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Evaluation of Process parameter in WIRE-Electric Discharge Machining of High Carbon High Chromium Steel

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Abstract-*In this research work an attempt has been made to analysis the effects of input parameters such as Pulse On time, Pulse Off time and Peak current, on output parameter such as material removal rate. The experiment was performed with different combination values of input parameter. An attempt has been made to optimize the machining conditions for MRR based on (L9 Orthogonal Array) Taguchi methodology. Experiments were carried out under varying pulse-on-time, pulse-off-time, and peak current. An orthogonal array, the signal-to-noise (S/N) ratio, and the analysis of variance (ANOVA) were employed to the study the MRR in the WEDM of High Carbon High Chromium Steel.*

Keywords –WEDM ,MRR

I. INTRODUCTION

WEDM is a specialized thermal machining process capable of accurately machining parts which have varying hardness, complex shapes and sharp edges that are very difficult to be machined by traditional machining methods. The practical technology of WEDM process is based on the conventional EDM sparking phenomenon utilizing the widely accepted non-contact technique of material removal. In WEDM material is eroded from the work piece by a series of discrete sparks occurring between work piece and wire electrode separated by a stream of dielectric fluid, which is continuously fed to the machining zone with the help of nozzle. Figure 1.1 shows schematic representation of WEDM machining process. The dielectric fluid is used to remove debris and heat from the machining zone. The dielectric fluid which is used in this process is de-ionized water which has low viscosity, no fire hazards, high cooling rate and high MRR. That is why water is used as dielectric in most of the WEDM system. However, today's WEDM process is commonly conducted on work pieces that are totally submerged in tanks filled with the dielectric fluid. Such submerged method of WEDM promotes temperature stabilization and efficient flushing especially where the work piece has varying thickness.

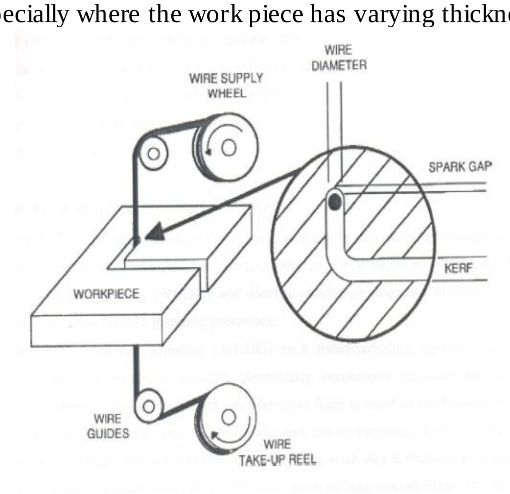

Figure 1.1 Schematic Diagram of WEDM System

The WEDM process makes use of electrical energy generating a channel of plasma between the cathode and anode and turns it into thermal energy at a temperature in the range of 8000-12000^{0}C or as high as 20000^{0}C initializing a substantial amount of melting and vaporizing of material on the surface of each pole. When the pulsating direct current power supply occurring between 20000 and 30000 Hz is turned off, the plasma channel breaks down. This causes a sudden reduction in temperature and pressure allowing the molten particles to flush from the pole surfaces in the form of debris.

WEDM uses a thin wire continuously feeding through the work piece, which enables parts of complex shapes to be machined with high accuracy. A varying degree of taper ranging from 15^0 for a 100 mm thick to 30^0 for a 400 mm thick work piece can also be obtained on the work surface. The servo system maintains the gap between wire and the work piece which varies from 0.025 to 0.05 mm. WEDM power supply senses the voltage between the electrodes and then sends the relevant signals to the servo system which maintains a desired gap between the electrodes. WEDM eliminates the need for pre-shaped electrodes, which are commonly required in EDM to perform the roughing and finishing operation. In the case of WEDM, the wire has to make several machining passes along the profile to be machined to obtain the required dimensional accuracy and surface finish quality. The dimensional Accuracy is of the order of ±7µm or even lower in some cases. WEDM uses de-ionized water instead of hydro-carbon oil as dielectric fluid. The de-ionized water is not suitable for conventional EDM as it causes rapid electrode wear, but its low viscosity and rapid cooling rate make it ideal for WEDM. Filtration of dielectric fluid before re-circulation is highly essential so that a change in its insulation qualities during the process is minimal.

II. EXPERIMENT DETAIL

The experiments were carried out on wire-cut EDM machine of Electronica Machine Tools Ltd. housed in Advanced Manufacturing Laboratory of Mechanical Engineering Department, NIT, Kurukshetra.

Wire Edm Machine Tool

There are four basic elements of WEDM machine tool - the power supply system, the positioning system, the drive system and the dielectric system. All the four basic sub systems are distinct from conventional EDM.

