Application of ANFIS for Prediction Micro Holes in EDM

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Abstract

The present work demonstrates the optimization process of Micro- hole of Electrical Discharge Machining (EDM) by Adaptive Neuro Fuzzy Inference System (ANFIS). The workpiece material was copper alloy. The current, gap distance and pulse on time were the control parameters of EDM. The process has been successfully modeled using ANFIS model constructs a fuzzy inference system in MATLAB 7.2 Software Gaussian type for optimization of micro diameter, were adopted during the training and testing process of ANFIS model in order to compare the prediction accuracy of micro diameter by one membership function. Finally, the comparison of ANFIS results with experimental data indicates that adoption of Gaussian membership function in proposed system achieved satisfactory accuracy. Prediction using ANFIS model compared with experimental values of micro holes at correspond ratio 98.37%.

Keywords: EDM, ANFIS.

1. Introduction

The principle of electrical discharge machining (EDM) is the removal of material by erosion through the creation of sparks 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]. In addition, EDM does not make direct contact between the electrode and the workpiece eliminating mechanical stresses, chatter and vibration problems during machining [2]. 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 [3]. EDM is the machining process of controlled erosion of electrically conductive materials by the rapid and repetitive spark discharge between the workpiece (anode) and the tool (cathode) separated by flooded dielectric fluid through the small gap (about 0.02 to 0.5) mm, and known as spark-gap [4]. Electrical discharge machining is a process that removes metal with good dimensional control from any soft or hard metal. It cannot be used for machining glass, ceramics or other non-conducting materials [5].

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 [6].

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 [7].

The literature describes significant contributions to micro-EDM process. Fleischer et al. (2004) [8] demonstrated that micro-cutting tools can be used to fabricate micro-geometries in soft, ductile materials such as aluminium and brass. Morgan et al. (2004) [9] showed that micro-grinding tools made by micro-EDM can fabricate micro-geometries in hard and brittle materials such as tungsten carbide and glass. Other recent examples include Kuo and Huang (2004) [10], who used micro-EDM to fabricate channels in tungsten carbide to produce a micro mould for plastic injection moulding. Seong et al. (2007) [11] demonstrated the influence of EDM pulse condition on the micro EDM properties. Voltage, current, and on/off time of the pulse were selected as experimental parameters based on a simple equation for the material removal rate. The pulse condition is particularly focused on the pulse duration and the ratio of off-time to on-time, and the machining properties are reported on tool wear, material removal rate, and machining accuracy. The experimental results show that the voltage and current of the pulse exert strong effect on the machining properties and the shorter EDM pulse is more efficient to make an accurate part with a higher material removal rate. Mahendran et al. (2010) [12] have focused on the principle of micro-EDM, the types of EDM processes, dielectric fluid, types of generators, EDM process parameters, the material removal rate (MRR) and the tool wear ratio (TWR). Micro-EDM process is based on the thermoelectric energy between the workpiece and an electrode. Micro-EDM is a newly developed method to produce micro-parts in the range of 50 -100 μm. This paper is essential for the development in the research to fabricate the micro-EDM with micro actuator tool feed mechanism machine. Muttamara et al. (2010) [13] propose Cu, CuW and AgW for electrode materials for (micro-EDM), which are produced with block electrode on insulating Si3N4. With these electrodes, some trials were evaluated considering the EDM conditions. The machining properties were estimated by the removal rate and tool wear ratio. Nguyen et al. (2012) [14] studied the electrochemical reaction in die sinking micro-EDM using deionizer water as dielectric fluid by employing short voltage pulse. MRR of micro-EDM in deionizer water is much higher than in hydrocarbon oil. However, using high frequency and short duration pulse will reduce MRR. This leads to the unanticipated additional material removal from the workpiece which affects the machining shape and quality.

The objective of this work is to study the influence of machining parameters of EDM on Micro Hole Cutting of copper alloy workpiece using, stainless steel electrode and diesel fuel dielectric solution, using DC current and low voltage (140V) to cut (0.7mm) thickness of copper (Cu) alloy workpieces in order to obtain the micro holes. The second order optimization model in terms of machining parameters is developed for Micro Diameter prediction using Adaptive Neuro Fuzzy Inference System (ANFIS) on the basis of experimental results.

2. Experimental Work

Experiments were done on EDM machine with a dielectric solution. The essential machining parameters for EDM were listed in table 1, which are typical sequence of machining regimes used for the finishing phase of a non-conventional EDM second electrode operation. A schematic of the experimental apparatus of the EDM machine as shown in Fig. 1. All the experiments have been conducted on a CNC- EDM machine model (CM 323C), located at the Machine Tool Laboratory in University of Technology.

