OPTIMIZATION OF PROCESS PARAMETERS OF MACHINING H-11 DIE STEEL IN WIRE EDM

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Abstract— WEDM (Wire Electrical Discharge Machining) is one of the most important machining method with which complex geometries can be machined irrespective to the material hardness and toughness, and capable of producing a fine, precise, corrosion and wear resistant surface.H-11 DIE STEEL material is mostly used in manufacturing of punching tool, mandrels, mechanical press forging die, plastic mould and die casting dies, aircraft landing gears, helicopter rotor blade and shaft. Because of high hardness, toughness and compressive stress of H-11 DIE STEEL, it is difficult to machine by other conventional process, so we use WEDM to machine it. This paper presents a study that investigates the effect of various WEDM process parameters (pulse on and off time, peak current, wire feed rate) on machining quality like MRR and surface roughness of H-11 DIE STEEL, and to obtain optimum set of process parameters by using GRA (Grey Relational Analysis) optimization method.

Keywords— MRR, Surface Roughness, Grey Relational Analysis.

I. INTRODUCTION

Accompanying the development of mechanical industry, the demands for alloy materials having high hardness, toughness and impact resistance are increasing. Nevertheless, such materials are difficult to be machined by traditional machining methods. Hence, non-traditional machining methods including electrochemical machining, ultrasonic machining, electrical discharging machine (EDM) etc. are applied to machine such difficult to machine materials [[1]]. WEDM process with a thin wire as an electrode transforms electrical energy to thermal energy for cutting materials. With this process, alloy steel, conductive ceramics and aerospace materials can be machined irrespective to their hardness and toughness. Furthermore, WEDM is capable of producing a fine, precise, corrosion and wear resistant surface [[2]] as shown in figure 1. WEDM is considered as a unique adoption of the conventional EDM process, which uses an electrode to initialize the sparking process. However, WEDM utilizes a continuously travelling wire electrode made of thin copper, brass or tungsten of diameter 0.05-0.30 mm, which is capable of achieving very small corner radii. The wire is kept in tension using a mechanical tensioning device reducing the tendency of producing inaccurate parts. Water is used as dielectric in WEDM, because of its low viscosity and rapid cooling rate [[4]].

H-11 is special hot-worked chromium tool-steel with good hardness and toughness properties. It has varied practical applications such as manufacturing of punching tools, mandrels, mechanical press forging die, plastic mould and die-casting dies, aircraft landing gears, helicopter rotor blades and shafts. The working life and dimensional accuracy of H-11 steel dies and tools can be improved with suitable heat treatment. The H-11 die steel plate blank has been heated to a temperature of 1025^0C with half an hour soak time followed by quenching in a 500^0C hot salt bath. It is then tempered in three cycles with maximum temperature of 550^0C and 2 hours of soak time to obtain a final hardness of 55 HRC. The chemical composition of this material as obtained by EDAX (Electro Dispersive X-ray Spectroscopy) test is given in Table 1.

Table 1- Chemical composition of H-11 DIE STEEL

Constituent	C	Si	Mn	P	S	Cr	Mo	V
% Composition	0.33	0.53	0.27	0.012	0.027	5.30	1.40	0.53

