Optimization of MRR and SR by employing Taguchis and ANOVA method in EDM

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Abstract - *The main objective of the present work is to maximize the Material Removal Rate (MRR) and minimize the Surface Roughness (SR) value. Experiments were performed by Yang et al. (2009) on die-sinking machine by using an Electric Discharge Machine. The process parameters considered in their experimental work include discharge current (I), source voltage (V), pulse-on time (Ton) and pulse-off time (Toff). We have applied the Taguchi's method and there DOE and Taguchi based ANOVA analysis to optimize the above stated two process performance factors i.e. MRR and SR. The main results from the present analytical work are summarized as the most important parameter with the aspect of MRR is discharge current (I), as the discharge current (I) shows the contribution ratio of the order of 33.33 %. The performance of SR is most affected by the factor B. The contribution ratios of discharge current (I) is Re 33.16 % and after that factor C , pulse-on time (Ton) have 30.62%.*

Key Words: MRR, SR, Taguchi Method, ANOVA analysis

1. INTRODUCTION

Traditional Machining, also known "conventional machining" requires the presence of a tool that is harder than the work piece to be machined. This tool should be penetrated in the work piece to a certain depth.
Furthermore, a relative motion between the tool and work piece is responsible for forming or generating the required shape of the object. The absence of any elements in any machining process such as the absence of tool-work piece contact or relative motion makes the process a non-traditional or non-conventional one [1].

Electrical Discharge Machining (EDM) is now a well-known modern manufacturing process, machining process, into which electrically conductive material is removed via means of controlled erosion through a series of electric-sparks of short duration (in micro seconds) and high current density between the electrode and the work-piece. In this process (EDM) electrode and the work-piece both are submerged in a dielectric bath, containing kerosene or distilled water [2].

1.1 WORKING MECHANISM OF EDM

As above said that during the EDM process, thousands of sparks per-second are generated, and each spark produces a tiny crater in the object material along the cutting path by melting and vaporization.

The top surface of the work-piece afterward re-solidifies and cools at a very high rate. Electrical Discharge Machining (EDM) uses thermal energy to achieve a high-precision metal-removal process from a fine, precisely, accurate controlled electrical discharge. The electrode is used to move towards the work-piece until the gap is small enough so that the impressed voltage is great enough to ionize the dielectric [1].

Short duration discharges are generated in a liquid dielectric gap, which separates tool and work piece (in EDM, there is no physical contact between tool and wok-piece) . The material is removed with the erosive effect of the electrical discharges from tool and work piece. EDM does not make direct contact between the electrode and the work piece thus it can eliminate mechanical stresses, chatter and vibration problems during machining [3-4].

1.2 WORKING PRINCIPLE OF EDM

In EDM, the machining process is carried out within the dielectric fluid which creates path for discharge. When potential difference is applied between these two surfaces of work-piece and tool, the dielectric gets ionized and electric sparks/discharge are generated across the two terminals. An external direct current power supply is connected across the two terminals to create the potential difference.

The polarity between the tool and work-piece can be exchanged but that will affect the various performance parameters of EDM process. For extra material removal rate (MRR) work-piece is connected to positive terminal as two third of the total heat generated is generated across the positive terminal. As the work-piece keep on fixed on the base by the fixture arrangement, the tool helps in focusing the intensity of generated heat at the place of shape impartment.

The working and principle components of EDM are shown in below Figure 1.

