APPLICATION OF COACTIVE-ANFIS TO PREDICT MICRO-EDM PERFORMANCES

BY

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ABSTRACT

Micro Electrical Discharge Machining (µEDM) is one of the most demanding manufacturing processes available today. The selection of µEDM parameters remains a challenge since it is frequently based on machinist intuition and heuristic approaches. In recent years, soft computing and artificial intelligence have been used to model and predict the µEDM machining process. However, artificial intelligence has not been established for predicting µEDM performances based on material properties. Therefore, this research proposed a model that considers the material properties, such as thermal conductivity, melting point, and electrical resistivity. Since µEDM is a non-linear and stochastic process, Coactive Neuro-Fuzzy Inference Systems (CANFIS) was proposed to model and predict the multiple µEDM performances on various materials. The material properties, feed rate, capacitance, and gap voltage are the input parameters in a three-level design based on a full factorial experiment. The CANFIS model can accurately predict the material removal rate (MRR), total discharge pulse, overcut, and taperness in a single model. The mean average percentage error (MAPE) from the model prediction for test dataset of various outputs such as MRR, total discharge pulse, overcut and taper angle were found to be 9.5% (90.5% accuracy), 8.9% (91.1% accuracy),16.9% (83.1% accuracy) and 15.7% (84.3% accuracy) respectively. This research proposes a novel approach in modelling and predicting µEDM performances by considering workpiece's materials using artificial intelligence.

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خلاصة البحث

تعد عملية التفريغ الكهربائي الصغيرة (μEDM) واحدة من أكثرعمليات التصنيع المتاحة اليوم تطلبًا. يبقى اختيار معلمات μEDM في التحدي نظرًا لأنه يعتمد كثيرا على الحدس الميكانيكي والنهج الاستكشافية. في السنوات الأخيرة ،اتسع استخدام الحوسبة اللينة والذكاء الاصطناعي لنمذجة عملية تصنيع μEDM والتنبؤ بها. ومع ذلك ، لم يتم إنشاء الذكاء الاصطناعي للتنبؤ بأداء μEDM بناءً على خصائص المواد. ولأجل ذلك ، يقترح هذا البحث نموذجًا مع مراعاة لخصائص المواد ، مثل التوصيل الحراري ، ونقطة الانصهار ، والمقاومة الكهربائية. نظرا إلى أن μEDM عملية غير خطية وعشوائية ، فقد تم اقتراح Coactive Neuro-Fuzzy Inference Systems (CANFIS) لنمذجة وتوقع أداء μEDM المتعدد على مواد مختلفة. خصائص المواد ، ومعدل التغذية ، والسعة ، وفجوة الجهد هي معلمات الإدخال في تصميم ثلاثي المستويات يعتمد على تجربة العوامل الكاملة. كان نموذج CANFIS قادرًا على التنبؤ بدقة بمعلمات أداء ، μEDM وهو معدل إزالة المواد (MRR) ، ونبض التفريغ الكلي، والقطر الزائد، والنسيج في نموذج واحد. تم العثور على متوسط خطأ النسبة المئوية (MAPE) من التنبؤ النموذجي لمجموعة بيانات الاختبار من المخرجات المختلفة مثل MRR ونبض التفريغ الإجمالي والقطع الزائد وزاوية الاستدقاق ٩,٥٪ (٩٠,٥٪ دقة) و ٨,٩٪ (٩١,١٪ دقة)) ،١٦,٩٪ (٨٣,١٪ دقة) و١٥,٧٪ (٨٤,٣٪ دقة) على التوالي. يقترح هذا البحث نهجًا جديدًا في النمذجة والتنبؤ بأداء μEDM بالاتخاذ في مواد قطعة العمل باستخدام الذكاء الاصطناعي.

