AN ULTRASONIC VIBRATION DEVICE FOR MICRO ELECTRO-DISCHARGE MACHINING

BY

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A dissertation submitted in fulfilment of the requirement for the degree of Master of Science (Mechatronics Engineering)

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ABSTRACT

Micro-machining technologies have enjoyed a recent resurgence due to massive demands in many engineering, production and manufacturing sectors. Micro Electric Discharge Machining (μ-EDM) is one of the most popular techniques available to produce microscopic features and components for various industries. Micro electro-discharge machining (μ-EDM) uses electro-thermal energy from repetitive sparks generated between the tool and workpiece to remove material from the latter. This technique can ensure better machining performance in terms of reduced Heat Affected Zones and surface finishing. It also comes with inherent disadvantages such as high machining time, low material removal rate (MRR) and unstable machining. One of the bottlenecks of μ-EDM is the phenomenon of short circuits due to the physical contact between the tool and debris (formed during the erosion of the workpiece). To overcome these factors, vigorous flushing of dielectric fluid is performed. Adequate flushing of the debris can be achieved by applying low amplitude high-frequency vibration to the workpiece. The vibration aids in carrying away the debris accumulated in the spark-gap region. In this research, a novel design of an ultrasonic vibration fixture has been proposed. This fixture will facilitate vibration of the workpiece that is required to improve machining performance. Further enhancement of the design leads to better machining performance. System Identification helps to determine the nature of the system and model the input-output response. The oscillation of the system can be easily characterized and validated using System Identification. This study, however, shows that the application of vibration does not yield beneficial results for the μ-EDM for all the parametric conditions. The results of this study suggest that vibration-assisted μ-EDM becomes less effective as the discharge energy is increased (primarily by increasing the capacitor value of the RC pulse generator). Similarly, the reduction of the occurrence of the short circuit was profound when the low discharge energy level with low voltage and low capacitor setting of the RC Pulse generator was used. The overall scale of the overcut with various discharge energy and μ-EDM speed varied from 1μm/s to 11μm/s for the conventional μ-EDM process. At a low capacitor value (10 pF), ultrasonic vibration reduces tool wear by ~31%. As a result of using the ultrasonic vibration device, the average increase in MRR of ~ 46% was achieved across all voltage levels.

خلاصة البحث

تمتعت تقنيات الآلات الدقيقة بالانتعاش مؤخرًا بسبب الطلبات الهائلة في العديد من قطاعات الهندسة والإنتاج والتصنيع. تعد عملية التفريغ الكهربائي الدقيق (μ-EDM) واحدة من أكثر التقنيات شيوعًا المتاحة لإنتاج ميزات ومكونات مجهرية لمختلف الصناعات. تستخدم آلية التفريغ الكهربائي الدقيق (μ-EDM) الطاقة الكهوروحرارية من الشرر المتكرر المتولد بين الأداة وقطعة العمل لإزالة المواد من الأخير. يمكن أن تضمن هذه التقنية أداء معالجة أفضل من حيث تقليل المناطق المتأثرة بالحرارة وتشطيب الأسطح. كما أنها تأتي مع عيوب متأصلة مثل وقت المعالجة المرتفع ، وانخفاض معدل إزالة المواد (MRR) والمعالجة غير المستقرة. إحدى اختناقات μ-EDM هي ظاهرة الدوائر القصيرة بسبب التلامس المادي بين الأداة والحطام (المتكون أثناء تآكل قطعة العمل). للتغلب على هذه العوامل ، يتم إجراء التنظيف القوي لسائل العزل الكهربائي. يمكن تحقيق التنظيف الكافي للحطام عن طريق تطبيق اهتزاز عالي التردد منخفض السعة على قطعة العمل. يساعد الاهتزاز في نقل الحطام المتراكم في منطقة فجوة الشرر. في هذا البحث ، تم اقتراح تصميم جديد لجهاز الاهتزاز بالموجات فوق الصوتية. ستعمل هذه الوحدة على تسهيل اهتزاز قطعة العمل المطلوبة لتحسين أداء المعالجة. يؤدي التحسين الإضافي للتصميم إلى أداء تصنيعي أفضل. يساعد تعريف النظام على تحديد طبيعة النظام ونمذجة استجابة المدخلات والمخرجات. يمكن تمييز تذبذب النظام والتحقق من صحته بسهولة باستخدام "تعريف النظام". ومع ذلك ، تُظهر هذه الدراسة أن تطبيق الاهتزاز لا يسفر عن نتائج مفيدة لـ μ-EDM لجميع الظروف بالنسبة للمتغيرات. تشير نتائج هذه الدراسة إلى أن μ-EDM المدعوم بالاهتزاز يصبح أقل فعالية مع زيادة طاقة التفريغ (بشكل أساسي عن طريق زيادة قيمة المكثف لمولد نبض RC). وبالمثل ، كان الحد من حدوث ماس كهربائى عميقًا عند استخدام مستوى طاقة التفريغ المنخفض مع الجهد المنخفض وإعداد المكثف المنخفض لمولد RC Pulse. تباين الحجم الكلي للقطع الزائد مع طاقة التفريغ المختلفة وسرعة μ-EDM من (ثانية واحدة) μm / s1 إلى (احدى عشر ثانية) μm / s11 لعملية μ-EDM التقليدية. عند قيمة مكثف منخفضة (pF 10) ، يقلل الاهتزاز بالموجات فوق الصوتية من تآكل الأداة بحوالي 31٪. نتيجة لاستخدام جهاز الاهتزاز

