Application of Taguchi Grey Relational Analysis to optimize the process parameters in wire electrical discharge machine.

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Abstract

In this report the effect of Process parameters on material removal rate(MRR) and surface roughness of HCHCR-D2(high carbon high chromium steel) die steel are investigated as MRR and Surface roughness in W-EDM(wire electrical discharge machining) are of crucial importance and Taguchi L9 orthogonal array and Grey Relational Analysis techniques are used for optimization of parameters. For experimentation Pulse on time (Ton), Pulse off time (Toff), Peak current (Ip), and wire feed rate(Wf) are taken as input parameters while MRR and Surface roughness are taken as output parameters. For each experiment Surafce roughness is calculated by using Surface finish tester and MRR is calculated by measuring the difference in weight of workpiece before and after machining with time required for machining.

Keywords: *Wire electrical discharge machining, HCHCR-D2 Material, Taguchi Grey Relational analysis technique..*

1. Introduction

1.1 Wire Electrical Discharge Machining Process:

Wire Electrical Discharge Machining (W-EDM) is widely used manufacturing process used to machine conductive materials due to its capability of producing intricate and complex shapes irrespective of hardness and toughness of material. It can produce more complex two and three dimensional shapes through conducting materials This process is extensively used in mould and die making industries, nuclear industry, aerospace industry etc. . In WEDM (wire electrical discharge machining) material removal takes place due to electro thermal process. A series of electrical pulses generated by pulse generator unit is applied between the work piece and travelling wire electrode which generate series of discrete sparks between the electrode and work piece. While the machining is continued, the machining zone is continuously flushed with water passing through the nozzles on both sides of the work piece.

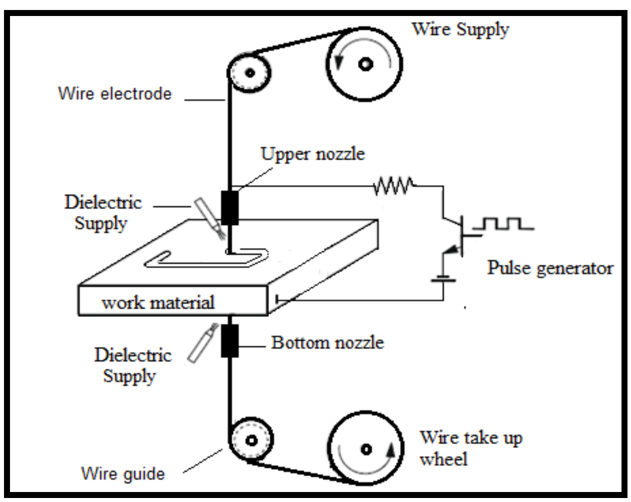

Fig 1.1: Schematic Representation of WEDM process

2. Problem Definition:

In CNC Wire electrical discharge machine, Process parameters like pulse on time(Ton), pulse off time(Toff), Input Current(Ip), wire feed rate(Wf) play an important role as it affects the MRR (material removal rate) and Surface roughness. Most of the times this machines are operated by workers; If process parameters are not set properly then it results in low MRR as well as Surface finish. If at some point amount of stock removed from the electrode becomes greater than the amount being removed from the work piece, the wire electrode breaks and discharge is stopped.The overall objective is to produce high quality product at low cost to the manufacturer.Optimization is a process that finds a best, or optimal, solution for a problem of process parameters is the best way to solve this problem. Taguchi L9 Orthogonal array and Grey Relational analysis used to set optimal set of parameters.

3. Methodology:

3.1 Design of Experiment:

The design of experiments (or experimental design) is the design of any task that aims to describe or explain the variation of information under conditions that are hypothesized to reflect the variation. The term is generally associated with true experiments in which the design introduces conditions that directly affect the variation, but may also refer to the design of quasi-experiments, in which natural conditions that influence the variation are selected for observation.

3.2 Work piece Material:

The work piece material is HCHCR-D2 (high carbon high chromium steel) with dimension (Diameter 40mm, Thickness 26mm, weight 230gm) is used for experimentation. The Brass wire with diameter 0.25mm is used as electrode. Pure distilled water is used as dielectric medium. Fig. 4.2 shows actual working zone of WEDM and Table 4.1 shows the Percentage of Composition of HCHCR-D2.

