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Kerf Width Optimization in Wire-Cut Electrical Discharge Machine by using Taguchi Method

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Graphical abstract

Abstract

Today, in most of wire cut electrical discharge machine (WEDM), the suitable machining parameters are relied based on the data from machine manufacturer and the experience of operators. The situation became more difficult when involving numerous and diverse range of parameters and the lack of experience. Normally, the parameter tables given by the machine manufacturer is only for basic machining operation but not for optimum machining condition. The optimal machining parameters only can be achieved by determining significant parameters that are affecting the machining performance. In this paper, a Taguchi Method quality design and analysis of variance (ANOVA) is used to determine the optimal kerf width for material tool steel grade DF-2 for machining process with WEDM. The optimum machining parameter is obtained by using a analysis of signal-to-noise (S/N) ratio. After several experiments, it can be ascertained the significant parameter contributed to the kerf witdh are the open circuit voltage(47%), pulse duration(20%) and wire speed(15%). The average of kerf width from the three experiments was 0.255mm and from that, the error margin is only 1.53%, which satisfied our data .

Keywords: WEDM; Taguchi Method; kerf width; ANOVA

Abstrak

Dalam proses pemesinan menggunakan mesin pemotong dawai nyah elektrik (WEDM) pada hari ini, parameter pemesinan yang sesuai bergantung pada data yang dibekalkan oleh pembuat mesin and pengalaman operator. Keadaan ini bertambah sukar dengan bilangan parameter yang banyak dan pengalaman operator yang terhad. Secara amnya, jadual parameter yang dibekalkan oleh pembuat mesin tidak dilengkapi untuk beroperasi dalam keadaan yang optimum. Pengoptimuman hanya dapat dicapai dengan menentukan nilai parameter signifikan yang mempengaruhi proses pemesinan. Dalam kajian ini, kaedah reka bentuk kualiti Taguchi dan analisa variasi (ANOVA) digunakan dalam pengoptimuman nilai kelebaran kerf bagi proses pemesinan bahan gred DF-2 dengan menggunakan WEDM. Nilai optimum pemesinan didapati melalui analisa nisbah isyarat-ke-hingar(S/N). Setelah beberapa eksperimen dilakukan, keputusan yang didapati mengesahkan nilai lebar kerf dan parameter yang signifikan seperti voltan litar terbuka(47%), jangka masa denyutan(20%) dan kelajuan wayar(15%).

Kata kunci: WEDM; kaedah Taguchi; lebar kerf; ANOVA

■1.0 INTRODUCTION

Today, Wire-cut Electrical Discharge Machining (WEDM) is one of the most extensively used non-conventional material removal process. The uniqueness of WEDM is because it converts thermal energy for machining electrically conductive parts regardless of hardness. WEDM has been widely used in machining industry due to its distinctive advantages for manufacturing mould, die, automotive, aerospace and surgical components [1]. Therefore, for most WEDM users, it is very important to maintain a good stability of performance during machining and obtain higher productivity through WEDM machining. In general, WEDM machining is a thermal-electrical process where materials are eroded from a work piece by a series of discrete sparks between the work piece and wire as the tool electrode. With WEDM, high degree of accuracy of work piece dimensions and very fine surface finishing can be obtained. Therefore, WEDM is suitable for applications that involve the manufacturing process of stamping dies, extrusion dies and prototype parts. In contrast, the conventional machining process took long hours for fabrications of precision work piece because of manual grinding and polishing [5].

