Studying Parameters of EDM Based Micro- Cutting Holes Using ANOVA

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ABSTRACT

Micro -EDM is one of an important method in machining holes which is used in wide applications to fabricate medical devices and small dies. This work study the process of producing micro holes for copper alloy workpieces using, stainless steel electrode and dielectric solution (tap water), using DC current and low voltage (70V) to cut (0.7mm) thickness of copper (Cu) alloy workpieces in order to obtain the micro holes.

This work included an experimental work for electrical discharge machining (EDM) to produce micro holes with different diameters (400, 300, 210, 200, 120, 100, 85, 75, 70) µm.

The objective of this work is to obtain an optimal setting of EDM parameters to produce micro holes in copper alloy to achieve the optimal values of required holes diameters.

A regression model has been developed to represent this process. An approach has been made to optimize the process parameters (current, gap distance, machining time) using ANOVA analysis. This analysis was performed to obtain the most significant factors influencing the production of micro holes.

Keywords: EDM, Regression Model, ANOVA.

دراسة العوامل للتشغيل بالشرارة الكهربائية لقطع الثقوب الدقيقة باستخدام طريقة ANOVA

الخلاصة

التشغيل بالشرارة الكهربائية الدقيق هو احد الطرق المهمة لتشغيل الثقوب وله تطبيقات واسعة في تصنيع الأجهزة الطبية والقوالب الصغيرة. هذا العمل يدرس عملية انتاج ثقوب دقيقة لعينات من سبيكة النحاس باستخدام قطب من الفولاذ المقاوم للصدأ ومحلول (الماء الصافي)، باستخدام تيار مستمر وفولتية قليلة (70 فولت) لقطع عينات من سبيكة النحاس بسمك (0.7ملم) للحصول على ثقوب دقيقة.

هذا العمل يتضمن جانب تطبيقي للتشغيل بالشرارة الكهربائية لإنتاج ثقوب دقيقة ذات أقطار مختلفة (400, 300, 210, 200, 120, 100, 85, 75, 70)µm.

الهدف من هذا العمل الحصول على أمثل القيم لعوامل التشغيل بالشرارة الكهربائية لانتاج ثقوب دقيقة لسبيكة النحاس لتحقيق أمثل القيم لاقطار الثقوب المطلوبة.

تم تطوير نموذج ارتداد لتمثيل هذه العملية. وتم عمل مقاربة لتحقيق امثلية عوامل العملية وهي (التيار، مسافة الفجوة، زمن التشغيل) باستخدام طريقة تحليل التفاوتات (ANOVA). استخدام هذا التحليل للحصول على العوامل الاكثر تأثير في انتاج الثقوب الدقيقة.

INTRODUCTION

The principle of Electrical Discharge Machining (EDM) is the removal of material by erosion process through the creation of electrically generated spark between workpiece and tool. The effectiveness of the EDM process is largely determined by the type of power supply used. The power supply is used to convert the alternating current input into a pulsed unidirectional direct current required to produce the spark [1]. Micro Electrical Discharge Machining (Micro-EDM) is quite similar with the principals of EDM, it is a thermal process that uses electrical discharges to erode electrically conductive materials. EDM has a high capability of machining the accurate cavities of dies and molds. EDM is an effective technique in the production of micro components that are smaller than 100μm. EDM is a contactless process that exerts every small force on both the workpiece and tool electrode [2].

As one of non-contact processing technology, Micro-EDM has very unique technology advantages and wide application prospects in the field of micro-fabrication. In practical applications, Micro-EDM has some problems, such as low efficiency and poor stability. For example, during electrode anti-copy process, it is often found that the discharge is discontinuous, resulting in low efficiency. At present, it lacks deep theoretical and applicant research in the respect of accurate recognition on gap state, which fails to provide the stable control of Micro-EDM with enough guidance [3].

Micro-EDM is a material removal process employing discharges between a workpiece and a microscale electrode that are submerged in dielectric fluid. Discharges occur when the electric field between the electrode and workpiece exceeds a critical value and the dielectric breaks down. Either increasing the electric potential or reducing the separation distance between the electrode and workpiece may cause the field to exceed the critical value. Charging and discharging the capacitor in a RC circuit governs the potential difference, while electronics control the separation distance by monitoring feed rate and short circuits. Energy from each discharge melts a microscopic amount of material, which is subsequently washed away after the voltage drops and the discharge collapses [4].

