Study of the Influence of the Input parameters of Wire Electro Discharge Machining on the Cutting Speed and Gap Current of H11 tool steel using Correlation – Regression and ANOVA

Tenzing Dorjee Pradhan

Senior Lecturer, Advanced Technical Training Centre, Bardang, Singtam, Sikkim, India

Abstract— **Setting up of the Input parameters in a multi input machining setup like the Wire Electro Discharge Machine (WEDM) also known as WireEDM is a very difficult task. This is due to the fact that the multiple measurable outputs are dependent on, most of the time, a combination of the Input variables and rarely are dependent solely on one of the input parameters. Researchers are continuously studying the relationship between the Input variables and the output responses. Machining of H11 tool steels in WEDM is and area where research has been few. Since H11 tool steel is one of the most commonly used chromium hot work steels, the author has taken up for study of the same.**

This work deals with the study of influence of the input parameters selected, i.e Pulse on time (Ton), Pulse off time (Toff), Peak Current (Ip) and Wire feed (Wf) on the Cutting Speed (CS) and Gap Current (GC) using Correlation-Regression analysis and ANOVA.

A L16 orthogonal array based on Taguchi method was designed. The relationship was studied using ANOVA and linear regression.

Keywords—**ANOVA, Orthogonal array, Regression, WEDM.**

I. INTRODUCTION

There has always been a demand of the manufacturers of WEDM on the study of the process parameters and their influences on the output responses of various materials. There has always been a research gap as the number of materials being machined in WEDM is innumerable and thus innumerable possibilities. The author has taken up H11 tool steel as a material for the study of the influence of few of the important machining parameters against the output responses.

II. LITERATURE REVIEW

Hatchek [1] reports that the thickness of the workpiece has a major influence on the cutting speed, whereby thicker the material faster the cut. He had concluded that since there is a longer length of wire electrode in a thicker work piece , it provides for more of an opportunity for the occurrence of the spark. **Nihat Tosun et.al [2]** had investigated the effect with an optimization of the machining parameters on the cutting width also known as kerf and material removal rate (MRR) in wire electrical discharge machining (WEDM) operations. They had conducted the experiments under varying pulse duration, open circuit voltage, wire speed and dielectric flushing pressure. Taguchi Experimental design was used for designing of the experiments. **H.Singh et al [3]** in his research had concluded that the material removal rate (MRR) was directly increasing with the increase in the pulse on time (Ton) and also the peak current while it also decreased with the increase in the (Toff) pulse off time and the (SV) Servo Voltage. **Sonum Dhiman et al [4]** in their experiment on S7 steel using WEDM found out that the cutting rate (CR) increased with the pulse on time but only upto a certain range after which the MRR started decreasing. It also decreased with the increase of pulse duration and the servo voltage. There was also an increase in CR with the increase in the peak current. There however was not effect of Wire Feed and Wire Tension on the CR. **Trezise [5]** in the report had concluded that the fundamental limit on machining accuracy depends solely on the dimensional consistency of the wire and also on the positional accuracy of the worktable. **et.al [6]** had found a relation between the wire vibrations which occur during the machining processes in the wire and the occurrence of short circuits, which resulted in lower cutting speeds and an increased possibility of wire rupture. **Sho et al. [7]** reported that the machining rates increase with increase in zinc (Zn) content in the wire. This was due to the 'heat sink' effect produced in the wire by the zinc coating thereby cooling the core of the wire.

The above mentioned work highlights that the process parameters like Voltage, Current, Ton, Toff dominates the output parameters namely MRR, Surface Roughness etc.

III. EXPERIMENTS CONDUCTED

1) *Experimental Setup*

A. *Workpiece* - H11 tool steel was chosen as the material for the study and optimisation. The reasons for the same being:-

- Not much research has been made for study of H11 steel in wire EDM process

- It is suitable for designing highly stressed structural parts such as aircraft landing gear
- It is one of the most predominantly used Chromium Hot Work tool steel

The size of the specimen is at 20mm X 60mm with the thickness kept at 10mm.

The hardness of the specimen was measured at 52.5 (Rockwell C) air-cooled from 982°C, 45 minutes.

