Experimental study of H-21 punching dies on wire-cut electric discharge machine using Taguchi's method.

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Abstract: - This experimental study of metal cutting focuses on the features of tools, input work materials and machine parameter settings influencing process efficiency and output quality characteristics. A major factor for selection of optimal machining condition is to achieve the goal of higher machining process efficiency. To design and implement an effective process control for metal cutting operation by parameter optimization, there is a need to balance the quality and cost of every operation resulting in improved and reduced failure of a product under consideration. Present investigation is to optimize the process parameters for single response optimization using Taguchi's L_{18} orthogonal array. Experiments were carried out on H-21 die tool steel as work piece electrode and zinc coated brass wire as a tool electrode. Response parameters are cutting speed, surface roughness and die width. The feature which makes optimization most powerful in comparison to other methods is its ability to handle multiple performance parameters in the form of constraints. The experimental results are then transformed into a signal to noise ratio(S/N) ratio. The S/N ratio can be used to measure the deviation of the performance characteristics from the desired value. The optimal level of the process parameter is the level with the highest S/N ratio. A statistical analysis of variance (ANOVA) is performed to identify the process parameters that are statistically significant.

Keywords: - H-21 die tool steel, CNC, L_{18} Orthogonal Array, S/N ratio, ANOVA.

I. INTRODUCTION

WEDM refers to wire electrical discharge machining. Wire electrical discharge machining or WEDM is a metal working process, with the help of which a material is separated from a conductive work piece, by means of electrical erosion. The wire never comes in contact with the conductive work piece. The wire electrode leaves a path on the work piece, which is slightly larger than the wire. Most often a 0.010" wire is used which creates a 0.013" to 0.014" gap. The wire electrode once passed through the work piece cannot be reused.

The wire electrode and the work piece are held at an accurately controlled distance from one another, which are dependent on the operating condition and refer to as spark gap. This gap prevents the mechanical contact of tool and work. The movement of wire is controlled numerically to achieve the dimensional shape and accuracy of the desired output. Principle of wire electrical discharge machining puts impulse voltage between electrode wire and work piece through impulse source, controlled by servo system, to get a certain gap, and realize impulse discharging in the working liquid between electrode wire and work piece. Numerous tiny holes appear due to erosion of impulse discharging, and therefore get the needed shape of work piece (as show in figure 1). Electrode wire is connecting to cathode of impulse power source, and work piece is connecting to anode of impulse power source. When work piece is approaching electrode wire in the insulating liquid and gap between them getting small to a certain value, insulating liquid was broken through; very shortly, discharging channel forms, and electrical discharging happens.

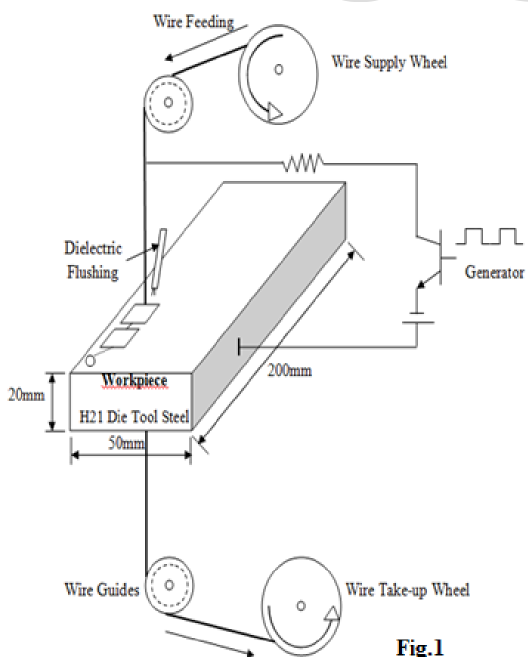

Fig.1

- The procedure should happen in the liquid with insulate capacity, for example sponification and de-ionized water, the liquid could act as medium of discharging channel and provide cooling and flushing.
- Electrical discharging should be short time impulse discharging, as with short discharging time, the released heat won't affect inside material of work piece, and limits energy to a tiny field and keep characteristics of cool machining of wire cut EDM machine.

