination of input variable for the minimum spark gap is given as: pulse on time=20μs, high value of dielectric pressure= 15 kef/cm2, high value of pulse off time= 50 μs, voltage of 50V respectively. Improper setting of pulse on time and pulse off time can lead to wire breakage which in turn leads to increase in machining time. The developed model agrees with the conformation results by less than 6%.

Shah et al. [5] studied the multiple process parameters optimization of wire EDM on Inconnel-600 using RSM. Four input process parameters of wire EDM (namely Peak Current (IP), Pulse on time (TON), Pulse off time (TOFF) and Wire Feed rate (WF) were selected as variables to study the process performance in terms of MRR. In the present work, the parametric optimization method using Taguchi's robust design is proposed for wire EDM machining of Inconel-600. This material is gained dominance, where high strength and hardness is required at elevated temperatures. So, experimentation was done by using Taguchi's mixed L_{18}orthogonal array. Finally it concluded the effects of pulse on time, pulse off time, peak current, wire feed rate setting are experimentally investigated in machining of Inconel-600 using CNC wire EDM process. The level of importance of the machining parameters on the MRR is determined by using ANOVA and it is shown that pulse on time, pulse Off time, peak current are most significant.

Rajurkar et al. [6] presented paper on an experimental investigation of wire EDM of titanium alloy as work piece material. The objective of this study to investigate the effect of seven process parameters including pulse width, servo reference voltage, pulse current, wire tension, cutting speed, wire rupture and surface integrity on cutting speed and SR. A TaguchiL_{18} design of experiment (DOE) was applied. The ANOVA also indicated that voltage, injection pressure, wire feed rate and wire tension have non-significant effect on the cutting speed. Scanning Electron Microscopic (SEM) examination of machined surfaces was performed to understand the effect of different wires on work piece material surface characteristics. Based on the experiments results of wire EDM obtained they found that titanium indicates peak current and pulse width have significant effect on cutting speed and surface roughness. They concluded that cutting speed of machining decreases with increasing time between pulses and when wire tension increases with increase in SR. The wire breakage in machining of titanium is sensitive to electrical process parameters such as time between two pulses, pulse width, wire tension and injection pressure.

Patil et al. [7] reviewed the recent developments in wire EDM. It reports on the wire EDM research relating to performance measures improvement, process parameters optimization. A wide range of wire EDM industrial applications for the variety of materials is reported with variations. The paper also discusses the future trend of research work in wire EDM. From the literature review, MRR or production is improved by increasing the wire feed, pulse on time, gap voltage, peak current but major problem with increasing peak current, gap voltage is that SR and kerf quality were decreases. By increasing pulse off time SR increases but, decrease MRR.

Balasubramanian et al. [8] presented an effective approach to optimize process parameters for wire EDM. The objective of this study is to obtain higher MRR and lower SR. Pulse on time, pulse off time, peak current, gap voltage, wire tension and wire feed rate were the six control factors taken each at four different levels. The grey relational analysis is used for multiple performance characteristics. From eight experiments based on the orthogonal array of L_8 the bestcombination of parameters were found. Compared with Taguchi's method the proposed method is more scientific. For data pre-processing in the grey relational analysis process, SR was taken as the 'smaller the better' and MRR was taken as the 'larger the better'. The experiment calculates the best factor combination and the predicted values are closer to the observed values**.** This approach easily converts the multiple performance characteristics into the grey relational analysis, thus simplifying the analysis. The results show that the optimal condition based on the method can offer better overall quality.

Patil and Naik [9] performed the experimental investigation to study the effect of single process parameter on performance measurements in wire EDM with stainless steel 410. The effects of the single machining parameter on the responses such as MRR, SR were investigated in this study. There are 9 experimental readings taken for all process parameters to analyze effect of single process parameters on performance measures. The findings are, MRR increases with increase in peak current, pulse on time and wire feed. Also, SR increases with increase in peak current, pulse on time and wire feed.

