SIMULTANEOUS OPTIMIZATION OF MULTIPLE QUALITY CHARACTERISTICS IN WIRE EDM

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ABSTRACT

In this experiment work MRR(material removal rate & SR (surface roughness) are considered as basic quality characteristics output(O/P) and four parameters such as Gap Voltage, Wire feed rate, Gap Current & Pulse are considered as input(I/P) parameter. Here Taguchi method along with relative weight technique is applied simultaneously for all four parameters to get maximum Material removal rate (MRR) and minimum Surface roughness (S_R). In this technique quality loss of each quality characteristics is converted in to normalized quality loss. Total normalized quality loss and multiple signal to noise (S/N) ratio is then calculated to give optimal parameter setting i.e., gap voltage, wire feed rate, gap current & pulse(duty factor) to get maximum material removal rate and minimum surface roughness

KEYWORDS: Output (O/P), Material Removal Rate (MRR), Input (I/P)

There is a general tendency of removal of small material from electrodes if electrical sparking occurred between them. In wire cut electrical discharge machining (WEDM) the cost of machining is rather high due to its initial investment for the machine and the cost of wire which is used as tool in this machine also. Generally this process is economical for complex job and difficult to machine a material in other process.eg. Manufacturing of press dies moulds & special form of inserts

Generally parameters like spark gap, cutting width, gap current ,duty factor(pulse rate) have great influence to yield different combination of quality characteristics such as material removal rate(MRR) & S_R(surface roughness) etc. But to achieve both higher material removal & better surface finish is extremely difficult in WEDM by using particular set of parameter combination. Hence it can be considered as multi-objective optimization problem .

To optimize process parameters, classical arrays have been developed by Sir Roland Fisher in 1920. The practical difficulty with classical approach is that they were too much costly and time consuming and also do not guarantee to give optimal results. Ginichi Taguchi suggest a special technique in response to need to obtain scientific information when almost no funding was available to conduct large experiments .Taguchi made a major contribution by introduction a “Noise” in the factorial experiments.

Taguchi method is designed to handle the optimization of single performance characteristics (i.e., either MRR or S_R) & for optimization of multiple performance characteristic ,this method encounter with several problem . Therefore loss associated with each characteristic can’t be added directly. So to optimize both the quality characteristics simultaneously, Taguchi method is coupled with various technique like fuzzy logic, gray relational analysis, ANN (Artificial neural network) etc.

In this experimental work relative weight technique is proposed. In this technique quality loss of each

Quality characteristic is converted into normalized quality loss. Total quality loss and multiple signal to noises(S/N) ratio is then calculated to give optimal parametric setting. In this experimental work MRR and S_R are selected as basic quality characteristics as out put and four parameters such as Gap- voltage, Wire feed rate, Gap current and Pulse are considered as input. The results of the experimental work give the optimum parametric setting for EDM process by combining Taguchi and relative weight technique.

EDM PRINCIPLE

Electrical discharge machining is a thermo electric process and it removes material from the work piece by erosion process.EDM produce heat that melts and vaporize the electrically conductive work piece material immersed in a dielectric fluid e.g., Hydrocarbon (deionised water) or mineral oil (kerosine). A wire about 0.05-0.30 mm diameter is used as an electrode .Here straight polarities normally used i.e. tool is -ve and work piece is positive.

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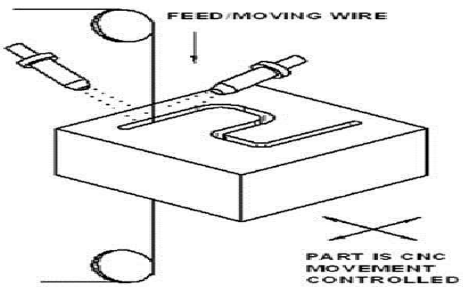

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WHAT ARE TAGUCHI METHODS

Taguchi methods are special techniques

1. Which flows on design and controls the factors affecting the quality of production and improve it?
2. To develop superior design of both product as well as manufacturing process.
3. Which leads to excellence in the selection and setting of product/process design parameters?
4. Which reveals systematically the complex cause-effect relationship between design parameters and performance which affect quality

QUALITY AND THE LOSS FUNCTION

According to Taguchi, a product does not cause a loss only when it is outside specification but whenever it deviates from its target value. The smaller the performance variation , the better the quality. The larger the performance variation, the better the quality. This loss can be approximately evaluated by Taguchi loss function, which unites the financial loss with the function specification through a quadratic relationship.