There are many significant contributions to micro-EDM going back for 40 years. In 1968, Kurafuji and Masuzawa (1968) created a dimeter ϕ6-μm hole in 50 μm thick carbide [5]. Through the years, micro-EDM developed into a versatile tool for fabricating a variety of micro mechanical components as shown by Masuzawa and Tönshoff (1997) [6] and Morgan (2004) [7]. Other recent examples include Kuo and Huang (2004) [8], who used micro-EDM to fabricate channels in tungsten carbide to produce a micro mould for plastic injection moulding. Meeusen and et al. (2003) [9] and Michel and et al. (2000) [10] used micro-EDM to fabricate micro sensors and micro pumps. Allen and Lecheheb (1991) [11] and Masuzawa and et al. (1994) [12] fabricated micro nozzles, and Ansel and et al. (2002) [13] fabricated micrometer-scale gripping tools for assembling micro devices. Micro-EDM is also suitable for producing micro structures in hard tooling materials such as tungsten carbide [14].

Micro-EDM is suitable for these and similar applications because its low discharges energy generate smooth surfaces while its negligible forces prevent fragile workpieces from breaking. Micro-EDM does face two significant challenges: high electrode wear and low Material Removal Rate (MRR). Electrode wear, which results from each discharge removing some material from the electrode, degrades the geometric accuracy of machined features. However, this effect can be minimised when making micro pockets with the Uniform Wear Method, presented by Yu and et al. (1998a,b) [15, 16] and Pham and et al. (2004) [17], but this method further compromises the MRR. These issues have made industrial acceptance of micro-EDM slow, but new advances in micro-cutting and micro-grinding provide complementary technologies that can improve the accuracy and increase MRR. Egashira and Mizutani (2002) [18] and Fleischer and et al. (2004) [19] demonstrated that micro-cutting tools can be used to fabricate micro-geometries in soft, ductile materials such as aluminium and brass. Wada and et al. (2002) [20] and Morgan and et al. (2004) [21] showed that micro-grinding tools made by micro-EDM can fabricate micro-geometries in hard and brittle materials such as tungsten carbide and glass.

In this work, the settings of EDM process parameters were determined by using the analysis of variance (ANOVA) method, and regression analyses are employed to find the optimal values and to analyze the effect of the EDM process parameters on holes diameters values.

EXPERIMENTAL SETUP

The experiments were cutting several holes with diameters (400, 300, 210, 200, 120, 100, 85, 75, 70) μm of copper alloy workpieces with dimension (6.9×5.3×0.7)mm using stainless steel electrode on 0.7 mm depth of workpiece. Table (1) shows physical properties of workpiece material. The experimental parameters were summarized in Table (2).

EDM system was build for machining of copper alloy workpieces. The EDM machine was attached with a power supply current pulses during discharging. Throughout the experiments, the dielectric fluid was the tap water. For better control of the environment, the dielectric fluid was kept in a Pyrex (glass) container during each run of the experiments. Figure (1) & Figure (2) showing the elements of the designed EDM operation and schematic diagram of the Microhole EDM respectively.

EXPERIMENTAL PROCEDURES AND RESULTS

Regression Model

To determine the function of hole diameter of three variables (current, gap distance and machining time), a regression model is proposed.
The proposed regression model is of the form:

$$y = a_0 + a_1 x_1 + a_2 x_2 + a_3 x_3 \quad \text{... (1)}$$

Multiple regressions solves for unknown coefficients a_0, a_1, a_2, a_3 by minimizing the sum of the squares of the deviations of the data from the model (least squares fit). Using Matlab Software, the Regression Model has been developed for the experiments as follows:

$$\text{Hole Diameter} = 106.6416 - 31.7857\ (\text{Current}) + 233.3333\ (\text{Gap Distance}) + 25.2632\ (\text{Machining Time}) \quad \text{... (2)}$$

Equation (2) represents the mathematical model for the designed Microhole EDM process.

Analysis of Variance (ANOVA)

ANOVA is formulated for identifying the significant factors which have greater contribution (%). A better indication for the relative effect of the different machining parameters on hole diameter obtained by decomposition of variance.

In this work nine experiments were conducted at different parameters. For this experiment ANOVA analysis array was used, Matlab Software was used to design an ANOVA analysis.

The relative importance of cutting parameters with respect to whole diameter was investigated to determine more accurately the optimum combinations of machining parameters by using ANOVA.