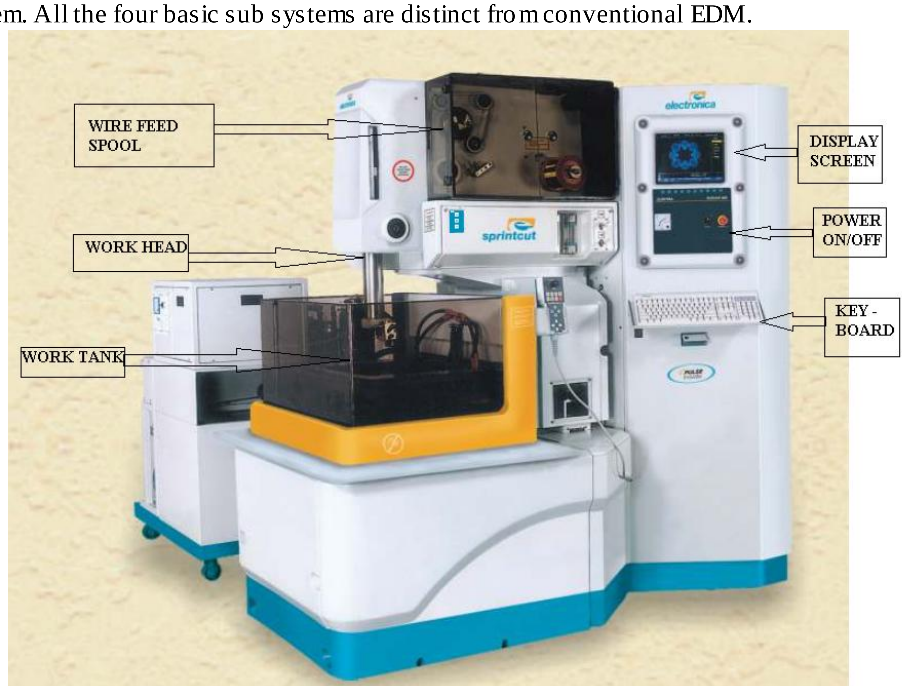

Fig. 1.2: Wire EDM Machine Tool

Technical Specifications of Machine Tool

The experiments were carried out on a wire-cut EDM machine (ELEKTRA SPRINTCUT 734) of Electronica Machine Tools Ltd. installed at Advanced Manufacturing Laboratory of Mechanical Engineering Department, N.I.T., Kurukshetra, and Haryana, India. The WEDM machine tool (Figure 1.2) has the following specifications:

Design	Fixed column, moving table
Table size	440 x 650 mm
Max. workpiece height	200 mm
Max. workpiece weight	500 kg

Main table traverse (X, Y)	300, 400 mm
Auxiliary table traverse (u, v)	80, 80 mm
Wire electrode diameter	0.25 mm (Standard)
	0.15, 0.20 mm (Optional)
Generator	ELPULS-40 A DLX
Controlled axes	X Y, U, V simultaneous / independent
Interpolation	Linear & Circular
Least input increment	0.0001mm
Least command input (X, Y, u, v)	0.0005mm
Input Power supply	3 phase, AC 415 V, 50 Hz
Connected load	10 KVA
Average power consumption	6 to 7 KVA

Process Parameters for Experiments:
There are several parameters which affect the MRR of WEDM process. On the basis of literature review parameters were taken for experimentation as shown in Table 1.1.

Table 1.1 Process Parameters with their ranges

Symbol	Input Parameter	Range of Process Parameter
A	Pulse ON Time (T ON)	100 – 135 machine units (actual unit µs)
B	Pulse OFF Time (T OFF)	30 – 65 machine units (actual unit (µs)
C	Peak Current (IP)	70 – 230 Amp

Work piece Material:
The work piece material selected for the study is High Carbon High Chromium Steel of 100mm×100mm× 25mm thickness.

Table 1.2 Composition of work material

Constituent	**C**	**Si**	**Mn**	**S**	**P**	**Ni**	**Cr**	**Mo**	**Cu**	**Fe**
%	**2.02**	**0.33**	**0.37**	**0.27**	**0.026**	**0.062**	**11.55**	**0.023**	**0.009**	**Rest**

Experimental Data for MRR
The experiments were conducted by selecting L-9 orthogonal array. Based on the experimental design the specimens were prepared and the value of the selected machining characteristic i.e. MRR is reported in Table 1.3.