Patel et al. [10] investigated the effects of the wire EDM process parameters on the machining quality of stainless steel AISI 304 and to obtain the optimal sets of process parameters so that the quality of machined parts can be optimized. The Taguchi technique has been used to investigate the effects of the wire EDM. Three levels of each of the factors will be selected and experiments are designed by Taguchi methodology. L_9 orthogonal array was used, and experiments were performed as designed by Taguchi method. They concluded that Pulse on time, Input power, pulse off time and wire tension significantly effects on surface roughness. Pulse off time was found to have the effect on SR. Increase in pulse off time value of SR is also decreased. Pulse on time, Input power, pulse off time and wire tension significantly effects on MRR. Increase in Pulse on time, the value of MRR is increased.

Sachdeva et al. [11] performed the experimental investigation to optimize the process parameters for single response optimization using Taguchi'sL_{18} orthogonal array. Experiments were carried out on H-21 die tool steel as workpiece electrode and zinc coated brass wire as a tool electrode. Response parameters were cutting speed, SR and die width. The feature which makes optimization more powerful in comparison to other methods is its ability to handle multiple performance parameters in the form of constraints. The experimental results are then transformed into a signal to noise (S/N) ratio. The S/N ratio was used to measure the deviation of the performance characteristics from the desired value. The optimal level of the process parameter is the level with the highest S/N ratio. A statistical ANOVA was performed to identify the process parameters that are statistically significant. Based on grey relational analysis, they predicated optimal value of quality characteristics given as: cutting speed= 3.71 mm/min, die width= 10.06 mm, SR= 2.32 µm.

Prajapati et al. [12] studied the effect of process parameters like pulse on time, pulse off time, voltage, wire feed and wire tension on performance measures like MRR, SR, Kerf and Gap current of wire EDM for AISI A2 tool steel. The experiments were performed using Taguchi orthogonal arrayL_{27}. Response surface methodology was used to analyze the data for optimization and performance. Pulse off time, pulse on time were the significant factor for surface roughness and spark gap was significant factor for kerf width.

Subrahmanyam and Sarcar [13] evaluated optimal parameters for machining with wire EDM using Grey-Taguchi method. For these experiments H13 hot die steel is used as the workpiece. Multiple responses of the two parameters MRR and SR are identified with the help of Grey-Taguchi Method. The experiments were performed by considering different input process parameters pulse on time, pulse off time, Peak Current, Spark gap Voltage, Wire tension, Wire Feed rate, Servo Feed, Flushing pressure of a dielectric fluid. The experiments were designed by using Taguchi L_{36} orthogonal array. Mathematical relation between the input process parameters and performance characteristics established by the Regression analysis method. The established mathematical models are used in estimating the MRR, SR without conducting experiments.

Manikandan et al. [14] studied Optimized Machining Process Parameters in wire EDM. In this research paper, the performance parameters of wire EDM are founded based on MRR, SR and kerf Width. The machining parameters of wire EDM which influenced on the performance parameters were pulse on time, pulse off time, discharge current, arc gap, flushing pressure, servo voltage and wire tension. Taguchi design of experiments is used to conduct experiments by varying the parameters servo voltage, pulse on time and pulse off time. The process performance is measured in terms of MRR, kerf width and SR. In this paper, wire EDM experiment using 0.25 mm diameter copper wire (with zinc coated) & EN-31 tool Steel workpiece has been done for optimizing MRR, kerf width, Surface finish and reducing cost of manufacturing. By using multi-objective optimization technique grey relational theory, the optimized value is obtained for maximum MRR, minimum SR and Kerf width are given as: pulse on time= 131 µs, pulse off time= 36 µs, wire tension= 6 kgf.

Research Issue

It was found that many researchers have employed different optimization techniques like Taguchi method, Grey Relational analysis, Fuzzy logic to find out the optimum cutting condition for wire EDM operation. But less work has been done by using the TOPSIS method. The effect of machining parameters on Stainless Steel grades AISI 410 has not been fully explored using wire EDM. After a study of the existing literature, a number of gaps have been observed in machining of wire EDM.

