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Process Parameter Optimization of WEDM for AISI M2 & AISI H13 by Anova & Analytic Hierarchy Process

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Abstract-
WEDM is a widely recognized unconventional material cutting process used to manufacture components with complex shapes and profiles of hard materials. In this thermal erosion process, there is no physical contact between the wire tool and work materials. AISI M2 and AISI H13 materials are taken for studyand molybdenum wire electrode diameter (0.18mm); experiment is conducted according to Taguchi's L_{16} OA, with input parameters as Peak current, Pulse on, Pulse off their response on MRR, Surface Roughness, Kerf width & Spark Gap is analysed to check the significance of each using ANOVA. Process parameter optimization is done by Analytic Hierarchy Process with the criteria Maximum MRR, minimum kerf and surface roughness. It is observed that for material AISI M2 at low value of peak current (1 A), pulse off (20µs) and pulse on (30µs) we can minimize surface roughness (3.30µm), kerf width (0.195 mm) and maximize MRR (0.022 g/min),from the selected levels whereas for material AISI H13 Peak current (1A), Pulse On (40µs) and high Pulse Off (30µs) we get better Surface roughness (3.71 µm), kerf width (0.196mm) and maximum MRR (0.020g/min), from the selected levels.

Index Terms- WEDM, DOE, Orthogonal array, MRR, Ra, Kw, AHP, Molybdenum wire.

I. INTRODUCTION

Electrical discharge machining (EDM) is an important non-traditional machining process which makes uses of precisely controlled electric sparks between the tool electrode and work piece for machining. A small portion of the work piece as well as the tool electrode are melted and vaporized by each spark. This melted portion of electrodes is ejected with the help of dielectric fluid and some portions of the melted electrodes are resolidified on the work piece. This re solidified portion is known as re cast layer [1]. S.S. Mahapatra et.al have optimized the WEDM parameters using Taguchi method and observed that combination of significant factors for each performance measure is different and developed mathematical model using non-linear regression method. Conformation experiments have shown less than 5% prediction error for each performance measures such as MRR, SF and kerf [2]. Ramakrishnan and L. Karunamoorthy have modelled and optimized Inconel 718 on WEDM and established the effect of various machining parameters such as pulse on time, wire feed speed, delay time and ignition current. Pulse on time, delay time and ignition current were influenced more than wire feed on MRR [3]. U.Esme et.al observed that increase in pulse duration, voltage and wire speed increase the surface roughness whereas increase in flushing pressure of dielectric fluid decrease the surface roughness [4]. The investigations made by J.T Hung et.al revealed that pulse on time is one of the significant factors that influence surface roughness [5]. The previous researchers established that pulse duration, voltage, and dielectric pressure are the desired combination to control the surface finish [6]. Manna and Bhattacharyya (2010) established mathematical models relating to the machining performance criteria like material removal rate (MRR), surface roughness (SR) and spark gap and gap current using the Gauss elimination method for effective machining of Al/SiC-MMC using ANOVA method to optimize the response variables[7]. Kuriachen Basil et alinvestigated the effect of voltage, dielectric pressure, pulse on-time and pulse off-time on spark gap of Ti6AL4V alloy. It has been found that pulse on time and pulse off time have the more impact on the spark gap[8]. Batish A et al. (2010) Experimented on edm using seven different process parameters to study their effect on MRR, TWR, SR, using a specially design Taguchi L_{27} OA, using dummy treatment. The process conditions that affects the three responses were identified and optimized together using AHP a method to obtain more reliable global weight of different alternatives on workpiece material. It was observed that powder in the dielectric improved the MRR [9].

From the literature reviewed it has been found that most of the work is done on brass electrode whereas molybdenum wire is not commonly used.The present work mainly concentrate on the effect of pulse on time, pulse off time, peak current and two different workpiece AISI M2& AISI H13 are chosen for machining in order to check the responses i.e. MRR, surface roughness, Kerf width , spark gap.

