APPLICATION OF RESPONSE SURFACE METHODOLOGY FOR DETERMINING HOLE DIAMETER MODEL IN EDM BASED MICRO HOLES CUTTING PROCESS

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ABSTRACT

Micro-EDM is one of an important process in machining holes which is used in wide applications to fabricate medical devices and small dies.20 samples were run by using CNC EDM machine was used for machining of conducting materials such as copper alloy workpieces for tap water dielectric by supplied DC current values (4, 6 and 10A), gap distance (0.3, 0.4 and 0.5mm) and machining time (5, 7 and 10min). Voltage of (70V) was used to cut 0.7mm thickness of copper (Cu) alloy workpieces to obtain the micro holes (400, 300, 210, 200, 120, 100, 85, 75, 70) µm.

The present work demonstrates the optimization process of hole diameter producing using electrical discharge machining (EDM) by RSM (Response Surface Methodology). The current, gap distance and machining time were the control parameters of EDM. RSM method was used to design the experiment using a second–order response surface. The process has been successfully modeled using RSM and model adequacy checking is also carried out using Minitab Software. Finally, an attempt has been made to estimate the optimum machining conditions to produce the best possible responses within the experimental constraints.

KEYWORDS: Electrical Discharge Machining (EDM), Response Surface Methodology (RSM).

تطبيق طريقةاستجابة السطح لحساب نموذج قطر الثقب في عملية قطع الثقوب الدقيقة المعتمدة على التشغيل بالتفريغ الكهربائي

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الخلاصة:

التشغيل بالشرارة الكهربائية الدقيق هو احد الطرق المهمة لتشغيل الثقوب وله تطبيقات واسعة في تصنيع الأجهزة الطبية والقوالب الصغيرة. تم قطع 20 نموذج باستخدام ماكنة CNC–EDM لمواد موصلة من سبيكة النحاس في محلول عازل من ماء الحنفية بتسليط قيم تيار مستمر (4, 6 و 10 أمبير)، مسافة الفراغ (0.3, 0.4 و 0.5 ملم) وزمن تشغيل (5 و 7 و 10 دقيقة). الفولتية المستخدمة هي 70 فولت لقطع سمك 0.7 ملم للنماذج وذلك للحصول على ثقوب ميكروية بالأقطار التالية (400, 300, 210, 200, 120, 100, 85, 75, 70) μm.

هذا العمل يثبت مثالية عملية قطر الثقب بالتشغيل بالتفريغ الكهربائي بطريقة استجابة السطح. تم اعتماد كل من التيار، مسافة الفجوة وزمن التشغيل كعوامل رئيسية للسيطرة على التشغيل بالتفريغ الكهربائي. تم استخدام طريقة استجابة السطح لتصميم تجربة من المرتبة الثانية لاستجابة السطح. نجحت عملية النمذجة باستخدام طريقة استجابة السطح وباستخدام برنامجMinitab . تم فحص النموذج المصمم لتحديد ظروف التشغيل المثلى لإنتاج أفضل استجابة ممكنة خلال التجربة.

INTRODUCTION

Electrical Discharge Machining (EDM) is one of the most widely used non-conventional machining processes in industry. EDM is based on the principle of removing material by means of repeated electrical discharges between the tool termed as electrode and the workpiece in the presence of a dielectric fluid (Sang, 2005).

EDM uses thermal energy to achieve a high precision metal removal process from accurately controlled electrical discharge, the electrode is moved towards the workpiece until the gap is small enough so that the impressed voltage is great enough to ionize the dielectric (Hofy, 2007).

