INFLUENCE OF PROCESS PARAMETERS ON PERFORMANCE OF WIRE EDM BY MULTI-OBJECTIVE GENETIC ALGORITHM

Gajanand Rathore¹ and Amber Batwara²

^{1,2}Department of Mechanical Engineering, Poornima College of Engineering, Jaipur, 302022.

ABSTRACT

Wire EDM machines are developed to cut any type of material which have soft to hard behavior in present era. Material must have conductive in nature for this type of machine operation like metals, alloys etc. Wire EDM machine can cut complex design as well as simple design of cut by its nature, sometime very complex cut designs are also easily cut by this machine.

The steady nature of parts being machined in wire electrical discharge machining is troublesome in light of the fact that the procedure parameters can't be controlled successfully. These are the greatest difficulties for the scientists and engineers. Producers endeavour to discover control variables to enhance the machining quality in view of their operational encounters, manuals or fiddled endeavours. Keeping in see the uses of material modern industrial steel (medium carbon steel), it has been chosen and has been machined on wire-cut EDM (Maxicut-e) of Electronica Machine Tools Limited. All experiments are carried out in CIPET, Jaipur.

The target of the present work was to explore the impacts of the different WEDM process parameters on the machining quality and to acquire the ideal arrangements of process parameters with the goal that the nature of machined parts can be streamlined. The whole arrangement of investigations was done in a staged way. The analyses in each stage were rehashed three times. The Taguchi system has been utilized to explore the impacts of the WEDM procedure parameters and in this manner to foresee sets of ideal parameters for ideal quality attributes. The response surface approach (RSM) in conjunction with single piece and focus point configuration has been utilized to build up the observational models for reaction qualities. Development of mathematical models for cutting rate and cutting time using response surface methodology. MOGA optimization technique was also applied in this study for analysis and prediction of results.

KEYWORDS

Wire EDM machine, DOE technique, RSM method, Modal equation, MOGA

1. INTRODUCTION

Now days the industries uses non-conventional machining method like electric, chemical, sound, light which are helpful to machine the hard component and convert them into complicate shape. The machining processes are non-conventional in the sense that instead of using traditional tools for machining, some form of energy is used. The problem of high complexity in shape, size and higher demand for of accuracy and surface finish can be solved by non-conventional machining.[4]

EDM is a machining technology which is today one of the state of the art machining processed for metals. EDM is a controlled metal removal process that is used to remove metal by means of electric spark erosion. When electric current is supply, a spark is generated between the work piece and the electrode creating high temperature which causes erosion on the surface of work piece as well as on the electrode. The temperature is controlled by regulating the spark gap between the electrode and the work piece. Figure 1 is shown the setup of the wire EDM. The tool

is made cathode and work piece is anode. The electrode and work piece should have good electrical conductivity to generate the good spark. The material removal rate (MRR) and surface finish are controlled by the frequency and the spark intensity. A thin gap is maintained between the tool and work piece. Both tool and work piece are submerged in a dielectric fluid. Deionised water, kerosene and EDM oil are very common type of dielectric used in EDM machining process

Figure 1. Working principle of wire EDM [5]

2. EXPERIMENTAL WORK

The working input parameters for current study was looked over past research work, yet machine factors were additionally consider in this research examination work. Straight forward rectangular cut was decided for cut utilizing wire EDM machine. Every specialized determination of machine with constraints was considered in this section. Machine which was utilized for this examination was Maxicut-e WEDM (see figure 3). Modern variant of steel was decided for this research examination work. The machine was introduced in CIPET, Jaipur. The essential execution measures in WEDM are cutting time and cutting rate. In WEDM operations, cutting rate decides the financial aspects of machining and rate of creation though over cut means level of exactness and dimensional precision.

Figure 2. Design of Cut

Figure 3. WEDM installed at CIEPT Jaipur

The modern steel sheet of 75mm x 75mm x 0.75mm size has been utilized as a work piece material for the present analyses. This modern industrial steel is normally hot-worked industrial steel with moderate hardness and sturdiness properties. Chemical composition of industrial steel is carbon 0.20%, Mn 0.45% and others 0.15%.