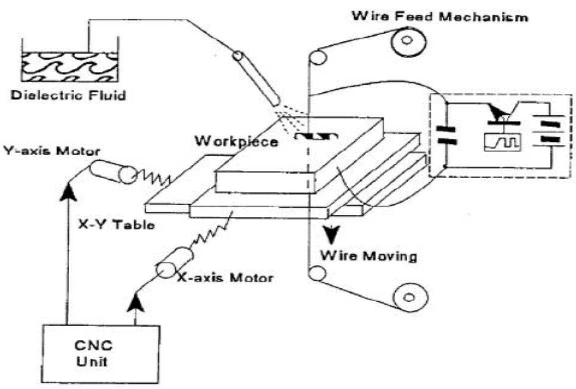

Figure 1: Schematic Diagram of the Basic Principle of WEDM Process

Maher et al. [1] studied an experimental investigation of wire electric discharge machining (WEDM) for improving the process performance. Janardhanet al. [2] developed a pulse discrimination algorithm for classifying the discharge pulses into open circuit, normal, arc and short circuit pulses. K. Kanlayasiri et al. [3] investigated the effects of machining parameters on surface roughness of wire EDM DC53 die steel. Y.S. Lioet al. [[5]] studied performance such as metal removal rate, gap width, surface roughness, sparking frequency, average gap voltage and normal ratio (ratio of normal sparks to total sparks) are determined. G. SELVAKUMAR et al. [[6]]based on the Taguchi experimental design (L9 orthogonal array) method, performed a series of experiments considering pulse-on time, pulse-off time, peak current and wire tension as input parameters. S. Suresh Kumar et al.[[7]] analyzed to optimize the process parameters such as peak current, pulse on time, wire feed rate and wt.% of Boron Carbide (B4C) that affect the output responses, namely, kerf width (K) and surface roughness (SR), through the Grey Relational Analysis (GRA). Rajarshi Mukherjee et al.[[8]] selected the optimal values of different process parameters, such as pulse duration, pulse frequency, duty factor, peak current, dielectric flow rate, wire speed, wire tension, effective wire offset of wire electrical discharge machining (WEDM) process is of utmost importance for enhanced process performance.

III. EXPERIMENTAL DETAILS

The experiments were accomplished on an ELECTRONICA SPRINTCUT WEDM machine. Following steps were followed in the cutting operation:

1. The wire was made vertical with the help of verticality block.
2. The work piece was mounted and clamped on the work table.
3. A reference point on the work piece was set for setting work co-ordinate system (WCS). The programming was done with the reference to the WCS. The reference point was defined by the ground edges of the work piece.
4. The H-11 hot die steel plate of 40mm x 40mm x 10mm size are mounted on the ELECTRONICA SPRINTCUT WEDM machine tool as shown in figure 2 were cut into 10mmx10mmx10mm size.

While performing various experiments, the following precautionary measures were taken:

1. To reduce error due to experimental set up, each experiment was repeated three times in each of the trial conditions.
2. The order and replication of experiment was randomized to avoid bias, if any, in the results.
3. Each set of experiments was performed at room temperature in a narrow temperature range (32±2^{o} C).
4. Before taking measurements of surface roughness, the work piece was cleaned with acetone.

The summary of experimental conditions is listed in Table 2. The experimental results after laser micro-drilling were evaluated in terms of the following measured machining performances: (1) MRR, (2) Surface Roughness. The surface roughness of the samples was measured using Mitutoyosurftest SJ-201P, and MRR is calculated as the difference between initial and final weight per unit time.

Table 2 –Process parameters and their levels

Factors	Parameters	Level 1	Level 2	Level 3
A	Pulse on Time	6	8	10
B	Pulse off Time	5	6	7
C	Peak Current	2	4	6
D	Wire Feed	3	5	6

Figure 2: Pictorial View of WEDM Machine Tool

III. GREY RELATIONAL ANALYSIS

This analysis can be used to represent the grade of correlation between two sequences so that the distance of two factors can be measured discretely. In the case when experiments are ambiguous or when the experimental method cannot be carried out exactly, grey analysis helps to compensate for the shortcoming in statistical regression**.** Grey relation analysis is an effective means of analyzing the relationship between sequences with less data and can analyze many factors that can overcome the disadvantages of statistical method [[15]].

3.1 Data pre-processing

The normalization is taken by three approaches. If the target value of original sequence is infinite, then it has a characteristic of "the-larger- the-better" (e.g. benefit). The original sequence can be normalized as follows [15].

$$x_i^*(k) = \frac{x_i^*(k) - \min x_i^0(k)}{\max x_i^0(k) - \min x_i^0(k)}$$

If the expectancy is the-smaller-the-better (e.g. cost and defects), then the original sequence should be normalized as follows:

$$x_i^*(k) = \frac{\max x_i^0(k) - x_i^0(k)}{\max x_i^0(k) - \min x_i^0(k))}$$

If the expectancy is nominal-the-best (e.g., the age), if there is a definite target value to be achieved, then the original sequence should be normalized as follows:

$$x_i^*(k) = 1 - \frac{|x_i^0(k) - x^0|}{\max x_i^0(k) - x^0}$$

Table 3-Experimental layout using an L9 orthogonal array and multi-performance results