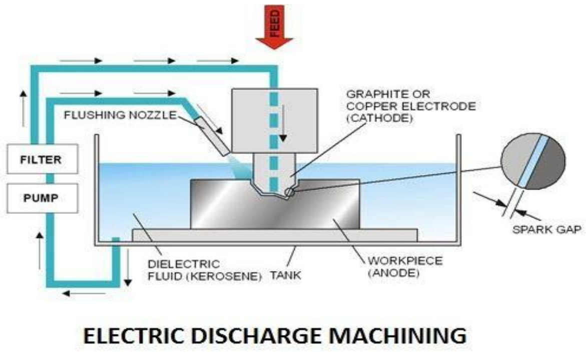

Fig.1: Working and principle components of EDM

2. NEED FOR OPTIMIZATION IN EDM

Optimization is performing or applied in order to obtain the best (optimum) desired result under the given specified experimental conditions. In any engineering machine system, engineers have taken many technological and executive decisions at various stages.
The most significant objective of the decision is either to minimize the effort/time required or maximize the desired results/benefits of the product or advantage in term of economics.
In EDM, traditional method of selection of parameters combinations does not provide satisfactory or desired results. Optimization of process parameters of EDM has been treated as single-objective Optimization process and multi-objective Optimization problem. Designs of experiments (DOE) techniques like Taguchis method, Response Surface methodology (RSM) etc. are used to reduce the experimental runs in actual manner.

3. LITERATURE SURVEY

A review on current research trends in electrical discharge machining (EDM) presented by[5]. They presented the research trends in EDM on ultrasonic vibration, dry EDM machining, EDM with powder additives, EDM in water and modeling technique in predicting EDM performances.

Bhattacharyya et al. [6] has developed mathematical models for surface roughness, white layer thickness and surface crack density based on response surface methodology (RSM) approach utilizing experimental data. It emphasizes the features of the development of comprehensive models for correlating the interactive and higher-order influences of major machining parameters i.e. peak current and pulse-on duration on different aspects of surface integrity of M2 Die Steel machined through EDM.
Tzeng et al. [7] had proposed an effective process parameter optimization approach that integrates Taguchi's parameter design method, response surface methodology (RSM), a back propagation neural network (BPNN), and a genetic algorithm (GA) on engineering optimization concepts to determine optimal parameter settings of the WEDM process under consideration of multiple responses. Material removal rate (MRR) and work-piece surface finish on process parameters during the manufacture of pure tungsten profiles by wire electrical discharge machining (WEDM).

Specimens were prepared under different WEDM processing conditions based on a Taguchi orthogonal array (TOA) of 18 experimental runs. The results were utilized to train the BPNN to predict the material removal rate and roughness average properties. Tzeng and Chen [8] analysed a hybrid method including a back-propagation neural network (BPNN), a genetic algorithm (GA) and response surface methodology (RSM) to determine optimal parameter settings of the EDM process. The parameters MRR, EWR and work-piece surface finish (SF) during the manufacture of SKD61 by electrical discharge machining (EDM) have been optimized. Muthuramalingam and Mohan [9] found by their experimental analysis that the current intensity (CI) of the EDM process affects the material removal rate (MRR) greatly and they developed Taguchi-DEAR methodology based optimization of electrical process parameters. Marafona and Wykes [10] described an investigation into the optimization of material removal rate (MRR) in the electric discharge machining (EDM) process with copper tungsten tool electrode. From the experimental results, it has been proved that large current intensity would result in higher material removal rate.Matoorian et al. [11] presented the application of the Taguchi robust design methods to optimize the precision and accuracy of the EDM turning process for machining of precise cylindrical forms on hard and difficult-to-machine materials.

3.1. Objective of the Present Work

From the above literature review, it was observed or can be conclude that a lot of work by using the various optimization techniques (like RSM, GA, BPNN, FEM) have been used in order to optimization of various parameters Electrical Discharge Machining (EDM) process and its different parameters. The Taguchi DOE and ANOVA analysis based Optimization is the evolutionary algorithms which were used by positively by the various investigators. However, these both optimization techniques (simultaneously) have not been used in the optimization of the Electrical Discharge Machining (EDM) process parameters where the optimal setting is required for a better performance.
The main objective of the present work is to maximize the Material Removal Rate (MRR) and minimize the Surface Roughness (SR) value.
Experiments were performed by [12] on die-sinking machine by using an Electric Discharge Machine. They applied Simulated Annealing (SA) optimization method in order to maximize the MRR and minimize the SR. The process parameters considered in their experimental work include discharge current (I), source voltage (V), pulse-on time (Ton) and pulse-off time (Toff).