B. *Machine used* – Electronica Sprintcut – 734 was used with the electrode/wire being soft brass of 0.25 mm diameter and the dielectric used was de-ionised or distilled water. 4 axes CNC with precision guideways

a) Maximum cutting speed of 160 mm^2/min
b) Best surface finish – 0.8 µ Ra
c) Taper ±30°/50 mm
d) Flushing pressure – 12 kgf
e) Wire feed (max) – 12m/min
f) Wire Tension – (max) – 12 grams
g) Voltage Range – 0 – 100 V

Figure 1 Wire EDM Sprintcut 734

h) Tool – Soft Brass wire of 0.25 mm thickness
i) Dielectric used – Deionized or Distilled water

C. *Input Variables Selected* :-

- Ton – Pulse On Time
- Toff – Pulse Off Time
- Ip – Peak Current
- Wf – Wire Feed

D. *Output response* –

a. **Cutting Speed (mm/min)** :- Cutting speed forms a very important criteria when calculating the MRR. The formula for calculation of MRR is given as :-

$$MRR = ktv_c\rho \text{ [7]} \qquad (1)$$

Where, k is the Kerf width (mm), *t* is the thickness of work piece (mm), *vc is* the Cutting speed (mm/min) and ρ is the Density of the work piece material (g/mm3).

Thus observation of this response is very important as it is used for calculation of MRR which is also one of the most important responses in Wire EDM. (Higher the CS value, better it is

b. **Gap Current (mA)** – This is one of the "bad" discharges in Wire EDM and badly affects the performance of the machine [8]. (Lower the value, better it is)

2) Design of Experiments

For the present work a 4 level 4 factor L16 factorial design was developed. **MINITAB** software has been used to design the orthogonal array for the present work.

The levels for the Input parameters selected, Pulse on Time (Ton), Pulse off time (Toff), Peak Current (Ip) and Wire Tension (WT) are shown in the Table 1 and the design matrix is depicted in Table 2

Table 1 Levels used for Input parameters

S. No	Parameter	Unit	Level			
			1	2	3	4
1	Ton	µsec	15	20	25	30
2	Toff	µsec	30	40	50	60
3	Ip	mA	140	160	180	200
4	WT	Machine units	5	6	7	8

3) Conduction Of Experiments

The experiments were conducted adhering strictly to the orthogonal array design. The roughness of surface was measured using **Mitutoyo's Surftest J210.**

4) Design Matrix

Table 2 Design matrix and Observation Table

Expt. Number	Input Process parameters			
	Ton	Toff	Ip	Wf
C1	1	1	1	1
C2	1	2	2	2
C3	1	3	3	3
C4	1	4	4	4
C5	2	1	2	3
C6	2	2	1	4
C7	2	3	4	1

C8	2	4	3	2
C9	3	1	3	4
C10	3	2	4	3
C11	3	3	1	2
C12	3	4	2	1
C13	4	1	4	2
C14	4	2	3	1
C15	4	3	2	4
C16	4	4	1	3

IV. RESULT AND DISCUSSION

1) Response Table

Table 3 shows the response table for the experiment conducted

Table 3 Response Table

Expt. No	Input Process parameters				Output	
	Ton	Toff	Ip	WT	GC	CS
C1	15	30	140	5	5.500	3.000
C2	15	40	160	6	3.000	3.190
C3	15	50	180	7	1.800	1.920
C4	15	60	200	8	1.000	1.250
C5	20	30	160	7	6.000	2.110
C6	20	40	140	8	4.800	3.500
C7	20	50	200	5	2.900	3.240
C8	20	60	180	6	1.000	1.200
C9	25	30	180	8	6.000	3.600
C10	25	40	200	7	7.000	3.300
C11	25	50	140	6	2.700	2.630
C12	25	60	160	5	1.200	1.900
C13	30	30	200	6	0.800	3.200
C14	30	40	180	5	5.500	3.000
C15	30	50	160	8	4.000	3.460
C16	30	60	140	7	2.500	1.800

2) Influences On Gap Current (GC)