3. DESIGN OF EXPERIMENT AND RESEARCH METHODOLOGY

Every work has fixed research methodology for completion of work with good effort and quality of data. Flow diagram presents the research methodology of this work in detail.

Figure 4.Flow Diagram of present research work

In show inquire about work two diverse DOE techniques were embraced for test work, so factors were chosen for Taguchi strategy and RSM procedure and present in this segment of research work. It's a powerful statistical technique which assists in studying multiple variables and in maximization of learning using a minimum of resources. The effects of process parameters were studied by various researchers from last decades. It is very difficult to design, experiments for any type of research and here a scientific approach is helpful for researchers which is known as "DESIGN OF EXPERIMENT".[7]

Taguchi suggests orthogonal cluster (OA) for laying out of investigations. These OA"s are summed up Graeco-Latin squares. To outline an examination is to choose the most reasonable OA and to dole out the parameters and communications important to the fitting segments. The utilization of direct diagrams and triangular tables proposed by Taguchi makes the task of parameters straightforward. The exhibit drives all experimenters to plan practically indistinguishable investigations (Roy, 1990). Total 16 experiments are show in table 2.[8]

Table 1. Levels and factors

Process Parameters	Symbol	Range
Pulse on time	Ton	2-10
Pulse off time	Toff	2-10
Peak Current	Current	4-10
Wire Feed	WF	3-10

Table 2. L16 orthogonal array

Sr. No.	Ton	Toff	feed	Current
1	4	4	3	2
2	4	6	5	4
3	4	8	7	6
4	4	10	9	8
5	6	4	5	6
6	6	6	3	8
7	6	8	9	2
8	6	10	7	4
9	8	4	7	8
10	8	6	9	6
11	8	8	3	4
12	8	10	5	2
13	10	4	9	4
14	10	6	7	2
15	10	8	5	8
16	10	10	3	6

Response surface philosophy (RSM) is a gathering of numerical and factual systems valuable for examining issues in which a few free factors impact a needy variable or reaction, and the objective is to streamline this reaction. In numerous trial conditions, it is conceivable to speak to autonomous factors in quantitative frame as given in Equation. At that point these variables can be thought of as having a useful association with reaction as takes after:

$$Y = \phi(X_1, X_2, \dots, X_K) \pm e_t$$

For the present work, RSM has been connected for building up the scientific models as different relapse conditions for the quality normal for machined parts created by WEDM process. In applying the reaction surface procedure, the needy variable is seen as a surface to which a numerical model is fitted.

Table 3. Design matrix for present study using RSM method

RunOrder	PtType	Blocks	Ton	Toff	Feed	Current
1	0	1	7	7	6	5
2	2	1	10	4	6	5
3	0	1	7	7	6	5
4	2	1	7	4	6	8
5	2	1	7	10	9	5
6	2	1	10	10	6	5
7	2	1	10	7	3	5
8	2	1	4	7	3	5
9	2	1	10	7	6	2
10	2	1	10	7	9	5
11	2	1	7	7	9	8
12	2	1	4	7	9	5
13	2	1	7	4	9	5
14	0	1	7	7	6	5
15	2	1	7	4	6	2
16	2	1	4	7	6	2
17	2	1	4	10	6	5
18	2	1	10	7	6	8
19	2	1	7	10	3	5
20	2	1	7	7	9	2
21	2	1	4	7	6	8
22	2	1	7	10	6	8
23	2	1	4	4	6	5
24	2	1	7	7	3	8
25	2	1	7	7	3	2
26	2	1	7	4	3	5
27	2	1	7	10	6	2

4. RESULT AND DISCUSSION

All experiments were designed according to taguchi and RSM technique, which were presented in table 2 and table 3. Experimental results in term of cutting time and cutting rate is presented in table. Main outcomes focused in this study are following: [SN ratio methodology, ANOVA Analysis, Model equations generation and MOGA approach].