III. EXPERIMENTAL SETUP AND PROCEDURE

Experimental setup

Figure 1: Experimental Setup

The machine used for experiments is Electronica sprint cut wire EDM, Model-ELPULS-40 A DLX, incorporated with zinc coated brass wire technology which is installed at Able Tools, M.I.D.C. Gokul Shirgaon, Kolhapur, Maharashtra, India. The machine consists of a coordinate worktable, wire running system, wire frame, Microcomputer based control cabinet and dielectric supply system. In this machine zinc coated brass wire is used to perform cutting operation. Workpiece is mounted on the worktable with the help of clamps and bolts and the micro controller delivers the pulse signals to the servo motors which rotates accordingly and through the variable gears, lead screws and nuts, these motions will be transmitted to the worktable for performing the cutting operation.

Performance measures characteristics

MRR is the rate at which the material is removed from the work piece. Its unit is mm^3/min. The material is removed from the work piece because of series of recurring spark between the two electrodes. The MRR can be defined as the rate of material removed per minute or the ratio of change in volume of workpiece during machining divided by duration of machining.

$$MRR = V_c * B * H$$

Where, V_c= Cutting speed of machining (mm/min)
B= Kerf width (mm)
H= Depth of cut (mm)

In this study, Mitutoyo Surface Roughness Tester SJ-210 is used to measure the average arithmetic surface roughness (Ra) with a cut-off length of 0.8 mm. The surface roughness was measured three times and the average is reported for analysis purpose.

Design of Experiments

Table 1: Input Parameters with Levels value

Sr.No.	Machining Parameters	Level 1	Level 2	Level 3	Level 4
1.	Peak Current (A)	190	200	210	220
2.	Pulse on Time (machine Unit)	110	113	116	119
3.	Wire Feed (m/min)	2	3	4	5

Table 2: Fixed Parameters

Sr.No.	Fixed Parameters	Set Value
1.	Wire Tension	6
2.	Pulse off Time	42
3.	Servo Voltage	20
4.	Servo Feed	2120

As per table 1, L_{16} orthogonal array of “Taguchi method” has been selected for the experiments design in MINITAB 17. In this work, sixteen experiments based on Taguchi (L_{16}) design of experiments were conducted (Table 3) and results were obtained for MRR, SR. The statistical software, Minitab 17 was used and the results obtained for all the experimental runs were statistically analyzed using ANOVA at 95% confidence level and the effects of the selected variable were evaluated.

Table 3: Final Measurement Data

Sr No	Peak current (A)	Pulse on time (machine unit)	Wire feed (m/min)	MRR ($mm^3/min.$)	SR (µm)
1	190	110	2	3.518493	1.37
2	190	113	3	5.027029	2.61
3	190	116	4	4.765268	2.57
4	190	119	5	4.713772	3.27
5	200	110	3	5.143032	1.47
6	200	113	2	4.225868	1.64
7	200	116	5	5.788893	2.15
8	200	119	4	4.162633	2.57
9	210	110	4	3.519017	2.09
10	210	113	5	4.774998	3.30
11	210	116	2	4.632155	2.29
12	210	119	3	4.676787	2.18
13	220	110	5	4.117623	2.85
14	220	113	4	4.628590	2.29
15	220	116	3	4.713592	2.42
16	220	119	2	4.946605	2.21

IV. TOPSIS METHOD

TOPSIS method is a technique for order preference by similarity to ideal solution. The positive ideal solution is a solution that maximizes the benefit criteria and minimizes the cost criteria, whereas the negative ideal solution maximizes the cost criteria and minimizes the benefit criteria. The so-called benefit criteria are those for maximization, while the cost criteria are those for minimization. The best alternative is the one, which is closest to the ideal solution and farthest from the negative ideal solution.

Step by step process of TOPSIS described below

1. The Decision Matrix is formulated which is based on the information available regarding problem. If numbers of alternatives are M and criteria is N then decision matrix is,

$$X_{M\times N} = \begin{bmatrix} x_{11} & x_{12} & .. & x_{1N} \\ x_{21} & x_{22} & .. & x_{2N} \\ .. & .. & .. & .. \\ x_{M1} & x_{M2} & .. & x_{MN} \end{bmatrix}$$