IMPORTANCE OF ADDITIVES

The product performance 'Y' depends on several different influencing parameters P, Q,R,S etc. The additive model has the form

$Y = M_I + P_i + Q_j + R_k + S_l + E$, where MI is the mean value of Y in the region of experiment, Pi,Qj etc are the individual or main effects of the influencing factor P Q and E is an effort term

The additivity assumption also implies effects of the factors P, Q, R etc on performance Y are separable . Under this assumption the effect of each factor can be linear, quadratic or of higher order, but the additive model assumes that there exist no cross product effect (interaction) among individual factors. The presence of additivity also simplifies the analysis of experimental data. Additivity of effects also leads to major reduction in the number of experiments that need to be run. When the additivity assumption holds, it is possible to estimate the main factor effects using a single set of experiments based on orthogonal design. The experiment guided by an orthogonal array may not use all column but it must use every row of the array . The number of rows in an orthogonal array determines the total number of experiments to be run in the investigation.

SELECTION OF ORTHOGONAL ARRAYS

Selection of orthogonal array depends on

1. Number of factors selected
2. Number of levels selected

In the present case, there are four control factors each at three levels and no noise factors are taken into consideration. Hence selection of orthogonal array is taken from the standard orthogonal set. The L9 orthogonal array is selected to fit the four control factor with their three levels.

The S/N ratio is a predictor of quality loss that isolates the sensitivity of the products function to noise factors. In robust design one minimizes this sensitivity to noise by seeking combinations of the design parameter settings that maximize the S/N ratio. Further use of the S/N ratio attains robustness independent of target

There are three standard types of SN ratios depending on the desired performance response (Phadke,1989):

- Smaller the better (for making the system response as small as possible):

$$SN_S = -10 \log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right)$$

- Nominal the best (for reducing variability around a target):

$$SN_T = 10 \log\left(\frac{y^{-2}}{S^2}\right)$$

- Larger the better (for making the system response as large as possible):

$$SN_L = -\log 10\left(\frac{1}{n}\sum_{i=1}^{n} \frac{1}{y_i^2}\right)$$

These SN ratios are derived from the quadratic loss function and are expressed in a decibel scale. Once all of the SN ratios have been computed for each run of an experiment, Taguchi advocates a graphical approach to analyze the data. In the graphical approach, the SN ratios and average responses are plotted for each factor against each of its levels.

SELECTION OF OPTIMIZATION PROCESS

1. Identify Facors For Experiment :Identify different factors and their levels by brainstorming method categorizing them into signal factor, control factor, noise factor
2. Selection Of Quality Characteristics: It is advisable that it start an engineering or economic goal(objective); then identify the basic mechanism and physical laws affecting it and then choose the appropriate quality characteristics.
3. Computation Of Normalized Quality Loss:As each quality characteristics has different units of measurement, it is important to normalized the quality loss which can be given b

$Y_{ij} = L_{ij} / L_i$ & $(0 < Y_{ij} <1)$
Where Y_{ij} = Normalized quality loss
L_{ij} =Q loss for ith quality characteristics at j^{th} trial /run

4. Computation Of Total Normalized Quality Loss: A weighting factor(W) is assigned to each quality characteristics which are to be optimized. It Yij is the loss function associated with ith quality characteristics at jth trial condition ;K is the number of quality characteristics, then total normalized quality loss can be computed as:

$$Y_j = \sum_i^K WiYij$$

5. Determination Of Significant Factor/ Interraction Effects Optimal Setting:
   In order to identify the significant factor or interaction effects; the use of analysis of varience (ANOVA) is recommended. ANOVA is powerful tool to separate the total variability of multiple S/N ratio into the contribution made by each of the factors and error term
6. Perform Confirmation Trial Or Experiment: Predicted and actually observed S/N ratios are compared separately. If they are close enough, interaction effects are assumed to be negligible but if there is a large difference further experimentation is needed to verify the presence of interaction effects.