4.1 EXPERIMENTAL RESULTS FOR TAGUCHI METHOD

In present study WEDM experiments were performed using orthogonal array design experiment table made by taguchi method for square shape work piece material. Response characteristics are selected by literature review. Selected orthogonal array were present in table 2.

The experimental results for cutting time (CT) and cutting rate (CR) are given in Table 4. 16 experiments were conducted using Taguchi experimental design methodology and each experiment was simply repeated three times for obtaining proper S/N values. Minitab software was used to carry out all results.

Table 4. Experimental Results of Cutting Time and Cutting rate

Trial	Cutting Time (sec)			S/N Ratio	Cutting Rate (mm/sec)			S/N Ratio
	T1	T2	T3		T1	T2	T3	
1	151.243	151.692	151.700	-43.61	0.375	0.376	0.383	-8.45
2	151.684	150.537	151.715	-43.59	0.380	0.375	0.385	-8.40
3	151.246	151.181	151.614	-43.59	0.379	0.381	0.385	-8.36
4	150.439	150.239	151.605	-43.56	0.380	0.380	0.389	-8.33
5	151.127	151.658	151.493	-43.60	0.376	0.375	0.377	-8.49
6	150.066	150.199	152.171	-43.56	0.372	0.370	0.383	-8.52
7	151.597	151.649	151.989	-43.62	0.385	0.384	0.391	-8.25
8	151.246	151.381	151.915	-43.60	0.384	0.381	0.390	-8.29
9	151.251	150.973	152.702	-43.61	0.373	0.372	0.385	-8.48
10	151.536	151.649	151.876	-43.61	0.379	0.376	0.385	-8.40
11	151.843	151.247	151.038	-43.60	0.381	0.382	0.389	-8.31
12	151.368	151.612	152.087	-43.61	0.381	0.382	0.395	-8.27
13	152.191	152.547	152.306	-43.65	0.376	0.378	0.386	-8.40
14	151.816	152.286	153.100	-43.65	0.383	0.382	0.385	-8.32
15	151.117	150.721	152.440	-43.60	0.376	0.378	0.381	-8.44
16	150.317	151.040	152.384	-43.59	0.378	0.379	0.388	-8.36

EFFECT ON CUTTING TIME

Effect of process parameters on cutting time of test piece were present in this section. Outcome of taguchi method for S/N ration data were show in figure 5 and figure 6 for CT response. It must be clear that the machine used for experimental work was quite old and have some overwhelming issues with it, but due to lack of availability new machine, all experiments were performed on this machine with all safety and research measures to get proper results.

It was shown in figure 4 that Ton and current factors show more effect on CT response than other variables (factors) of WEDM machine. The results were changed with other research work and the reason was machine condition and its make year. S/N ratio was selected smaller is better because minimum time for cut was desirable for WEDM machining process

Figure 5.Effects of Process Parameters on Cutting time (S/N Data).

Figure 6.Residual Plots for Cutting time (S/N ratio)

Residual plots were also present in this section for selected responses to identify the problems like non normality, non-random variation, non-constant variance, higher-order relationships, and outliers. These residuals plots were shown in figure 6 for S/N ratio data for response CT. Points will not follow the straight line of normal probability which means residuals were less normal distributed for this response variable. The reason was data collection on the machine and some errors present in machine. Since residuals exhibit no clear pattern, there is no error due to time or data collection order.

It was found that no single factor was non-significant which means all variables were significant for present response CT. If any factor was treated as non-significant variable, then it was pooled from calculation part of ANOVA.