The basic principle in EDM is the conversion of electrical energy into thermal energy through a series of discrete electrical discharges occurring between the electrode and workpiece immersed in the dielectric fluid. The insulating effect of the dielectric is important in avoiding electrolysis of the electrodes during the EDM process. Spark is initiated at the point of smallest inter-electrode gap by a high voltage, overcoming the dielectric breakdown strength of the small gap. At this stage, erosion of both the electrodes takes place, after each discharge, the capacitor is recharged from the DC source through a resistor and the spark that follows is transferred to the next narrowest gap. The cumulative effect of a succession of sparks spreads over the entire workpiece surface lead to its erosion to a shape which is approximately complementary to that of the tool. The dielectric serves to concentrate the discharge energy into a channel of very small cross-sectional area. It also cools the two electrodes and flushes away the products of machining from the gap. A servo system is employed to ensure that the electrode moves at a proper rate to maintain the right spark gap, and to retract the electrode, if short-circuiting occurs (Shitij, 2008).

On switching on the power supply, electric field is set-up in the gap between the electrodes. The electric field reaches maximum value at the point where the gap between the electrodes is smallest.

Spark location is determined by the gap distance and the gap conditions. In the presence of electrically conductive particles in the gap, thin particle bridges are formed. When the strength of the electric field exceeds the dielectric strength of the medium, electric breakdown of the medium takes place. Ionization of the particle bridges takes place and a plasma channel is formed in the gap between the electrodes. During the discharge phase, a high current flow through the plasma channel and produces high temperature on the electrode surfaces. This creates very high pressure inside the plasma channel creating a shock wave distribution within the dielectric. The plasma channel keeps continuously expanding and with it the temperature and current density within the channel decreases. Plasma channel diameter stabilizes when a thermal equilibrium is established between the heat generated and the heat lost to evaporation electrodes and the dielectric. This enlarged channel is still under high pressure due to evaporation of the liquid dielectric and material from the electrodes.

The evaporated material forms a gas bubble surrounding the plasma channel. During this phase, high energy electrons strike the workpiece and the positively charged ions strike the tool (for negative tool polarity). Due to low response time of electrons, smaller pulses show higher material removal from the anode whereas, longer pulses show higher material removal from the cathode. The plasma channel de-ionizes when power to the electrodes is switched off. The gas bubble collapses and material is ejected out from the surface of the electrodes in the form of vapors and liquid globules. The evaporated electrode material solidifies quickly when it comes in contact with the cold dielectric medium and forms solid debris particles which are flushed away from the discharge gap. Some of the particles stay in the gap and help in forming the particle bridges for the next discharge cycle. Power is switched on again for the next cycle after sufficient de-ionization of dielectric has occurred (Sourabh, 2008).

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 (Chi, 2011).

Micro-EDM is a material removal process employing discharges between a workpiece and a micro scale 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 (Chris, 2005). (Lakshmanan, 2013) study the optimization process for EDM parameters using response surface methodology.

The objective of this work is to study the influence of machining parameters of EDM on Micro Hole Cutting of 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 alloy workpieces in order to obtain the micro holes. The second order mathematical model in terms of machining parameters is developed for Hole Diameter prediction using response surface methodology (RSM) on the basis of experimental results.

EXPERIMENTATION AND MEASUREMENT OF RESPONSE

The experiments include cutting 20workpieces of copper alloy with thickness (0.7)mm using stainless steel electrode with different current to each electrode (4, 6 and 10)A, The gap between the electrode and the workpiece are (0.3, 0.4 and 0.5) mm. The fixed machining conditions were summarized in **Table (1, 2 and 3)**.

The EDM machine was attached with a power supply current pulses during discharging. The polarity of tool-electrode was negative (-) and the polarity of workpiece was positive (+). Throughout the experiments, the dielectric fluid has been the tap water which can transport the high spark current between the tool-electrode and workpiece. The EDM machine used in this work is shown in **Figure (1)**. All the experiments have been conducted on a CNC- EDM machine (ZNC 435L), located at the Machine Tool Unit, Center of Training & Workshops in the University of Technology, Baghdad.