By this process of multi-criteria optimization, we can simultaneously optimize different quality characteristics.

EXPERIMENTATION DETAIL

AGIE CUT 220 CNC WIRE CUT EDM manufacturer AGIE of Switzerland is used for experimentation with high carbon die steel as work piece material. The hardness of work piece material was measured on Rockwell hardness tester and found to be 60 HRC

1) Technical Specification Of Surface Roughness Measuring Instrument:
   Make: Taylor Harbson Pression
   Least count = 0.02 Ra
2) Technical Specification Of Height Gauge:
   Micro hite
   Tesa Swiss made
   Least count = 1μ
3) Work Piece Material:
   High chromium high carbon dies steel: T21 5Cr 12
   C =2-2.30%
   Si =0.10-0.35%Mn =0.25-0.50%
   Cr =11.0-13.0%
   Mo = 0.80 Maximum
   V = 0.80 Maximum
3 Dielectric Fluid:
   Distilled water with Ph balance 7.0 is used as dielectric fluid
4) Wire Material: Wire electrode material is brass with tensile strength more than 45 Kgf per mm^2
5) Control Facors:

I. Gap Voltage(V): Gap voltage is measured directly by voltmeter in build in machine

II. Wire feed rate(W):Wire feed rate is measured by the relation

$W = \Pi DN/ 1000$

Where , W =Wire feed

D = Diameter of wire

N =Wire drum speed

III. Gap current (I):It is measured directly by ammeter attached with machine

IV. Duty factor(D): It is the ratio of pulse on time (T_{on}) and pulse off time (T_{off})

Duty factor = T_{on}/ T_{off}

6) Selection Of Optimization Process:

In this experiment relative weight based Taguchi method is used for achieving multi-objective optimization of EDM.

SELECTION OF LEVEL OF FACTORS

1) Gap Voltage Level (1) =30 V

Level (2) = 35 V

Level (3) =40 V

2) Wire feed Level (1) =90 mt/ min

Level (2) = 100 mt/min

Level (3) =120 mt/min

3) Gap current Level (1) = 8 amp

Level (2) =10 amp

Level (3) 12 amp

4) Duty factor Level (1) = 7

Level (2) =5

Level (3) = 3

Table 1: Obsevation For MRR By Using Orthogonal Array

Expt No	Voltage (V)	Feed (W)	Current (I)	Duty Factor (D)	Width of Cut (mm)	Machining Time (Min)	Cutting Speed (mm/Min)	MRR Mm3/ Min
1	V1	W1	I1	D1	10.99	10 min45sec=10.75	1.022	7.154
2	V1	W2	I2	D2	11.042	11min.25sec =11.41	0.967	6.769
3	V1	W3	I3	D3	11.025	10min.47sec=10.78	1.022	7.154
4	V2	W1	I2	D3	11.033	10min.43sec=10.72	1.029	7.203
5	V2	W2	I3	D1	11.024	11min.20sec=11.33	0.972	6.804
6	V2	W3	I1	D2	11.025	13min.05sec=13.08	0.842	5.894
7	V3	W1	I3	D2	11.031	12min.30sec=12.5	0.882	6.174
8	V3	W2	I1	D3	11.020	10min.45sec=10.75	1.025	7.175
9	V3	W3	I2	D1	11.025	11min.22sec=11.36	0.970	6.79

Standard value for spark gap and wire diameter is taken as 0.05 mm and 0.25 mm respectively

