Parametric Analysis And Mathematical Modelling Of MRR And Surface Roughness For H-11 Material On Wire Cut EDM By D.O.E Approach

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ABSTRACT

at present Industrial application needs the use of advanced materials like tool steels, super alloys, ceramics, and composites with high precision and high surface quality. These materials are hard and difficult to machine. To meet these challenges, non-conventional machining processes are being employed to achieve higher metal removal rate, better surface finish and greater dimensional accuracy.

Wire electric discharge machining (WEDM) is a specialized controlled discrete spark erosion non conventional machining process capable of accurately machining parts having complex shapes irrespective of material hardness. WEDM becomes a competitive and economical machining option which fulfils the requirement of short product development cycle. This process is affected by so many control parameters. WEDM is a complex machining process controlled by a large number of process parameter such as Pulse duration, Specific energy, discharge frequency and discharge current intensity. For optimal machining performance the setting of various input parameters plays a crucial role on output viz. Material removal rate, Surface roughness, kerf width, Little change in one parameter greatly affect the output. Hence process parameter optimization needs for variety of material. In present an attempt is made to investigate the effect of varying pulse on time, pulse off time, flushing pressure, servo voltage, wire feed rate and wire tension on H-11 material to analyze effect on the Material Removal Rate and Surface finish using ANOVA analysis and multi response Taguchi base optimization will be carried out.

A Taguchi design of experiment (DOE) approach with L27 Orthogonal Array employed to conduct this experiment. Newest software was used to perform the ANOVA (analysis of Variance) and confirmation test conducted to verify as well as compare the results from the theoretical prediction using software. And In this produces higher mathematical modelling; develop scalar measurement software tool in VB-6 for measurement of kerf width, and another software tool based on mathematical model.

Keywords- WEDM, ANOVA, MRR, SR, Mathematical Modelling, R-Squared Value

I. INTRODUCTION

WEDM is a non conventional thermo electric material removal method for conductive materials to cut intricate shapes and profiles with a thin wire electrode. The electrode is a thin wire of a diameter 0.05 – 0.25 mm copper or brass coated with molybdenum. As wire feeds from reel to reel, material is eroded from work material by a series of discrete sparks occurring between the work piece and the wire under the presence of dielectric fluid which is continuously fed to the machining zone [1]. The WEDM process makes use of electrical energy generating a channel of plasma between the cathode and anode [2] and turns it into thermal energy at a temperature in the range of 8000–12,000 ºC [3]. When the pulsating direct current power supply occurring between 20,000 and 30,000 Hz is turned off, the plasma channel breaks down. This causes a sudden reduction in temperature allowing circulating dielectric fluid to implore plasma channel and flush molten particles from the pole surfaces in form of microscopic debris [4]. Erosion of metals by spark was first reported by Joseph Priesily in 1978, however controlled machining by sparks was first introduced by Lazarenko in Russia in 1944. The first British patent was granted to Rudorff in 1950 [5]. In 1974 D.H. Dulebohn applied optical-line follower system to automatically control shape of component to be machined by WEDM process [6]. By 1975, its popularity was rapidly increasing, as the process and its capabilities were better understood by the industry.

II. EXPERIMENTAL PROCEDURE

A. Material specification

Wire-cut EDM is commonly used when low residual stresses are desired, because it does not require high cutting forces for removal of material. H-11 is a Die tool steel. This can be used in the toughened condition. H-11 offers high corrosion resistance, wear strength and high hardness. The chemical composition tested at Malguru Trading co, Kadi of the selected work material is shown in Table 1.

Chemical	Obtained Value	Required Value
Carbon	0.39	0.32 - 0.45
Chromium	5.12	4.75 - 5.5
Manganese	0.35	0.2 - 0.5
Molybdenum	1.7	1.1 - 1.75
Phosphorus	0.03	0.03 max
Silicon	1.1	0.8 - 1.2
Sulphur	0.02	0.03 max
Vanadium	0.95	0.8 - 1.2

Table 1 Material specification: H11

H-11 Material generally used in Hot-work forging, Extrusion, Manufacturing punching tools, Mandrels, Mechanical press forging die, Plastic mould, Die-casting dies, Aircraft landing gears, Helicopter rotor blades and shafts, etc.