A. *Graphs depicting the relationship between Input parameters and the response*

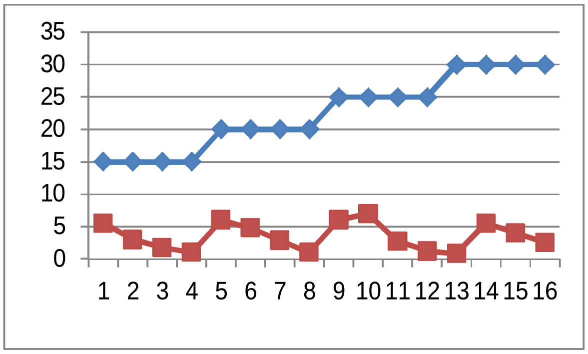

Figure 2 Ton vs GC

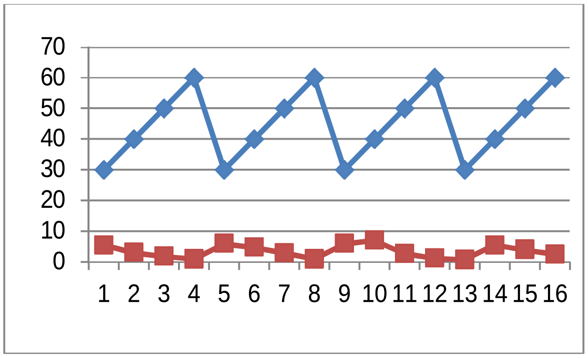

Figure 3 Toff vs GC

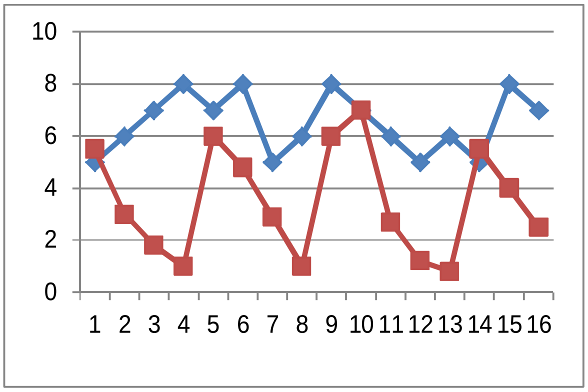

Figure 4 WT vs GC

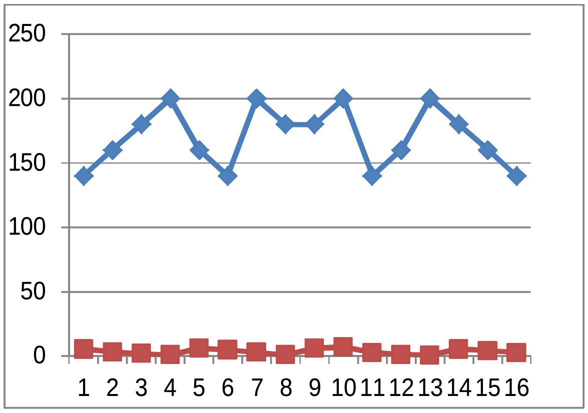

Figure 5 Ip vs GC

B. Karl Pearson Correlation

The Correlation Coefficient for Gap Current against the Input Parameters is calculated using the following formula:-

$$r = \frac{\sum_i (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_i (x_i - \bar{x})^2}\sqrt{\sum_i (y_i - \bar{y})^2}} \quad (1)$$

The following is a table of the correlation between the Gap Current and the Input Parameters. The table also gives a brief description of the result

Table 4 Correlation between Gap Current and Input Parameters

Sl. No	**Input Parameters**	**Corelation Coeeficient (r)**	**Coefficient of Determination (r^2)**	**Remarks**
1	Ton	0.092981	0.008645	The value of R is 0.093. Although technically a positive correlation, the relationship between your variables is weak (*nb*. the nearer the value is to zero, the weaker the relationship).
2	**Toff**	**-0.64809**	**0.420020**	**The value of R is -0.6481. This is a moderate negative correlation, which means there is a tendency for high X variable scores to go with low Y variable scores (and vice versa).**
3	Ip	-0.15682	0.024592	The value of R is -0.1568. Although technically a negative correlation, the relationship between your variables is only weak (*nb*. the nearer the value is to zero, the weaker the relationship).
4	WT	0.165145	0.027273	The value of R is 0.1651. Although technically a positive correlation, the relationship between your variables is weak (*nb*. the nearer the value is to zero, the weaker the relationship).

It was observed that the most influential parameter for Gap Current is Pulse Off Time (Toff)

The plot of graph in Figure 5.1 and the value of Correlation coefficient show that the Toff i.e. the Pulse off time has a major effect on the outcome of the Gap current and the influence is negative. Which means that higher the value of Toff, higher is the smaller is the Gap current. Since Gap current is a bad discharge, the value needs to be smaller thus a balanced value needs to be found for Toff.

