World Academy of Science, Engineering and Technology
International Journal of Mechanical and Mechatronics Engineering
Vol:4, No:10, 2010

CNC Wire-Cut Parameter Optimized Determination of the Stair Shape Workpiece

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***Abstract*—**The objective of this research is parameters optimized of the stair shape workpiece which is cut by CNC Wire-Cut EDM (WEDW). The experiment material is SKD-11 steel of stair-shaped with variable height workpiece 10, 20, 30 and 40 mm. with the same 10 mm. thickness are cut by Sodick's CNC Wire-Cut EDM model AD325L.

The experiments are designed by 3^k full factorial experimental design at 3 level 2 factors and 9 experiments with 2 replicate. The selected two factor are servo voltage (SV) and servo feed rate (SF) and the response is cutting thickness error. The experiment is divided in two experiments. The first experiment determines the significant effective factor at confidential interval 95%. The SV factor is the significant effective factor from first result. In order to result smallest cutting thickness error of workpieces is 17 micron with the SV value is 46 volt. Also show that the lower SV value, the smaller different thickness error of workpiece. Then the second experiment is done to reduce different cutting thickness error of workpiece as small as possible by lower SV. The second experiment result show the significant effective factor at confidential interval 95% is the SV factor and the smallest cutting thickness error of workpieces reduce to 11 micron with the experiment SV value is 36 volt.

***Keywords*—**CNC Wire-Cut, Variable Thickness Workpiece, Design of Experiments, Full Factorial Design

I. Introduction

THE mechanism of Wire-cut Electric Discharge Machine ,*WEDM*, uses electricity to cut the metal with a brass wire conductors resulting in the discharge as shown in Fig.1

The work of WEDM is like cutting wood using a fret saw. WEDM are cutting as such, but uses electricity instead of saw cutting. WEDM will cut the material that has electrical conductivity. Harden steel and carbide are cut by WEDM. The advantages of WEDM over CNC conventional machine is the very hard material can be cut. The current cutting condition that controls WEDM to cutting different height as stair shape show in Fig. 2 cannot be controlled the accuracy of workpiece cutting thickness. The stair height is 10, 20, 30 and 40 mm in the same piece as show in Fig. 2 normally, the cutting parameter are designed to cut with constant workpiece height.

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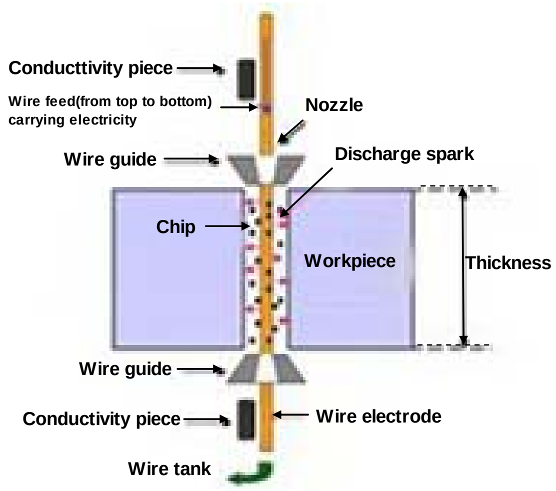

Fig. 1 Mechanism of Wire-cut EDM [1]

In this case, the operators cannot select an optimal cutting condition to cut stair shape workpiece for more accuracy thickness. For the result example in Table I, three pass cutting workpiece stair shape with height 10, 20, 30 and 40 mm in the same piece was cut by selected cutting condition for 20 mm constant height.