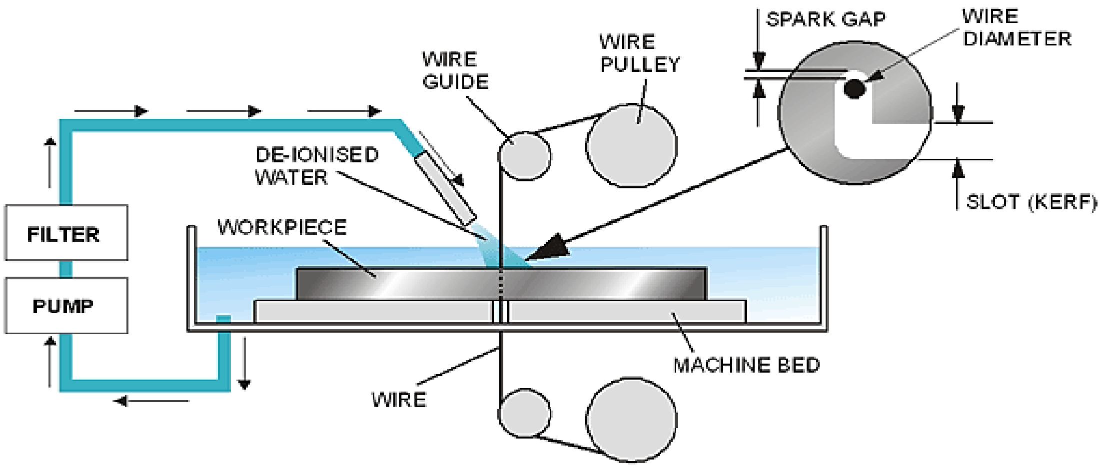

Figure 1: Details of WEDM setup

II. EXPERIMENTAL SET UP

The experimental set up adopted for the present study is given in fig. 2. The WEDM experiments were conducted in Concord DK 7732BOAMA machine using 0.18 mm molybdenum wire as the tool electrode. Pulse on time, pulse off time, peak currentand two different workpiece are the four WEDM parameters that were selected for investigations. In this experimental study Taguchi's L16 Orthogonal Array is adopted because this gives all possible combinations of machine parameters. All other machine parameters were kept constant during the time of experiment.

III. EXPERIMENTAL DESIGN BASED ON DOE

Full factorial design of two factors with four levels each andtwo factors with two levels each was conducted which consist of 16 runs (each experiment is conducted three times making 48trials). For the analysis of the experiments 95% confidence level is adopted.ANOVA table helped to find out the significant factors and to establish the mathematical relationship between the and machining parameters and response variables.

