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Parametric Optimization of Wire Electrical Discharge Machining Process using Taguchi Technique

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Abstract:
"Electro-Discharge Machining (EDM)" is a widely utilized non-conformist machining proceduresed for material eliminationin aerospace, die making, automotive and other organizations. The present study focuses on investigating the outcome of procedurevari ables like"gap voltage (Vg), sensitivity, beat on time, Pulse off time (Toff) and diameter of the tool" on "material elimination rate (MER)". The work piece used is high-speed steel (HSS) and the device material used is "electrolytic copper (Cu)". "Taguchi's L9 orthogonal array" has been utilized to carry out the tests. Minitab 17 software has been used for the analysis. Considering the result of various factors on process, the effect of the significant process parameters needs to be investigated. The process parameters havebeen observed to have different effect on the machining process and the output responses are dependent on them. Hence finding out the utmost appropriate set of procedure variables to increase the material removal rate for wire EDM process needs investigation for which process optimization may be used. MRR is observed be maximum if gap voltage is 5, sensitivity 5, pulse on interval will be 5 and pulse off interval will be 1.

***Keywords**: Wire EDM, Taguchi Technique, Material Removal Rate, Optimization, Orthogonal Array, Steel*

1. Introduction

"Electrical Discharge Machining" process involves removing material[1], [2]as of the work piece in method of wreckage by pulses generated in between the cathode and anode surfaces immersed in the dielectric medium. The process is thermoelectric in nature[3]. When the conductors are detached by a minor distance, there is a formation of short discharges due to the ionization of the dielectric. There occurs a continuous bombardment of electrons and ions creating a plasma channel in the discharge gap due to the increased temperature in the range of 8000ºC-12000ºC. There is a continuous erosion of material during the spark-on-time.EDM characteristically workings with materials that remain electrically conductive. Wire-cut EDM finds wide range of applications[4] which include cutting plates of about 300mm thickness, making components like tools, dies and punches from difficult-to-machine materials " .Wire EDM machining"[5] being an electro-thermal procedure by principle uses a Thin metal tube, mixed with de-ionized water used as the dielectric medium. Mostly brass wire is used which cuts the metal through the depth during machining in the form of electric sparks. A metallic wire of diameter around 0.1 mm of steel, brass or copper shapes the work piece along a planned path during its constant circulatory motion. Deionized water directly injected around the wire is used as dielectric. During machining, when

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the requirement is to produce surfaces with low residual stresses, WEDM is commonly used since high cutting forces are not involved for removing the material. In case of low power requirement, slight changes in the workpiece material mechanical properties occur. WEDM is implemented for machining complex parts and precise components when machining exotic materials. Wire is fed continuously, and the axis movements are computer numerically controlled. The wire takes the path of the contour and the required shape is generated.