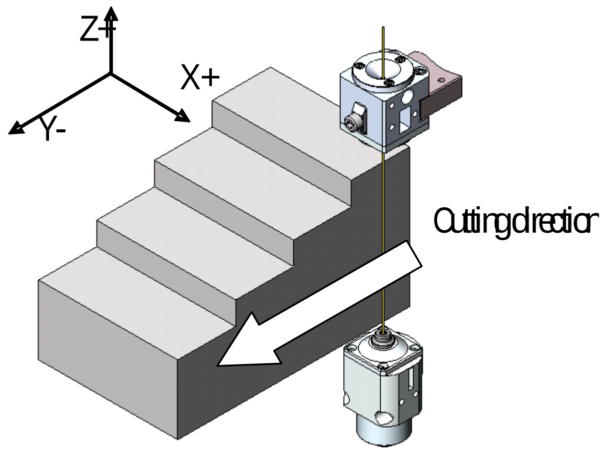

Fig. 2 The cutting of variable thickness of workpiece with WEDM

The accept thickness error of WEDM for 1, 2 and 3 pass cutting is 20, 15 and 10 microns, respectively. From the result in table I, the thickness errors were randomly and out of specification.

The objective of this research was parameters optimized by statistical design of experiments for the stair shape which was cut by CNC Wire-Cut EDM (WEDW). The experiment material was SKD-11 steel of stair-shaped with variable height workpiece 10, 20, 30 and 40 mm. with same 10 mm. thickness, were cut by Sodick's CNC Wire-Cut EDM model AD325L. The experiments were designed by 3^k full factorial experimental design at 3 level 2 factors and 9 experiments with 2 replicate. The selected two factor were servo voltage (SV) and servo feed rate (SF).

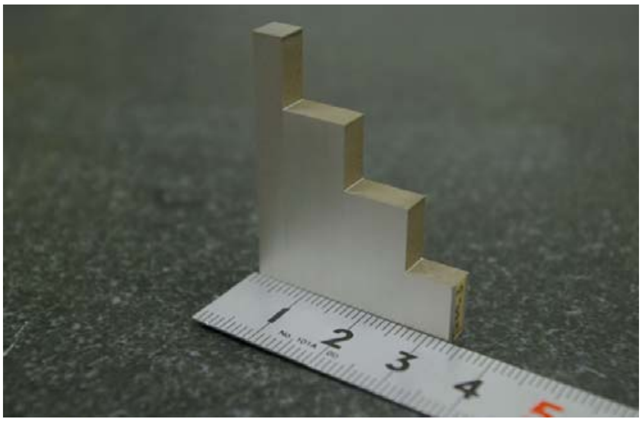

Fig.3 Stair shape workpiece cutting by Wire-Cut Electrical Discharge Machine

TABLE I
CUTTING SIZE ERROR IN THICKNESS 10, 20, 30 AND 40 MM

Cutting pass	Measure position	Size of workpiece in each workpiece thickness (mm)				Average Cutting thickness error (Micrometer)
		10	20	30	40	
	Top	4.995	4.989	4.980	4.983	
1	Center	5.000	4.997	4.989	4.981	20
	Bottom	4.998	5.000	4.996	4.990	
	Top	5.004	5.010	5.006	5.003	
2	Center	5.004	5.007	5.006	5.005	8
	Bottom	5.005	5.011	5.010	5.007	
	Top	5.003	4.997	4.983	4.975	
3	Center	5.003	4.997	4.984	4.970	34
	Bottom	5.004	4.999	4.989	4.982	

II. LITERATURE REVIEW

Machine Wire Cut (Wire-Cut Electric Discharge Machine: WEDM) first used in 1960, which evolved from EDM in 1974. Dulebohn be applied to fiber optic control systems to automate the WEDM Later in 1975, its popularity is rapidly increasing as people know and understand many processes in industry. Later in the late 1970's solutions are set computer control (CNC) to use in WEDM are consequences. Has been used extensively to cut holes in the surpassed the wire that passes part to cut jobs at the WEDM in manufacturing will work press forming work dies RP Job aircraft parts, medical equipment and head Cut (Ho. et al., 2004)[2].