The design of experiments technique is a very powerful tool, which permits to carry out the modeling and analysis of the influence of process variables on the response variables (Box, 1987). Improving the produced hole diameter is still challenging problem that restrict the expanded application of the technology. Semi-empirical models of hole diameter for various workpiece and tool electrode combinations have been presented by various researchers. The influence of current, gap distance and machining time, over the hole diameter on copper alloy workpieces have been studied. The optimum processing parameters are very much essential to produce precise hole diameters, since these materials, which are processed by EDM are costly and the process is expensive too.

As the number of variables is 3, a total of 20 experiments were planned for this investigation, shown in **Table 1**. Experiments were carried out using CNC EDM. **Table 2** shows the specification of EDM machine.

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 parameter hole diameter is selected as response variable.

The machining parameters and their levels are shown in **Table 3**.

METHODOLOGY

Response surface methodology (RSM) investigates the interaction between several illustrative variables and one or more response variables (Box, 1987).The most important purpose of RSM is to use a series of designed experiments to attain an optimal response. A second-degree polynomial model is use in RSM. These models are only an approximation, but used because such a model is easy to estimate and apply, even when little is known about the process. The process of RSM includes designing of a series of experiments for sufficient and reliable measurement of the response and developing a mathematical model of the second order response surface with the best fittings. Obtaining the optimal set of experimental parameters, thus produce a maximum or minimum value of the response. The Minitab Software was used to analyze the data (Minitab, 2003).

RESULT AND DISCUSSIONS

Using the experimental results for hole diameter as shown in **Table4**, response surface model is developed for the adequacy of the model is then performed in the subsequent step. The F ratio is calculated for 95% level of confidence.

The final response equation for hole diameter is given by second order model as (1):

Hole Diameter = 129.439 – (93.998* A) + (23.230* B) + (45.089* C) + (86.997 A^2) - (32.037 * B^2) + (1.891* C^2) - (28.376 *A*B) – (10.173* A*C) + (19.628 * B*C) …………………………(1)

Where: A: Current, B: Gap Distance and C: Machining Time.

When (R^2) approaches unity, the better the response model fits the actual data.

For the proposed model the value of coefficient of determination (R^2) is found to be 98.97%and adjusted R^2statistic (R^2adj) is 98.04%. This shows that the model for Hole diameter can be regard as significant for fitting and predicting the experimental results.

Table 4 shows the values of 'P' for each term on the performance of Hole diameter, The value of 'P' less than 0.05 (i.e., α=0.05, or 95% confidence) indicates that the obtained models are statistically significant. The current, gap distance and machining time are found to be *significant* factors that affect the producing of specifying hole diameter along with the square effect of current, gap distance, and the interaction effect of (A*B) and (B*C). Whereas the interaction effect of the input variables (A*C) and (C*C) are *insignificant*.

The normal probability plot of residuals for hole diameter as shown in **Figure (2)**.

It is expected that data from experiments form a normal distribution. It reveals that the residual fall on a straight line, implying that the errors are spread in a normal distribution. Here a residual means difference in the observed value (obtained from the experiment) and the predicted value or fitted value. This is also, confirmed by the variations between the experimental results and model predicted values analyzed through residual graphs, and are presented in **Figure (3)**.

The parametric analysis has been carried out to study the influences of the input process parameter Current, Gap Distance and Machining Time on the process response, hole diameter during EDM process. Three-dimensional response surface plots are formed based on the quadratic model to evaluate the variation of response. The plots are shown in **Figures (4,5 and 6)**.These plots can also give further assessment of the correlation between the process parameters and response as follow:

1.Hole diameter decreases with decreases in gap distance and machining time as shown in **Figure (4)**.

2. Hole diameter decreases with increasing current and increases with increasing machining time as shown in **Figure (5)**.

3. Hole diameter decreases with increasing current and increases with increasing gap distance up to max. value at 0.4 as shown in **Figure (6)**.

CONFIRMATION TEST

The optimization plot as shown in **Figure(7)** provides the optimum values for all the input parameters using response optimizer. The optimum values are as follows:

Optimum current is 6A, Optimum Gap distance is0.5 mm, Optimum Machining Time is 6.7191minto get hole diameter 150 μm.