Table 3.1: Percentage of Composition of HCHCR-D2 (Wt %)

C	Mn	Cr	Si
2	0.2-0.35	12	0.2-0.35

Fig.3.1: Work piece

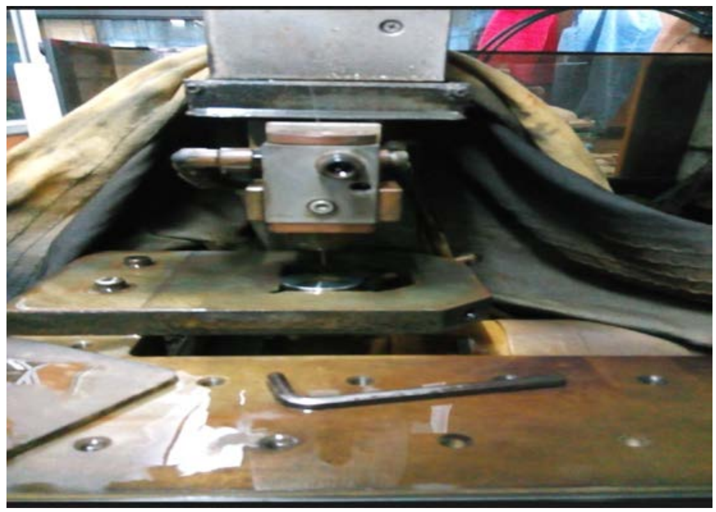

Fig.3.2: Working zone of Wire electrical discharge machining

3.3 ELECTRA Wire Cut Electric Discharge Machine:

ELECTRA Wire Cut Electric Discharge Machine (Manufactured by Electronica Machines Tools Ltd) is used in this investigation. Once wire is wound on the wire drum, that particular amount of wire is used for all experiments of each material and it has been replaced once the material is changed. Work material is tightly clamped on working table with the help of suitable fixture so as to avoid any relative motion between the work piece and electrode.

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Constant dielectric flow is ensured during the experimentation.Fig.3 shows the CNC WEDM machine used for experimentation.

Fig 3.3: Wire-EDM Machine

4. Case Study:

In experimental study 8mm hole is created in the work piece with brass wire. MRR (material removal rate) is calculated by measuring the difference in weight of work piece before and after machining and time required to create a through hole. Surface roughness (Ra) is calculated by MITUTOYO Surface Tester Master.

4.1 Taguchi L9 Orthogonal Array:

Table 5.1 shows process parameters with their level for this experiment. The Taguchi method involves reducing the variation in a process through robust design of experiments. The overall objective of the method is to produce high quality product at low cost to the manufacturer.

Table 4.1: Process parameters with their levels.

Sr. No	Process Parameters	Unit	Level 1	Level 2	Level 3
1	Pulse on time(Ton)	µs	127	128	129
2	Pulse off time(Toff)	µs	45	46	47
3	Input current(Ip)	A	210	220	230
4	Wire feed(Wf)	m/min	3	4	5

Taguchi Proposed to acquire the characteristics data by using orthogonal arrays, and to analyse the performance measure from data to decide the optimal process parameters. The designed matrix of input parameters with output parameters such as MRR (material removal rate) and Surface roughness (Ra) for HCHCR-D2 (High carbon high chromium steel) shown in table 5.4. Selection of a particular OA is based on the number of levels of various factors. Here, Number of levels (L)=3 and No of factors(f)=4 therefore Degree of Freedom (DOF) can be calculated by using Eq. as DOF = f x (L-1) =8,the orthogonal array should be equal to or greater than DOF,here 9>8 hence L9. Each machining parameter is assigned to a column of OA and 9 machining parameter combinations are designed.

Table 4.2: Designed matrix of input and output parameters

Trial No	Ton	Toff	Ip	Wf	MRR (gm/min)	Ra(**µm**)
1	127	45	210	3	0.66	1.9
2	127	46	220	4	0.92	2.1
3	127	47	230	5	1	2.7
4	128	45	220	5	0.66	1.8
5	128	46	230	3	1.06	1.9
6	128	47	210	4	0.82	1.3
7	129	45	230	4	1.12	1.4
8	129	46	210	5	0.82	1.8
9	129	47	220	3	1.12	1.5

4.2 Grey relational Analysis:

The grey analysis was first proposed many decades ago but has been extensively applied only on the last decade. Grey analysis has been broadly applied in optimizing the performances involving multiple responses.