II. EXPERIMENTAL METHODOLOGY

Taguchi method uses a special design of orthogonal array to study the entire parameter space with only a small number of experiments. The experimental results are then transformed into a signal to noise ratio(S/N) ratio. The S/N ratio can be used to measure the deviation of the performance characteristics from the desired value. the lower the better, the higher the better, and the nominal the better. Therefore the optimal level of the process parameter is the level with the highest S/N ratio. Furthermore, a statistical analysis of variance (ANOVA) is performed to identify the process parameters that are statistically significant. The optimal combination of the process parameter can then be predicted based on the above analysis. The main objective of Taguchi method to analyze the experiment is

1. To estimate the best or the optimum condition for a product or process
2. To estimate the contribution of individual parameters and interaction
3. To estimate the response under the optimum condition.

III. EXPERIMENTAL SETUP AND PROCESS PARAMETERS SELECTED

Figure 2 shows the stepwise procedure for Taguchi experimental design and analysis as shown below in figure. 2

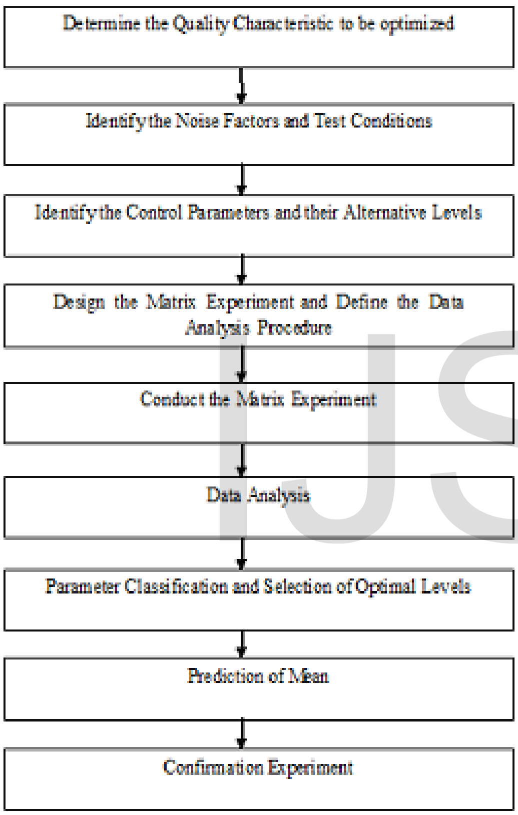

Fig.2

Fig.3 Sprint-cut WEDM

The experiments were carried out in CNC sprint cut wire EDM of Electronic a Machine tool ltd shown in figure 3. The pulse generator capacity of the machine is 40A. The pulse generator supplies the electrical energy to the spark gap in the form of pulses. The machine tool unit comprises of a main worktable (called X-Y table) on which the work piece is clamped an auxiliary table (called U-V table) and wire drive mechanism.

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Work piece Electrode: - The work piece material used in this investigation was H-21 die tool steel. Composition of H-21 die tool steel is C= 0.30%, Mn= 0.30% , Si=0.20% ,Cr= 3.60%, Ni=0.3%, W= 8.5%, V= 0.40%,Cu=0.25,P=0.03 and S=0.03. A H-21 die tool steel plate of size 200x50x20 (L x b x w) could reach the HB300 at the temperature of 650 C. Table 1 shows the physical properties of H21 die tool steel.

Density	8.19g/cm^3
Poisson's ratio (25ºC)	0.27-0.30
Thermal conductivity	27.0 W/mK
Specific heat (cal/gºC)	0.110

Table 1 Physical Property.

Tool Electrode: - Wire is used as an electrode and the electrode material used in this investigation was Zinc coated brass wire. Wire electrode having diameter 0.25mm was used. Zinc coated brass wire electrode can conduct high current as compare to simple copper wire

Selection of Process Parameters and their Ranges: - In order to obtain high cutting speed, accurate dimension and better quality of surface produced by WEDM process, the optimal level of WEDM process parameters need to be determined. Based on the critical review of literature, process variables of the WEDM were selected according to transient state.

The following process parameters were selected for this study as follows:

a. Current.
b. Pulse- ON time.
c. Pulse-OFF time.
d. Wire Speed
e. Wire Tension

In Sprint-cut wire EDM the value of current ranges b/w 10 to 230A, Pulse-ON time b/w 110 to 131, Pulse-OFF varies b/w 0-63, Wire speed 1-15m/min and Wire tension ranges between1 to 15N.