The commonly used WEDM wires are from brass, copper, tungsten or molybdenum, zinc or brass coated. However recently multi coated wires are also have been used [2]. For example, multi coated wires with the diameter of 0.30 mm are used for roughing cuts and 0.20 mm for finishing cuts. The wires have high electrical conductivity and tensile strength in which the tension is typically 60 % of its tensile strength [3]. In most of WEDM machining, the important performance measurements are the kerf width, material removal rate (MRR) and surface roughness. There are many WEDM machining parameters that can influence these performance measurements such as discharge current, discharge capacitance, pulse duration, pulse frequency, wire speed, wire tension and dielectric flushing pressure. However for any end user, it is difficult to utilize which are the optimal functions of the WEDM since there are too many adjustable parameters need to be considered. Several studies on the performance measurements in WEDM has been done with many different approaches [4,5,6,7,8,9]. In this paper, we investigated the effect of the machining parameters and their level of significance only on kerf width by using Taguchi Method. The result was statistically evaluated by using analysis of variance (ANOVA).

■2.0 MATERIAL AND METHOD

2.1 Taguchi Method

According to Thillaivanan *et al*. [10], Taguchi Method can be used to optimize the performance characteristics through process parameters setting and sensitivity reduction of the system performance. In addition, the Taguchi Method only requires minimum experimental cost and it can efficiently reduces the effect of the source of variation. However, there are uncontrollable factors that can cause the deviation of product functional characteristics from their target values and these deviations are called noise factors. A part from that, the Taguchi Method identifies these uncontrollable factors in order to balance these noise factors. These noise factors can be manipulated in order to make products that are robust with respect to all noise factors. So, the selection process of the control factors is an important stage in the design of an experiment (DOE). Since many factors possible can be included, it could be possible to identify non-significant variables at the earliest opportunity. Taguchi Method can create a standard orthogonal array to accommodate this requirement [11].

Taguchi Method also used a signal-to-noise (S/N) ratio as the quality characteristic of choice. The S/N ratio is used as a measurable value instead of standard deviation. This is because of the fact that as the mean decreases, the standard deviation also will decrease and vice versa. Two of the applications in which the concept of S/N ratio is useful are the improvement of quality through variability reduction and the improvement of measurement. The S/N ratio depends on the type of characteristic, where that higher value that represents a better machining performance such as MRR is known as higher is better (HB). On the other hands, the characteristic that have lower value that represents a better machining performance, such as surface roughness and kerf width is called lower is better (LB). In this paper, we focused on the characteristic of LB for the kerf width. The loss function (L) for objective of LB is defined as the following equation.

$$L_{LB} = \frac{1}{n}\sum_{i=1}^{n} y_i^2 \tag{1}$$

where, *n* is the number of iteration, *y* is the experimental result. From Equation (1), we can determine the Mean Square Deviation (MSD) as follows,

$$\frac{1}{n}\sum_{i=1}^{n} y_i^2 = y_1^2 + y_2^2 + y_3^2 + \ldots + y_n^2 \; / n \\ = MSD \tag{2}$$

and the S/N ratio as follows,

$$S/N = -10\log(MSD) \tag{3}$$

2.2 Experiment

In this paper, four different factors at two levels of WEDM machining will be presented. The fractional factorial design that we adopted is L_{16} orthogonal array [12]. The L_{16} orthogonal array was chosen because its capability to determine the interactions among factors. Each row of the matrix represents one trial, in which these trials are carried out randomly. Table 1 shows the factors that are considered to have significant effect to the kerf width and their value levels used in the experiment. The factors are open circuit voltage (OV), pulse duration (ON), wire speed (WF) and dielectric flushing pressure (WA).

Table 1 Factors of kerf width effect

No	**Factors**	**Unit**	**Level 1 (Low)**	**Level 2 (High)**
1	Open Circuit Voltage (OV)	[volt]	4.0	24.0
2	Pulse Duration (ON)	[μs]	4.0	18.0
3	Wire speed(WF)	[mm/s]	2.0	15.0
4	Dielectric flushing pressure (WA)	[Kg/cm^2]	4.0	8.0

The experiments were performed on a Legend II Technology HQ-35F with high precision three axis CNC WEDM as shown in Figure 1.The basic components of the WEDM consists of a wire, work table, servo control system, power supply and dielectric supply system. The work piece that is used was a general-purpose oil hardening material tool steel grade DF-2 from ASSAB Steel with a dimension of 400mm X 100mm X 10mm. The input parameters of the WEDM are selected according to the type of machining material, height of the work piece and tool material by using the manual provided by the machine manufacturer or customized by user.