Table 1.3 Experimental Data for MRR

Experiment No.	A	B	C	Cutting Speed (v_c) (mm/min)		$MRR = k.t.v_c$ (mm^3/min)		Average MRR (mm^3/min)	S/N Ratio
1	103	35	120	0.76	0.63	6.50	5.44	5.97	15.41
2	103	40	160	0.51	0.73	4.36	6.24	5.30	14.07
3	103	50	230	0.23	0.34	1.97	2.90	2.43	7.24
4	110	35	160	1.77	1.54	15.13	13.23	14.18	22.98
5	110	40	230	1.11	1.22	9.49	10.49	9.99	19.96
6	110	50	120	0.34	0.40	2.91	3.45	3.18	9.95
7	125	35	230	2.55	2.78	21.80	23.82	22.81	27.14
8	125	40	120	1.0	0.88	8.55	7.56	8.05	18.07
9	125	50	160	0.61	0.81	5.22	6.99	6.10	15.43
Average Mean of MRR ($\overline{T}$)								Average Mean of MRR ($\overline{T}$)	8.67

Where

k = kerf width

t = thickness of the material

v_c = cutting speed

The kerf is expressed as the sum of the wire diameter and twice the wire work piece gap. The kerf (cutting width) used to find the metal removal rate determines the accuracy of the finished part. The gap between wire and work piece usually ranges from 0.025 to 0.075mm and is constantly maintained by the computer controlled positioning system.

III. EXPERIMENT RESULTS

The effect of three input parameters on MRR in WEDM process has been examined. The input parameters are pulse ON time (TON), pulse OFF time (TOFF) and peak current (IP). The experiment is performed on tool steel D2 of thickness 25mm with brass wire of diameter 0.25mm as the tool electrode. The analysis is carried out with the help of Minitab 15 software. The results of experiments show that the pulse ON time (TON), pulse OFF time (TOFF) and peak current (IP) have significant influence on the material removal rate (MRR).

A. EFFECT OF PROCESS PARAMETERS ON MRR

The Figure 1.1 shows that MRR increases as the pulse ON time and peak current increase from level 1 to level 2 and then from level 2 to level 3. It is also revealed from the figure that MRR decreases with increasing values of pulse OFF time

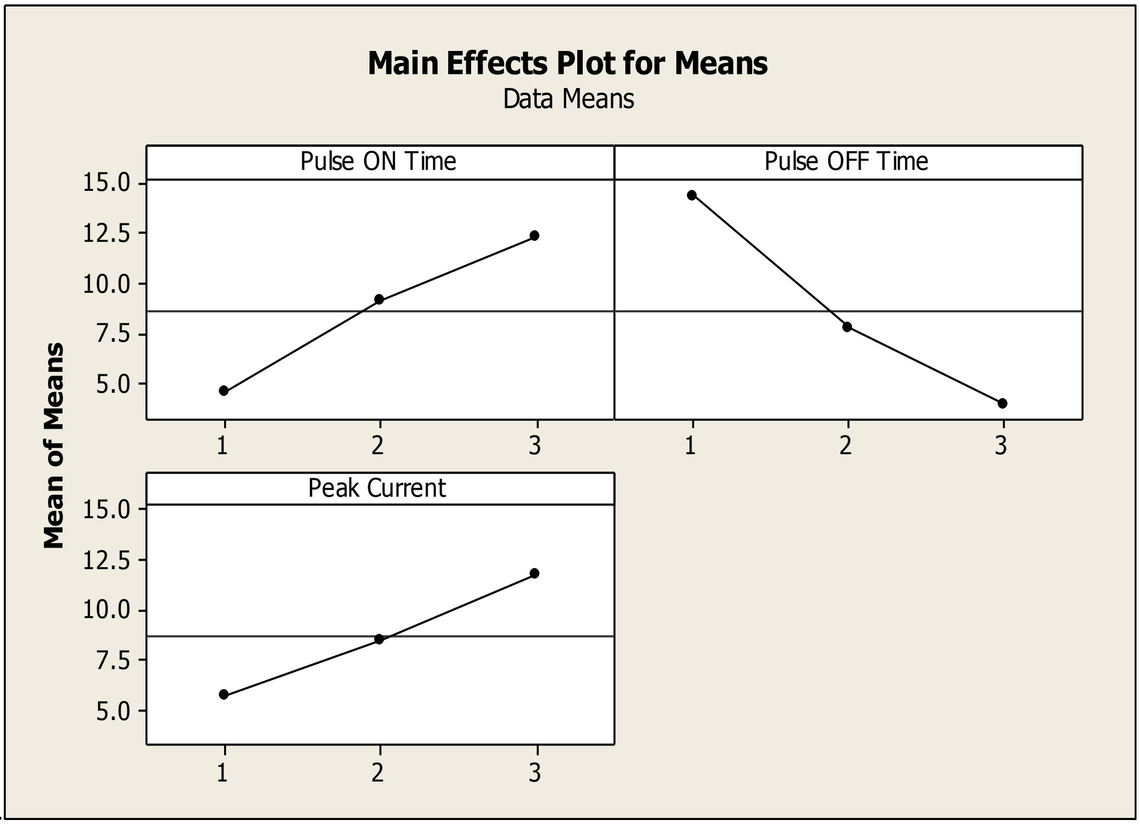

Figure 1.2: Effect of Process Parameters on MRR (Raw Data)