Sr. No.	Level	Control Factors A	B	C	D	E
1	**1**	180	120	48	3	6
2	**2**	190	124	52	4	7
3	**3**	200	128	56	5	8
4	**4**	210				
5	**5**	220				
6	**6**	230				

Table 2 Levels for various control factors

Selection of Orthogonal Array (OA) and Parameter Assignment: -

Before selecting a particular OA to be used as a matrix for conducting the experiments, the following two points were first considered

1. The number of parameters and interactions of interest
2. The number of levels for the parameters of interest.

Sr. No	Parametric Trial conditions A	B	C	D	E
1	1	1	1	1	1
2	1	2	2	2	2
3	1	3	3	3	3
4	2	1	1	2	2
5	2	2	2	3	3
6	2	3	3	1	1
7	3	1	2	1	3
8	3	2	3	2	1
9	3	3	1	3	2
10	4	1	3	3	2
11	4	2	1	1	3

12	4	3	2	2	1
13	5	1	2	3	1
14	5	2	3	1	2
15	5	3	1	2	3
16	6	1	3	2	3
17	6	2	1	3	1
18	6	3	2	1	2

Table 3 Orthogonal Array Selection

Degree of freedom (DOF) associated with each factor is equal to (no. of level -1). Therefore total degree of freedom for the five factors is (5+2+2+2+2) = 13. As per Taguchi's method the total DOF of selected OA must be greater than or equal to the total DOF required for the experiment. So an L18 OA (a standard Mixed-level OA) having 17 (=18-1) degree of freedom was selected for the present analysis. The experiments were conducted at each trial conditions as given in table 3.

IV. RESULT AND DISCUSSION

Effect of parameters on die width

Level No	Peak Current A	Pulse-ON B	Pulse OFF C	Wire Speed D	Wire Tension E
1	50.39	50.28	49.53	51.86	50.64
2	50.69	53.90	55.12	51.73	52.21
3	49.60	54.33	54.53	54.06	55.86
4	57.88				
5	51.85				
6	57.2				
DELTA	8.28	4.26	5.59	3.40	5.23
RANK	1	4	2	5	3

Table 4 Response table for S/N ratio (Nominal is best)

Level No	Peak Current A	Pulse-ON B	Pulse OFF C	Wire Speed D	Wire Tension E
1	10.07	10.08	10.07	10.06	10.07
2	10.07	10.05	10.05	10.06	10.05
3	10.08	10.05	10.07	10.06	10.06
4	10.06				
5	10.05				
6	10.04				
Delta	0.04	0.02	0.02	0.01	0.2
Rank	1	2	3	5	4

Table 5 Response Table for Mean

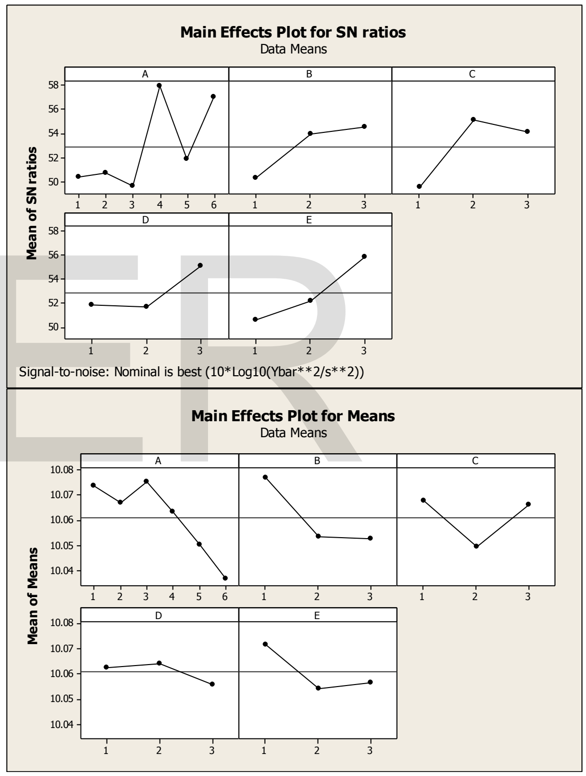


Fig 4 Main Effect Plot for S/N ratio and MEAN

The ANOVA of the raw data is obtained with the help of MINITAB 15 and is given in table 6 and 7. Here in these tables Seq SS= Sum of squares, DOF= degree of freedom, Adj SS= adjusted SS, Adj MS= adjusted mean square or variance.