Sl. no	Ton(µs)	Toff (µs)	Ip(A)	Wire Feed(WF)	MRR(mm/Min)	Surface Roughness(µm)
1	6	5	2	3	1.7044	2.54
2	6	6	4	5	3.9679	2.41
3	6	7	6	6	3.0094	2.13
4	8	5	4	6	8.5144	2.35
5	8	6	6	3	2.3747	1.42
6	8	7	2	5	1.9863	2.12
7	10	5	6	5	3.6192	2.39
8	10	6	2	6	2.3111	2.64
9	10	7	4	3	6.0023	2.78

Table 4-Sequences of performance characteristic after data preprocessing

Sl.no	MRR	Surface Roughness
1	0	0.1764705
2	0.3323788	0.2720588
3	0.1916299	0.4779411
4	1	0.3161764
5	0.0984287	1
6	0.0413950	0.4852941
7	0.2811747	0.2867647
8	0.0890895	0.1029411
9	0.6311160	0

3.2 Grey relational coefficient and grey relational grade

Following data pre-processing, a grey relational coefficient is calculated to express the relationship between the ideal and actual normalized experimental results. The grey relational coefficient can be expressed as follows [15]:

$$\zeta_i(k) = \frac{\Delta_{\min} + \zeta.\Delta_{\max}}{\Delta_{0i} + \zeta.\Delta_{\max}}$$

Where Δ0i (k) is the deviation sequence of the reference sequence $\chi^*_0(k)$ and the compatibility sequence χ^*_i (k) namely;

$$\Delta_{0i}(k) = \left\| x_0^*(k) - x_i^*(k) \right\|$$

$$\Delta_{\min}(k) = \max_{\forall j \in i} \min_{\forall k} \left\| x_0^*(k) - x_j^*(k) \right\|$$

$$\Delta_{\max}(k) = \max_{\forall j \in i} \max_{\forall k} \left\| x_0^*(k) - x_j^*(k) \right\|$$

$$\gamma_i = \frac{1}{n} \sum_{k=1}^{n} \zeta_i(k)$$

ζ is distinguish or identification coefficient: ζε [0, 1], ζ= 0.5 is generally used. After obtaining the grey relational coefficient, the average of the grey relational coefficient is normally taken as grey relational grade (γ_i).

Table 5- The deviation sequence

Sl.no	Δ0i (k) for MRR	Δ0i (k) for Surface Roughness
1	1	0.8235295
2	0.6676212	0.7279412
3	0.8083701	0.5220589
4	0	0.6838236
5	0.9015713	0
6	0.958605	0.5147059
7	0.7188259	0.7132353
8	0.9109105	0.8970589
9	0.368884	1

Table 6- Grey Relational coefficient and grey relational grade

Sl.no	Grey relational coefficient of MRR	Grey relational coefficient of surface roughness	Grey relational Grade	Order
1	0.579256	0.3777777	0.478516	9
2	0.7441488	0.4071856	0.5756672	5
3	0.6640964	0.4892085	0.5766524	4
4	1.737768	0.4223602	1.080061	1
5	0.6199356	1	0.809967	2
6	0.5956952	0.4927536	0.544224	7
7	0.7128860	0.4121212	0.56250	6
8	0.6158321	0.3578947	0.486863	8
9	1	0.3333333	0.666666	3

Table 7- Response table for Grey Relational Grade

Parameter	L1	L2	L3	Max-Min
Ton	0.5436	0.8114	0.5720	0.2678
Toff	0.7070	0.6241	0.5858	0.1212
Ip	0.6517	0.6244	0.7333	0.1089
WF	0.6220	0.6016	0.7037	0.1021

IV. RESULT AND DISCUSSION

In the present study the MRR and Surface Roughness for different parameters were measured and the experimental runs were listed in Table-3. Typically lower the value of Surface Roughness and higher the values of MRR were desired. Therefore the data sequences have smaller-the-better characteristics for Surface Roughness and larger-the-better characteristics for MRR.

It is clearly observed from Table-6 and Figure: 3 that the parameter settings of experiment number-4 have the highest Grey Relational Grade. Thus the fourth experiment (Ton=8, Toff=5, Ip=4, WF=6) gives the best multi-performance characteristics among nine experiments. Larger the Grey relational Grade means the comparability sequence exhibit a stronger correlation with reference sequence.