Table 1: Specifications of EDM machine.

Machine Used	CNC EDM (CM 323C)
Electrode	Stainless Steel 304
Electrode Polarity	Negative
Workpiece	Copper Alloy
Dielectric solution	Diesel fuel

Figure 1: CNC- EDM machine model (CM 323C).

The electrode penetration through the workpiece, connected to the negative polarity was used. The electrodes used were made of stainless steel 304 of cylindrical shape with different diameters and all of them less than 1mm in diameter, as shown in Fig. 2.

The practical implementation of EDM machine, the copper to be machined is dipped in to an appropriate dielectric solution (diesel fuel). The percentages of chemical composition of copper workpiece material are given in table 2.

The mechanical and physical properties of the workpiece are shown in table 3. The workpieces are prepared in the dimensions of 80×50×0.7 mm.

A pulsed voltage (140V) is applied between the tool-electrode (cathode) and the workpiece (anode).

The tool-electrode is dipped to a few millimeters into the dielectric.

Figure 2: The electrodes used in micro-EDM.

Table 2: Chemical composition properties of copper workpiece.

Element	Mn	Fe	Ni	Cu
Composition (%)	0.04	0.09	0.13	99.74

Table 3: Some of material properties of copper alloy.

Young Modulus (GPa)	**110-128**
Shear Modulus (GPa)	140
Tensile Strength (MPa)	350.50
Density (g/cm^3)	8.94
Melting Point (°C)	1084.62
Poisson ratio	0.34

EDM depends on the voltage and current for workpiece machining. Typical voltage values are around 140V. High current values are around (4-10A). At this point, the density of gas bubble produced is so high that they coalesce into a gas film isolating the tool electrode from the dielectric. The electrical field in this film is high enough to allow electrical sparks between the tool electrode (Stainless Steel) and the dielectric (diesel fuel). This spark is generated in the space between the tool-electrode and workpiece (copper). The spark creates a small difference between gap distances; therefore a localized location is less likely to be subjected to a spark until the sites around this point have been machined to the same level.

The spark creates a temperature high enough to melt the workpiece (copper) and create a chip which is then carried away from the work area by the dielectric solution (diesel fuel).

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 and 70) µm, as shown in Fig. 3. The parameter hole diameter is selected as response variable.

The machining parameters and their levels are shown in table 4.

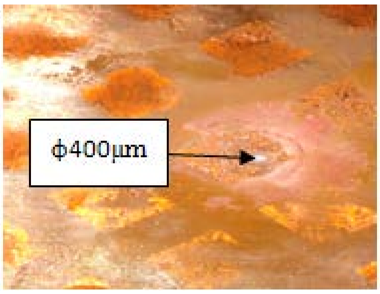


Figure 3: The micro hole φ400µm.

Table 4: Different variables used in the experiment and their levels.

Variable	Coding	Level		
		1	2	3
Current (A)	Input1	4	6	10
Gap Distance (mm)	Input2	0.3	0.4	0.5
Pulse ON (µs)	Input3	5	10	25

During the experiments, the other parameters: 140V, 7kg/cm^2 dielectric flushing pressure and 9 holes were machined. The micro diameter of the holes is measured using Mitutoyo PJ300 Profile Projector Optical Comparator. The results are shown in table 5.

Table 5: Experimental parameters and results.

No.	Current (A)	Gap Distance (mm)	Pulse ON (µs)	Micro diameter (µm)
1	4	0.3	25	400
2	6	0.4	10	120
3	10	0.5	5	70
4	4	0.4	5	100
5	6	0.5	25	85
6	10	0.3	10	300
7	4	0.5	10	75
8	6	0.3	5	210
9	10	0.4	25	200

3. Adaptive Neuro Fuzzy Inference System (ANFIS)

In the present work, develop the intelligent model for optimization Micro-holes using Adaptive Neuro Fuzzy Inference System. The process parameters taken in to consideration were the current, gap distance and pulse on time. The ANFIS was used to optimization the micro diameter results. The parameters that were used are shown in table 6.

Table 6: ANFIS parameters.

Membership functions	Gaussian type
No. of input	3
No. of output	1
Output Name	Micro diameter
No. of membership functions	3 3 3
No. of epoch	20
Learning type	Hybrid
Rules No.	27

The main problem with fuzzy logic is that there is no systematic procedure to define the membership function parameters. ANFIS eliminates the basic problem in fuzzy system design, defining the membership function parameters and design of fuzzy if-then rules, by effectively using the learning capability of neural network for automatic fuzzy rule generation and parameter optimization [15]. Using a given three input (current, gap distance and pulse on time) on one output (micro diameter) data set, the Adaptive Neuro Fuzzy Inference System constructs a Fuzzy Inference System whose membership function parameters are tuned using either a back propagation algorithm alone, or in combination with a least squares type of method.