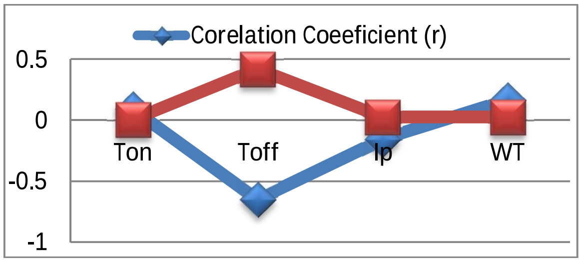

Figure 6 Correlation of Input parameters v/s GC

C. REGRESSION ANALYSIS

Using MINITAB software the regression equation was determined and the plot of actual to the predicted value was made.

The regression formula was found using the MINITAB software and the Regression equation is given below:-

Gap Current = 8.45 + 0.0335 Ton - 0.117 Toff - 0.0141 Ip + 0.298 WT (2)

Based upon (2), the following is the table depicting the Predicted and the Actual value with the error% also shown. The table 5 shows the same.

Table 5 Table showing values of GC (Predicted) and GC (Actual)

Expt. No.	GC(Predicted)	GC (Actual)
C1	5.0	5.5
C2	3.8	3.0
C3	2.7	1.8
C4	1.5	1.0
C5	5.4	6.0
C6	4.9	4.8
C7	1.9	2.9
C8	1.4	1.0
C9	5.6	6.0
C10	3.9	7.0
C11	3.3	2.7
C12	1.5	1.2
C13	4.9	0.8
C14	3.7	5.5
C15	3.7	4.0
C16	2.5	2.5

The residual plot of GC is shown in Figure 7. This residual plot in the graph and the interpretation of each residual plot indicate below.

1. Normal probability plot indicate outlines don't exist in the data, because standardized residues are between -4 and 4.

   Residuals versus fitted values indicate the variation is constant.

   Histogram shows the data are not skewed.
2. Residual versus order of the data indicate that systematic effects in the data due to time of data collection order.

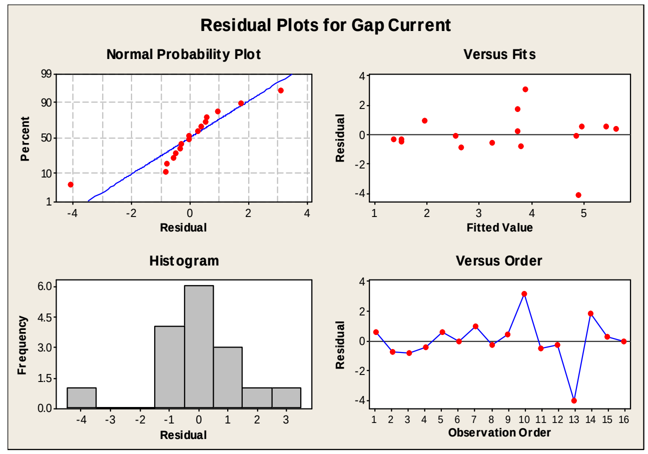

Figure 7 Residual Plots for Gap Current

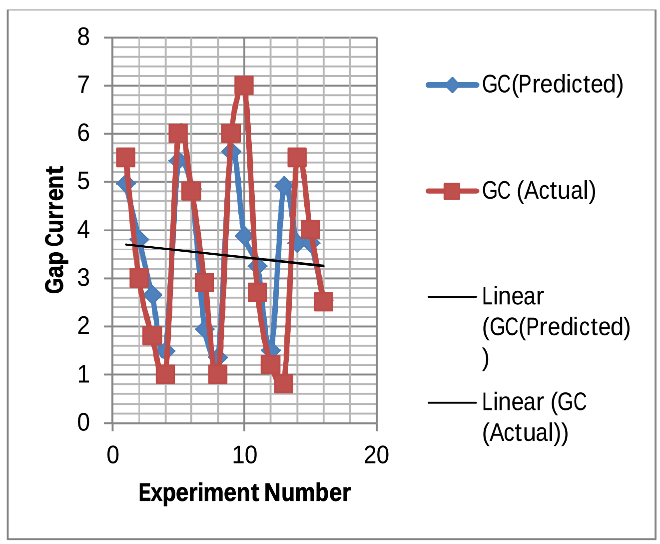

Figure 8 Graph for Predicted v/s Actual values for GC

D. ANOVA

ANOVA was performed using MINITAB software. A GLM was performed for which the following is the result.