The multi-objective problem can be converted into single objective optimization using GRA technique.

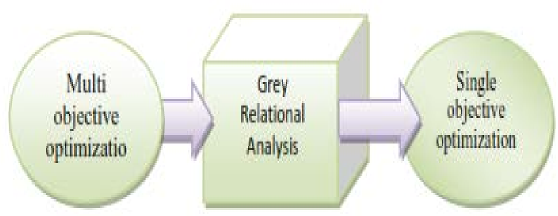

Fig. 4.1: purpose of grey relational analysis

In Grey relational analysis, experimental data i.e., measured features of quality characteristics are first normalized ranging from zero to one. This process is known as Grey relational generation. Next, based on normalized experimental data, Grey relational coefficient is calculated to represent the correlation between the desired and actual experimental data. Then overall Grey relational grade is determined by averaging the Grey relational coefficient corresponding to selected responses. The overall performance characteristic of the multiple response process depends on the calculated Grey relational grade. This approach converts a multiple response process optimization problem into a single response optimization situation with the objective function is higher Grey relational grade. The optimal parametric combination is then evaluated which would result highest Grey relational grade.

4.2.1 Steps in GRA

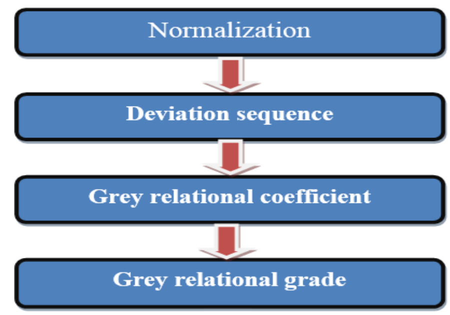

Fig. 4.2: Steps in GRA

(a) Normalization:

It is the first step in the grey relational analysis; a normalization of the S/N ratio is performed to prepare raw data for the analysis where the original sequence is transferred to a comparable sequence. Linear normalization is usually required since the range and unit in one data sequence may differ from the others. A linear normalization of the S/N ratio in the range between zero and unity is also called as the grey relational generation. Further analysis is carried out based on these S/N ratio values. When the range of the series is too large or the optimal value of a quality characteristic is too enormous, it will cause the influence of some factors to be ignored. The original experimental data must be normalized to eliminate such effect. There are three different types of data normalization according to whether we require the LB (lower-the-better), the HB (higher-the-better) and NB (nominal-the-best). The normalization is taken by the following equations.

(a) HB (higher-the-better)

$$x_i(k) = \frac{y_i - min\ y_i\ (k)}{max\ y_i(k) - min\ y_i\ (k)}$$ ……..…………………… ……………………… (4.1)

(b) LB (lower-the-better)

$$x_i(k) = \frac{max\ y_i(k) - y_i\ (k)}{max\ y_i(k) - min\ y_i\ (k)}$$ …………….... ………………………………… (4.2)

(c) NB (nominal-the-best)

$$X_i^*\ (k) = \frac{y_i\ (k) - y_i}{max\ y_i(k) - y_i\ (k)}$$ ……………………………… …………….……… (4.3)

Here, i= 1, 2… m; k=1, 2… n

Where $x_i(k)$ is the value after the grey relational generation, min $y_i(k)$ is the smallest value of $y_i(k)$ for the k^{th} response, and max $y_i(k)$ is the largest value of $y_i(k)$ for the k^{th} response. An ideal sequence is $x_0(k)$ for the responses. The purpose of grey relational grade is to reveal the degrees of relation between the sequences say, [$x_0(k)$ *and* $x_i(k)$, i = 1, 2,3.......,9].