4. Results and Discussions

Using a given input/output dataset, the Adaptive Neuro Fuzzy Inference System model constructs a fuzzy inference system, as shown in Fig. 4 the Adaptive Neuro Fuzzy Inference System model structure with four layers, three input [current (input1), gap distance (input2) and pulse on time (input3)], nine hidden and one output micro diameter (output) of the network. The suggested of ANFIS model by fuzzy rule at trapezoidal membership function, as shown in Fig. 5.

The training dataset and testing dataset are obtained from experiments data. The input/output dataset was divided randomly into two stages: training dataset, consisting 9 of the input/output dataset and testing dataset, consisting 9 of the data.

ANFIS information's:
Number of nodes: 78
Number of linear parameters: 108
Number of nonlinear parameters: 18
Total number of parameters: 126
Number of training data pairs: 9
Number of testing data pairs: 9
Number of fuzzy rules: 27

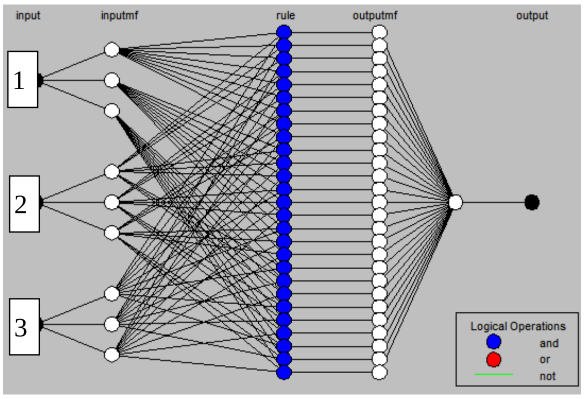


Figure 4: Adaptive Neuro Fuzzy Inference System architecture.

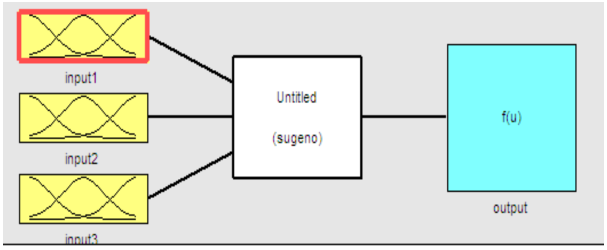


Figure 5: Fuzzy rule architecture of membership function.

In order to determine the optimal network architecture, various network architectures were designed; different training algorithms were used. The number and type of membership functions, method optimization hybrid or back propagation, and number epoch were changed. Then the best adaptive network architecture was determined. The training epoch for each network is 20, hybrid method optimization, the best results given 3 membership function Gaussian type. When the network training was successfully finished, the Adaptive Neuro Fuzzy Inference System was tested with validation data. Fig. 6 shows the flowchart for predicting the micro diameter (output) using ANFIS model.

Fig. 7 (a, b and c) shows the 3D surface profile obtained during neuro fuzzy modeling and the effect of the machining parameters [current (input1), gap distance (input2) and pulse on time (input3)] on the micro diameters (output).

In this work, three levels of each factor were selected. Following are the cutting parameters used in the experimental: current (4, 6 and 10 A), gap distance (0.3, 0.4 and 0.5 mm) and pulse on time (5, 10 and 25 µs). Thus, there were totally 9 number of experiments in this paper. The input layer of ANFIS consists of three parameters (current (input1), gap distance (input2) and pulse on (input3)) and the output layer corresponds to micro diameter (output). One type of predication were obtained by one type of membership, Gaussian membership function, were chosen and applied to model. These prediction and error results are shown in table 7.