In Table-7 A_2, B_1, C_3, D_3 show the largest value of grey relational grade for factor A, B, C, and D respectively. Therefore A_2, B_1, C_3 and D_3 are the condition for optimal parameter combination of the cutting process.

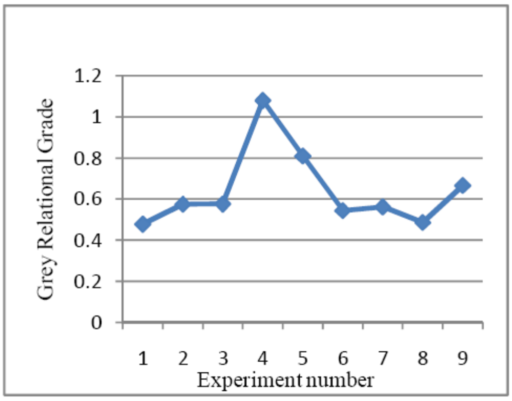

Figure 3: Grey Relational Grade

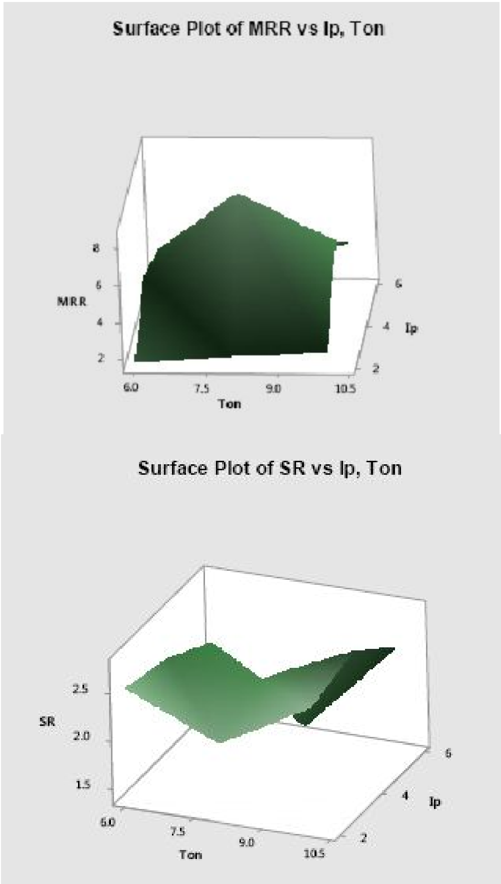

Figure 4: Response plot

It is observed from the response graph (fig-4) that the MRR and Surface Roughness increases with increase in peak current. Because in wire EDM, the discharge energy produces high temperature at the point of spark on work piece surface with increase in Ip as a result a large amount of material is melted and vaporized so the MRR is more. Also the top surface of the work piece cools down quickly as a result ridge surface and micro cracks are induced (due to high tensile residual stress) on the surface. So the surface roughness increases with increase in peak current. When the Ton increases the MRR and Surface Roughness increases. Increase in Ton time means the thermal energy on the work piece surface increases as a result more material is melted and vaporized so MRR is increases and surface roughness increases.

CONCLUSION

The effect of pulse on time, pulse off time, peak current, and wire feed rate on MRR and Surface finish were experimentally investigated in machining of H-11 DIE STEEL using ELEKTRA SPRINTCUT 734 WEDM machine. The Grey relational analysis was used to optimize the WEDM parameters for H-11. Based on the result of the present study following conclusions were drawn:

1. Increase in peak current leads to increase in MRR and surface roughness.
2. Increase in pulse ON time leads to increase in MRR and surface roughness.
3. Increase in wire feed rate leads to slight increase in cutting rate.

The optimized parameters are shown in Table-8

Table -8: Optimized parameter

Process parameters	Symbols	Unit	Optimum value for MRR	Optimum value for Surface Roughness
Pulse on time	Ton	µs	10(level A3)	8(level A3)
Pulse off time	Toff	µs	5(level B1)	5(level B1)
Peak current	IP	A	4(level C2)	4(level C2)
Wire feed	WF	m/min	6(level D3)	6(level D3)

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