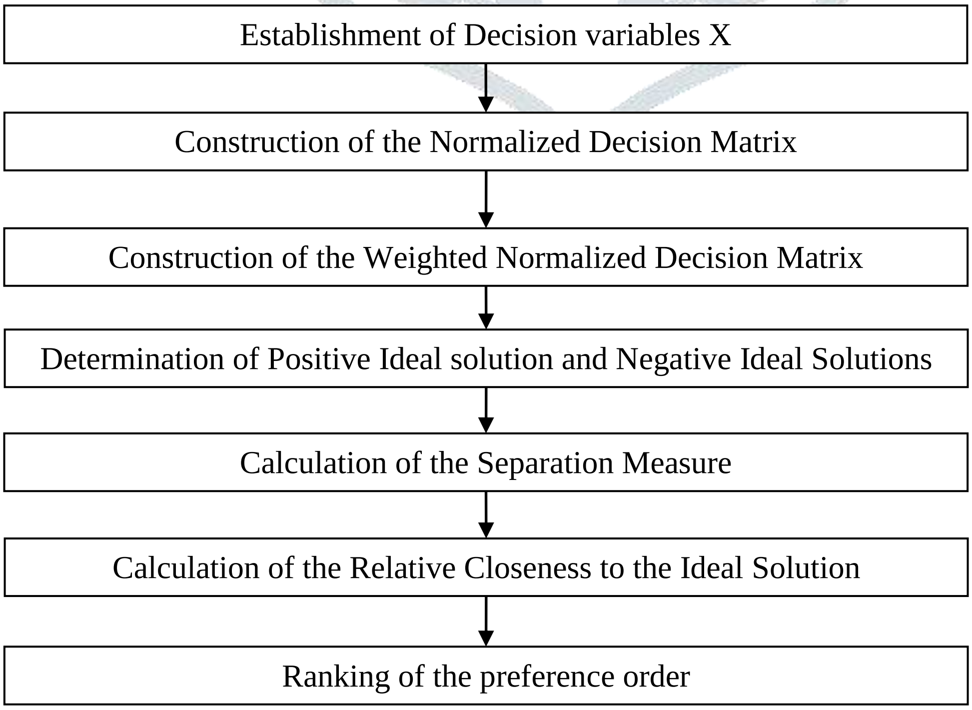

Figure 2: Step by step process of TOPSIS

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3. In this step decision matrix is converted to Normalized Decision Matrix. So that scores obtain in different scales become comparable. An element (x'_{ij}) of the normalized decision matrix can be calculated by following equation,

$$x'_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}}$$

   Therefore, normalized decision matrix is,

$$X'_{M\times N} = \begin{bmatrix} x'_{11} & x'_{12} & .. & x'_{1N} \\ x'_{21} & x'_{22} & .. & x'_{2N} \\ .. & .. & .. & .. \\ x'_{M1} & x'_{M2} & .. & x'_{MN} \end{bmatrix}$$

4. The normalized matrix is then converted to Weighted Normalized Matrix (W) by multiplying each column of normalized matrix with associated criteria weight.

$$W_{ij} = w \times x'_{ij}$$

   The weighted normalized decision matrix is,

$$W = \begin{bmatrix} W_{11} & W_{12} & .. & W_{1N} \\ W_{21} & W_{22} & .. & W_{2N} \\ .. & .. & .. & .. \\ W_{M2} & W_{M2} & .. & W_{MN} \end{bmatrix}$$

5. In next step select the positive ideal (J^+) and negative ideal (J^-) for each attribute.
6. In this step separation measures are calculated. The separation measures are calculated by using the n-dimensional Euclidean distance method. The separation of each alternative from the positive-ideal solution is given as,

$$S_i^+ = \sqrt{\sum_{i=1}^{n} (W_i - J^+)^2}$$

   The separation of each alternative from the negative-ideal solution is given as,

$$S_i^- = \sqrt{\sum_{i=1}^{n} (W_i - J^-)^2}$$

7. Finally, relative closeness value of each alternative to ideal solution is calculated as follow,

$$C_1 = \frac{S^-}{S^+ + S^-}$$

8. Now ranking is done in descending order of the relative closeness value. Larger relative closeness value indicates a good performance of the alternative.
9.

Data Analysis

The machining run with the greatest Relative Closeness value will indicate the optimal combination of parameters. The main effect plot for Relative Closeness is shown in Table 5.