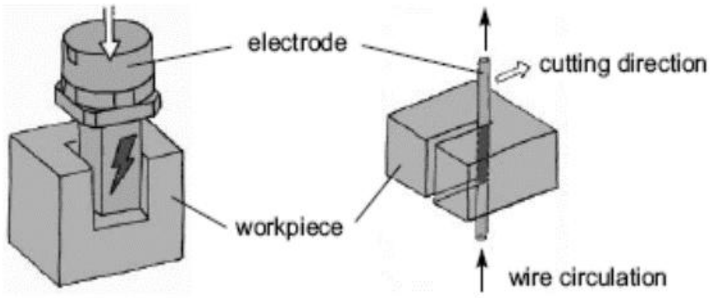

Figure.1.1“Die-dipping EDM”Figure.1.2“Wire-cut EDM”
Figure.1 Types of EDM

WEDM is among the most important machining operations[6] in manufacturing industries owing to its ability to produce intricate shapes, produce parts with utmost accuracy and precision[7]. Many process variables are involved in the process and hence the real problem is to identify the optimal procedurefactors.Chiandussideliberate a mathematical model and used multi-objective optimization to obtain resultsin comparison to several benchmark problems. Many researchers have focused on conducting experiments and optimizing the process parameters. Y.C. Linperformed experiments and used “ANOVA and F-test”[8] to identify the importantfactorsrelated with machining characteristics like “EWR, MRR and SR[9]”. Lodhi optimized the machining factors for “AISI D3 steel utilizing Taguchi technique[10]” and minimized the surface roughness. The influence of pulse current, pulseoff time, on-time and wire feedstuff wereassessed by using “ANOVA” K.M. Pateldeveloped a model to improve surface finish and optimized the process variables to discover the best set of procedurefactors.Selected“L_{27} orthogonal array with six control factors[11]” to perform the experiments. A. Kumar used multi-objectprocess using GRA based Taguchi technique to improve the procedurefactors. Tripathy et al. (2016, 2017, and 2018) studied the influence of additionof various powders to the di-electric liquid for H-11 diesteel and investigated the influence of input responses on MRR, TWR, EWR, SR, RLT[12] and micro-hardness. Multi-objective optimization was used, and the appropriate set of procedurevariables was available.Since previous studies it could be observed that though lot of research has been performed using EDM, the studies involving the use of wire EDM needs much more attention. EDM is a process in which there are several input process parameters controlling the process. Determining the significant process parameters is an important study and should involve more focus. The present work focuses on finding out the optimum parameter setting during wide EDM of high-speed steel using copper tool.

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2. Experimental Details

2.1. Machine and Materials

The experiments have been conducted using WEDM machine, model (EMS-5535IPS50). HSsteel has been taken as anode and copper has been taken as the cathode. The dielectric used during the WEDM process was paraffin oil. The input parameters considered are spark breakcurrent, sensitivity, pulse off time and pulse on time. Wire diameter has been kept constant. The HS plate has been cut into 9 equal parts having dimensions "4.7 x 1.2 x 1.2" cm respectively. The weights of all the 9 work pieces were measured before machining. The work pieces were clamped one after another, maintaining a spark gap of 0.05mm. The machining processes were carried out for 10 minutes for each run. After carrying out the machining operation the weight of all the work pieces were calculated. The differences in mass of the workpiece earlier machining and later machining was m which gives us the value of MRR (Material Removal Rate). Mean MRR for different "voltage level, sensitivity, pulse off time and pulse on time level" were taken and analysis was done using MINITAB 17. The ideafactors selected were break voltage, sensitivity, pulse off time (Toff) and pulse on time (Ton) in three level illustrates in Table1. Figure.2. illustrates the experimental set-up used for the experiments.

Figure.2. Wire-EDM Machine

The workpiece material is HSS (High Speed Steel) and the tool material used is electrolytic copper. The dielectric fluid used for the experiment is paraffin oil.

Table 1: Input factorsand their points

Parameters	L1	L2	3 L
Gap Voltage	1	5	9
Sensitivity	2	5	8
T on(μs)	1	5	9
T off(μs)	1	5	9

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2.2 Design of Experimentations

"Taguchi's technique" uses statistical concepts neardecrease the cost involved and improve the overall quality by minimizing the number of runs to be performed during experimentation using optimization of process variables at different levels.

2.2.1 Experimental Design Strategy

Scientific and engineering approach for investigation is to study "one factorat a time or several factors, one at a time," which involves a larger number of investigationalruns and thus increases the cost involved in the entire process. It becomes difficult to determine the communication between the factors and the optimum setting of factors may notbe identified. To overcome this difficulty, DOE approach is used to effectively plan andperform the experiments using statistics. DOE is user defined and the effect of every singlefactor affecting the process may be studied with ease in cases where several factorscontrol the process."Taguchi recommends" the utilization of orthogonal arrays (OA) to conduct the experiments.The parameters influencing the output response may be categorized into two types:controllable and uncontrollable factors.Design ofexperiments involve assigningsignificant parameters tosuitable columns given by orthogonal array. Identicalexperimental runs are obtained by using array in designing. Choosing the control factors with levels is the most important aspect. Further analysis establishes the optimal condition affecting the process. The most appropriate condition may be identified by analyzing the behavior of the process parameters.

2.3 Methodology

L_9 orthogonal range(array) was utilizedfor the experimentationbasing upon Taguchi's method involving the following major steps:

1. Orthogonal range (array) was chosen depending upon the number of process variables selected and the runs to be performed was determined.
2. Collection of data.
3. Data analysis and interpretation to discover the effect of significant procedurefactors.