Table 6 ANOVA for Gap Current

General Linear Model: Gap Current versus Ton, Toff, Ip, Wf

Factor	Type	Levels	Values
Ton	fixed	4	15, 20, 25, 30
Toff	fixed	4	30, 40, 50, 60
Ip	fixed	4	140, 160, 180, 200
Wf	fixed	4	5, 6, 7, 8

Analysis of Variance for Gap Current, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Ton	3	4.402	4.402	1.467	0.41	0.759
Toff	3	33.452	33.452	11.151	3.11	0.188
Ip	3	1.912	1.912	0.637	0.18	0.905
Wf	3	14.392	14.392	4.797	1.34	0.408
Error	3	10.747	10.747	3.582		
Total	15	64.904				

S = 1.89269 R-Sq = 83.44% R-Sq(adj) = 17.21%

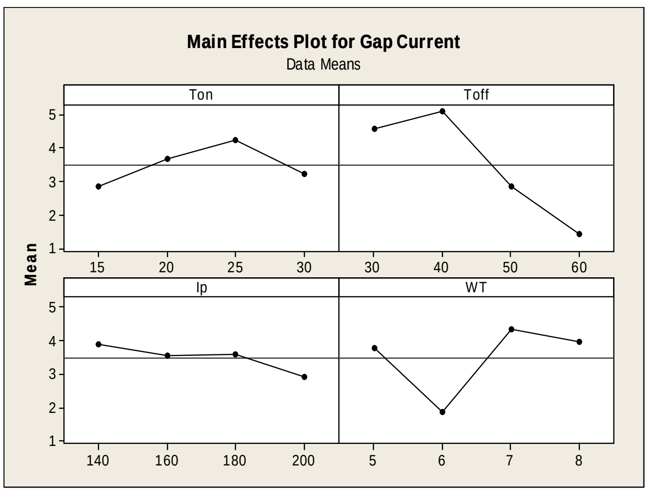

Figure 9 Graph for Predicted v/s Actual values for GC

The ANOVA strengthens the findings of the Correlation and also lists Toff as having the highest influence on Gap Current. The figure 9 shown the main effect plot of the parameters whereby it shows that the Gap Current has the lowest value when Toff is the highest