Table 4: Weighted Normalized Matrix

Run	**Weighted Matrix**					
	MRR			**SR**		
1	0.030922	0.03534	0.044175	0.011843	0.015233	0.021969
2	0.033869	0.038708	0.048385	0.016537	0.021271	0.030677
3	0.02575	0.029429	0.036786	0.015093	0.019413	0.027998
4	0.03013	0.034435	0.043043	0.020581	0.026472	0.038179
5	0.037634	0.04301	0.053762	0.010616	0.013654	0.019692
6	0.036785	0.04204	0.05255	0.018848	0.024243	0.034963
7	0.034491	0.039419	0.049273	0.017476	0.022478	0.032418
8	0.034493	0.03942	0.049275	0.023614	0.030374	0.043805
9	0.043896	0.050166	0.062708	0.01531	0.019692	0.028399
10	0.034222	0.039111	0.048889	0.015743	0.020249	0.029203
11	0.025746	0.029424	0.03678	0.009893	0.012725	0.018352
12	0.034941	0.039932	0.049915	0.023831	0.030652	0.044207
13	0.036196	0.041367	0.051709	0.015959	0.020528	0.029605
14	0.033895	0.038738	0.048422	0.016537	0.021271	0.030677

15	0.034869	0.039851	0.049813	0.018559	0.023872	0.034428
16	0.03046	0.034811	0.043514	0.018559	0.023872	0.034428

Table 5: Separation Measures Matrix with Relative Closeness

Run	S+	S-	Relative Closeness	Rank
1	0.015861767	0.018188046	0.53416	4
2	0.01534105	0.014272308	0.481955	8
3	0.023065637	0.012455357	0.350648	12
4	0.022508967	0.00702186	0.237781	16
5	0.007607743	0.023655985	0.706659	2
6	0.015368478	0.015066719	0.495043	6
7	0.015651582	0.013887653	0.470143	10
8	0.022597137	0.01053282	0.317924	14
9	0.007720262	0.024996684	0.714029	1
10	0.014321888	0.015395049	0.518056	5
11	0.021847097	0.019866808	0.476263	9
12	0.022602831	0.011067585	0.328704	13
13	0.012675187	0.016856029	0.570787	3
14	0.015316358	0.01429384	0.482734	7
15	0.016450994	0.01330668	0.447168	11
16	0.02035092	0.0094158	0.31632	15

The values of Relative Closeness at various levels of input parameters are tabulated in Table 5. It is clearly observed that experiment number 9 is best alternative among all 16 experiments.

V. RESULTS

Optimum Condition of Wire EDM by Using TOPSIS Method

In order to see the effect of process parameters on the relative closeness, experiments were conducted using L_{16} orthogonal array. The experimental data is given in Table number 3. The main effect plot of relative closeness for each parameter at levels 1, 2, 3 and 4 for experimental data are plotted in Figure 3.It is also evident that relative closeness is minimum at fourth level of pulse on time and maximum at first level of pulse on time.