The width of cut can be calculated from the relation

$$b = 2Wg + d$$

Where' Wg' is spark gap, 'd' is diameter of wire and 'b' is width of cut

$$b = 2(0.05) + 0.25 = 0.35 \text{ mm}$$

The material removal rate (Volumetric) can be calculated by equation

MRR(Volumetric) $= V_C \times b \times h$

For Experiment No 1

MRR1 = 1.022 x 0.35 x 20

The remaining value can be obtained by using the same equation on above table-1

Table 2: Oputation Of Normalised And Total Normalized Quality Loss For MRR

Trial No	MRR Yi	Loss function $L_{ij} = \frac{1}{Y_i^2}$	Normalized quality Loss ,Yij $= \frac{L_{ij}}{L_I}$	Total Normalized quality loss $,Y_{ij}$
1	7.154	0.0195	0.6794	0.6794
2	6.769	0.0218	0.7595	0.7595
3	7.154	0.0195	0.6794	0.6794
4	7.203	0.0192	0.6689	0.6689
5	6.804	0.0216	0.7526	0.7526
6	5.894	0.0287*	1.0000	1.0000
7	6.174	0.0262	0.9128	0.9128
8	7.175	0.0194	0.6759	0.6759
9	6.79	0.0216	0.7526	0.7526

Total Normalized Quality Loss for MRR can be computed using

$$Y_j = \sum W_i Y_{ij}$$

Where Wi = Weighting factor for first quality characteristics (MRR)

Wi = assumed i.e. equal weightage

Table 3: Total Normalized Quality Loss For 2nd Quality

Expt No	Voltage (V)	Feed (W)	Current (I)	Duty Factor (D)	Surface roughness (Ra)
1	V1	W1	I1	D1	2.56
2	V1	W2	I2	D2	2.58
3	V1	W3	I3	D3	2.60
4	V2	W1	I2	D3	2.84
5	V2	W2	I3	D1	3.10
6	V2	W3	I1	D2	2.54
7	V3	W1	I3	D2	2.96
8	V3	W2	I1	D3	2.46
9	V3	W3	I2	D1	2.28

Total Normalized Quality Loss for S_R can be similarly computed using

$$Y_I = \sum W_i Y_{ij}$$

Here also W_i i.e. Weighting factor for second quality characteristic is assumed to be one giving equal weightage to every quality characteristics.

Toytal Normalized Quality loss for both MRR and S_R can be simply calculated by adding them together.

(Y_{ij}) MRR + (Y_{IJ}) S_R = Y Total

(Y_{ij}) MRR + (Y_{IJ}) S_R = Total Normalized quality Loss (Y)

Table 4: Computation Of Normalized And Total Normalized Quality Loss For Surface Roughness

Trial NO	SR (Y_i)	Loss function $L_{ij} = Y_i^2$	Normalized Quality Loss $Y_{ij} = \frac{L_{ij}}{L_i}$	Total Normalized Quality Loss Y_{ij}
1	2.56	6.5536	0.6819	0.6819
2	2.58	6.6564	0.6926	0.6926
3	2.60	6.7600	0.7034	0.7036
4	2.84	8.0658	0.8393	0.8393
5	3.10	9.6100*	1.0000	1.0000
6	2.54	6.4516	0.6713	0.6713
7	2.96	8.7616	0.9117	0.9117
8	2.46	6.0516	0.6297	0.6297
9	2.28	5.1984	0.5409	0.5409

Table 5:

0.6794	+	0.6819	=	1.3613
0.7595	+	0.6926	=	1.4521
0.6794	+	0.7036	=	1.3828
0.6689	+	0.8393	=	1.5082
0.7526	+	1.0000	=	1.7526
1.0000	+	0.6713	=	1.6713
0.9128	+	0.9117	=	1.8245
0.6759	+	0.6297	=	1.3056
0.7526	+	0.5409	=	1.2936