For the purpose of observing the degree of influence of the process parameters in EDM, three factors, each at three levels, as shown in Tables (3) was taken. The factors, levels and Degree of Freedom (DOF), as shown in Table (4).

The experimental layout was developed based on ANOVA orthogonal array experimentation technique. An L9 orthogonal array experimental layout was selected to satisfy the minimum number of experiment conditions for the factor and levels presented in Table (5).Table (6) shows the Standard L9 Orthogonal Array with Observations.

ANOVA is an objective decision making tool for detecting any differences in the average performance of groups of items tested. ANOVA helps in testing the significance of all main factors and their interactions by comparing the mean square against an estimate of experimental errors at specific confidence levels.

The percentage contribution (P) can be calculated as the sum of the squared deviations divided by the total sum of squared deviations. The F**-** test is a tool to see which design parameters have a significant effect on the quality characteristic. In the analysis, the F**-** ratio is a ratio of the mean square error to the residual error, and this traditionally used to determine the significance of a factor.

CONCLUSIONS

This work has presented an investigation on the optimization and the effect of machining parameters on producing hole diameter for micro EDM of copper alloy. The main conclusions which can be deduced from this work can be summarized as follows:

1- The P – value reports the significance level (suitable and unsuitable) in Table (7). Percent (%) is defined as the significance rate of the process parameters on the hole diameter. The percent numbers depict that the gap distance (20.63%), machining time (5.11%) and current (1.72%) have significant effects on the hole diameter.

2- From ANOVA computations, it is revealed that gap distance and machining time are predominant factors which affect the diameter gap distance (20.63%) influences more on micro cutting hole based EDM of copper alloy followed by machining time (5.11%) and current (1.72%) as shown in Table (7).

3- 0.7mm thickness of Cu can be machined with holes machine about (70-400μm), which is the applied range in this work.

4- From the developed regression model, equation (2), the generated model can be used for obtaining the value of diameter within any input values of current, gap distance and machining time.

5-Besed on applying ANOVA method as an optimization tool to design process parameters, the optimal setting of process parameters for optimal diameter is at current (10A), gap distance (0.4mm) and machining time (5min).

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Table (1) Physical properties of workpiece material.

Workpiece Material	Melting point (K)	Thermal conductivity (W/m·K)	Specific resistance (Ω·m)
Cu	1356	398	1.682×10^{-4}

Table (2) Machining Conditions.

Electrode polarity	Negative
Discharge current [A]	10
Open voltage [V]	70
Machining fluid	Tap water
Gap thickness [mm]	0.04
Machining time [min]	10, 8, 7, 5, 3

Table (3) EDM Process Parameters.

Process Parameters	Parameters Designation	Levels		
		L1	L2	L3
Current (A)	A	4	6	10
Gap Distance (mm)	B	0.3	0.4	0.5
Machining Time (min)	C	5	7	10

Table (4) Factors, Levels and Degree of Freedom.

Factor Code	Factor	No. 0f Levels	Degree of Freedom
A	Current	3	2
B	Gap Distance	3	2
C	Machining Time	3	2
	Total Degree of Freedom		6
	Minimum number of experiments		7

Table (5) Standard L9 Orthogonal Array.

Exp. No.	Current (A)	Gap Distance (mm)	Machining Time (min)
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Table (6) Standard L9 Orthogonal Array with Observations.

Exp. No.	Current (A)	Gap Distance (mm)	Machining Time (min)	Diameters (μm)
1	4	0.3	5	200
2	4	0.4	7	300
3	4	0.5	10	400
4	6	0.3	7	100
5	6	0.4	10	210
6	6	0.5	5	85
7	10	0.3	10	120
8	10	0.4	5	70
9	10	0.5	7	75

Table (7) Analysis of Variance (ANOVA) for Diameters.