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ABSTRACT IN BAHASA MALAYSIA

Mikro Pemesinan Nyahcas Elektrik (µEDM) adalah merupakan salah satu proses pembuatan yang mendapat permintaan yang tinggi pada ketika ini. Pemilihan parameter µEDM masih lagi menjadi cabaran kerana ia sering ditentukan berdasarkan gerak hati juruteknik dan pendekatan heuristik yang mencabar untuk dimodelkan. Kebelakangan ini, pengkomputeran lembut dan kecerdasan buatan banyak digunakan untuk memodel dan meramal proses µEDM. Walau bagaimanapun, kecerdasan buatan belum lagi digunakan untuk meramal prestasi µEDM berdasarkan kepada sifat bahan. Oleh itu, penyelidikan ini mencadangkan suatu model yang mengambil kira sifat bahan, seperti kekonduksian terma, takat lebur dan daya tahan elektrik. Oleh kerana µEDM ialah proses yang tidak linear dan stokastik, sistem inferens neuro-kabur koaktif (CANFIS) telah diketengahkan untuk memodel dan meramal pelbagai prestasi µEDM untuk pelbagai jenis bahan. Sifat bahan, kadar suapan, kapasitansi dan jurang voltan adalah dipilih sebagai parameter input yang direka bentuk dalam tiga peringkat berdasarkan eksperimen berfaktorial penuh. Model CANFIS ini berjaya meramal dengan tepat prestasi µEDM yang terdiri daripada kadar penyingkiran bahan (MRR), jumlah pulsa nyahcas, lebihan potongan dan ketirusan hanya dengan satu model. Peratusan ralat min mutlak (MAPE) daripada ramalan model untuk data ujian bagi pelbagai prestasi seperti MRR, jumlah pulsa nyahcas, lebihab potongan dan ketirusan masing-masing mencatatkan 9.5% (90.5% ketepatan), 8.9% (91.1% ketepatan), 16.9% (83.1% ketepatan) and 15.7% (84.3% ketepatan). Penyelidikan ini mencadangkan pendekatan baharu dalam memodel dan meramal prestasi µEDM dengan mengambil kira sifat bahan mengunakan kecerdasan buatan.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science in Engineering.

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Dean, Kulliyyah of Engineering

DECLARATION

I hereby declare that this thesis is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

Wan Ahmad Bin Wan Azhar

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LIST OF SYMBOLS

τ	Time constant (s)
R	Resistance (Ω)
C	Capacitance (F)
Vcc	DC supply (V)
E	Discharge energy per pulse (J)
V	Gap voltage (V)
T_{on}	Pulse on-time (s)
T_{off}	Pulse off-time (s)
f	Pulse frequency (Hz)
V_w	Volume of material removed from workpiece (m^3)
T_m	Machining time (s)
h	Thickness of workpiece (m)
π	Pi
d	Top surface hole diameter (m)
b	Bottom surface hole diameter (m)
V_e	Volume of material remove from electrode (mm^3)
D_f	Hole entrance diameter (m)
D_{Tool}	Electrode’s diameter (m)
D_{top}	Top surface hole diameter (m)
D_{Bottom}	Bottom surface hole diameter (m)
R^2	Goodness-of-fit measure
x	Variable name

$T(x)$	Term-set of x
U	Universe of discourse
G	Syntactic rule
M	Semantic rule
X	Universe of discourse
μNL	Membership values for negative large
μNS	Membership values for negative small
μDP	Membership values for desired position
μPS	Membership values for positive small
μPL	Membership values for positive large
AND	Conjunction
OR	Disjunction
max	Maximum
$\cup$	Union operator
$\cap$	Intersection operator
prod	Product
Min	Minimum
probor	Probabilistic OR
N_{Rules}	Number of rules
N_{Input_terms}	Number of input terms
i	Number of input variable
j	Linguistic terms
x_i	Crisp input
k	*k*-th number of nodes

m	m-th number of networks
$\overline{W_k}$	Normalized activation value of the k-th node
f_k	Consequence parameters
λ	Thermal conductivity (W/mK)
θ	Melting point (K)
ρ	Electrical resistivity (Ωcm)
E_d	Discharge energy per pulse (J)