Table 5. Analysis of Variance for Cutting Time (S/N ratio Data)

Source	DF	Seq. SS	Adj SS	Adj MS	F	P
Ton	3	0.002855	0.002855	0.000952	65.63	0.003
Toff	3	0.001299	0.001299	0.000433	29.87	0.010
Feed	3	0.001765	0.001765	0.000588	40.57	0.006
Current	3	0.003386	0.003386	0.001129	77.83	0.002
Residual Error	3	0.000044	0.000044	0.000015		
Total	15	0.009349				

DF - degrees of freedom, SS - sum of squares, MS - mean squares (Variance), F-ratio of variance of a source to variance of error, $P < 0.05$ - determines significance of a factor at 95% confidence level

Best part of Taguchi method was response table's generation for raw data and S/N ratio data, which gives rank of factor as per response variable. So in this section response tables were present for raw and S/N ratio data in table 5. The rank was generated by delta of S/N ratio and mean data of selected response variable. Minitab software was used to assign this task for present study. As per table 6 current was most critical ranked factor for selected response, whereas Toff was least ranked factor to effect the selected response. Ton was second ranked and feed of wire was third rank among all factors.

Table 6. Response Table for Cutting Time

Level	Ton	Toff	feed	Current
1	-43.59	-43.62	-43.59	-43.63
2	-43.60	-43.61	-43.61	-43.62
3	-43.61	-43.61	-43.62	-43.60
4	-43.63	-43.60	-43.62	-43.59
Delta	0.04	0.03	0.03	0.04
Rank	2	4	3	1

EFFECT ON CUTTING RATE (CR)

Figure 7: Effects of Process Parameters on CR

Figure 8. Residual Plots

Residual plots were also present in this section for selected responses to identify the problems like non normality, non-random variation, non-constant variance, higher-order relationships, and outliers. These residuals plots were shown in figure 8 for S/N ratio data for response CR. Points will not follow the straight line of normal probability which means residuals were less normally distributed for this response variable. The reason was data collection on the machine and some errors present in machine. Since residuals exhibit no clear pattern, there is no error due to time or data collection order.

Table 7. Analysis of Variance for Cutting Rate (S/N ratio Data)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Ton	3	0.001430	0.001430	0.000477	0.72	0.601
Toff	3	0.050748	0.050748	0.016916	25.72	0.012
Current	3	0.010576	0.010576	0.003525	5.36	0.101
Residual Error	3	0.034772	0.034772	0.011591	17.62	0.021
Residual Error	3	0.001973	0.001973	0.000658		
Total	15	0.099500				

Table 8. Response Table for Cutting Rate (S/N ratio Data)

Level	Ton	Toff	feed	Current
1	-8.389	-8.458	-8.412	-8.325
2	-8.390	-8.414	-8.403	-8.353
3	-8.367	-8.344	-8.367	-8.408
4	-8.385	-8.315	-8.349	-8.445
Delta	0.023	0.143	0.063	0.120
Rank	4	1	3	2

The rank only indicate the relative importance of each factor, but it means that only factor which has highest rank was most important, was wrong outcome, least rank factor have also importance for study and it was finalized by ANOVA analysis.

4.2 EXPERIMENTAL RESULTS FOR RSM

Table 9. Response results for cutting time (CT) and cutting rate (CR)

Run Order	PtType	Blocks	Ton	Toff	Feed	Current	Cutting Time	Cutting Rate
1	0	1	7	7	6	5	151.828	0.326
2	2	1	10	4	6	5	153.378	0.337
3	0	1	7	7	6	5	152.352	0.328
4	2	1	7	4	6	8	151.575	0.344
5	2	1	7	10	9	5	151.722	0.342
6	2	1	10	10	6	5	153.111	0.347
7	2	1	10	7	3	5	152.975	0.323
8	2	1	4	7	3	5	149.946	0.361
9	2	1	10	7	6	2	154.883	0.379
10	2	1	10	7	9	5	153.762	0.342
11	2	1	7	7	9	8	151.380	0.356
12	2	1	4	7	9	5	150.868	0.342
13	2	1	7	4	9	5	152.320	0.324
14	0	1	7	7	6	5	151.941	0.344
15	2	1	7	4	6	2	153.206	0.365
16	2	1	4	7	6	2	151.381	0.349
17	2	1	4	10	6	5	150.680	0.319
18	2	1	10	7	6	8	152.950	0.342
19	2	1	7	10	3	5	151.704	0.312
20	2	1	7	7	9	2	152.991	0.342
21	2	1	4	7	6	8	150.155	0.364
22	2	1	7	10	6	8	150.547	0.354
23	2	1	4	4	6	5	150.987	0.360
24	2	1	7	7	3	8	151.363	0.353
25	2	1	7	7	3	2	153.071	0.340
26	2	1	7	4	3	5	151.574	0.330
27	2	1	7	10	6	2	153.060	0.358