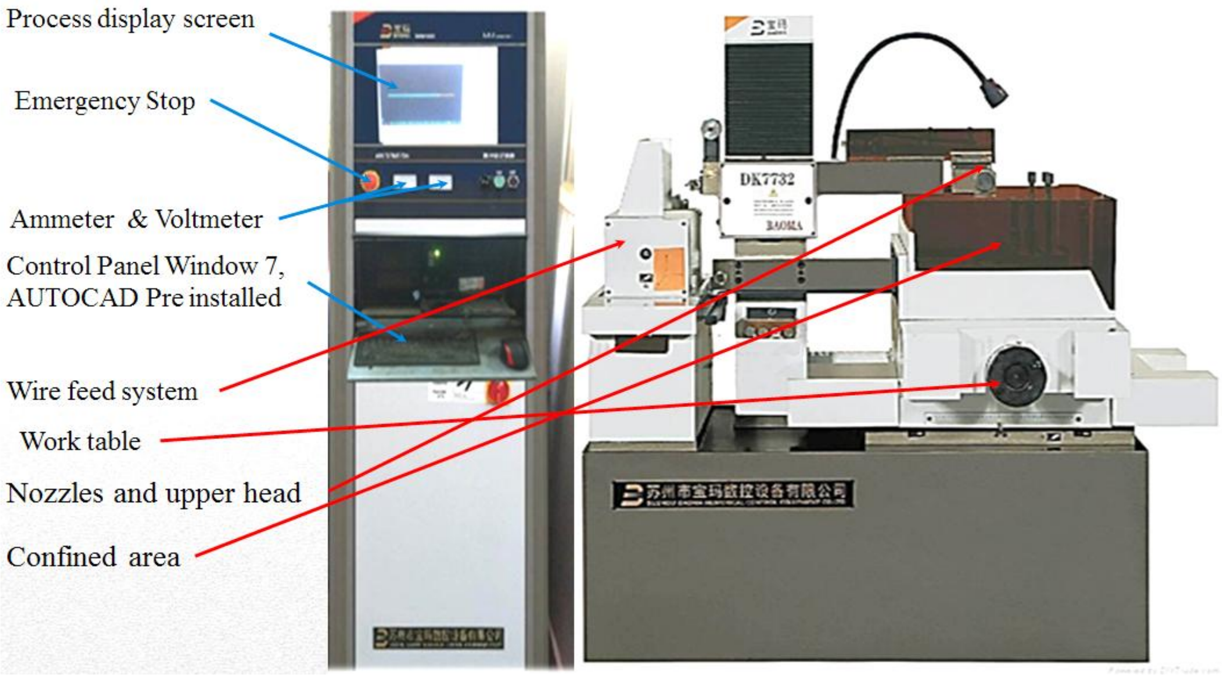

Figure 2: Concord DK 7732(Boama) four axis molybdenum wire cutting machine

Table 1.Machining Parameters and Levels

Process Parameters	**Symbols**	**Units**	**Selected Levels Level 1**	**Level 2**	**Level 3**	**Level 4**
Peak Current	I_P	**A**	**1**	**2**	**3**	**4**
Pulse On time	T_{ON}	**µs**	**30**	**35**	**40**	**45**
Pulse Off time	T_{off}	**µs**	**20**	**30**	**-**	**-**
There are two workpiece AISI M2 & AISI H13						

IV. RESULTS AND DISCUSSIONS

This section discusses the influence of the process parameters on the response variables i.e. MRR, Surface roughness, kerf width , spark gap. The main objective of this discussion is to assess the variation of these responses with respect to the change in the process parameters. The various machining parameters and corresponding results of MRR, SR, KW, SG. (average of three readings) are tabulated in Table 2. Material removal rate (MRR) is calculated by taking initial weight before cutting and difference observed after cutting divided by time period in minutes using SAMON digital weighing machine having accuracy of 100 mg, Kerf is calculated by digital Mitutoyo profile projector at 10x and 20 x zoom at three different positions. Wire diameter is checked after each cut using digital micrometer. Surface roughness is calculated using Mitoya SJ-201 machine. The sparking gap was calculated using the following equation:$\text{Spark Gap} = \left(\frac{\text{Kerf width} - \text{Wire diameter}}{2}\right)$ mm.

Here in the table 2:**A**-Peak current **B**- Pulse on**C**- Work piece **D**-Pulse Off

Table 2.Experimental Design and Results

S.No	**AHP**	**A**	**B**	**C**	**D**	**MRR**	**Kerf**	**Spark Gap**	**SR** (Ra)
1	A1	1	30	M2	20	2.8	0.195	0.0075	3.3
2	A2	1	35	M2	20	3.18	0.197	0.0085	3.46
3	A3	1	40	H13	30	2.57	0.195	0.0075	3.71
4	A4	1	45	H13	30	2.31	0.198	0.009	3.82
5	A5	2	30	H13	20	5.01	0.205	0.0125	3.97
6	A6	2	35	H13	20	4.88	0.209	0.0145	4.31
7	A7	2	40	M2	30	4.58	0.208	0.014	4.52
8	A8	2	45	M2	30	4.07	0.207	0.0135	4.67
9	A9	3	30	M2	30	5.22	0.21	0.015	4.32
10	A10	3	35	M2	30	5.6	0.20	0.014	4.42
11	A11	3	40	H13	20	5.91	0.212	0.016	4.71
12	A12	3	45	H13	20	5.78	0.213	0.0165	4.83
13	A13	4	30	H13	30	6.94	0.212	0.016	4.39
14	A14	4	35	H13	30	7.19	0.213	0.0165	4.6
15	A15	4	40	M2	20	7.77	0.216	0.018	4.76
16	A16	4	45	M2	20	7.38	0.214	0.017	4.87

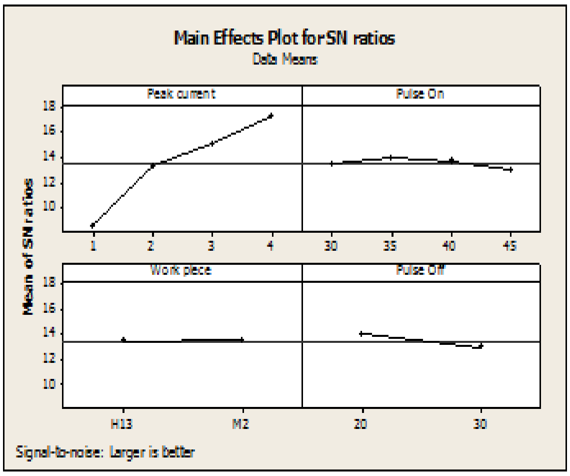

Fig. 3 Effect of control factors on MRR.