The Figure 1.3 also shows the same trends for S/N Data for all the three selected parameters. Tables 1.4 and 1.5 present the response values for mean and S/N ratio for MRR respectively.

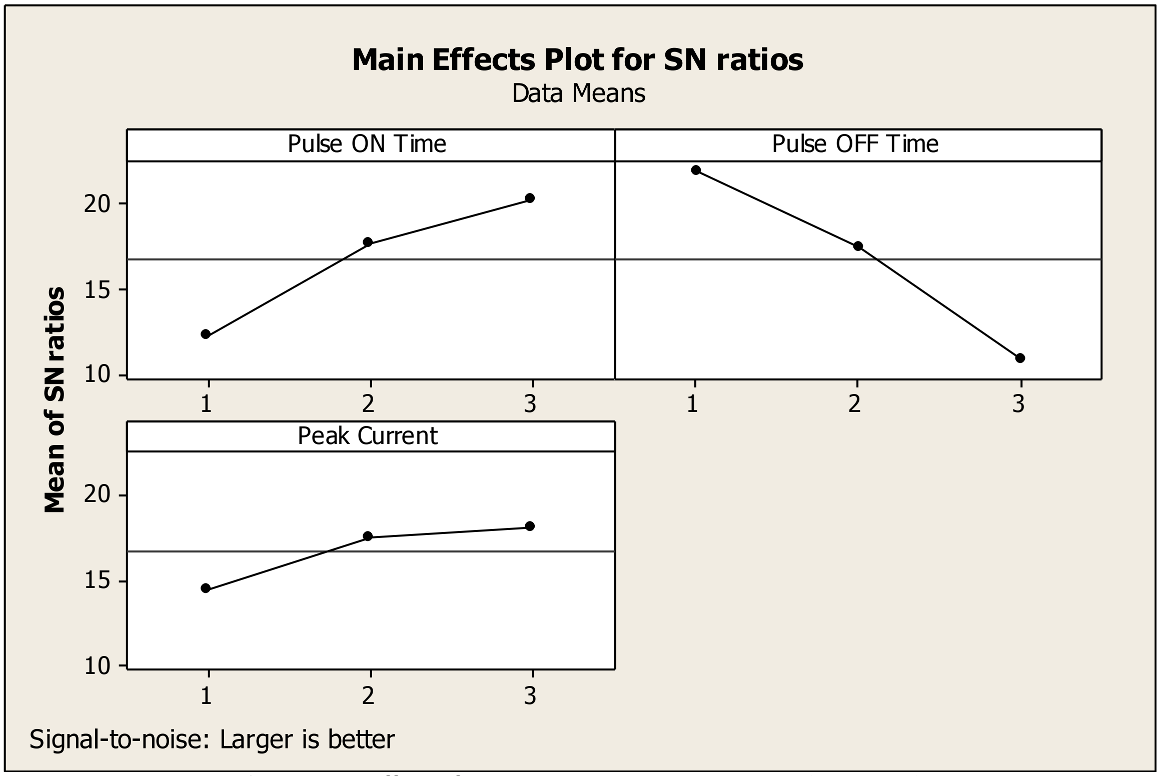

Figure 1.3: Effect of Process Parameters on MRR (S/N Data)

Table 1.4 Response Table for Means

Level	Pulse ON Time	Pulse OFF Time	Peak Current
1	4.57	14.32	5.74
2	9.12	7.78	8.53
3	12.32	3.90	11.74
Delta	7.76	10.42	6.01

Table 1.5 Response Table for S/N Ratios

Level	Pulse ON Time	Pulse OFF Time	Peak Current
1	12.24	21.84	14.48
2	17.63	17.37	17.49
3	20.21	10.87	18.11
Delta	7.97	10.97	3.63

Analysis Of Variance (ANOVA):

ANOVA is a statistical tool used to identify the significant factors affecting the response. The percent contribution of the factors on the response is also revealed in the analysis of variance.