To validate the parametric values obtained, an experiment was conducted with the previous optimum values, which yielded the hole diameter of 149 μm. This confirms that the proposed model is proved to be good enough to predict the hole diameter in EDM based Micro Holes Cutting Process.

CONCLUSIONS

Experimental investigation on electrical discharge machining of copper alloy is performed with a view to correlate the process parameters with the responses for produced hole diameter. The process has been successfully modeled using response surface methodology (RSM) and model adequacy checking is also carried out. The second-order response models have been validated. This study can help researchers and industries for developing a robust, reliable knowledge base and early prediction of Hole Diameter without experimenting with EDM process for copper alloy.

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Table (1): The experimental design matrix with coded factors.

Experiment No.	Current	Gap Distance	Machining Time
1.	0	0	0
2.	1	1	1
3.	0	0	0
4.	0	0	0
5.	-1	1	1
6.	0	1	0
7.	-1	0	0
8.	0	0	0
9.	-1	-1	1
10.	-1	-1	-1
11.	0	0	-1
12.	0	0	1
13.	0	0	0
14.	1	0	0
15.	-1	1	-1
16.	0	0	1
17.	0	-1	0
18.	1	-1	-1
19.	1	1	-1
20.	1	-1	1

Table (2): Specifications of EDM machine

Machine Used	CNC EDM (ZNC 435L)
Electrode	Stainless Steel
Electrode Polarity	Positive
Workpiece	Copper Alloy
Dielectric solution	Tap water

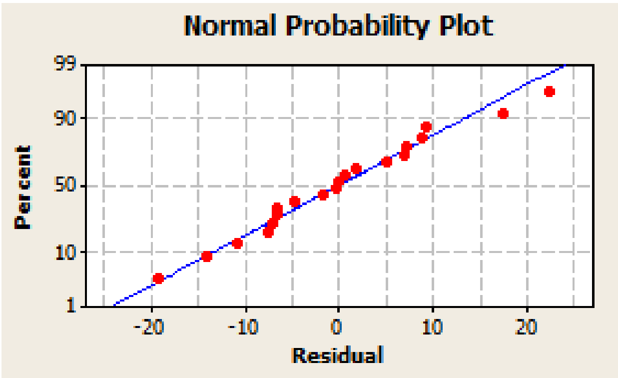
Table 3: Different variables used in the experiment and their levels.

Variable	Coding	Level		
		-1	0	1
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: Regression Coefficients for Hole Diameter.

Term	Coefficient	SE Coefficient	T	P
Constant	129.439	9.219	14.040	0.000
Current (A)	-93.998	4.348	-21.620	**0.000**
Gap Distance (B)	23.230	4.243	5.475	**0.000**
Machining Time (C)	45.089	3.982	11.323	**0.000**
A*A	86.997	8.532	10.197	**0.000**
B*B	-32.037	7.100	-4.513	**0.001**
C*C	1.891	7.780	0.243	0.813
A*B	-28.376	5.175	-5.483	**0.000**
A*C	-10.173	4.580	-2.221	0.051
B*C	19.628	4.849	4.048	**0.002**
R^2 = 98.97% R^2(prediction) = 93.24% R^2(adjusted) = 98.04%				

Figure (1): CNC Electric Discharge Machine (ZNC 435 L).



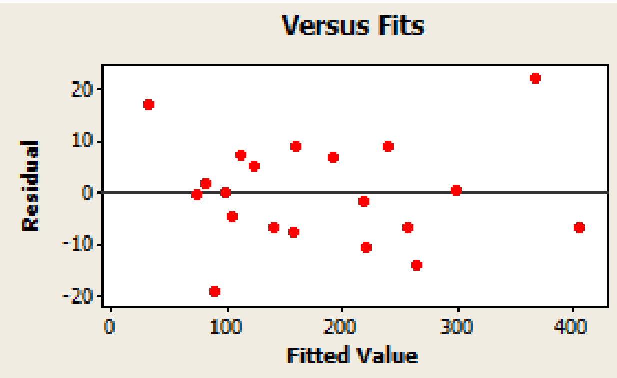


Figure (2): Normal Probability Plot.