LIST OF ABBREVIATIONS

FET	Field effect transistor
MRR	Material removal rate
PWM	Pulse width modulation
RC	Resistance-capacitance
MOSFET	Metal oxide semiconductor field effect transistor
EDM	Electrical discharge machining
TWR	Tool wear rate
DOC	Diametrical overcut
ANN	Artificial neural network
FIS	Fuzzy inference system
ANFIS	Adaptive neural fuzzy inference system
MODE	Multi-objective differential evolution
MOABC	Multi-objective optimization using an artificial bee colony algorithm
GA	Genetic algorithm
FEM	Finite element method
PSO	Particle swarm optimization
NN	Neural network
MTI	Material technology index
CANFIS	Co-active neural fuzzy inference system
MANFIS	Multi adaptive neural fuzzy inference system
Ti	Titanium
NL	Negative large

NS	Negative small
DP	Desired position
PS	Positive small
PL	Positive large
COG	Centre of gravity
WA	Weight average
LSE	Least square estimate
CNC	Computer numerical control
DAQ	Data acquisition

CHAPTER ONE

INTRODUCTION

1.1 RESEARCH BACKGROUND

Micro-manufacturing is a highly sought-after manufacturing process in the modern era. It enables the fabrication of microparts and components for various industries, including semiconductors, biomedical devices, automotive, and aerospace. Micro Electrical Discharge Machining (µEDM) is a micromachining process that uses an electrical spark to erode conductive material. The non-contact interaction between the electrode and the workpiece makes µEDM an effective method for machining metals regardless of their hardness. Hence, this eliminates mechanical stresses during the machining process.

Micro components and parts fabrication is a difficult task in the manufacturing process. For example, micro-hole machining requires a micron level setup. µEDM is a miniature version of EDM specifically designed for microfabrication. A low discharge energy per pulse is critical for micro-level machining, which is accomplished by controlling parameters such as gap voltage, feedrate, and power supply type.

Over the recent years, modelling and prediction of the µEDM machining process using soft computing and artificial intelligence have emerged. From the literature review, the different combinations of process parameters and performances, modelling techniques and workpiece –tool selection can lead to extensive research opportunities in modelling. So far, the implementation of artificial intelligence in predicting µEDM performances based on material properties is still not established. Therefore, proper modelling for µEDM performances on the different types of the workpiece material is needed for the µEDM application. Since EDM is a non-linear and stochastic process, coactive neuro-fuzzy inference system (CANFIS) is proposed to model and predict the μEDM performances.

1.2 PROBLEM STATEMENT

The implementation of artificial intelligence in predicting μEDM performances based on material properties is still not established. Moreover, the selection of μEDM parameters remains a challenge since it is frequently based on machinist intuition and heuristic approaches.

1.3 RESEARCH OBJECTIVES

The study aimed to achieve the following objectives:

1- To design and perform μEDM experiments by considering the material properties.

2- To implement and evaluate CANFIS model that incorporates material properties for μEDM application.

3- To evaluate the relationships between the process parameters and the μEDM performances.

1.4 RESEARCH METHODOLOGY

Flowcharts in Figure 1.1 summarized the research methodology.