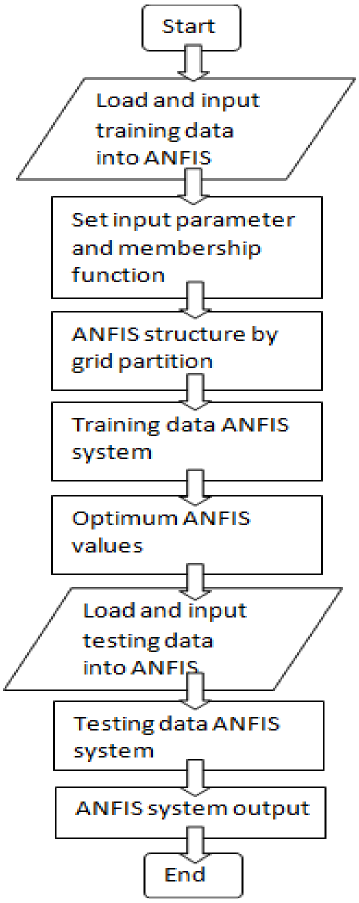
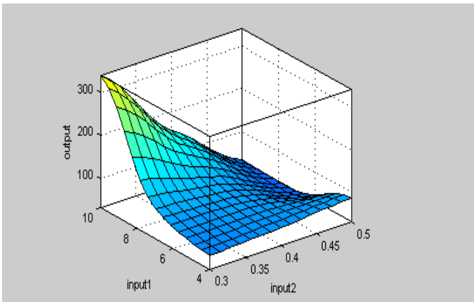
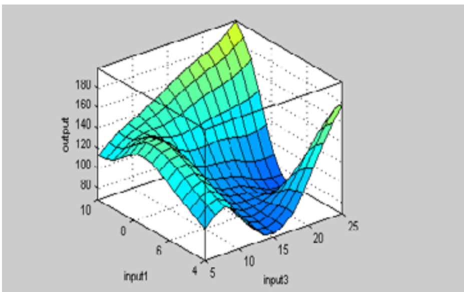


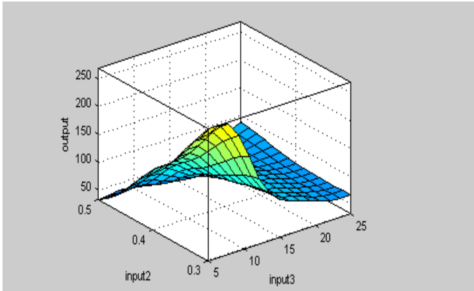
Figure 6: Flowchart of micro diameter prediction of ANFIS model.



(a)



(b)



(c)

Figure 7: (a, b and c). Comparison input and output in ANFIS, the current (input1), gap distance (input2) and pulse on (input3) influence on the micro diameter (output).

Table 7: ANFIS prediction and error results.

No. Experimental	Experimental results (μm)	Predicted results (μm)	Errors (%)
1	400	398.214	0.4465
2	120	123.551	-2.9591
3	70	67.583	3.4528
4	100	99.608	0.392
5	85	83.731	1.4929
6	300	301.930	-0.6433
7	75	77.441	-3.2546
8	210	207.995	0.9547
9	200	197.862	1.069
Average error (%)			1.6294

5. Conclusion

This paper proposes by using ANFIS method (Adaptive Neuro Fuzzy Inference System) in order to optimization micro diameter using EDM machine by different parameters in relation to different values. By employing the hybrid leering algorithm, ANFIS model can obtain the optimal Gaussian membership function of the fuzzy system. A total of 9 sets of experimental data are used for training and testing in ANFIS model. Current, gap distance and pulse on time variables were independent used as the variable parameters. Micro diameter values predicted by ANFIS are compared with the experimental results derived from the 9 data sets in order to determine the error. The ANFIS model predication made with one different method; the average error 1.6294% at accuracy 98.37%. The comparison indicates that the adoption of Gaussian membership function in ANFIS achieved very satisfactory accuracy.

6. References

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تطبيقات نظام التكيف العصبي غامض الاستدلال للتنبأ بالثقوب المايكروية في القطع بالشرارة الكهربائية

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الخلاصة

هذا العمل يدل على الطريقة المثلى لقطع الثقوب الدقيقة بالشرارة الكهربائية بواسطة استخدام نظام التكيف العصبي غامض الاستدلال. المادة المشغلة كانت سبيكة من النحاس. التيار، مسافة الفجوة وزمن استمرار النبضة هي عوامل سيطرة للقطع بالشرارة الكهربائية. هذه الطريقة أثبتت نجاح استخدام نموذج نظام التكيف العصبي غامض الاستدلال باستخدام برنامج الماتلاب 7.2 نوع غاوسي للحصول على الأقطار المثلى، اعتمدت أثناء عملية التدريب واختبار نموذج نظام التكيف العصبي غامض الاستدلال من أجل مقارنة دقة التنبؤ للأقطار الدقيقة دالة عضوية واحدة. وأخيراً، مقارنة النتائج لنظام التكيف العصبي غامض الاستدلال مع البيانات التجريبية تشير إلى أن اعتماد وظيفة غاوسي العضوية في النظام المقترح تحقق دقة مرضية. التنبأ باستخدام نموذج نظام التكيف العصبي غامض الاستدلال بالمقارنة مع القيم العملية للثقوب المايكروية عند نسبة تطابق 98.37%.