Figure (3): Residual Plot.

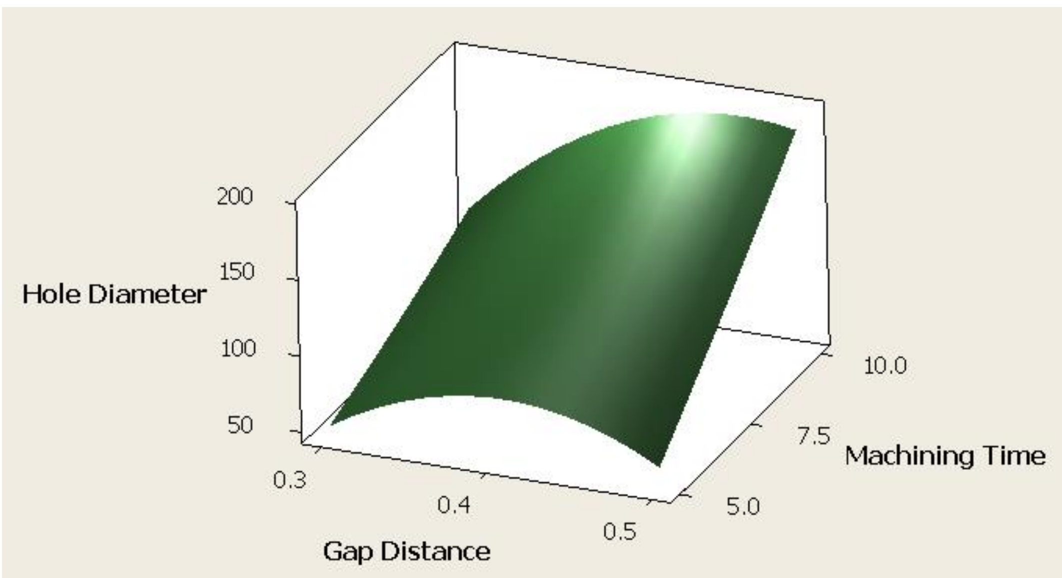


Figure4: Variation of Hole Diameter according to change of Gap Distance and Machining Time. Hold value is: Current = 7 A.

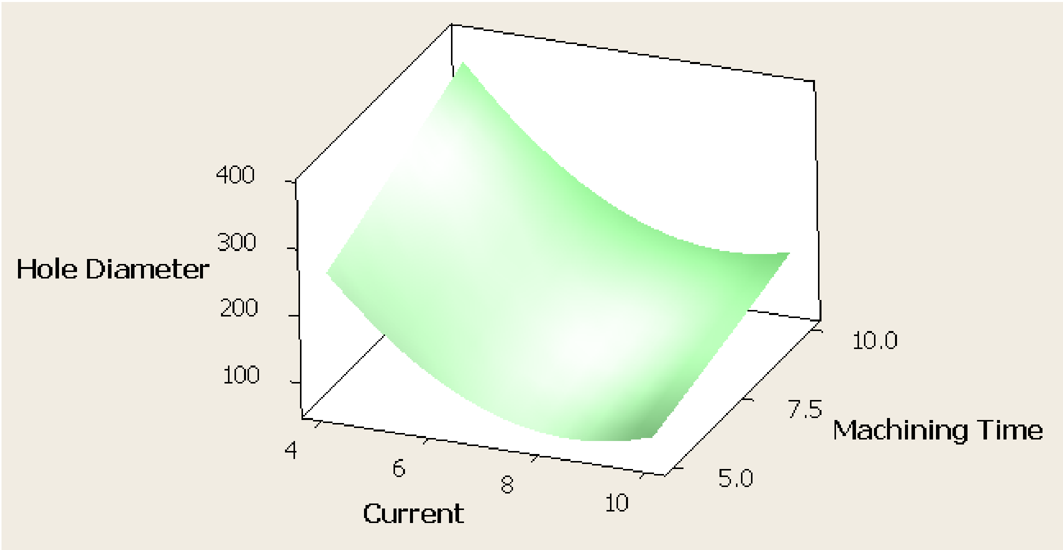


Figure5: Variation of Hole Diameter according to change of Current and Machining Time. Hold value is: Gap Distance = 0.4 mm.