Figure 1 Electrical wire-cut machine

■3.0 RESULTS AND DISCUSSION

Table 2 shows the measurement of the kerf width by using Vertical Beam Optical Comparator. The total length of the cutting path or kerf is 10 mm. For each experiment, the kerf width is measured at three different positions (Pos 1, 2 and 3) with the distance of 3 mm each other. An average of the three readings is used as data for the analysis. The S/N ratios of kerf width are computed using Equation (1), (2) and (3) for each measurements and the mean for S/N ratio of kerf width was taken as average of all treatment responses. The experimental findings are analyzed by using MINITAB version15.1, which is specifically used for design of experiment applications.

Table 2 Kerf width measured at 3 different positions

Kerf width (mm)			
Pos 1	**Pos 2**	**Pos 3**	**Average**
0.282	0.280	0.281	0.281
0.256	0.254	0.255	0.255
0.272	0.276	0.274	0.274
0.277	0.273	0.275	0.275
0.288	0.282	0.285	0.285
0.278	0.284	0.281	0.281
0.301	0.305	0.297	0.303
0.296	0.295	0.297	0.296
0.252	0.250	0.254	0.251
0.252	0.254	0.253	0.253
0.268	0.266	0.267	0.267
0.262	0.263	0.264	0.263
0.257	0.255	0.256	0.256
0.251	0.253	0.252	0.252
0.265	0.275	0.270	0.270
0.274	0.273	0.275	0.274

Table 3 shows the S/N ratio for kerf width. In addition, the effect of the four control factors on kerf width are demonstrated in Figure 2. It shows the correlation between the vertical axis as S/N ratio and horizontal axis as significant factors. It is apparent that the factor of OV, WF and ON can be treated as significant factors whereas factor WA are less significant factors in optimizing the kerf width of WEDM machining. The optimization of the WEDM process often proves to be a difficult task owing to the many regulating machining variables. A single parameter change will influence the process in a complex way (Scott *et al* 1991) [13]. Even though, the WEDM process is capable of generating precise and intricate profiles with small corner radii but a high wear rate is observed on the diamond wheel during the first grinding pass (Ho *et al* 2004) [14].

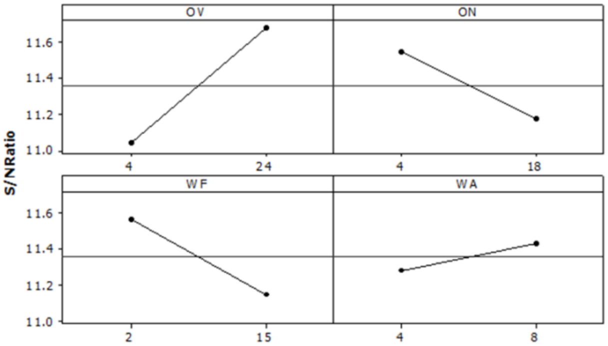

Figure 2 Main effect for S/N ratio with respect of kerf width

Table 3 S/N ratio for kerf width

(OV)	(ON)	(WF)	(WA)	Kerf width (mm)	S/N ratio
4	4	2	4	0.281	11.026
4	4	2	8	0.255	11.869
4	4	15	4	0.274	11.245
4	4	15	8	0.275	11.213
4	18	2	4	0.285	10.903
4	18	2	8	0.281	11.026
4	18	15	4	0.301	10.429
4	18	15	8	0.2955	10.589
24	4	2	4	0.252	11.972
24	4	2	8	0.253	11.938
24	4	15	4	0.267	11.470
24	4	15	8	0.2625	11.617
24	18	2	4	0.256	11.835
24	18	2	8	0.252	11.972
24	18	15	4	0.27	11.373
24	18	15	8	0.2735	11.261

The kerf width optimal machining condition and the result of ranking obtained from MINITAB is shown in Table 4. From these result, it can be ascertained that the optimal machining condition to obtain the minimum kerf width is at setting $A_2C_1B_1D_2$.