3. *Influence on Cutting Speed*

A. *Graphs depicting the relationship between Input parameters and the response*

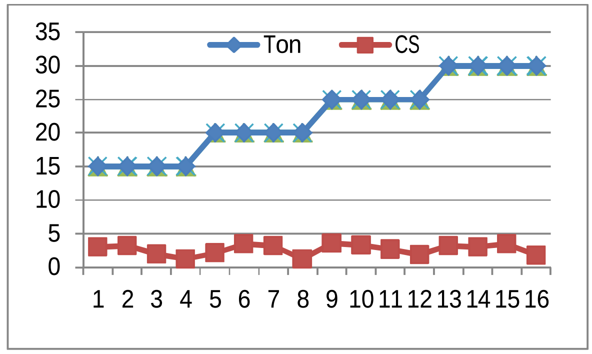

Figure 10 Ton vs CS

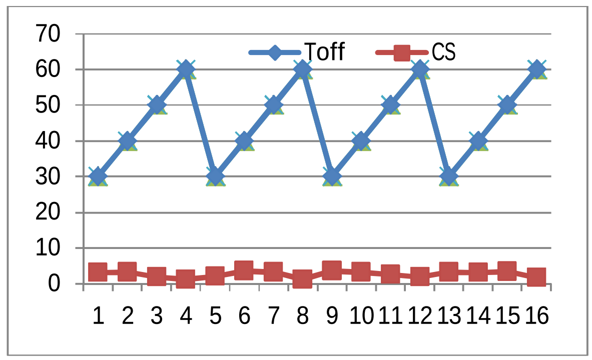

Figure 11 Toff vs CS

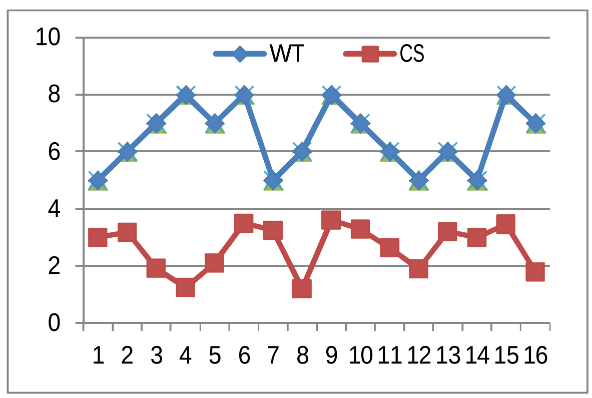

Figure 12 WT vs CS

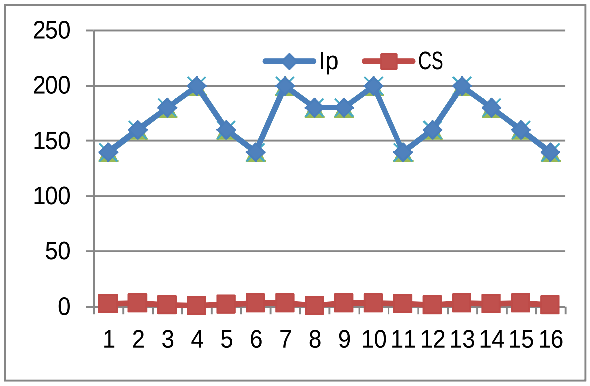

Figure 13 Ip vs CS

B. Karl Pearson Correlation

The Correlation Coefficient for Cutting Speed is also calculated as per equation given in (1)

The following is a table of the correlation between the Cutting Speed and the Input Parameters. The table also gives a brief description of the result

Table 7 Correlation between Cutting speed and Input Parameters

Sl. No	Input Parameters	Corelation Coeeficient (r)	Coefficient of Determination (r^2)	Remarks
1	Ton	0.270683	0.07327	The value of R is 0.2707. Although technically a positive correlation, the relationship between your variables is weak (*nb*. the nearer the value is to zero, the weaker the relationship).
2	**Toff**	**-0.67036**	**0.449388**	**The value of R is -0.6704. This is a moderate negative correlation, which means there is a tendency for high X variable scores to go with low Y variable scores (and vice versa).**
3	Ip	-0.02679	0.000718	The value of R is -0.0268. Although technically a negative correlation, the relationship between your variables is only weak (*nb*. the nearer the value is to zero, the weaker the relationship).
4	WT	0.032426	0.001051	The value of R is 0.0324. Although technically a positive correlation, the relationship between your variables is weak (*nb*. the nearer the value is to zero, the weaker the relationship).

It was observed that the most influential parameter for Cutting Speed is Pulse Off Time (Toff)

The plot of graph in Figure14 and the value of Correlation coefficient show that the Toff i.e. the Pulse off time has a major effect on the outcome of the Cuttings speed and the influence is negative. This means that higher the value of Toff, higher is the Cutting Speed.

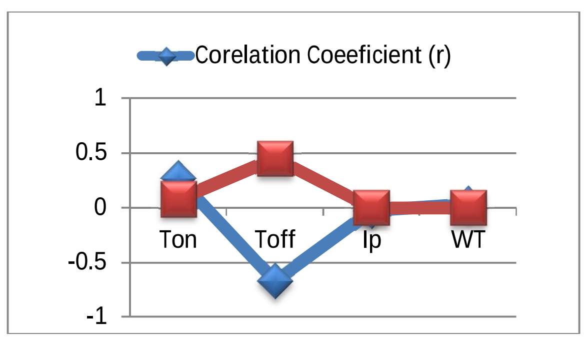

Figure 14 Correlation of Input parameters v/s CS

C. REGRESSION ANALYSIS

Using MINITAB software the regression equation was determined and the plot of actual to the predicted value was made.

The regression formula was found using the MINITAB software and the Regression equation is given below:-

CS = 3.93 + 0.0384 Ton - 0.0476 Toff - 0.00095 Ip + 0.023 WT **(3)**

Based upon (3), the following is the table number 8 is shown depicting the Predicted and the Actual value.