(b) Determination of deviation sequences, Δ_{0i}

The deviation sequence Δ_{0i} is the absolute the reference sequence x_0 (k) and the comparability sequence x_i (k) after normalization. It is determined using

$$\Delta_{0i} = |x_0\ (k) - x_i\ (k)|$$ …………………………………………….……… (4.4)

(c) Calculation of grey relational coefficient (GRC)

GRC for all the sequences expresses the relationship between the ideal (best) and actual normalized S/N ratio. If the two sequences agree at all points, then their grey relational coefficient is 1.

$$\xi_i(k) = \frac{\Delta_{min} + \theta\ \Delta_{max}}{\Delta_{0i}(k) + \theta\ \Delta_{max}}$$ ………………………………… ……………….……… (4.5)

Where, $\Delta_{0i} = \|x_o(k) - x_i(k)\| =$ difference of the absolute value $x_o(k)\ and\ x_i(k)$; θ is the distinguishing coefficient $0 \leq \theta \leq$ 1; $\Delta_{min} = \forall j^{min} \in i \forall k^{min} \|x_o(k) - x_j(k)\|$ = the smallest value of Δ_{0i} ; and Δ_{max} = $\forall j^{max} \in i \forall k^{max} \|x_o(k) - x_j(k)\|$ = largest value of Δ_{0i}. Comparability sequence and ζ is the distinguishing coefficient. The value of θ can be adjusted with the systematic actual need and defined in the range between 0 and 1, $\theta \in [0, 1]$. It will be 0.5 generally.

(d) Determination of grey relational grade (GRG):

The overall evaluation of the multiple performance characteristics is based on the grey relational grade. After averaging the grey relational coefficients, the grey relational grade γ_i can be computed as:

$$\gamma_i = \frac{1}{n} \sum_{k=1}^{n} \xi_i(k)$$ …………………………………… …...............……… (4.6)

Where, n = number of process responses.

If the two sequences agree at all points, then their grey relational coefficient is 1 everywhere and therefore, their grey relational grade is equal to 1. In view of this, the relational grade of two comparing sequences can be quantified by the mean value of their grey relational coefficients and the grey relational grade. The grey relational grade also indicates the degree of influence that a comparability sequence could exert over the reference sequence. Therefore, if a particular comparability sequence is more important than the other comparability sequences to the reference sequence, then the grey relational grade for that comparability sequence and reference sequence will be higher than other grey relational grades.

The higher value of grey relational grade corresponds to intense relational degree between the reference sequence $x_0(k)$ and the given sequence x_i (k). The reference sequence $x_0(k)$ represents the best process sequence. Therefore, higher grey relational grade means that the corresponding parameter combination is closer to the optimal.

Based on Taguchi's L9 Orthogonal Array design, the predicted data provided can be transformed into a signal-to-noise (S/N) ratio; based on three criteria. The loss function (L) for objective of HB and LB is defined as follows:

$$L_{HB} = \frac{1}{n}\sum_{i=1}^{n} \frac{1}{y_{MRR}^2} \quad (4.7)$$

$$L_{LB} = \frac{1}{n}\sum_{i=1}^{n} y_{SR}^2 \quad (4.8)$$

Table 4.3 Signal-to-Noise Ratio

Response values		S/N Ratio	
MRR(gm/min)	Ra(μm)	MRR(dB)	Ra(dB)
0.66	1.9	-3.60912	-5.5751
0.92	2.1	-0.72424	-6.4444
1	2.7	0	-8.6273
0.66	1.8	-3.60912	-5.1055
1.06	1.9	0.506117	-5.5751
0.82	1.3	-1.72372	-2.2789
1.12	1.4	0.98436	-2.9226
0.82	1.8	-1.72372	-5.1055
1.12	1.5	0.98436	-3.5218

Table 4.4: Normalization

Trial No	S/N Ratio		Normalized S/N Ratio	
	MRR(db)	Ra(db)	MRR	Ra
1	-3.6091	-5.5751	0	0.51921755
2	-0.7242	-6.4444	0.628037292	0.656151699
3	0	-8.6273	0.785704938	1
4	-3.6091	-5.1055	0	0.4452428
5	0.50612	-5.5751	0.895886568	0.51921755
6	-1.7237	-2.2789	0.410450818	0
7	0.98436	-2.9226	1	0.101394498
8	-1.7237	-5.1055	0.410450818	0.4452428
9	0.98436	-3.5218	1	0.195790518