B. Number of reading optimization based on Taguchi method

Control factors along with their levels are listed in Table 2. Full factorial design of experiments would require a large no. of runs; Hence Taguchi based design of experiment method was implemented. In Taguchi method Orthogonal Array provides a set of well balanced experiments, and Taguchi's signal-to-noise. (S/N) ratios, which are logarithmic functions of the desired output, serve as objective functions for optimization. It helps to learn the whole parameter space with a minimum experimental runs. Taguchi replaces the full factorial experiments with a lean, less expensive, faster partial factorial experiment. L27 Orthogonal array obtain based on the control factors.

Machining process Parameter		Level		
		1	2	3
1	Pulse On Time (µs)	110	120	130
2	Pulse Off Time (µs)	40	50	60
3	Flushing Pressure (kgf/cm2)	10	12	14
4	Wire Tension (gms)	660	900	1140
5	Servo Voltage (volts)	20	30	40
6	Wire Feed Rate(m/min)	4	8	12

C. Experimental setup

In this Experiment carried out by varying six control factors on Ultracut f1 machine of Electronica Pvt. Limited. Molybdenum coated brass wire of 0.25 mm diameter was used.

D. Specimen detail

Total 27 nos. of experiments has been carried out by slit on rectangle plate 30cm x 6cm x 1.2 cm of H-11 material. Peak current selected as constant. Specimen after machining for each thickness level shown in fig 1. Mass of material removal is calculated based on mass difference and theoretically based on kerf width. MRR is calculated based on it in mm3 /min. Surface roughness measured precisely with help of roughness tester Mitutoyo SJ-201P.

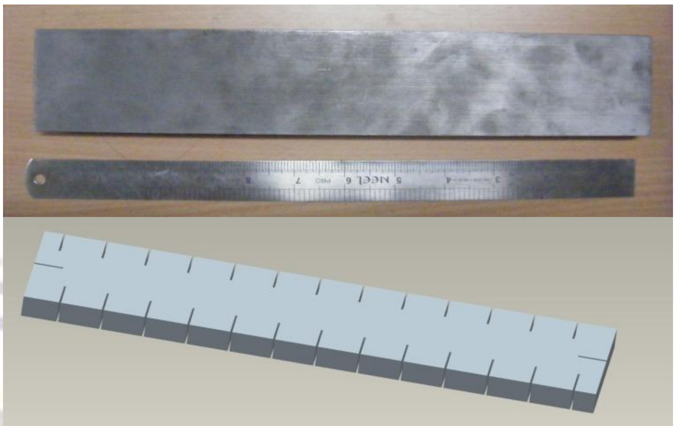

Figure 1 Raw material And Plan of experiment

III. Analysis And Results

A. Experimental Result

No	Pulse On Time	Pulse Off Time	Flushing Pressure	Wire Tension	Servo Voltage	Wire Feed Rate	MRR	SR
1	110	40	10	660	20	4	4.2002	3.3433
2	110	40	10	660	30	8	5.2373	2.9567
3	110	40	10	660	40	12	5.5358	2.7183
4	110	50	12	900	20	4	3.8817	3.2983
5	110	50	12	900	30	8	3.2681	3.0700
6	110	50	12	900	40	12	2.7243	2.6600
7	110	60	14	1140	20	4	2.1764	3.0883
8	110	60	14	1140	30	8	1.9229	2.7515
9	110	60	14	1140	40	12	1.6930	2.3967
10	120	40	12	1140	20	8	8.8227	3.2033
11	120	40	12	1140	30	12	6.8754	3.2255
12	120	40	12	1140	40	4	6.9591	3.3217
13	120	50	14	660	20	8	4.7662	3.2267
14	120	50	14	660	30	12	4.6112	3.3083
1	12	50	14	660	40	4	4.1	3.0

5	0						605	883
16	120	60	10	900	20	8	2.8299	3.2650
17	120	60	10	900	30	12	2.4744	3.4333
18	120	60	10	900	40	4	2.6198	3.1200
19	130	40	14	900	20	12	6.1622	3.9700
20	130	40	14	900	30	4	5.2004	3.3917
21	130	40	14	900	40	8	5.1926	2.6817
22	130	50	10	1140	20	12	4.9716	3.4817
23	130	50	10	1140	30	4	5.1677	3.4267
24	130	50	10	1140	40	8	3.8124	3.5083
25	130	60	12	660	20	12	3.9128	3.5383
26	130	60	12	660	30	4	4.5731	3.2767
27	130	60	12	660	40	8	3.9785	3.1550

B. DOE Analysis

Response surface methodology (RSM) is a technique that can be used to develop, improved and optimized process using a collection of statistical and mathematical techniques. This method has been applied in product development activities as well as improvement to the existing product. RSM is used in industry to analyse several input variables that will influence performance or quality characteristic of the product or process. The performance or quality characteristic is known as a response. In most cases, there will be more than one response in the application of RSM. RSM analysis on my experimental work by newest software.