3.2. Control factors and there levels

Four parameters namely: Discharge current (I), Source voltage (V), Pulse-on time (Ton) and Pulse-off time (Toff) are varied alternatively. During the experiments Material Removal Rate and Roughness Average (Ra) have also been noted down and given in Table 1.

Table -1: Process parameters and there levels

Input Parameters/Factors	Symbol	Level 1	Level 2	Level 3
Voltage (V)	A	80	160	200
Current (I) (A)	B	6	16	48
Pulse on time (Ton) (µs)	C	6.4	100	800
Pulse off time (Toff) (µs)	D	12.8	50	400

Taguchi constructed a special set of general designs for factorial experiments. The special set of designs or Taguchi Robust Design method uses a mathematical tool called orthogonal arrays (OAs) and Signal to Noise ratio (SNR) to study a large number of experimental process variables with a small/reduce number of experiments.
All the experiments and there corresponding values of MRR and SR are listed in a plan given in Table. 2.

Table -2: Experiments and there corresponding values of MRR and SR

Experiment Run No	A (Volt)	B (Amp)	C (µs)	C (µs)	MRR	Surface Roughness
1	1	1	1	3	0.2	2.62
2	1	1	3	1	0.3	2.87
3	1	2	1	3	0.3	3.05
4	2	1	3	1	0.2	2.68
5	2	2	2	1	20.4	8.32
6	2	2	3	2	55.1	9.31
7	3	1	3	4	0.3	2.05
8	3	1	3	2	0.3	2.69
9	3	2	2	1	54	10.43

The present Taguchi analysis is per-formed with help of MINITAB 17.0 software. For analysis we have selected the present experimental design in OAs L9 with degree of freedom (DOF) = 8. Four parameters and each of having three levels selected

3.3. Main effects plot for MRR

Figure 2 depicted the main effect of control factors terms viz. factors A, B, C and D on MRR. From the main effect plots, it has been observed that yield of MRR increases with increase in Voltage from 80 (V) to 160 (V) but after that its having decreasing value, MRR having continuous increasing phenomena when I (A) increases from 6 (A) to 16 (A) and 16 (A) to 48 (A) due to the formation of more non condensable volatile fractions by severe cracking at higher temperature MRR having increasing trend with pulse on Time (Ton) upto 100 (µs) and after that it starts decreasing.
It (MRR) when increases the Ton from 6.4 to 100 (µs) it happens due to the fact that because the discharge energy increases with the Ton upto certain value and peak current leading to a faster cutting rate.
Furthermore MRR having first increasing trend when pulse off Time increase from 12.8 to 50 and after that it having reducing values with increasing further value of Toff 50 to 400 (µs)

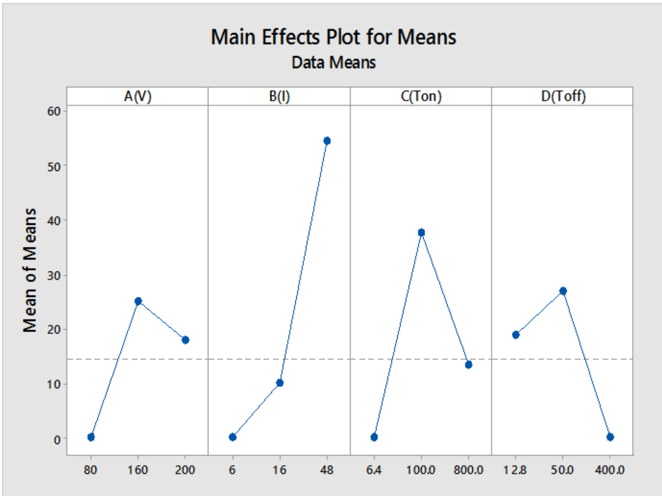

Fig.2: Main effect plots of different factors on MRR

3.4. Analysis of SN Ratio for MRR

Figure 3 shows the main effect plots of SN ratio of different actors terms viz. factors A, B C and D on MRR.
Here we select the options for larger or 'Higher is better (HB)'.It is observed from this Fig.3. and Table .3, that MRR have highest SN ratio for Voltage (V) at the level 2, but for the case of I (A) it is having highest for the third level. Similarly MRR have optimal value for pulse on Time (Ton) at 100 (µs) and for pulse off Time (Toff) at 50 (µs)