WEDM cutting process based on principles of electric heat that can be accurately cutting parts with complex shapes are difficult to cut. Part of edge cut is difficult to cut easily by WEDM technology WEDM based on taking advantage of the spark so that material come off where the spark is not the contact between the wire and WEDM is made the parts for the instruments used to head for a bite and make parts that are small and require high precision and good surface. Cutting machine that relied on discharge is not a traditional process. Electrical heating process. The erosion of material off the workpiece by spark between workpiece and wire by wire in a dielectric fluid. Electricity distribution will be made part melting and evaporation, and blown to wash out by the dielectric fluid, WEDM generate spark the wire (acting as electrodes) and part by water fine ions act as an intermediary for the electrical resistance and cutting the path defined by the program. The main goal of WEDM manufacturers and users will achieve stability and productivity by making better. Because new materials are being develop. Body parts are more complex. To overcome restrictions on use and WEDM in manufacturing growth increased continuously and rapidly. WEDM manufacturers and users to focus on success in the ability to manufacture with precision and surface interest. However, because of high variability, even workers with good skills can not be made to optimize. Effective way to solve this problem is to find the relationship between performance measurement process to fill the cutting condition used in the control (Mahapatra et al., 2003) [3].

WEDM process is a measure of variety and consistency of performance. Determine the best parameters with different performance properties is different. One possible way to solve such problems, problems with many variables to consider for the WEDM process, the first control and influence their level best corresponds to each variable and then it will resolve the conflict with relevant experience and knowledge engineering. However, the decision of men validity of results simply can not be assured. Beyond that different results can be found by different engineers. This means that the uncertainty in the control factor increases (Gauri et al., 2009) [4].

The problem when cutting with WEDM are wire break and instability cutting. These are major factors resulting in reduced performance for cutting WEDM. Especially when you look at cutting variable thickness workpiece. Traditional methods to determine the appropriate value for the cut is to select a value that is used for cutting the thickness of the smallest parts. This method will allow to reduce the possibility of the wire break and the lack of stability in cutting. However, the cutting speed is reduced dramatically (Liao et al., 2002) [5].

Ho et al. (2004) [2] found that the ON time wave, the frequency of discharge, the voltage open circuit, the servo voltage, capacity charge, speed tables and the intensity of current in the discharge ions affect the ability to cut jobs, such as surface roughness and cutting speed while the wire speed, wire tension and rate of flow of the medium with electrical resistance minimal impact.

Tarng et al. (1995)[6] The servo reference voltage (SV):

The value of the servo reference voltage high, resulting in a time of waiting for the release of energy also high. However, the cutting speed will gradually slow down. Leads to the average of the difference of the release energy, so the conditions of large energy release is more stable but the number of cycles of energy is released within less time for energy Because of the stable cutting surface accuracy of better.

Servo speed: the speed setting in motion when there is no load or the voltage higher than average the servo reference voltage (SV). General differences in the release of energy is less when the speed of movement of the work table is high and the result is a speed of cutting increased compliance with speed the movement of work table, but the accuracy of the surface is not good because the cutting speed increased.

Liao, YS and YP Yu. (2004)[7] showed that ON time and the servo voltage is a significant factor in the discharge. Period of time will make more power efficient discharge reduction. Energy used in cutting depends ON time to supply a very long time more energy will be a lot of which imply the power of cutting the high percentage of the performance energy is paid to the pieces come off and the material is reduced significantly. The impact of the servo voltage discharge at this value even more will be made effective discharge decreased reason is because the values that will affect the phase will result in discharging the valuable lot is made. more distance parts of the energy is less than the discharge near the work piece.

Kanlayasiri and Boonmung (2007)[8] the experimental design using the design strategy full factorial (2^k) where k is the number of control variables in the experiment. The value in this experiment is power (ON), the time to stop paying power (OFF), the current maximum (Ip) and the tension wire (Wt) and the experimental use confidence interval at 95% and using ANOVA tests various hypotheses. Before that can be used ANOVA, will test the residual is normal distribution or not, are independent of each other or not and a constant variation does.

Surface roughness describe by Fig.4 (Banleng and Prasert, 1981) [9]

The average roughness Ra is equal to the height of the rectangle. The long-term lm rectangle is equal to the area as total area of the rough on the southern and central lines.

The depth of roughness Rz that allows for the calculation of serial arithmetic mean of the depth of roughness (Z1 ... Z5) 5 values that are similar area.

Maximum roughness depth Rmax is a maximum depth of the groove roughness during lm.