Source	DOF	Seq. SS	Adj SS	Adj MS	F	P
A	5	1.17	1.17	0.235	15	0.01
B	2	42.9	42.9	21.48	13	0.00
C	2	41.0	41.0	20.52	13	0.00
D	2	0.34	0.34	0.171	11	0.02
E	2	0.13	0.13	0.067	4	0.09
Error	4	0.06	0.06	0.015		
Total	17	85.7				

Table 6 ANOVA for S/N data

Source	DOF	Seq. SS	Adj SS	Adj MS	F	P
A	5	0.09	0.09	0.01	1	0.34
B	2	3.49	3.49	1.74	14	0.00
C	2	3.53	3.53	1.76	14	0.00
D	2	0.00	0.00	0.00	0	0.93
E	2	0.01	0.01	0.00	0	0.50
Error	4	0.04	0.04	0.01		
Total	17	7.19				

Table 7 ANOVA for MEAN

Predicted optimal value of surface roughness is = (A4+B3+C2) – T_{avg} = 10.06 mm.

Effect of parameters on surface roughness

Average value of surface roughness is 2.81. Main effects of each parameter are calculated from response table 8 and 9 and shown in fig 5. These effects are plotted using MINITAB 15.

Level No	Peak Current A	Pulse-ON B	Pulse OFF C	Wire Speed D	Wire Tension E
1	-8.840	-8.653	-9.426	-8.885	-8.954
2	-8.996	-8.888	-8.829	-9.037	-9.176
3	-8.355	-9.321	-8.940	-8.940	-8.731
4	-8.427				
5	-9.370				
6	-9.734				
Delta	1.379	0.669	0.820	0.151	0.445
Rank	1	3	2	5	4

Table 8 Response Table for S/N Ratios (Smaller is better)

Level No	Peak Current A	Pulse-ON B	Pulse OFF C	Wire Speed D	Wire Tension E
1	2.765	2.713	2.963	2.785	2.811
2	2.818	2.790	2.766	2.837	2.881
3	2.628	2.925	2.699	2.807	2.737
4	2.642				
5	2.940				
6	3.063				
Delta	0.435	0.212	0.264	0.052	0.144
Rank	1	3	2	5	4

Table 9 Response Table for Means

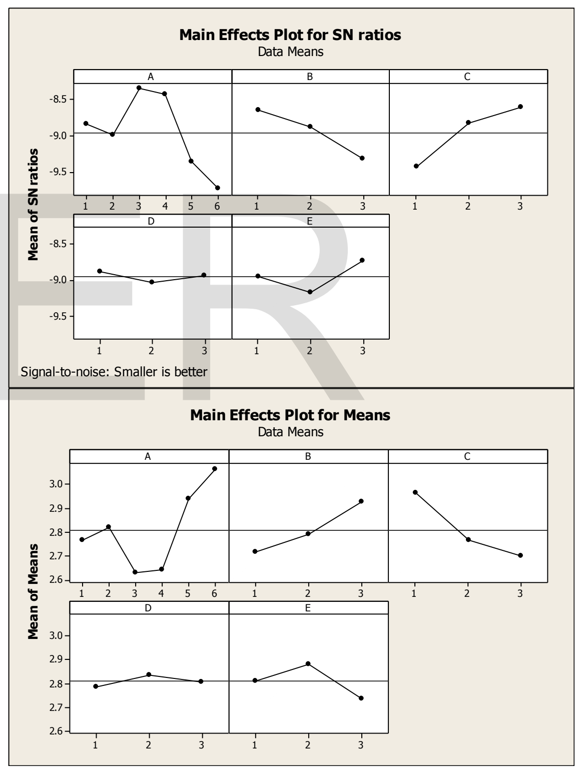


Fig 5 Main Effect Plot for S/N ratio and MEAN

It is clear from the S/N plots the maximum S/N ratio occurs correspond to A3, B1, C3, and D1and E3.

In order to study the significance of process parameters toward the Surface Roughness, analysis of variance (ANOVA) is performed.

The ANOVA of the raw data and S/N data are given in table 10 and 11.

Source	DOF	Seq. SS	Adj SS	Adj MS	F	P
A	5	4.2	4.2	0.85	2	0.15
B	2	1.3	1.3	0.69	2	0.20
C	2	2.1	2.1	1.07	3	0.12
D	2	0.0	0.0	0.03	0	0.88
E	2	0.5	0.5	0.29	1	0.43
Error	4	1.1	1.1	0.28		
Total	17	9.6				

Table 10 ANOVA for S/N Data

Source	DOF	Seq. SS	Adj SS	Adj MS	F	P
A	5	0.43	0.43	0.086	3	0.15
B	2	0.13	0.13	0.068	2	0.20
C	2	0.22	0.22	0.113	3	0.11
D	2	0.00	0.00	0.004	0	0.87
E	2	0.06	0.06	0.031	1	0.41
Error	4	0.11	0.11	0.028		
Total	17	0.98				