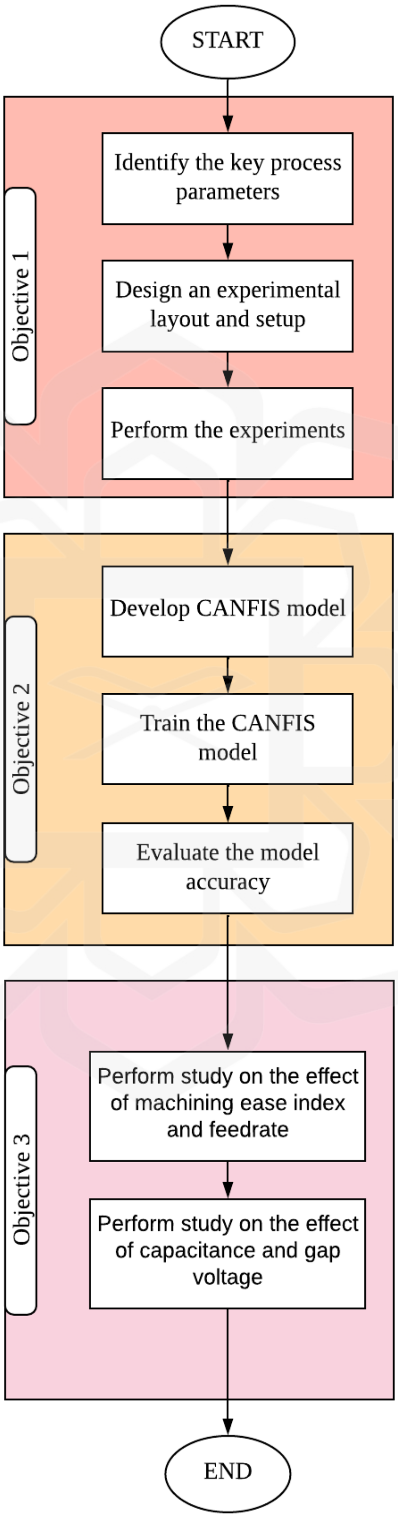

Figure 1.1 Research methodology flowchart

1.5 RESEARCH SCOPES

The research focuses on modelling and predicting µEDM performances for the different workpiece materials according to the ease of machining order through soft computing-based model. Hence, this research only focuses on micro-scale, die sinking EDM. The workpiece materials used were aluminium, copper, and stainless steel. The µEDM machine used for the experiment is an in-house-built µEDM machine. It is powered by an RC-based power supply. It was configured with a 1kΩ resistor with three parallel capacitors of 1nF, 10nF and 100nF. The gap voltage can be set from 50V to 100V.

1.6 RESEARCH SIGNIFICANCE

This research proposes a novel approach in modelling and predicting µEDM performances by considering workpiece's materials using artificial intelligence.

1.7 THESIS ORGANIZATION

This report is divided into five chapters, which are introduction, literature review, methodology, result and discussion and conclusion.

Chapter 1 introduces the fundamentals related to µEDM. The motivation of this research is also explained in this chapter.

Chapter 2 conducts a review of the literature on EDM principles and previous research on modelling and predicting EDM performance. This chapter discusses the prior literature and the research gap.

Chapter 3 describes the research flow and methodology. Additionally, modelling techniques such as fuzzy logic, ANFIS, and CANFIS architectures are discussed. The design of the experiment, as well as the experimental setup, are defined in this chapter.

This chapter also explains the training procedure and parameter selections for CANFIS modelling.

Chapter 4 summarises the experimental data gathered in Chapter 3. This chapter discusses the model's training result and accuracy in detail. Additionally, relationships between process parameters and µEDM performance were investigated.

Chapter 5 summarizes the research findings and presents the thesis’s recommendation.

CHAPTER TWO

LITERATURE REVIEW

2.1 OVERVIEW

Machining processes are divided into two classes by M. P. Groover (1996). To begin, traditional machining operations such as turning, drilling, and milling use sharp cutting tools to remove a chip from the workpiece. Non-traditional machining, on the other hand, refers to a range of operations that remove material using different mechanisms. Mechanical, thermal, electrical, chemical, or mixtures of these techniques are used by this group. These non-traditional methods are required to machine new materials with unique qualities, as well as to produce odd and complex part geometries and avoid surface damage caused by conventional machining. The examples of non-traditional methods are the Ultrasonic Machining (UM) and Electrochemical Machining (EM).

Joseph Priestly discovered the erosive impact of electrical discharges in the 1770s, which started the history of EDM (Ho & Newman, 2003; Kumar, Singh, Singh, & Sethi, 2009). During World War II, two scientists, Lazarenko and Lazarenko started working on electrical discharge machining at Moscow University, and later in 1950, the Lazarenkos introduced an EDM system that used a resistance-capacitance power source (Ho & Newman, 2003; Kumar et al., 2009; Pandey & Singh, 2010). With the implementation of Computer Numerical Control (CNC) in EDM in the 1980s, the efficiency of the machining operation improved (Ho & Newman, 2003; Kumar et al., 2009) Figure 2.1 illustrates the schematic diagram of EDM.