From the literature review it is show the relationship between the performance of cutting parameters, experimental design, testing to find the cutting parameter that caused the

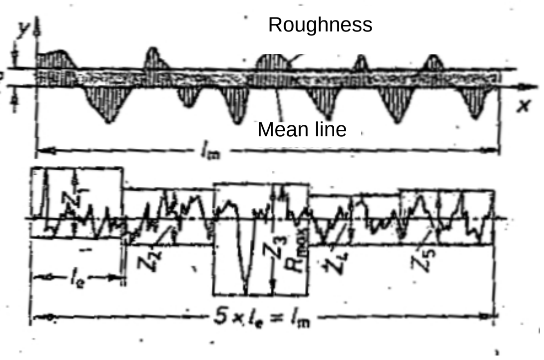

Fig. 4 Explain meaning of Ra, Rz and Rmax

cutting performance of the best. The cutting with the cutting parameters of WEDM machine different. Cutting performance will get the different result. Therefore, cutting parameter accuracy allows the performance of cutting up. One of the problems encountered when cutting with WEDM occurs when cutting variable thickness workpiece. The problem is during the cutting WEDM cutting areas in which change the thickness is wire break. In addition, the sizes of the specimen thickness in each are different. By finding the appropriate value to solve these problems. Require statistical methods to assist in the experiment. This research will lead to a full factorial experimental design used. Because the method is easy to understand and not complex.

III. Experimental Methods

A. *scope of this experiment*

1) Cutting by hard brass wire diameter 0.2 mm

2) Workpiece was steel type SKD-11

3) Cutting with dielectric fluid resistivity 55,000 to 65,000 (Ohms.cm)

4) Thickness Cutting error less than 20 micrometer

5) Cutting with stair shape workpiece that have height 10, 20, 30 and 40 mm as show in Fig.5

6) Three pass cutting.

7) Responses of this experiment was difference cutting thickness error.

8) Not consider other factor such as temperature, dielectric flow rate.

B. *Experimental Sequence*

1) Consideration factor for experiment

The consideration factor of this experiment were servo voltage (SV) and servo feed rate (SF). The gap voltage and gap between workpiece and wire were controlled by servo voltage (SV) and the response of wire speed changed by gap voltage was controlled by servo feederate (SF). During cutting, gap voltage was controlled follow with servo voltage (SV) by speed adjustment and the response of speed change was controlled by servo feederate (SF). The response of this experiment is cutting thickness error of workpiece.

2) Design of experimental

The full factorial 3^k design at 3 level 2 factors, 9 experiments, 2 replicate was designed for this experiment as show in table II.

TABLE II
FACTOR AND LEVEL IN 1ST SECTION EXPERIMENT

Factor	Level		
	High	Middle	Low
SV (Volt)	56	51	46
SF (mm/min/volt)	0.63	0.48	0.33

3) Experiment

The workpieces were cut into dimension as shown in Fig.5 The ten cutting thickness measuring points were measured as show in Fig. 6 by 0.001 mm resolution micrometer.

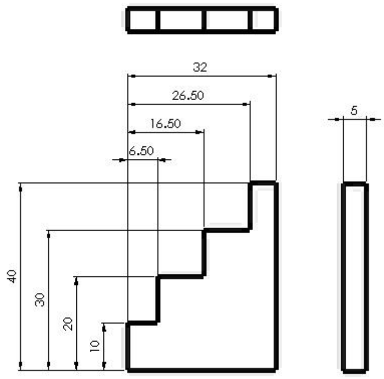

Fig. 5 Cutting workpiece dimension (unit: mm)