Table 4.5: Deviation sequence and grey relational coefficient

Trial No	Daviation Sequence		Grey Relational coefficient	
	MRR	Ra	MRR	Ra
1	1	0.48078	0.333333	0.5097971
2	0.372	0.34385	0.573419	0.5925236
3	0.2143	0	0.699991	1
4	1	0.55476	0.333333	0.4740427
5	0.1041	0.48078	0.827659	0.5097971
6	0.5895	1	0.458905	0.3333333
7	0	0.89861	1	0.357499
8	0.5895	0.55476	0.458905	0.4740427

9	0	0.80421	1	0.383374

Table 4.6: Grey relational grade

Expt. No	Process Parameters				Grey Relational Grade
1	127	45	210	3	0.421565192
2	127	46	220	4	0.582971289
3	127	47	230	5	0.84999542
4	128	45	220	5	0.40368804
5	128	46	230	3	0.668728092
6	128	47	210	4	0.396119365
7	129	45	230	4	0.678749476
8	129	46	210	5	0.466474072
9	129	47	220	3	0.691686998

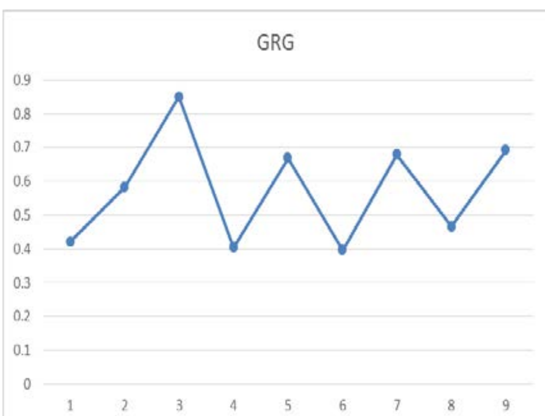

Fig. 4.3: Scatter plot of GRG vs order of experiment.

The mean of the grey relational grade for each level of the machining parameters is summarized and shown in Table 4.7

Table 4.7: The Main Effects of the Factors on the Grey Relational Grade

symbol	Parameter	Grey Relational Grade			Main Effect	Rank
		Level 1	Level 2	Level 3		
A	Ton	0.6182	0.4895	0.6123	0.1287	3
B	Toff	0.5013	0.5727	0.6459	0.1446	2
C	Ip	0.5709	0.5594	0.7325	0.1616	1
D	Wf	0.594	0.5526	0.5734	0.0414	4

The larger the grey relational grade, the better is the multiple performance characteristics. However, the relative importance among the machining parameters for the multiple performance characteristics still needs to be known, so that the optimal combinations of the machining parameter levels can be determined more accurately. Table4.7, the optimal parameter combination was determined as A1(pulse on time)-B3(pulse off time)-C3(Input current)-D1(wire feed rate).

4.2.2 Confirmation Test:

The purpose of the confirmation experiment is to validate the conclusions drawn during the analysis phase. After determining the optimum level of process parameters, a new experiment is designed and conducted with optimum levels of CNC W-EDM parameters obtained.

Table 4.8: Confirmation results

	Predicted	Experimental	Error
MRR(gm/min	0.99	1.06	0.07
Ra(μm)	2.22	2.26	0.04

Confirmatory experiments were performed using the optimum values and it was found that experimental response values were close enough to predicted values.

These values and percentage error between actual and predicted values of the responses are given in table 4.8 The percentage error between the actual and predicted values of the responses falls below 5%, which shows that the optimized value of CNC W-EDM process parameters obtained is good enough for achieving the target set during the experiment. The comparison again shows the good ,

4. Conclusions

Taguchi's L9 orthogonal array and Grey relational analysis were applied to improve the multi response characteristics such as MRR (material removal rate**)** and Surface roughness (Ra)

(a)The optimal parameter combination determined as A1(pulse on time)-B3(pulse off time)-C3(Input current)-D1(wire feed rate),Table 5.5

(b)Input Current(Ip) has maximum influence on both MRR and Surface Roughness.

(c) MRR and Surface Roughness increases with increase in Input Current (Ip).

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