Design Summary

Study Type	Response Surface	Runs	27
Design Model	Quadratic	Blocks	No Blocks

Factor	Coded Values		Mean	Std. Dev.
A	-1.000=110.00	1.000=130.00	120	8.164966
B	-1.000=40.00	1.000=60.00	50	8.164966
C	-1.000=10.00	1.000=14.00	12	1.632993
D	-1.000=660.00	1.000=1140.00	900	195.9592
E	-1.000=20.00	1.000=40.00	30	8.164966
F	-1.000=4.00	1.000=12.00	8	3.265986

C. Result Discussion for Material Removal Rate (MRR)

Std. Dev.		R-Squared	1
Mean	17.57259	Adj R-Squared	
C.V. %		Pred R-Squared	N/A
PRESS	N/A	Adeq Precision	1.6E-307

R1	=
20.41778	
3.978889	* A
3.005556	* B
-8.08056	* C
-5.49333	* D
2.638889	* E
-1.72278	* F
-8.13778	* A * B
-5.42556	* A * C
-2.78778	* A * E
3.438889	* A * F
4.565	* B * C
1.428889	* B * E
0.246111	* B * F
-0.83722	* C * E
0.622222	* C * F
0.55	* D * E
5.223889	* E * F
-1.02889	* A^2
-1.12889	* E^2
0.5	* A * B * E
0.736667	* A * B * F
-1.27	* A * C * E
2.013333	* A * C * F
-0.775	* B * C * E
0.295	* B * E * F
-6.33	* B * C * E * F

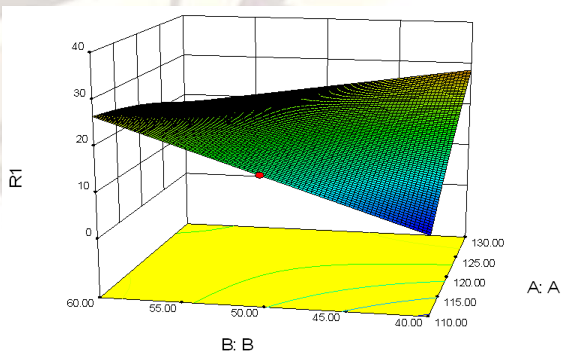

Figure 2 Factor A-B vice R1 3D Graph

MRR increases with increasing Pulse On time and decreasing with increasing Pulse OFF time. There is little effect of thickness and Flushing pressure over MRR. ANOVA analyses calculate F-ratio for Pulse ON time 17.58 and for Pulse Off time 62.5. Percentage contribution of Pulse on time and Pulse off time is based on ANOVA is 17.08 % and 60.78 % respectively. And Mathematical model is 100% Correct found.

Increasing pulse on time sustain spark for longer period so more thermal energy is generated which leads to increase material removal rate. Pulse Off time controls length of time that the electricity applied to wire is turned off between each spark. During off time particles are flushed out of the gap. Increasing off time mean slower cutting, increased stability and less wire breakage. Sufficient flushing pressure is needed for proper functioning. In sufficient flushing lead to wire breakage because of obstructing plasma channel. Increasing flushing pressure with increase Pulse on time necessary for higher MRR.

D. Result Discussion for Surface Roughness (SR*)*

Std. Dev.		R-Squared	1
Mean	2.682222	Adj R-Squared	
C.V. %		Pred R-Squared	N/A
PRESS	N/A	Adeq Precision	0

R2	=
2.397778	
-0.57778	* A
0.234167	* B
0.098333	* C
0.2475	* D
-0.24333	* E
0.568889	* F
0.288333	* A * B
0.151667	* A * C
0.758333	* A * E
-0.78778	* A * F
-0.08	* B * C
-0.35667	* B * E
0.2	* B * F
0.015833	* C * E
0.2825	* C * F
-0.08917	* D * E
-0.75806	* E * F
0.164444	* A^2
0.173056	* E^2
0.27	* A * B * E
-0.06167	* A * B * F
-0.135	* A * C * E
-0.16333	* A * C * F
-0.1925	* B * C * E
-0.1775	* B * E * F
0.2675	* B * C * E * F