Table 6: Cobined S/N Ratio For MRR & S_R

Expt No	Voltage (V)	Feed (W)	Current (I)	Duty Factor (D)	Total	Nj (Multiple S/N Ratio) -10 log (Yij)	
1	V1	W1	I1	D1	1.3613	-1.3395	V1 = - 4.3669
2	V1	W2	I2	D2	1.4521	-1.6199	V2 = - 6.4518
3	V1	W3	I3	D3	1.3828	-1.4075	V3 = - 4.8875
4	V2	W1	I2	D3	1.5082	-1.7845	W1 = - 5.7354
5	V2	W2	I3	D1	1.7526	-2.4368	W2 = - 5.2148
6	V2	W3	I1	D2	1.6713	-2.2305	W3 = - 4.756
7	V3	W1	I3	D2	1.8245	-2.6114	I1 = - 4.7281
8	V3	W2	I1	D3	1.3056	-1.1581	I2 = - 4.5224
9	V3	W3	I2	D1	1.2936	-1.1180	I1 = - 6.4557
							D1 = - 4.8943
							D2 = - 6.4618
							D3 = - 4.3581

Table 7: Calculation For Average S/N Ratio By Factor Level For MRR

Expt. No	Voltage (V)	Feed (W)	Current (I)	Duty Factor (D)	Total	Nj (Multiple S/N Ratio) -10 log (Yij)	
1	V1	W1	I1	D1	7.154	17.0909	V1 = 16.9307
2	V1	W2	I2	D2	6.769	16.6104	V2 = 16.4045
3	V1	W3	I3	D3	7.154	17.0909	V3 = 16.5216
4	V2	W1	I2	D3	7.203	17.1502	W1 = 16.684
5	V2	W2	I3	D1	6.804	16.6552	W2 = 16.794
6	V2	W3	I1	D2	5.894	15.4082	W3 = 16.3788
7	V3	W1	I3	D2	6.174	15.8113	I1 = 16.5385
8	V3	W2	I1	D3	7.175	17.1164	I2 = 16.7993
9	V3	W3	I2	D1	6.79	16.6373	I1 = 16.5191
							D1 = 16.7944
							D2 = 15.9433
							D3 = - 17.1191

Optimum level for maximum MRR = V1-W2-I2-D3

NOTE: The Level of V, W, I & D Corresponding to Maximum (S/N) Ratio Is Cosideredas Optimum for the Factor

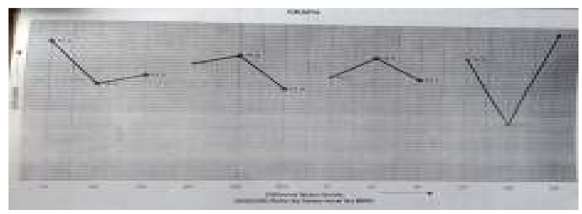


Table 8: Calculation For Average S/N Ratio By Factor Level For S_R

Expt. No	Voltage (V)	Feed (W)	Current (I)	Duty Factor (D)	Total S_R	(S/N) S_R = - 10 $\log_{10}(Y^2)$	AVG(S/N)
1	V1	W1	I1	D1	2.56	- 8.1647	V1 = - 8.2321
2	V1	W2	I2	D2	2.58	- 8.2323	V2 = - 8.9967
3	V1	W3	I3	D3	2.60	- 8.2994	V3 = - 8.1343
4	V2	W1	I2	D3	2.84	- 9.0663	W1 = - 8.8856
5	V2	W2	I3	D1	3.10	- 9.8272	W2 = -8.6260
6	V2	W3	I1	D2	2.54	- 8.0966	W3 = -7.8515
7	V3	W1	I3	D2	2.96	- 9.4258	I1 = - 8.0266
8	V3	W2	I1	D3	2.46	- 7.8187	I2 = - 8.1524
9	V3	W3	I2	D1	2.28	- 7.1586	I1 = - 9.1841
							D1 = - 8.3835
							D2 = - 8.5849
							D3 = - 8.3948

Optimum level for minimum S_R = V2-W1-I3-D2

NOTE: The level of V, W, I & D corresponding to maximum (S/N) ratio is considered as optimum for the factor