Table 11 ANOVA for Mean Data

Predicted optimal value of surface finish is = (A3+B1+C3+D1+E3- 4Tavg) = 2.32μm

Effect of parameters on cutting speed

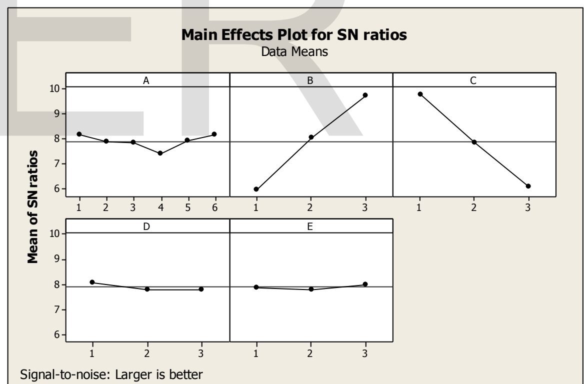
Average value of Cutting speed, calculated from raw data is 2.59mm/min. it is clear from the S/N plots the maximum S/N ratio occur corresponding A6, B3, C3, D1 and E3. Therefore the optimum value will be corresponds to these factor but the only significant factor would be chosen. This factor will be chosen from the ANOVA table.

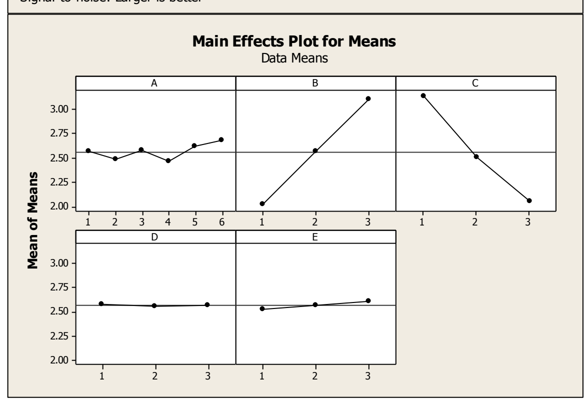
Level No	Peak Current A	Pulse-ON B	Pulse OFF C	Wire Speed D	Wire Tension E
1	8.161	5.937	9.773	8.089	7.894
2	7.862	8.032	7.837	7.811	7.789
3	7.839	9.714	6.075	7.784	8.001
4	7.410				
5	7.914				
6	8.181				
Delta	0.771	3.777	3.698	0.305	0.212
Rank	3	1	2	4	5

Table 12 Response table for s/n ratio (larger is better)

Level No	Peak Current A	Pulse-ON B	Pulse OFF C	Wire Speed D	Wire Tension E
1	2.560	2.023	3.133	2.574	2.523
2	2.485	2.561	2.502	2.551	2.562
3	2.578	3.103	2.052	2.562	2.603
4	2.463				
5	2.613				
6	2.673				
Delta	0.210	1.079	1.081	0.023	0.080
Rank	3	2	1	5	4

Table 13 Response table for mean





The ANOVA of the raw data and S/N data are given in table 14 and 15.

Source	DOF	Seq. SS	Adj SS	Adj MS	F	P
A	5	1.1	1.1	0.23	15.14	0.01
B	2	42	42	21.4	1382	0.00
C	2	41	41	20.5	1320	0.00
D	2	0.3	0.3	0.17	11.02	0.02
E	2	0.1	0.1	0.06	04.34	0.09
Error	4	0.0	0.0	0.01		
Total	17	85	85			

Table 5.4 ANOVA for S/N data

Source	DOF	Seq. SS	Adj SS	Adj MS	F	P
A	5	0.0	0.0	0.0	1.5	0.3
B	2	3.4	3.4	1.7	147	0.0
C	2	3.5	3.5	1.7	147	0.0
D	2	0.0	0.0	0.0	0.0	0.9
E	2	0.0	0.0	0.0	0.0	0.5
Error	4	0.0	0.0	0.0		
Total	17	7.1				

Table 5.5 ANOVA for MEAN

Optimal value of cutting speed = (A6+B3+C1+D1 - 3T_{Avg}) = 3.71mm/min

CONFIRMATION EXPERIMENT

Confirmation experiment is conducted for the cutting speed, die width and for surface roughness.

Quality characteristic	Predicted optimal value of quality characteristic	Confirmation experimental Value
Cutting speed	3.71 mm/min.	3.60 mm/min
Die Width	10.06 mm	10.05mm
Surface Roughness	2.32µm	2.40 µm

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