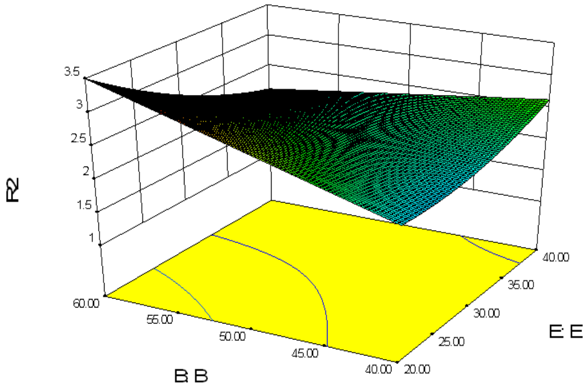

Figure 3 Factor B-E vice R2 3D Graph

Fig.3 shows that Surface Roughness is affected by Material Thickness, Pulse on Time, Wire Tension and Servo voltage. ANOVA analyses calculate F-ratio for all parameters. Percentage contributions of Pulse on time, Material Thickness are more. Increasing pulse on time sustain spark for longer period so more thermal energy is generated which leads to increase material removal rate.

Resulting craters will be broader and deeper; therefore the surface finish will be rougher. Increasing thickness spread thermal energy over larger area, hence burnout surface is less, resulting higher surface finish. Servo voltage maintains the gap properly. Lower the value smaller the kerf width. Higher the servo voltage higher is gap which increase plasma channel. Increasing wire tension increase surface roughness.

IV. CONCLUSION

This paper presents analysis of various process parameters and drawn following conclusions from the experimental study:

- Process parameters affect different response in different ways. Hence need to set parameter based on requirement.
- MRR increase by increasing Pulse on Time, flushing pressure and reduces with increasing Pulse OFF Time.
- Increasing Pulse ON Time also increase Surface Roughness.
- Material Thickness has little effect on MRR but it has significant effect over surface finish. Increasing Thickness reduces Surface Roughness and increase surface finish.
- Little interaction effect found for Surface Roughness between wire tension and flushing pressure.
- And 4th order mathematical model 100% suitable for this experiment prediction
- And develop a new software tool based on mathematical model for eyases calculation.

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REFERENCES

[1] Puri, A.B.; Bhattacharyya, B. (2003): An analysis and optimization of the geometrical inaccuracy due to wire lag phenomenon in WEDM, *International Journal of Machine Tools Manufacturing. 43, 2, pp.151–159.*

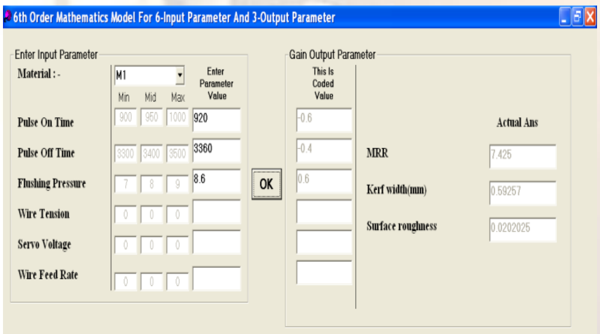
[2] Shobert, E.I. (1983): What happens in EDM, Electrical Discharge Machining: Tooling, Methods and applications, *Society of manufacturing Engineers, Dearbern, Michigan, pp. 3–4.*

[3] Boothroyd, G.; Winston, A.K. (1989): Non-conventional machining processes, *Fundamentals of Machining, Marcel Dekker, Inc, 491.*

[4] E.C. Jameson, Description and development of electrical discharge machining (EDM), Electrical Discharge Machining, *Society of Manufacturing Engineers, Dearbern, Michigan, 2001, pp. 16.*

[5] P.K. Mishra, Non conventional Machining, *Narosa Publishing House, Delhi, 2005, pp. 86 .*