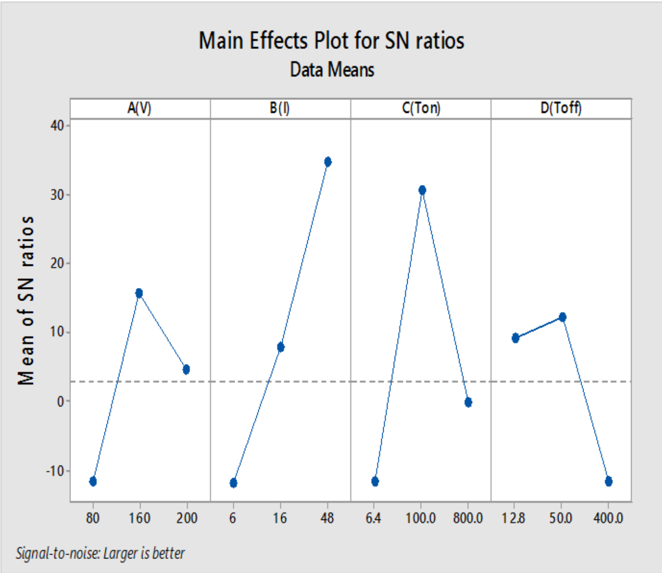

Fig.3: SN ratio plots of different factors effects on MRR

Table.3. Response Table for SN ratios of MRR

Response Table for Signal to Noise Ratios Larger is better				
Level	A	B	C	D
1	-11.6315	11.8663	11.6315	9.1447
2	**15.6787**	7.8675	**30.5078**	**12.0952**
3	4.5776	**34.7355**	-0.0617	-11.6315
Delta	27.3103	46.6018	42.1393	23.7267
Rank	3	1	2	4

4. ANALYSIS OF VARIANCE (ANOVA) ANALYSIS FOR MRR

After performing the Design of Experiments (DOE) performance, it is necessary to perform ANOVA which, comes under the Taguchi Grey (TG) method. Analysis of variance (ANOVA) performed after evaluating DOE analysis to establish the optimal geometric and flow parameters. The present ANOVA is performed with the confidence of 90% and the significance level (or error level of) 10%.

The overall of or cumulative of all factors ANOVA analysis have been performed and reported on the Table 4.10.

The ANOVA analysis in Table 4. indicate that source voltage (V), discharge current (I), pulse-on time (Ton) and pulse-off time (Toff) influence the contribution performance values with 19.53 %, 33.33 %, 30.14 % and 16.97 %, respectively. The contribution percentage of each factor on MRR is also tabulated in Table 4.

Table.4. Analysis of Variance for All factors collectively SN Ration for MRR

ANOVA: MRR versus Factors A,B,C and D						
Source	DF	Adj SS	Adj MS	F-Value	P-Value	Contribution Percentage (%)
A	1	27.37	27.37	1.25	0.326	19.53
B	1	2564.66	2564.66	117.09	0.000	33.33
C	1	37.45	37.45	1.71	0.261	30.14
D	1	84.90	84.90	3.88	0.120	16.97
Error	4	87.62	21.90			
Total	8	4458.92				

Model Summery		
S	R-sq.	R-sq. (adj)
4.68017	98.04%	96.07%

At the last model summery table have also been presented which shows the 98.04 % of R2 which shows the accuracy of the present model results.

4.1. OPTIMIZATION OF THE PRESENT RESULTS FOR MRR

The analysis of the results gives the combination factors resulting in maximum MRR among the investigated experimental configurations are A = 160 V (A2), B = 48 A (B3), C = 100 μs (C2) and D = 50 μs (D3). Consequently, A2B3C2D2 is defined as the optimum condition of design parameters related to the MRR according to the “HB” situation.