Depending on the significance of the factors in the ANOVA, these are classified as under:

- Class I factors are those which are significant in both the ANOVAs and these affect both the mean value and the variance around the mean.
- Class II factors are those which are significant in ANOVA for S/N Data only and these affect only the variance around the mean value.
- Class III factors are those which are significant in ANOVA for raw data only and affect only the mean value.
- Class IV factors are those which are not significant in either of the ANOVAs and hence affect nothing.

Proper control should be exercised on the appropriate setting of the class I, II and III factors. However, the class IV factors may be set at some economical levels.

The ANOVAs for raw data and S/N data are reported in Tables 1.6 and 1.7 respectively. It is clear from Tables 1.6 and 1.7 that all the three factors are significant in both the ANOVAs and hence fall in the category of Class I factors affecting both the mean and variance around the mean of MRR.

Table 1.6: Analysis of variance for MRR (Raw Data)

Source	Degree of freedom (DF)	Sum of Squares (SS)	Mean Square	F Statistic	Probability (p)	Percentage Contribution
Pulse ON Time	2	182.31	91.15	25.38*	0.000	27.50
Pulse OFF Time	2	332.60	166.30	46.30*	0.000	50.17
Peak Current	2	108.52	54.26	15.11*	0.001	16.36
Error	11	39.51	3.59	-	-	5.97
Total	17	**662.93**				
$F_{0.05\ (2,11)} = 2.98$						

*Significant at 95% confidence level.

Table 1.7: Analysis of variance for MRR (S/N Data)

Source	Degree of freedom (DF)	Sum of Squares (SS)	Mean Square	F Statistic	Probability (p)	Percentage Contribution
Pulse ON Time	2	99.30	49.65	60.60*	0.016	32.44
Pulse OFF Time	2	182.52	91.26	111.40*	0.009	59.62
Peak Current	2	22.64	11.32	13.82	0.067	7.4
Error	2	1.64	0.82	-	-	0.54

Total	8	**306.10**	
$F_{0.05\ (2,2)} = 19.0$			

*Significant at 95% confidence level.

Selection of Optimal Levels

Table 1.4 and 1.5 clearly reveal that the third level of pulse on time (A3), first level of pulse of time (B1) and third level of peak current (C3) are the highest points in both the figures and hence represent the optimal setting of the parameters.

Estimating Optimal Performance

The optimal combination of machining parameters has already been determined. However, the final step is to predict and verify the improvement of the observed values through the use of the optimal combination level of machining parameters. The estimated mean for MRR can be calculated with the help of Equation reproduced below.

$$\eta = \overline{T} + \left(\overline{A_3} - \overline{T}\right) + \left(\overline{B_1} - \overline{T}\right) + \left(\overline{C_3} - \overline{T}\right)$$

Substituting values of $\overline{T}$, $\overline{A_3}$, $\overline{B_1}$ and $\overline{C_3}$ from tables 1.3 and 1.4

$$\eta = \mathbf{21.04}\ \mathrm{mm^3/min}$$

For calculation of CI_{CE}, the following equation has been used.

$$CI_{CE} = \sqrt{F_{\alpha(1,v)} . V_e \left[\frac{1}{R} + \frac{1}{n_{eff.}}\right]}$$

Where

$F_{\alpha(1,v)}$ = F-ratio at level of significance α (or confidence level of 1-α) against DOF of mean (always equal to one) and error DOF of v (2) = $F_{0.05\ (1,11)} = 4.84$

V_e = Error variance = 3.59 (Table 1.6)

R = Number of confirmation experiments = 3

$$n_{eff.} = \text{Effective no.of replications} = \frac{\text{Total no.of trials or Experiments}}{1 + \text{Total DOF associated in the estimation of mean value}}$$

$$= \frac{18}{1+6} = \frac{18}{7} = 2.57$$

CICE (MMR) = ±3.54

The confidence interval for MRR is $17.50 < \mu_{MRR}$ ($\mathrm{mm^3/min}$)< 24.58

IV. CONCLUSION

The optimal setting of process parameters is as under:

- Pulse ON Time: 121 machine units, Pulse OFF Time: 30 machine units, Peak Current: 210 amperes.
- All the process parameters significantly affect the mean value and variance around mean value of MRR at 95% confidence level.
- The percent contribution of process parameters in affecting MRR is as under:
  Pulse ON Time = 27.50%
  Pulse OFF Time = 50.17%

Peak current = 16.36%

- The 95% Confidence Interval of MRR is 17.50 < μ_{MRR} (mm^3/min)< 24.58

Three confirmation tests were conducted at the optimal setting of process parameters and the average value of MRR was recorded. The average value of MRR achieved was 22.10 mm^3/min which lies between the predicted CI_{CE}.

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