2.4 Signal -to-noise proportion

The raw data review and the S / N data analysis is conducted in the present inquiry. The results of the chosen WEDM method parameters on the output characteristics identified were explored via raw data dependent key effect plots. The optimum state of each of the output characteristics was defined by the analysis of S/N data aided by the raw data analysis. No outside collection was used, and tests at each laboratory site were replicated three times instead. As mentioned earlier, the S / N ratio is a concomitant statistic.A concurrent calculation takes into consideration two characteristics of a system, and folds these characteristics into a single amount or merit measure. The S / N ratio integrates in a single variable all the parameters (the standard degree of output characteristics and the variation around these standard). A large S/N value means that the signal is substantially stronger than the natural impact of noise factors. With minimum variance, plant procedure associated with the maximum S / N still achieves optimum efficiency. The S / N ratio consolidates several repetitions (which involve at least two data points) into one number. The equation for measuring smaller S/N ratios is better (LB), greater is better (HB) and optimal (NB) feature forms are as follows. The calculations are shown in Table 2.

Table 2: S/N ratio calculation

1	Larger the Better	"$(S/N)_{HB}$ = -10 log (MSD_{HB}) Where, $MSD_{HB} = \frac{1}{R}\sum_{j=1}^{R}(1/y_j^2)$"
2	Smaller the Better	"$(S/N)_{LB}$ = -10 log (MSD_{LB}) Where, $MSD_{LB} = \frac{1}{R}\sum_{j=1}^{R}(y_j^2)$"
3	Nominal the Best	"$(S/N)_{NB}$ = -10 log (MSD_{NB}) Where, $MSD_{NB} = \frac{1}{R}\sum_{j=1}^{R}(y_j - y_0)^2$" Where R = Repetitions.

Table 3 shows the coded inputs for the Taguchi design of experiments in three levels.

Table 3: Coded inputs used for the experiments

Gap Voltage	Sensitivity	Ton	Toff
1	1	1	1
1	2	2	2
1	3	3	3
2	1	2	3
2	2	3	1
2	3	1	2
3	1	3	2
3	2	1	3
3	3	2	1

3. Results and Considerations

3.1 "Analysis for material removal rate"

The analysis was done using MINITAB 17 software. Minitab provides the static response for fixed level of feature characteristics under the test. The best set of procedurefactors provides a robust design by controlling the noise factors. Figure 3 and Figure 4 show the keyresult plot for means and "signal to noise proportion" used to obtain the optimized set of procedure variables.The objective of the study is to obtain "maximum material removal rate". MRR being. Theupperthe-better type of feature characteristic, the S/N proportion is calculated. The raw information and S/N proportion for "material removal rate" is givenThe MRR ("material removal rate") was intended by the following way-:

MRR is expressed as:

$$MRR = \frac{W_i - W_f}{\rho_w \times t} \text{ mm}^3/\text{min}$$

Where,

W_i= Initial mass of the work-piece.

W_f = Final mass of the work-piece.

ρ_w = "Density" of the work-piece.

t = "Machining time".

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Then all the values of the three levels including the MRR were input in the MINITAB 17 software illustrated in Table 4.

Table 4: Input table for calculation.

Gap Voltage	Sensitivity	Pulse on Time	Pulse off Time	MRR
1	2	1	1	0.01975
1	5	5	5	0.0396
1	8	9	9	0.0197
5	2	5	9	0.00994
5	5	9	1	0.0497
5	8	1	5	0.01996
9	2	9	5	0.00907
9	5	1	9	0.00906
9	8	5	1	0.03947

Table 5: Output table for S/N proportion and mean

Run	Gap Voltage	Sensitivity	Pulse on Time	Pulse off Time	MRR/min	S/N Ratio	Mean
1	1	2	1	1	0.01975	-34.0887	0.01975
2	1	5	5	5	0.0396	-28.0461	0.03960
3	1	8	9	9	0.0197	-34.1107	0.01970
4	5	2	5	9	0.00994	-40.0523	0.00994
5	5	5	9	1	0.0497	-26.0729	0.04970
6	5	8	1	5	0.01996	-33.9968	0.02996
7	9	2	9	5	0.00907	-40.8489	0.00907
8	9	5	1	9	0.00906	-40.8574	0.0096
9	9	8	5	1	0.03947	-28.0747	0.03947