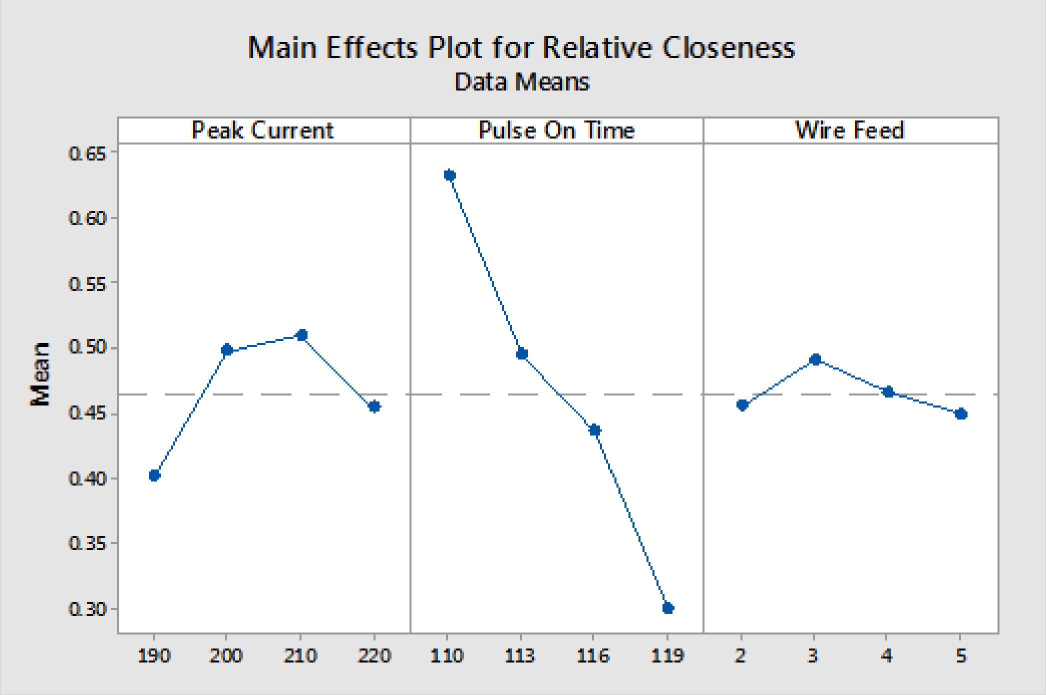

Figure 3: Main Effect plot for Relative Closeness

Increase in pulse on time decreases relative closeness because increasing pulse on time number of electrons striking the work surface in a single discharge increases thus surface roughness is increases. But the effect of peak current and wire feed on relative closeness is very less.

Table 6: ANOVA for Relative Closeness using Adjusted SS

Source	DF	Adj. SS	Adj. MS	F-Value	P-Value	% Value
Peak Current	3	0.028819	0.009606	6.38	0.027	11.12
Pulse on Time	3	0.226243	0.075414	50.08	0.001	87.29
Wire Feed	3	0.004097	0.001366	0.91	0.491	1.59
Error	6	0.009036	0.001506			
Total	15	0.268194				

S=0.038062 R. sq=96.63%

Table 7: Response Table for Relative Closeness

Level	Peak Current	Pulse on Time	Wire Feed
1	0.4011	**0.6314**	0.4554
2	0.4974	0.4944	**0.4911**
3	**0.5093**	0.4361	0.4663
4	0.4543	0.3002	0.4492
Delta	0.1081	0.3312	0.0419
Rank	2	1	3

The mean values of Relative Closeness at various levels of input parameters are tabulated in Table 7. It is clearly observed that the optimal machining parameters for the wire EDM are peak current= 210 A (level 3), pulse on time= 110 µs (level 1), wire feed= 3 m/min (level 2), which is the best multi-performance characteristics among the sixteen experiments shown in bold highlight. From ANOVA of relative closeness (Table 6) peak current and pulse on time has significant effect on relative closeness but wire feed is insignificant effect on relative closeness. Pulse on time is most significant process parameter affecting the relative closeness with around 87.29% contribution.

Confirmation Experiment

The confirmation experiment is an essential step for validating results drawn from the experimental results. The optimum relative closeness characteristic at optimal levels of process parameters is shown in table 8.

The confirmation experiments have been conducted at the optimum settings of the process parameters. The following average values have been found for the quality characteristics considered:

(a) Average MRR = 5.998798 mm3/min

(b) Average SR = 2.12 µm

Table 8: Confirmation Experiment

Optimum Parameters	MRR (mm^3/min)	SR (µm)	Relative Closeness
Peak Current= 210 A Pulse on Time= 110 µs Wire Feed= 3 m/min	5.998798	2.12	0.764029

VI. CONCLUSION

In the presented work, experiments are carried out for performance measures MRR and SR with process parameters as peak current, pulse on time, wire feed. There are 16 experimental readings taken for all process parameters to conduct the analyzed effect of process parameters on performance measures. The ANOVA analysis is conducted to know the percentage contribution of the process parameters on relative closeness. ANOVA analysis results that the pulse on time and peak current are significant factors for relative closeness while wire feed is insignificant. The pulse on time is most significant parameter with percentage contribution about 87.29%. Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is done to find out optimal process parameter levels for maximum MRR and minimum SR. After TOPSIS analysis, it is found that optimal parameter levels are Peak Current level 3 (210 A), pulse on time at level 1 (110 µs), wire feed level 2 (3 m/min). Optimum response characteristic relative closeness is improved with 6.92% by employing TOPSIS method.

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