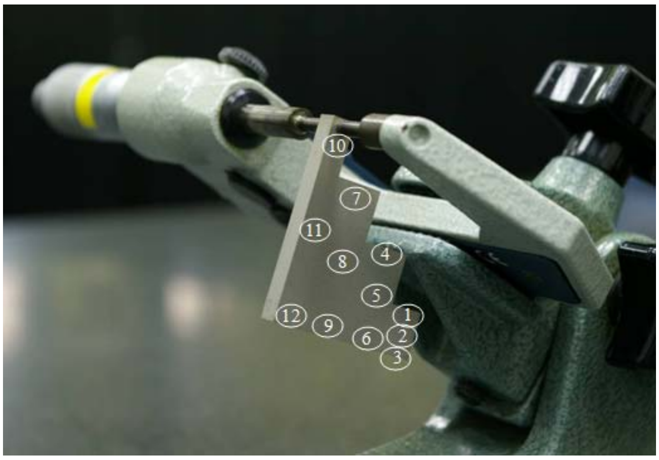

Fig. 6 Measurement position

TABLE III
TABLE FOR RECORD SIZE DATA

Measure position	Height of stair shape (mm)			
	10	20	30	40
Top	Point 1	Point 4	Point 7	Point 10
Center	Point 2	Point 5	Point 8	Point 11
Bottom	Point 3	Point 6	Point 9	Point 12

Cutting thickness error = (Maximum thickness size – Minimum thickness size) for each height of stair shape

IV. RESULT AND DISCUSSION

A. First experiment result

The Minitab software was used to sort the first experimental by randomly. The first experiment results are shown in Table IV.

The general full factorial design with confidential interval 95% (α = 0.05) analyze the experiment result by Minitab software with General Linear Model. The residual plots for cutting size error (Diff) show in Fig.8, that show the residual plots with a normal distribution, mean of error equals zero, constant variance and errors are independent.

From the analysis in Fig.9 consider the confidential interval of 95 percent (α = 0.05) are the main factors affecting significantly the factor SV (which is determined by the P-value less than 0.05) and with no interaction effect significantly. This is determined by the P-value greater than 0.05 and graphs with no potential impact on the Fig.10.

TABLE IV
FIRST EXPERIMENT RESULT

Order experiment	Level		Cutting thickness error (micrometer)	
	SV (volt)	SF (mm/min/volt)	1st replicate	2nd replicate
1	46	0.33	18	16
2	46	0.48	16	17
3	46	0.63	18	16
4	51	0.33	20	26
5	51	0.48	23	27
6	51	0.63	27	25
7	56	0.33	34	35
8	56	0.48	37	39
9	56	0.63	34	38

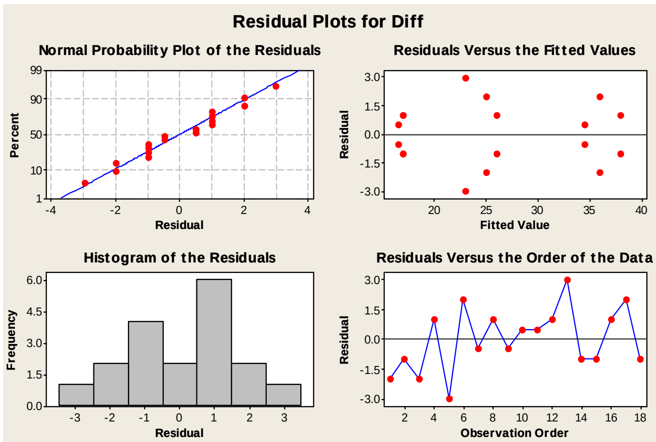

Fig. 8 Residual plot for cutting thickness error (Diff) in 1st experiment

General Linear Model: Diff versus SV, SF

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Factor  Type   Levels  Values
SV      fixed       3  46, 51, 56
SF      fixed       3  0.33, 0.48, 0.63


Analysis of Variance for Diff, using Adjusted SS for Tests

Source  DF   Seq SS   Adj SS  Adj MS       F      P
SV       2  1134.78  1134.78  567.39  118.76  0.000
SF       2    10.11    10.11    5.06    1.06  0.387
SV*SF    4    11.89    11.89    2.97    0.62  0.658
Error    9    43.00    43.00    4.78
Total   17  1199.78


S = 2.18581   R-Sq = 96.42%   R-Sq(adj) = 93.23%
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Fig. 9 Analyze data by Minitab software from the result in 1st experiment