Source	DOF	Sum of Square	Mean Square	F- Ratio Value	P-(Percentage Contribution) Value	% Contribution
Current	2	75016.7	37508.3	56.97	0.0172	1.72
Gap Distance	2	5066.7	2533.3	3.85	0.2063	20.63
Machining Time	2	24450	12225	18.57	0.0511	5.11
Error	2	1316.7	658.3			
Total	8	105850				

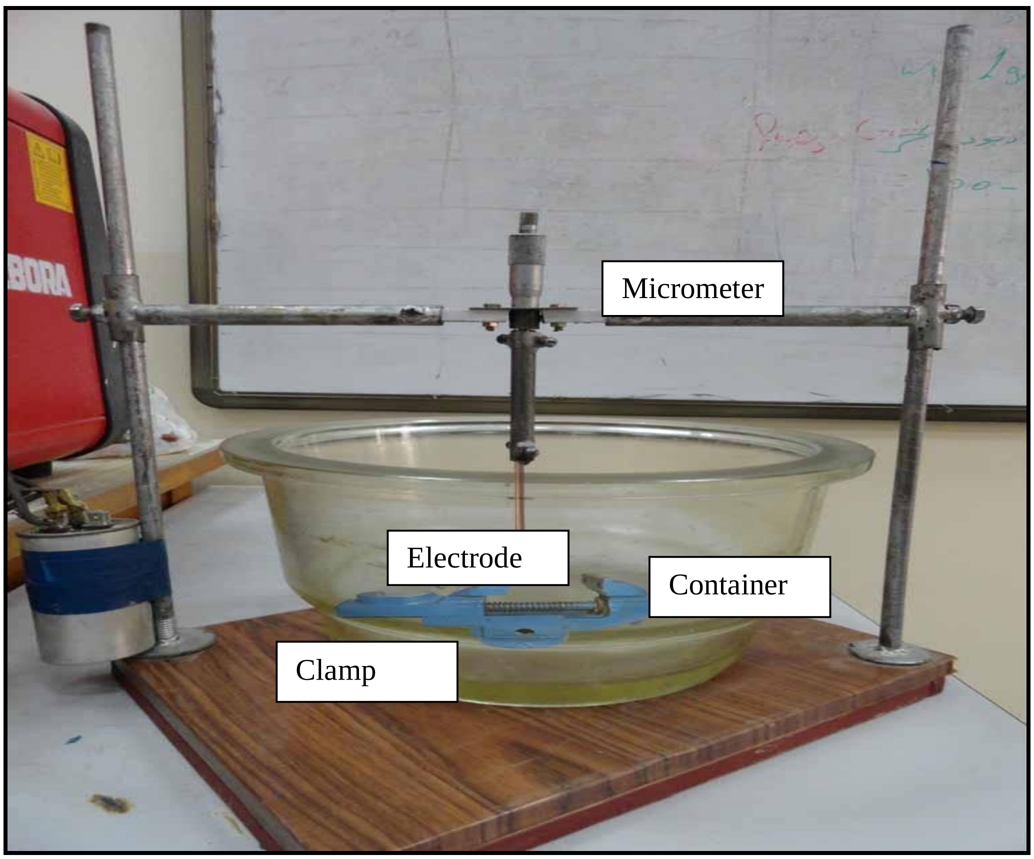

Figure (1) the elements of the designed EDM operation.

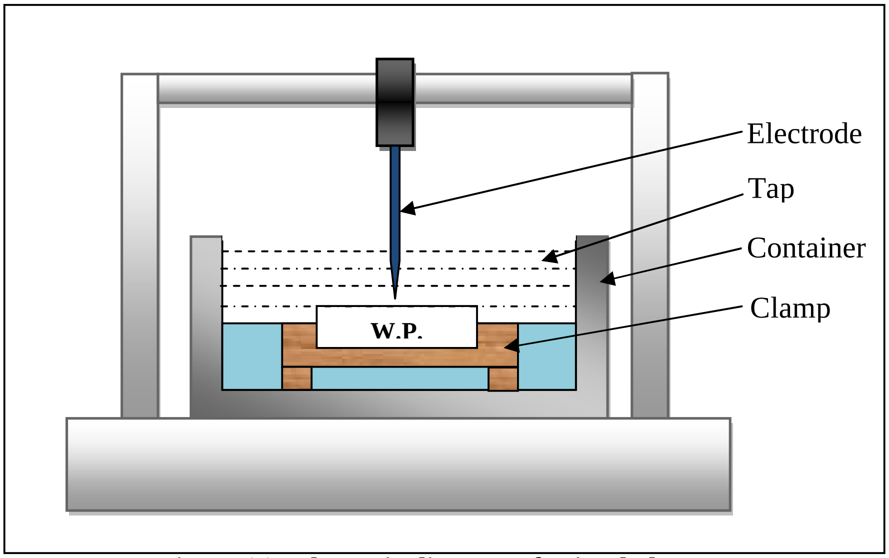

Figure (2) Schematic diagram of Microhole EDM.