The optimization has been performed corresponding to Maximum MRR with following subjected constraints with its minimum and maximum value. Optimization has been performed with the confidence of 90% and the error level of 10%.

The below Figure 4. indicate that the optimized value of MRR value is obtained as = 58.67 (mm3/min) or (g/h) while as per Yang et al. analysis by employing SA (simulated annealing) Algorithm it comes 54.93 which shows the 6.37 % deviation from their results while they applied the simulated annealing (SA) optimization method for L15.

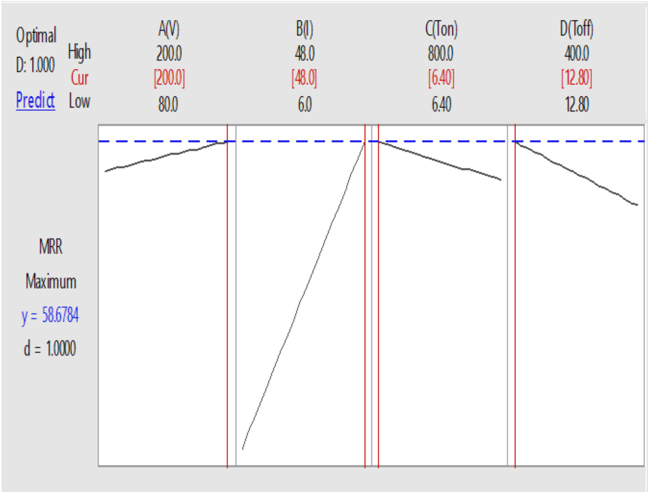

Fig. 4: Optimization of the present result for MRR.

In the present analysis the optimization of different controlling factors towards the MRR has also been optimized, in order to the analysis has been performed.

The Figure 5 indicate that the optimized values of different factors, which is (optimized value) obtained as for factor A = 134.20, for factor B = 7.00, for factor C = 374.79, while for factor D is obtained as D = 200.63.

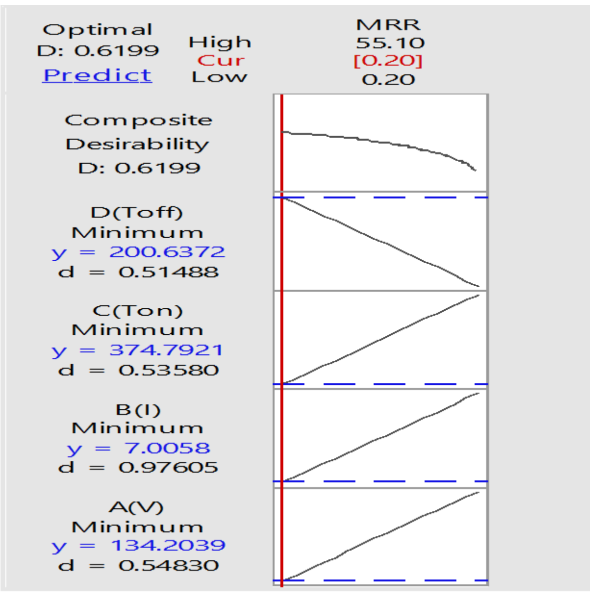

Fig. 5: Optimization of the Different factors.

4.5. MAIN EFFECTS PLOT FOR SURFACE ROUGHNESS

Figure 6 depicted the main effect of control factors terms viz. factors A, B, C and D on SR. From the main effect plots, it has been observed that yield of SR increases with increase in Voltage from 80 (V) to 160 (V) but after that it decreases when we switch the value of V from 160 to 200, for the factor B, SR having all increasing trends for all values of I (A) .