CUTTING TIME

In this section RSM technique was used to find significance or non-significance variables for selected response CT. the ANOVA analysis result was present in table 10 for CT response variable. Backward elimination method was applied to remove non-significant factors and their interactions. So only final ANOVA table was present here.

Table 10. ANOVA analysis for CT

Source	DF	SeqSS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Model	5	34.9870	95.21%	34.9870	6.9974	83.52	0.000
Linear	4	34.5001	93.89%	34.5001	8.6250	102.94	0.000
Ton	1	24.2037	65.87%	24.2037	24.2037	288.88	0.000
Toff	1	0.4096	1.11%	0.4096	0.4096	4.89	0.038
Feed	1	0.4846	1.32%	0.4846	0.4846	5.78	0.025
Current	1	9.4022	25.59%	9.4022	9.4022	112.22	0.000
Square	1	0.4869	1.33%	0.4869	0.4869	5.81	0.025
Current* Current	1	0.4869	1.33%	0.4869	0.4869	5.81	0.025
Error	21	1.7595	4.79%	1.7595	0.0838		
Lack-of-Fit	19	1.6079	4.38%	1.6079	0.0846	1.12	0.575
Pure Error	2	0.1516	0.41%	0.1516	0.0758		
Total	26	36.7465	100.00%				

As shown in table % contribution of each factor and their interaction was also show for this response variable. Most contributed variable was Ton and one variable Toff was non-significant for CT response.

Figure 9. Residual Plots for CT (RSM)

Residual plots were also present in this section for selected responses to identify the problems like non normality, non-random variation, non-constant variance, higher-order relationships, and outliers. These residuals plots was show in figure 9 for RSM data for response CT. Points will follow the straight line of normal probability which means residuals were normal distributed for this response variable. Since residuals exhibit no clear pattern, there is no error due to time or data collection order.

CUTTING RATE (MM/SEC)

In this section RSM technique was used to find significance or non-significance variables for selected response CR. the ANOVA analysis result was present in table 11 for CR response variable. Backward elimination method was applied to remove non-significant factors and their interactions. So only final ANOVA table was present here.

Table 11. ANOVA analysis for CR

Source	DF	Adj SS	AdjMS	F-Value	P-Value
Model	6	0.009935	0.001656	295.01	0.000
Linear	4	0.009875	0.002469	439.81	0.000
Ton	1	0.009666	0.009666	1722.08	0.000
Toff	1	0.000079	0.000079	14.08	0.001
Feed	1	0.000066	0.000066	11.70	0.003
Current	1	0.000064	0.000064	11.41	0.003
Square	2	0.000061	0.000030	5.40	0.013
Toff*Toff	1	0.000052	0.000052	9.31	0.006
Feed*Feed	1	0.000018	0.000018	3.25	0.086
Error	20	0.000112	0.000006		
Lack-of-Fit	18	0.000110	0.000006	5.73	0.159
Pure Error	2	0.000002	0.000001		
Total	26				

As shown in table % contribution of each factor and their interaction was also show for this response variable. Most contributed variable was Ton and one variable Feed*Feed was non-significant for CR response.

Figure 10. Residual Plots for CR (RSM)

Residual plots were also present in this section for selected responses to identify the problems like non normality, non-random variation, non-constant variance, higher-order relationships, and outliers. These residuals plots was show in figure10 for RSM data for response CR. Points will follow the straight line of normal probability which means residuals were normal distributed for this response variable. Since residuals exhibit no clear pattern, there is no error due to time or data collection order.