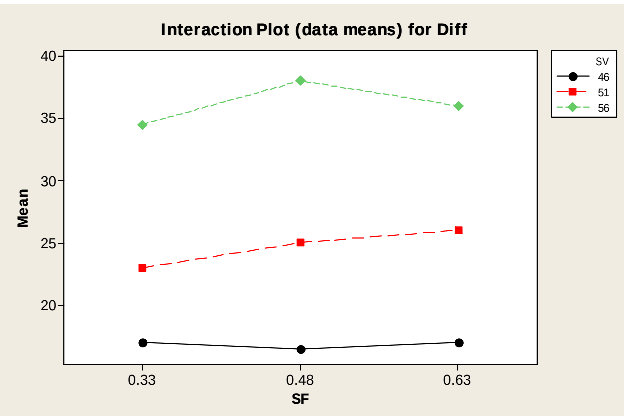

Fig. 10 Interaction plot for cutting thickness error (Diff) in 1st experiment

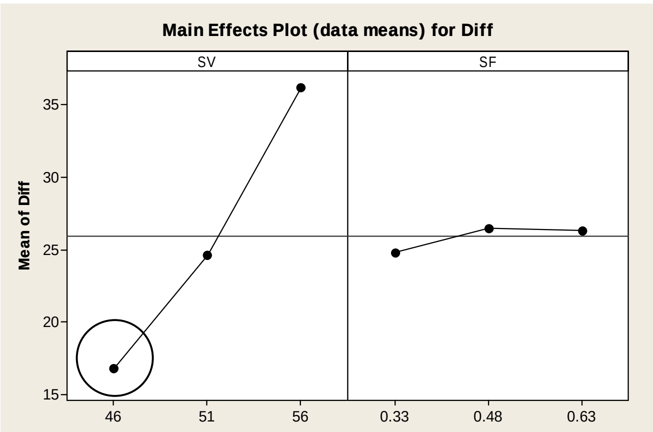

Fig. 11 Main effect plot for cutting thickness error (Diff) in 1st experiment

From main effect plot in Fig.11, the smallest cutting thickness error, with SV equal 46 volt.

B. Second experiment result

From the result of first experiment, the trend of factors SV will find that the cutting thickness error will be improved by reducing the factor SV.

The Minitab software was used to sort the second experimental by randomly. The second experiment results are shown in Table V.

With general full factorial design at confidential interval 95% (α = 0.05) then analyze the result by Minitab software with General Linear Model. The residual plot for cutting size error (Diff) show in graph at Fig.12, from the graph show that the residual plot have a normal distribution, mean of error equals zero, constant variance and errors are independent.

From the analysis in Fig.13 consider the confidential interval of 95 percent (α = 0.05) are the main factors affecting significantly the factor SV (which is determined by the P-value less than 0.05) and with no interaction effect significantly. This is determined by the P-value greater than 0.05 and graphs with no potential impact on the Fig.14.

TABLE V
SECOND EXPERIMENT RESULT

Order experiment	Level		Cutting thickness error (micrometer)	
	SV (volt)	SF (mm/min/volt)	1st replicate	2nd replicate
1	36	0.33	11	12
2	36	0.48	10	11
3	36	0.63	13	10
4	39	0.33	12	14
5	39	0.48	12	13
6	39	0.63	13	14
7	42	0.33	15	16
8	42	0.48	16	16
9	42	0.63	15	17

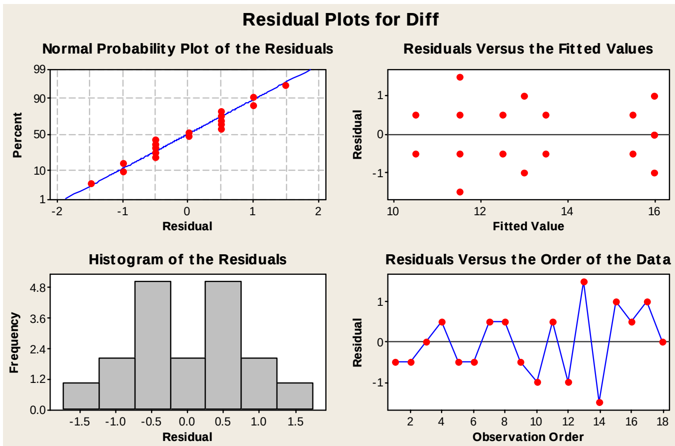

Fig. 12 Residual plot for cutting thickness error (Diff) in 2nd section experiment