Table 8 Table showing values of CS (Predicted) and CS (Actual)

Expt. No.	CS (Predicted)	CS (Actual)
C1	3.06	3.00
C2	2.588	3.19
C3	2.116	1.92
C4	1.644	1.25
C5	3.279	2.11
C6	2.845	3.50
C7	2.243	3.24
C8	1.809	1.20
C9	3.475	3.60
C10	2.957	3.30
C11	2.515	2.63
C12	1.997	1.90
C13	3.602	3.20
C14	3.122	3.00
C15	2.734	3.46
C16	2.254	1.80

The following figures, Figure 15. And Figure 16 shows the residual plots for Cutting Speed and the Graph plot for predicted v/s Actual values of CS respectively

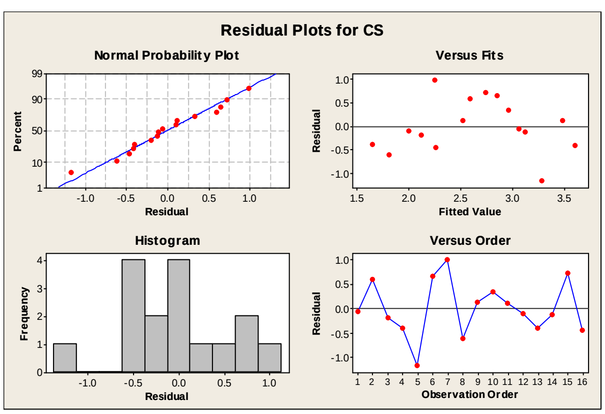

Figure 15 Residual Plots for Cutting Speed (CS)

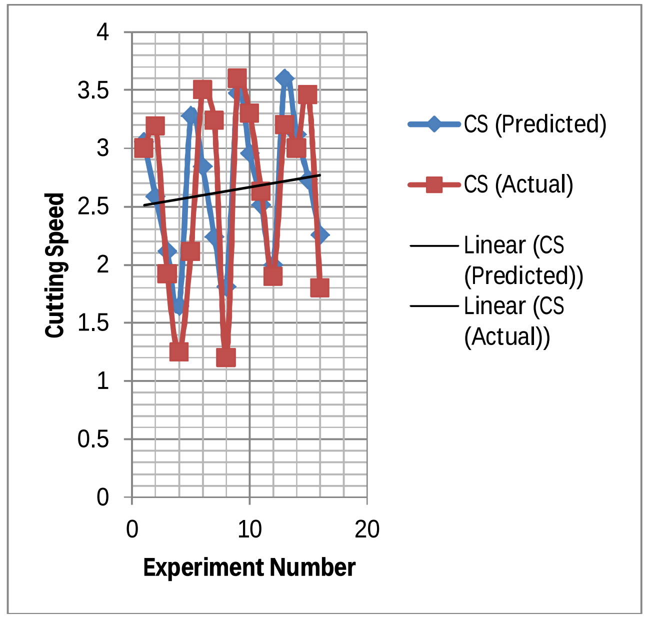

Figure 16 Graph for Predicted v/s Actual values for CS

D. ANOVA

ANOVA was performed using MINITAB software. A GLM was performed for which the following is the result as shown in table 9