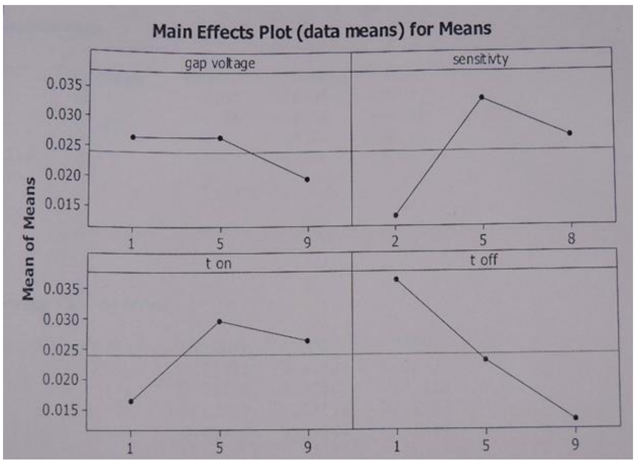

Figure.3 Main influence plot means of MRR

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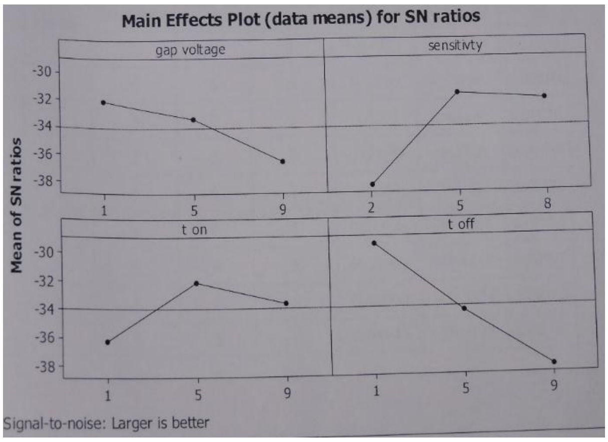

Figure 4. Main influence plot for SN proportion of "MRR"

It can be easily be detected for the experimental results that "MRR"rises with the rise in sensitivity and pulse on time for a certain duration of time and then reduces. By the rise in break voltage and Toff, The MRR decreases. Table 5 shows the case where the parameters follow larger the better trend. The corresponding values are illustrated in Table 5 and the answer table for means is illustrated in Table 6. Table 7 displays the variation of "MRR" with the process parameters.

Table 5: For larger is better

Level	Gap Voltage	Sensitivity	Ton	Toff
1	-32.08	-38.33	-36.31	-29.41
2	-33.37	-31.66	-32.06	-34.30
3	-36.59	-32.06	-33.68	-38.34
Delta	4.51	6.67	4.26	8.93
Rank	3	2	4	1

Table 6: Response table for Means

Level	Gap Voltage	Sensitivity	Ton	Toff
1	0.02635	0.01292	0.01626	0.03631
2	0.02653	0.03279	0.02967	0.02288
3	0.01920	0.02638	0.02616	0.01290
Delta	0.00733	0.01987	0.01341	0.02341
Rank	4	2	3	1

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4. Conclusion

In the present study, experiments were conducted using various process factorslike "break voltage (Vg), Sensitivity, Pulse off 'time, Pulse on timeand diameter of the tool" for HSS workpiece and copper tool. "L_9 orthogonal array"was utilized and "Taguchi design" was performed. Analysis of the results were done using statistical concepts which were further validated experimentally. The mainconclusions of the present learning are as charts:

The variations in the MRR for the different process parameters were found and it shows that MRR will be maximum if gap voltage will be 5, sensitivity will be 5, pulse off time will be 5 and pulse on time will be 1.

1. "MRR"rises with the rise in sensitivity and beat (pulse) on time for a certain duration of time and then reduces.
2. With the rise in break voltage and Toff, The MRR decreases.
3. The increase in MRR affects the surface texture and produces rough surfaces. The diameter overcut and surface roughness is also observed to be more in the cases where the volume of material removed is more.

Table 7: Table showing maximum MRR values for respective process parameters

Parameter	Value
Gap Voltage	5
Sensitivity	5
Ton	5
Toff	1

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