APPENDIX-A

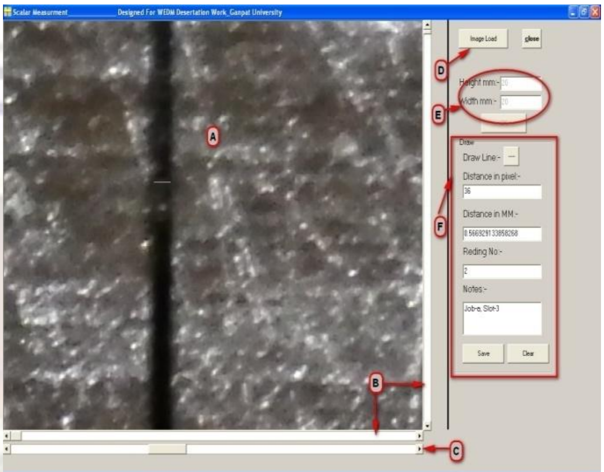


MATHEMATICAL MODEL SOFTWARE

```
Coding:-

Dim A As Integer
Dim B As Integer
Dim C As Integer
Dim D As Integer
Dim E As Integer
Dim F As Integer
Dim R1 As Double
Dim R2 As Double
Dim R3 As Double
Dim C1 As Double
Dim C2 As Double
Dim C3 As Double
Dim y1 As Double
Dim y2 As Double
Dim y3 As Double
Dim s1 As Integer
Dim s2 As Integer
Dim s3 As Integer
Dim b1 As Integer
Dim b2 As Integer
Dim b3 As Integer
Dim m1 As Integer
Dim m2 As Integer
Dim m3 As Integer
Private Sub Combo1_Click()
If Combo1.Text = "M1" Then
  Text11 = 1000
  Text10 = 900
  Text13 = 3500
  Text12 = 3300
  Text15 = 9
  Text14 = 7
ElseIf Combo1.Text = "M2" Then
  Text11 = 1000
  Text10 = 900
  Text13 = 3500
  Text12 = 3300
  Text15 = 2
  Text14 = 1
ElseIf Combo1.Text = "M3" Then
End If
Text22 = (Val(Text11) + Val(Text10)) / 2
Text23 = (Val(Text13) + Val(Text12)) / 2
Text24 = (Val(Text15) + Val(Text14)) / 2
End Sub

Private Sub Command2_Click()
y1 = Text16
y2 = Text17
y3 = Text18
s1 = Text10
s2 = Text12
s3 = Text14
b1 = Text11
b2 = Text13
b3 = Text15
m1 = Text22
m2 = Text23
m3 = Text24

If y1 > m1 Then
Text1 = (y1 - m1) / (b1 - m1)
Else
Text1 = (y1 - m1) / (m1 - s1)
End If
If y2 > m2 Then
Text2 = (y2 - m2) / (b2 - m2)
Else
Text2 = (y2 - m2) / (m2 - s2)
End If
```

```
[73]
[74]  IF Y3 > M3 THEN
[75]  TEXT3 = (Y3 - M3) / (B3 - M3)
[76]  ELSE
[77]  TEXT3 = (Y3 - M3) / (M3 - S3)
[78]  END IF
[79]  A = VAL(TEXT1.TEXT)
[80]  B = VAL(TEXT2.TEXT)
[81]  C = VAL(TEXT3.TEXT)
[82]  'D = TEXT4.TEXT
[83]  'E = TEXT5.TEXT
[84]  'F = TEXT6.TEXT
[85]  IF COMBO1.TEXT = "M1" THEN
[86]  ADD MODEL
[87]   ELSEIF COMBO1.TEXT = "M2" THEN
[88]   ADD MODEL
[89]  ELSEIF COMBO1.TEXT = "M3" THEN
[90]  END IF
[91]  TEXT7 = R1
[92]  TEXT8 = R2
[93]  TEXT9 = R3
[94]  END SUB
[95]  PRIVATE SUB FORM_LOAD()
[96]  LABEL2.CAPTION = "PULSE ON TIME"
[97]  LABEL3.CAPTION = "PULSE OFF TIME"
[98]  LABEL4.CAPTION = "FLUSHING PRESSURE"
[99]  LABEL5.CAPTION = "WIRE TENSION"
[100] LABEL6.CAPTION = "SERVO VOLTAGE"
[101] LABEL7.CAPTION = "WIRE FEED RATE"
[102] LABEL8.CAPTION = "MRR"
[103] LABEL9.CAPTION = "KERF WIDTH(MM)"
[104] LABEL10.CAPTION = "SURFACE
      ROUGHNESS"
[105] END SUB
```

APPENDIX-B



KERF WIDTH MEASUREMENT SOFTWARE