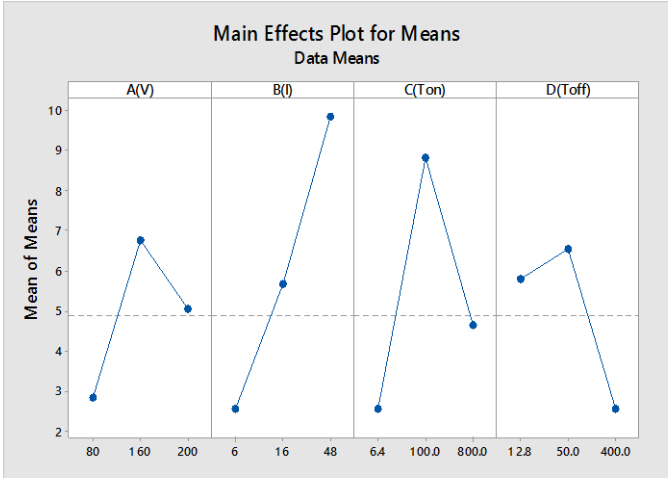

Fig.6: Main effect plots of different factors on Surface Roughness (SR)

SR having first increasing and after that decreasing trend with pulse on Time (Ton). It (SR) when increases the Ton from 6.4 to 100 (μs) and after that it decreases 100 to 800 (μs), Furthermore SR having decreasing trend when pulse off Time increase from 50 to 400 (μs).

4.5.1. Main Effects Plot for SN ratios

After implementing the numerical simulations, based on the prescribed Taguchi Orthogonal Array of Table 4.13, the results are transformed into signal-to-noise ratio (SNR). Figure7 shows the main effect plots of SN ratio of different actors terms viz. factors A, B C and D on MRR. Here we select the options for “Smaller is better (SB)”.

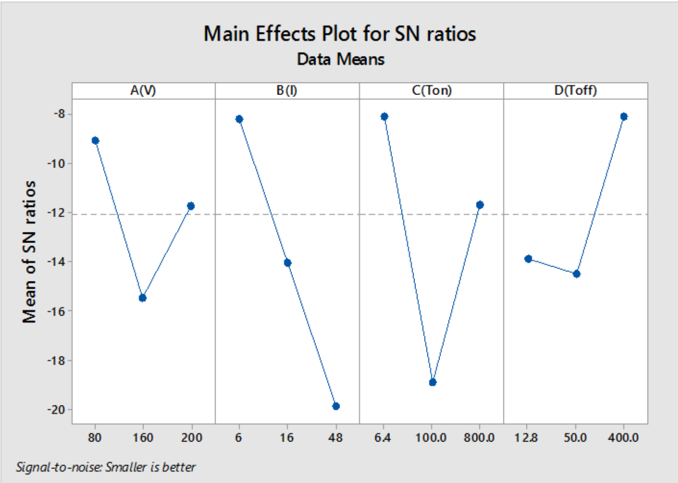

Fig .7: SNR plots of different factors on SR

4.5.2. Contribution Ratio of each factor for SR

The below Fig.ure8 indicate that the Source current (I) (Factor B), have the highest affecting parameters on SR which is 33.16 % contribution among the all. It is also observed from the table that the Pulse on time (Ton) i.e. factor C , is the second most significant factor among all factors as it shows 30.62 % contribution towards SR.

While factor D = 18.11 % affecting the SR values. Furthermore source voltage (V) has least contribution significance on the SR values at showing 18.09 %.

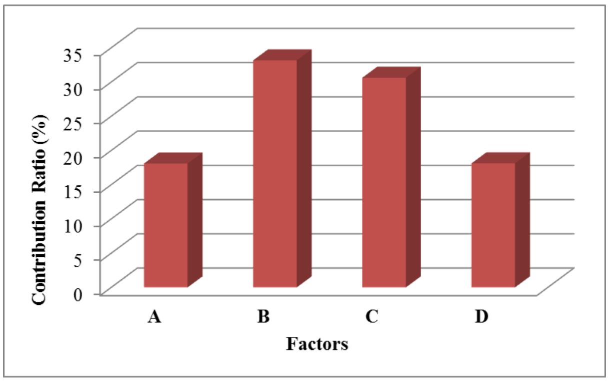

Fig.8: Contribution Ratio of each parameter to SR

4.5.3. Validation of Optimal combination of control factors for SR

The below Figure 9 indicate that the optimized value of SR value is obtained as = 5.04 (μm) while as per Yang et al. it was reported 2.07, while they have applied the simulated annealing (SA) optimization method.