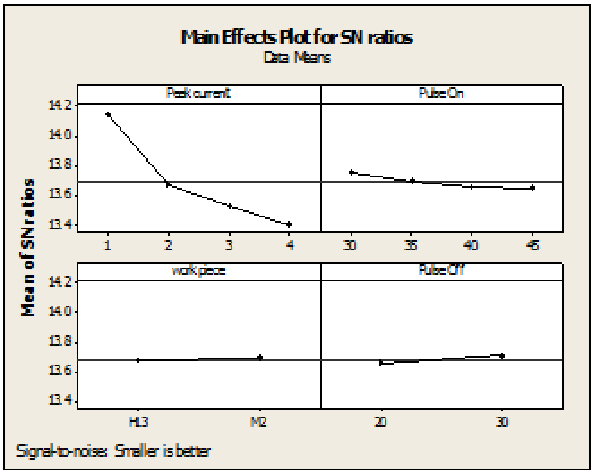

Fig. 4 Effect of control factors on Kerf Width.

Table. 3a S/N ratio response table for MRR

Response Table for Signal to Noise Ratios
Larger is better

Level	Peak current	Pulse On	Work piece	Pulse Off
1	8.616	13.530	13.484	14.075
2	13.294	13.979	13.611	13.020
3	14.997	13.664		
4	17.283	13.016		
Delta	8.667	0.963	0.127	1.055
Rank	1	3	4	2

Table. 4a S/N ratio response table for Kerf width

Response Table for Signal to Noise Ratios
Smaller is better

Level	Peak current	Pulse On	work piece	Pulse Off
1	14.14	13.75	13.68	13.66
2	13.67	13.69	13.69	13.71
3	13.53	13.66		
4	13.40	13.64		
Delta	0.74	0.11	0.01	0.05
Rank	1	2	4	3

For MRR,Current, pulse on time and pulse off time are the most significant factors while workpiece being the insignificant factor.As can be seen MRR increases with increase in current from 1Amp to 4 Amp. MRR is decreased with increase in pulse off time from 20µs to 30µs. The discharge energy increases with peak current and pulse on time resulting in faster material removal rate. Also as the pulse off time decreases, the amount of current discharges within a given period becomes more which results in higher material rate.

For Kerf Width, increased value for peak current and pulse on time leads to increased machining time. Longer machining time results in larger kerf values. Current has the highest rank signifying highest contribution to the kerf width and workpiece has the lowest rank in affecting kerf width.

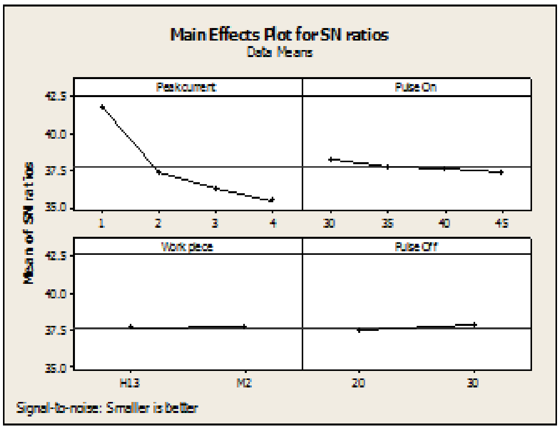

Fig. 5 Effect of control factors onSpark Gap.

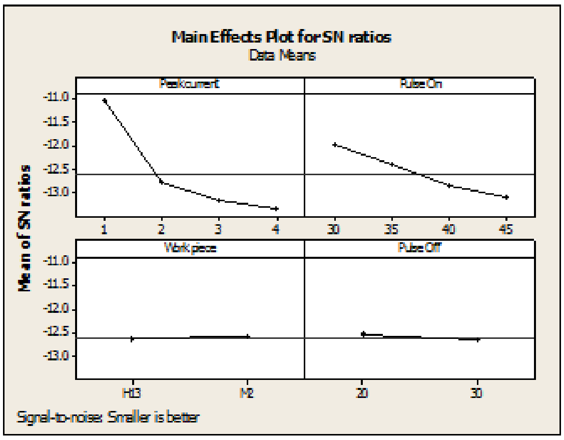

Fig.6 Effect of control factors on Surface Roughness (Ra)

Table. 5a S/N ratio response table for Spark Gap

Response Table for Signal to Noise Ratios
Smaller is better

Level	Peak current	Pulse On	Work piece	Pulse Off
1	41.83	38.24	37.67	37.57
2	37.33	37.73	37.78	37.88
3	36.28	37.60		
4	35.46	37.34		
Delta	6.37	0.90	0.10	0.30
Rank	1	2	4	3

Table. 6a S/N ratio response table for Surface roughness

Response Table for Signal to Noise Ratios
Smaller is better

Level	Peak current	Pulse On	Work piece	Pulse Off
1	-11.05	-11.98	-12.62	-12.53
2	-12.79	-12.41	-12.57	-12.66
3	-13.19	-12.88		
4	-13.35	-13.11		
Delta	2.31	1.14	0.05	0.12
Rank	1	2	4	3

For Spark Gap, current has the highest rank signifying highest contribution to Spark gap and workpiece has the lowest rank in affecting spark gap. Increased value for peak current and pulse on time leads to increased machining time. Longer machining time results in larger spark gap. Among all current and work piece are the most significant which has highest contribution in kerf width, pulse on time being the lowest.