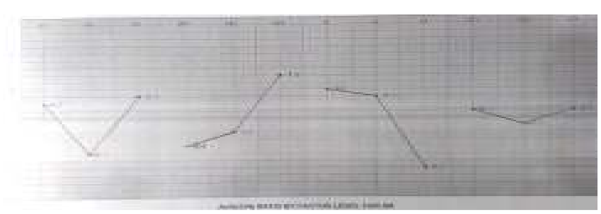


Table 9:

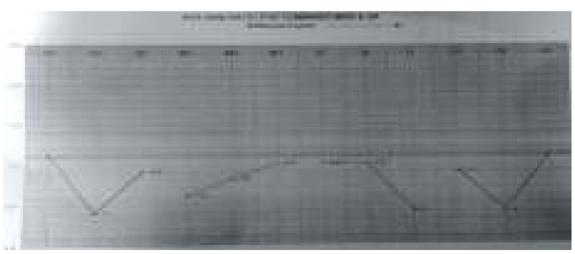
Expt. No	Voltage (V)	Feed (W)	Current (I)	Duty Factor (D)	Nj (Multiple S/N Ratio)	AVG Multiple (S/N)
1	V1	W1	I1	D1	- 1.3395	V1 = - 1.4556
2	V1	W2	I2	D2	- 1.6199	V2 = - 2.1506
3	V1	W3	I3	D3	- 1.4075	V3 = - 1.6291
4	V2	W1	I2	D3	- 1.7845	W1 = - 1.9118
5	V2	W2	I3	D1	- 2.4368	W2 = - 1.7382
6	V2	W3	I1	D2	- 2.2305	W3 = - 1.5853
7	V3	W1	I3	D2	- 2.6114	I1 = - 1.5760
8	V3	W2	I1	D3	- 1.1581	I2 = - 1.5074
9	V3	W3	I2	D1	- 1.1180	I1 = - 2.1519
						D1 = - 1.6314
						D2 = - 2.1539
						D3 = - 1.4500

Optimum factor level for MRR and minimum

S_R = V1 –W3-I2-D3

It is observed that by using optimum process characteristic values such as V1 = 30, W3 = 120, I2 = 10 AND D3 = 3,

The MRR will increase and S_R value will decrease in the experiment as shown below.



Optimised Value

Voltage (V)	Feed (W)	Current (I)	Pulse (D)	Width of cut (mm)	Machining Time(Min)	Cutting speed (V_C)	MRR (mm^3/min)	S_R
30	120	10	3	11.6	9 Min.45 sec = 9.75 min	1.2114	8.4799	0.78

CONCLUSION

Taguchi method can optimize only one quality characteristics hence it is supplemented with relative weight technique to simultaneously optimized MRR & S_R

Optimum level for getting maximum MRR was found to be V1-W2-I2-D3 and optimum level for getting minimum surface roughness was found to be V2-W1-I3-D2 but for getting higher MRR and lower SR simultaneously parametric setting suggested is V1-W3-I2-D3.

Apart from relative weight technique average method used in this experiment various other technique like Fussy logic, Artificial Neural Network(ANN) Grey Relational Analysis etc. also can be supplemented with conventional Taguchi method to achieve multi-criteria optimization.

REFERENCES

International Journal of Modern Engineers Research (IJMER) May-June 2013, **3**:1645-1648.

International Journal of Advance Trends in computer Science & Engineering. (2013) special Issue of ICETEM 2013- HELD ON 29-30 November 2013 in Sree Visvesvaraya Institute of Technology and science, Mahabubnagar-204, AP, India, **2**(6):12-17.

Mapatra S.S. and Patnaik A., 2007. Optimization of wire electrical discharge machining (WEDM) Process parameter using Taguchi method", The International Journal of Advanced Manufacturing Technology 34/9-10911-925.

Konda R., Rajurkar K.P., Busu R.R., Guha A. and Parson M., 1999. "Design of experiments to study and Optimize process Performance, International Journal of quality and reliability management, **16**:56-71.

Tosun N., Cogun C. and Tosun G., 2004. "A study of kerf and material. Removal rate in wire electrical discharge machining based on Taguchi method", Journal of material processing Technology, **152**:316-322.