Table 4 Ranking of S/N ratio

Parameters	DF	Seq SS	Adj SS	Adj MS	F	P
OV	1	1.64971	1.64971	1.64971	30.63	0.000
WF	1	0.69898	0.69898	0.69898	12.98	0.004
ON	1	0.54868	0.54868	0.54868	10.19	0.009
WA	1	0.09499	0.09499	0.09499	1.76	0.211
Error	11	0.59252	0.59252	0.5387		
Total	15	3.58486				

Decomposition of variance analysis by ANOVA was conducted in order to measure relative effects of different machining parameters on kerf width. Table 5 shows the results of machining parameters OV, WF, ON and WA obtained from ANOVA for the machining output.

Table 5 Results of ANOVA for kerf width

Level	OV (A)	ON (B)	WF (C)	WA (D)
1	11.04	11.54a	11.57a	11.28
2	11.68a	11.17	11.15	11.44a
Delta	0.64	0.37	0.42	0.15
Rank	1	3	2	4

In Table 5 *DF*, *Seq SS*, *Adj SS*, *Adj MS*, *F* and *P* represent degree of freedom, sequential sum of square, adjusted sum of square, adjusted mean of square, variance ratio and percentage of contribution respectively. Statistically, the result of variance ratio *F* test gave a good level of confidence. It is apparent, and was noted by that larger *F* value indicates the process parameters gave more effect to the performance characteristics. Based on the ANOVA analysis, we found that the significant [14] factors that effected the kerf width based on 95% confidence interval are OV, WF, and ON. The percent contribution are 47 % for OV, 20 % for ON and 15% for WF.

3.1 Regression Analysis

We investigated the relation between the effective factors and the kerf with by using a mathematical equation called the regression equation. The equation is derived based on the assumption that each factors and the machining response are linearly correlated between each other. By using MINITAB, the relation between the regression coefficient is obtained as shown in Table 6. Based on that, the derived regression equation is as follows,

$$Kerf \quad width = 0.274 - 0.00101OV - 0.000844ON + 0.000995WF - 0.00120WA \tag{4}$$

3.2 Confirmation Test

Finally, in order to validate our ANOVA analysis that the significant factors influenced the kerf width, we conducted confirmation test as the final stage. The optimal result predicted by MINITAB was $A_2C_1B_1D_2$ and the predicted S/N ratio was 12.0029. In addition, the predicted size of kerf width was 0.251mm. Three experiments have been conducted in order to obtain actual kerf width and then to compare the results with the predicted kerf from our analysis. The average of kerf width from the three experiments was 0.255mm and from that, the error margin is only 1.53%, which satisfied our data.

Table 6 Table ofc of regression analysis by MINITAB

Predictors	Coefficients	SE coefficient	T	P
Constant	0.274453	0.007374	37.22	0.00
OV	-0.0010094	0.0001835	-5.50	0.00
ON	0.0008437	0.0002622	3.22	0.008
WF	0.0009952	0.0002824	3.52	0.005
WA	-0.0012031	0.0009177	-1.31	0.217

■4.0 CONCLUSION

This paper presents the application of Taguchi Method coupled with the statistical analysis ANOVA to investigate the factors of open circuit voltage, pulse duration, wire speed, dielectric flushing pressure in WEDM process. The analysis shows that, the most effective parameters with respect to the kerf width are open circuit voltage, wire speed and pulse duration. The percent contribution are 47 % for OV, 20 % for ON and 15% for WF. Finally, the comparison between actual kerf width gave an error of 1.53%, which was very close to the predicted 0.251mm. This means that our analysis was valid and shows a very good reproducibility.

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