Table 9 ANOVA FOR CUTTING SPEED CS

General Linear Model: CS versus Ton, Toff, Ip, Wf

```
Factor  Type   Levels  Values
Ton     fixed       4  15, 20, 25, 30
Toff    fixed       4  30, 40, 50, 60
Ip      fixed       4  140, 160, 180, 200
Wf      fixed       4  5, 6, 7, 8


Analysis of Variance for CS, using Adjusted SS
for Tests

Source  DF   Seq SS  Adj SS  Adj MS     F      P
Ton      3   0.8165  0.8165  0.2722  0.77  0.582
Toff     3   6.9127  6.9127  2.3042  6.52  0.079
Ip       3   0.2591  0.2591  0.0864  0.24  0.861
Wf       3   1.0146  1.0146  0.3382  0.96  0.514
Error    3   1.0596  1.0596  0.3532
Total   15  10.0626


S = 0.594313   R-Sq = 89.47%   R-Sq(adj) = 47.35%
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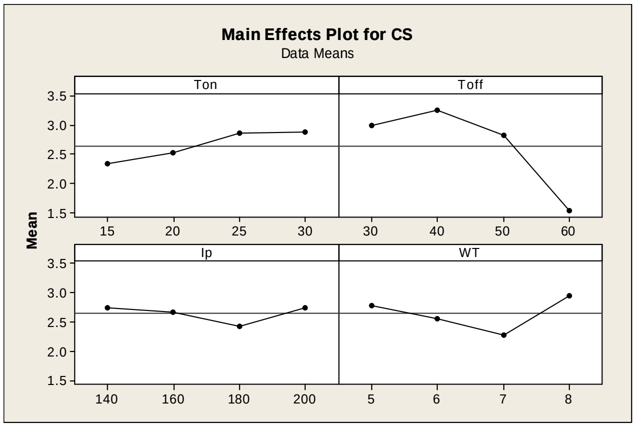

Figure 17 Main effect plot for CS

The ANOVA strengthens the findings of the Correlation and also lists Toff as having the highest influence on Cutting Speed. The figure 17 shown the main effect plot of the parameters whereby it shows that the Cutting speed has the highest value at Toff level 2.

V. CONCLUSION

This paper investigated the effects of the important input parameters on the Gap Current and the Cutting Speed of the material H11 in WEDM process.

The effect of Toff was found to be the highest for both the output responses with Ton also having an influence on the outcome.

REFERENCES

[1] Hatchek R. L, (Mar. 1984), “EDM Update '84”, American Machinist, pp. 113- 124.

[2] N. Tosun, C. Cogun, G. Tosun, A study on kerf and material removal rate in wire electrical discharge machining based on Taguchi method, [1] Journal of Materials Processing Technology 152 (2004) 316-322.

[3] Effects of process parameters on material removal rate in WEDM – H. Singh, R.Garg – Journal of Achievements in Materials and Manufacturing Engineering – Vol. 32 Issue 1 Jan 2009

[4] Analysis and Study the effects of various control factors of CNC-Wire Cut EDM for S7 steel – Sonum Dhiman, Ravinder Chaudhary, V.K. Pandey – Mechanical Engineering: An International Journal (MEIJ), Vol 1, No 1, May 2014

[5] Trezise K. E., (1982), “A Physicist’s view of Wire EDM”, Proceedings of the International Conference on Machine Tool Design and Research, Vol. (23), pp. 413-419

[6] Jennes, M., Snoeys, R., and Dekeyser, W.,(January 1984), “Comparison of various approaches to model the thermal load on the EDM- wire electrode”, Annals of CIRP, Vol. 33, pp.93- 98

[7] Sho H., Orimo T., and Fukui M., “The effect of electrode materials on the characteristics of machinability of wire electrode discharge machines”, Proceedings of the International symposium for “Electro Machining”, (ISEM-9), Nagoya, 1989, pp. 219- 222.

[8] Rajagopal K., and Noble C. F, (1979), “Some characteristics of wire electrode EDM” Proceedings of the 20th International Conference on Machine Tool Design and Research, Birmingham, pp. 557- 565.

[9] Scott D., Boyina S. and Rajurkar K. P., (1991), “Analysis and optimization of parameter combinations in Wire Electrical Discharge Machining”, International Journal of Production Research, Vol.29 (11), pp. 2189- 2207.

[10] Kim Chang Ho, Kruth Jean Pierre, (2001), “Influence of the Electrical Conductivity of dielectric on WEDM of Sintered Carbide”, Korean Society of Mechanical Engineers International Journal, Vol. 15, pp.1676- 1682.

[11] Y.S Tang, S.C. Ma, L.K. Chung (1995) “Determination of optimal cutting parameters in wire electrical discharge machining” International Journal of Machine Tools and Manufacture, Volume 35, Issue 12, December 1995, Pages 1693 – 1701

[12] Xiaoqian Sun, Yongchang Li - “An Intelligent Multi-Criteria Decision Support System for Systems Design” -, American Institute for Aeronautics and Astronautics

[13] Ahmet Hasçalýk, Ulaş Çaydaş - Experimental study of wire electrical discharge machining of AISI D5 tool steel Journal of Materials Processing Technology 148 (2004) 362–367

[14] Book title - High-speed Micro-electro-discharge Machining - By Shawn P. Moylan

[15] Zlatko Pavic, Vedran Novoselac – “Notes on TOPSIS Method” – International Journal of Research and Engineering and Science (IJRES) – ISSN 2320-9356 (2013)Volume 1 Issue 2 PP 05-12

[16] www.wikipedia.org