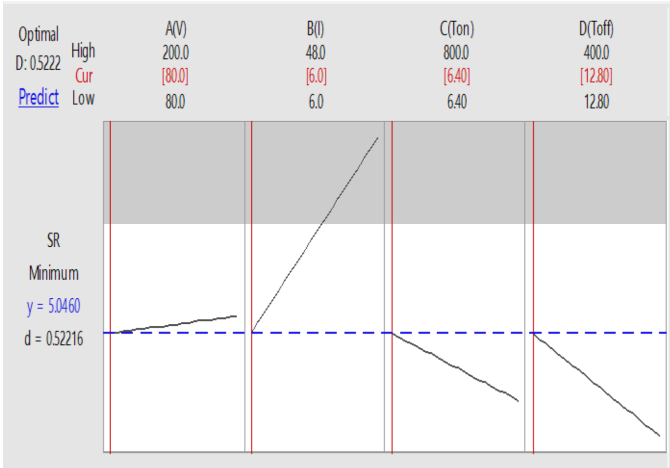

Fig. 9: Optimization of present results for factor SR

4.6. PROBABLE OPTIMUM DESIGNS CONDITIONS FOR MAXIMIZING THE MRR

Based on the above Taguchis DOE and ANOVA analysis the optimal experimental factors which having maximum MRR and minimum SR is tabulated in Table 5 for MRR and for SR in Table 6

Table 5. Optimum designs conditions for maximizing the MRR

	Parameters				Optimum Value (Present Analysis)	Optimum Value (Yang et al. (2009)
Factors	**A**	**B**	**C**	**D**	**MRR** (mm³/min)	
Optimum level	A-2	B-3	C-2	D-2	58.67	54.93
Optimum Value	160	48	100	50		

Table 6. Probable optimum designs minimizing the SR

	Parameters				Optimum Value (Present Analysis)	Optimum Value [12]
Factors	**A**	**B**	**C**	**D**	**SR** (μm)	
Optimum level	A-2	B-3	C-2	D-2	5.04	2.07
Optimum Value	160	48	100	50		

4.7. CONCLUSIONS

The present analytical study has been performed in order to find, the optimal parameters and system designed to maximize the Material Removal Rate and minimize the Surface Roughness from the controlling factors by employing Taguchi DOE method in details. The four different affecting (experimental) factors and two desired parameters have been analysed and selected. The desired factors are; MRR and SR in die-sinking EDM. The influence factors are chosen as discharge current (I), source voltage (V), pulse-on time (Ton) and pulse-off time (Toff). ANOVA analysis and their response and SNR table has been presented. Finally optimized parameters have also been investigated for both factors i.e. MRR and SR. The main results from the present analytical work are summarized as follows:

1. The most important parameter with the aspect of MRR is discharge current (I), as the discharge current (I) shows the contribution ratio of the order of 33.33 %.
By the analysis it is found that MRR can be improved by controlled change of discharge current (I). Optimum condition of design parameters is A2B3C2D2 and the optimum values of the parameters for maximum heat transfer condition are given as follows: A = 134.20, for factor B = 7.00, for factor C = 374.79, while for factor D is obtained as D = 200.63.

2. The performance of SR is most affected by the factor B. The contribution ratios of discharge current (I) is Re 33.16 % and after that factor C , pulse-on time (Ton) have 30.62%.
The optimum condition of design parameters is A2B3C2D2 and the optimum values of the SR is obtained as 5.04 (µm).
3. From the present analysis Optimized value of MRR value is obtained as = 58.67 (mm3/min) which shows the 6.37 % deviation from Yang et al. (2009).
4. The results show that in order to optimize the MRR and SR there is no need to perform all 81 experiments (34 = 81). Because performing all the experiments consume too much time and is not appropriate with respect to the experimental cost.
Therefore, the Taguchi method was successfully applied to the present work, with a very limited run number of experiments and with short span of time.

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