For surface roughness, as the peak current and pulse on time are increased, the discharge energy increases and this increase in discharge energy produce a larger crater, causing an increased value of surface roughness on the work piece. Also as the pulse off time decreases, the number of discharges increases this cause's poor surface finish.

Figure 3,4,5and 6 shows the shows graphically the effect and 3a,4a,5a and 6a shows S/N response table of the four control factors on MRR,Kerf,Spark gap,Surface roughness, by using MINITAB 16 software the effect of control factors can be predicted.

From the S/N ratio graph the optimum solution for MRR, KW, SG and SR are:

Table3.Results of Anova plots

Material Removal Rate	A4,B2,C1,D1(maximum)		Kerf Width	A4, B4, C1, D1 (minimum)
Spark Gap	A4,B4,C1,D1(minimum)		Surface roughness	A4, B4, C1, D2 (minimum)

4.1: Optimisation of result by Analytic Hierarchy Process (AHP): Analytic Hierarchy Process (AHP) is one of Multi Criteria decision making method that was originally developed by Prof. Thomas L. Saaty. In short, it is a method to derive ratio scales from paired comparisons. The input can be obtained from actual measurement such as price, weight etc., or from subjective opinion such as satisfaction feelings and preference. AHP allow some small inconsistency in judgment because human is not always consistent. The ratio scales are derived from the principal Eigen vectors **[10]**.

Table 4: Pairwise comparison matrix for different criteria

	MRR	SR	KW	CRITERIA WEIGHT
MRR	1	1/6	1/3	0.0960
SR	6	1	3	0.6529
KW	3	1/3	1	0.2509
$\lambda_{max} = 3.0266$				CR=0.022

4.2:AHP objective: To select the parameter from the Taguchi's design which can **maximize MRR, minimize Kerf and Surface roughness** (Criteria)

Global weight for alternatives of AISI M2

Alternatives for AISI M2 (Trial No.)	MRR priority weight	SR priority weight	KW priority weight	Global weight
A1(1)	0.003283	0.237621	0.084697	**0.325601**
A2(2)	0.003378	0.17798	0.064978	0.246336
A3(7)	0.0078	0.044492	0.022152	0.074445
A4(8)	0.005272	0.031175	0.023823	0.06027
A5(9)	0.010592	0.061553	0.015067	0.087211
A6(10)	0.011982	0.050978	0.022152	0.085112
A7(15)	0.027425	0.026053	0.00744	0.060917
A8(16)	0.02629	0.023171	0.009962	0.059424

Global weight for alternatives of AISI H13

Alternatives for AISI M2 (Trial No.)	MRR priority weight	SR priority weight	KW priority weight	Global weight
A1(3)	0.002855	0.171755	0.087935	**0.262546**
A2(4)	0.002855	0.158487	0.063063	0.224405
A3(5)	0.008441	0.109353	0.031879	0.149674
A4(6)	0.008174	0.064728	0.020574	0.093476
A5(11)	0.013598	0.030067	0.011891	0.055556
A6(12)	0.013065	0.024923	0.011891	0.048988
A7(13)	0.022347	0.056964	0.011891	0.091202
A8(14)	0.023236	0.036673	0.011891	0.071799

According to AHP, the optimum solution for material AISI M2 is A1 (1) having the greatest value in the column i.e. **0.325601 i.e.** Peak current = (1A); Pulse On-(30µs); Pulse Off= (20µs). Whereas for material AISI H13 the optimum solution is A1 (3) having the greatest value in the column i.e. **0.262546 i.e.** Peak Current= (1A), Pulse On= (40µs), Pulse On= (30µs).

4.3:Conclusion: For material AISI M2 it can be seen that at low value of peak current (1 A), pulse off (20µs) and pulse on (30µs) we can minimize surface roughness (3.30µm), kerf width (0.195 mm) and maximize MRR (0.022 g/min),from the selected levels. According to AHP criteria these are the optimum settings.
For material AISI H13 it is observed that at low Peak current (1A), Pulse On (40µs) and high Pulse Off (30µs) we get better Surface roughness (3.71 µm), kerf width (0.196mm) andmaximum MRR (0.020g/min), from the selected levels. According to AHP criteria these are the optimum settings.
On the above said settings we get high MRR, minimum Kerf width and good surface finish.

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