REGRESSION EQUATION FOR RESPONSES

$$\begin{aligned}
 \text{CT} &= 150.885 + 0.4734 \text{ Ton} - 0.0616 \text{ Toff} + 0.0670 \text{ Feed} - 0.595 \text{ Current} + 0.0300 \text{ Current*Current} \\
 \text{CR} &= 0.32766 + 0.009460 \text{ Ton} - 0.00359 \text{ Toff} - 0.00147 \text{ Feed} - 0.000770 \text{ Current} + 0.000317 \text{ Toff*Toff} + 0.000188 \text{ Feed*Feed}
 \end{aligned}$$

MODEL SUMMARY

	S	R ²	R ² (adj.)	R ² (pred.)
CT	0.289	95.21%	94.07%	91.93%
CR	0.0023	98.88%	98.55%	97.90%

4.3 MULTI OBJECTIVE GENETIC ALGORITHM (MOGA)

In present study MOGA optimization technique was also applied on regression modeling equations generated by RSM technique for both responses. Two functions were developed for these response equations. Function 1 represents cutting time, function 2 represents cutting rate.

After fitness function generation, data was entered into global optimization tools box, which was available in MATLAB software. Solver was selected as per requirement, for present study MOGA was selected as solver. All required data was entered into GUI window for present work. Population size was selected 100 for present study and after this selection of population size solver was run and results were generated.

Figure 11. Results from MOGA modeling in MATLAB

All possible results generated during modeling of MOGA technique were present in figure 11. As seen in figure some graphs represent only modeling generation of different parameters, but one graph represents the outcome of this MOGA technique, which was named score histogram. Although this technique provides the best optimum results for given functions, but in present study, all possible score results with factor values were present in table 12 for consideration. The selection of the best case depends on the user and its requirement. Optimum values for Fitness Functions using MOGA (2 fitness function)

Table 12. Optimum values for fitness functions and Factor's values for all fitness functions using MOGA

f1	f2	x1	x2
151.66	0.35	4.00	3.00
149.93	0.35	4.07	3.50
149.54	0.33	4.01	3.18
149.59	0.33	4.01	3.85
150.99	0.35	4.39	3.21
149.77	0.34	4.01	3.51
151.65	0.35	4.07	3.18
151.44	0.34	4.05	3.11
149.86	0.35	4.03	3.33
150.47	0.35	4.03	3.11
150.78	0.34	4.08	3.38
151.71	0.35	4.22	3.45
151.13	0.35	4.06	3.26
150.58	0.34	4.02	3.29
150.32	0.34	4.02	3.25
149.89	0.34	4.14	3.68
149.96	0.34	4.01	3.67
150.21	0.35	4.09	3.17
149.94	0.35	4.08	3.15
149.88	0.34	4.03	3.53
150.26	0.34	4.01	3.44
150.06	0.34	4.05	3.48
150.42	0.35	4.26	3.46
149.81	0.34	4.00	3.05
150.99	0.34	4.06	3.90
151.30	0.34	4.09	3.42
149.84	0.34	4.02	3.91
151.50	0.35	4.06	3.00
149.74	0.34	4.23	3.35
149.69	0.34	4.04	3.23
151.53	0.35	4.12	3.80
150.54	0.34	4.02	3.41
150.84	0.35	4.35	3.25
149.69	0.34	4.02	3.31
151.31	0.34	4.09	3.14

5. CONCLUSIONS

1. Model equations for response cutting time and cutting rate was predict accurately with Minitab software and show above 90% good prediction for responses and can be used by any cutting based machining process manufacture.

2. Optimization of model equations was performed for all four response equations using MOGA technique; it was useful to predict the role of optimum solution for WEDM machining process. In different practical applications, values of the process parameters can be controlled better if the process models are employed in different industrial applications

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