General Linear Model: Diff versus SV, SF

```
Factor  Type   Levels  Values
SV      fixed       3  36, 39, 42
SF      fixed       3  0.33, 0.48, 0.63


Analysis of Variance for Diff, using Adjusted SS for Tests

Source  DF  Seq SS  Adj SS  Adj MS      F      P
SV       2  66.333  66.333  33.167  27.14  0.000
SF       2   1.333   1.333   0.667   0.55  0.598
SV*SF    4   1.333   1.333   0.333   0.27  0.888
Error    9  11.000  11.000   1.222
Total   17  80.000


S = 1.10554   R-Sq = 86.25%   R-Sq(adj) = 74.03%
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Fig. 13 Analyze data by Minitab software from the result in 2nd section experiment

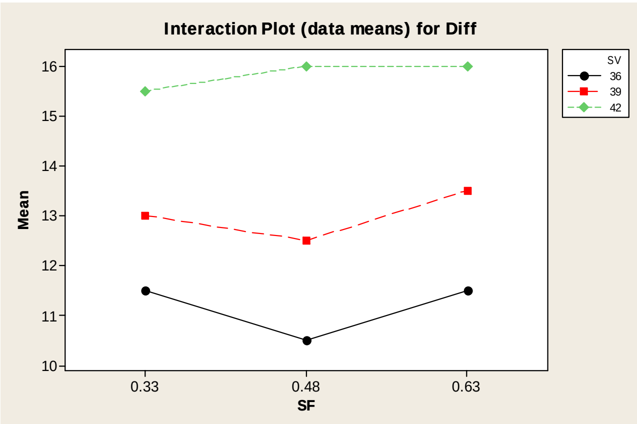

Fig. 14 Interaction plot for cutting thickness error(Diff) in 2nd section experiment

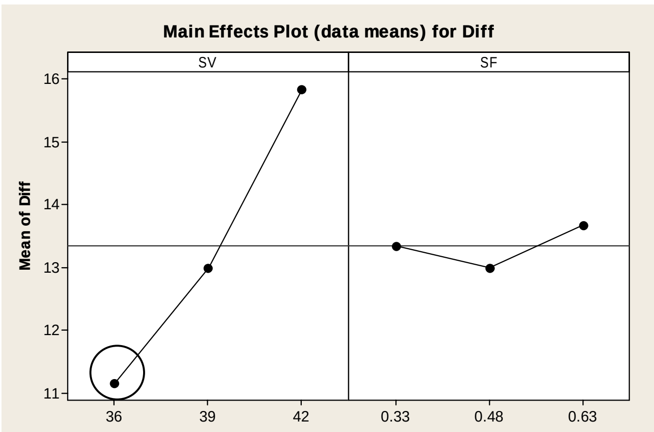

Fig. 15 Main effect plot for cutting thickness error(Diff) in 2st section experiment

From main effect plot in Fig.15, the smallest cutting thickness error, with SV equal 36 volt.

V. CONCLUSION

The first experiment result from Fig. 9, the p-value of Servo Voltage (SV) parameter was less than 0.05 so the SV parameter was the main factor affecting significantly at confidential interval of 95 percent (α = 0.05). The cutting thickness error was improved as decreasing servo voltage from Fig. 11, the first experiment result show the smallest thickness error with servo voltage equal to 46 volt which will had an cutting thickness error in the cutting equal to 17 micrometer.

The second experiment shows the improving cutting thickness error by reducing SV value. The main factors that affect significantly at confidential interval 95 percent of the responses to the factor SV which should select the level of factor SV equal 36 volts, which will had an cutting thickness error equal to 11 micrometer.

From both experiment results show the cutting thickness error was improved and depend on servo voltage error so the smaller servo voltage value, the better cutting thickness error. The servo voltage cannot be set less than 36 volts because the gap between wire and workpiece is too small.

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