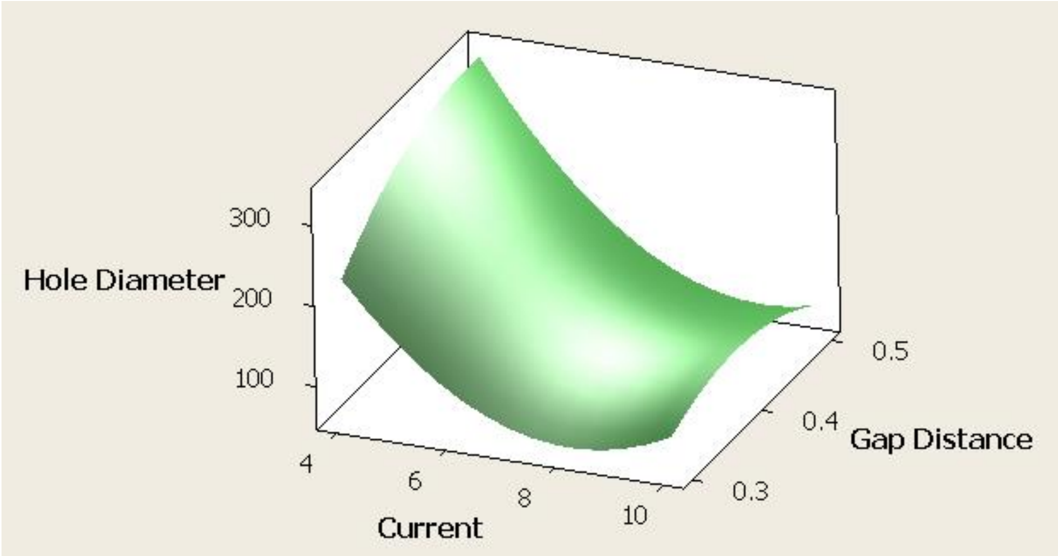


Figure (6): Variation of Hole Diameter according to change of Current and Gap Distance. Hold value is: Machining Time = 7.5 min.

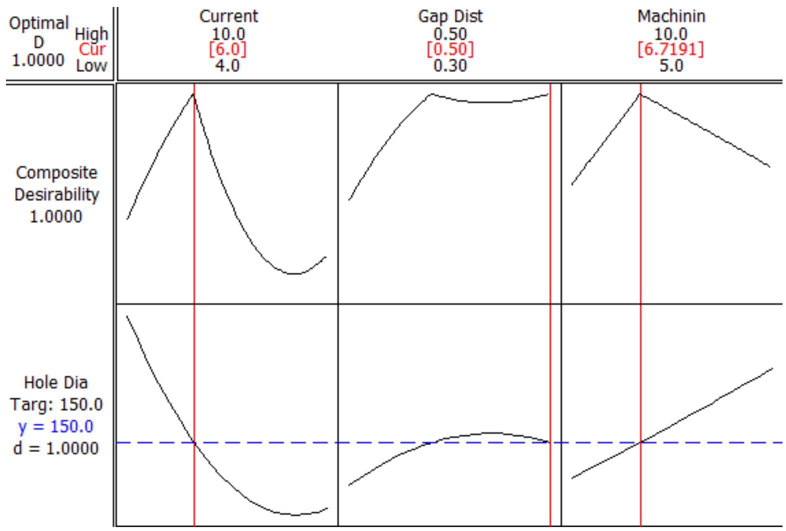


Figure (7): Optimization plot.