بالموجات فوق الصوتية ، تم تحقيق متوسط الزيادة في MRR بنسبة 46 ٪ تقريبًا عبر جميع مستويات الجهد.

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 dissertation for the degree of Master of Science (Mechatronics Engineering)

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DECLARATION

I hereby declare that this dissertation 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.

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LIST OF SYMBOLS

D_t	Diameter of entry hole
D	Diameter of tool electrode
V	Volume
B_1	Entry Area of the Hole
B_2	Exit Area of the Hole
h	Depth of the Hole
θ	Taper Angle
t	Sample thickness
µm	Micro-meter
Ra	Surface roughness
ω	Angular Frequency
s	Displacement
f	Frequency
v	velocity

LIST OF ABBREVIATIONS

EDM	Electric Discharge Machin
µ-EDM	Micro- Electric Discharge Machin
DC	Direct Current
CNC	Computer Numerical Control
PZT	Piezoelectric Transducer
kHz	Kilohertz
mm	Millimeter
UV	Ultrasonic Vibration
2-D	2 Dimensional
3-D	3 Dimensional
RC	Resistance Capacitance
OC	Overcut
SEM	Scanning Electron Microscope
MRR	Material Removal Rate
DT	Decision Tree
TWR	Tool Wear Rate
SVM	Support Vector Machine
pF	Picofarad
NB	Naive Bayes
SQ	Surface Quality
WEDM	Wire EDM

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

A popular microfabrication technique nowadays is the technique of Electric Discharge Machining (EDM). Microfabrication techniques are usually based on the techniques of nontraditional machining. In the realm of machining and micromachining, there are two major techniques involved. The conventional method deals with applying the cutting force directly to the workpiece while the tool is in contact. But this method faces an obstacle in the case of machining hard or brittle materials using tool of appropriate hardness. To overcome this obstacle, contactless non-traditional methods have been developed. These methods provide manufacturers with options to scale down and diversify the size and shape of machined products. EDM is such a process where material is removed from the workpiece via low energy electrical discharge. The electrical energy is converted to heat energy which is directly applied to the workpiece for achieving the removal of material. When EDM is applied to the domain of fabrication of parts that lie in the micrometer range, it is called micro-EDM or µ-EDM. Various process parameters govern the functionality of the EDM machine. It consists of a setup that includes a DC power supply, electrodes, dielectric fluid etc. EDM process can be hybridized with other processes for greater efficiency and material removal rate. One such process is the application of ultrasonic vibration to the EDM technique. During the machining process, removed material gets stuck in the gap that exists between the workpiece and the tool, or the in-electrode gap. A technique called flushing is applied to clear the gap of such undesirable blockage. The efficacy of this technique can be further enhanced by applying ultrasonic vibration directly to the workpiece. An ultrasonic vibration stage should be a perfect aiding device for imparting vibration to the workpiece.

1.2 PROBLEM STATEMENT

In conventional μ-EDM process, the flushing of debris is one of the problems which can be enhanced by ultrasonic vibration assisted μ-EDM. No investigation has been found based on the effectiveness of ultrasonic vibration as the μ-EDM's input factors are varied such as voltage, frequency, EDM speed, and capacitor. However, there is no such device available particularly for μ-EDM that can produce ultrasonic vibration during μ-EDM operation. Therefore, there is a need for a universal vibration device that can be used for any μ-EDM machine.

1.3 RESEARCH OBJECTIVES

In order to achieve the aim of this project, following objectives have been set:

1. To develop an ultrasonic vibration assisted fixture and its related controller.
2. To characterize the developed vibration device.
3. To compare the machining performance between vibration assisted μ-EDM and pure μ-EDM.
4. To mathematically model various observed experimental phenomena of vibration assisted μ-EDM.

1.4 RESEARCH METHODOLOGY

The methodology of the project begins with the literature survey and learn about the characteristic of μ-EDM and Piezoelectric Transducers and their performance. Following that, an ultrasonic vibration-assisted fixture was designed. The whole structure was designed in Solidworks software and then fabricated the fixture on a CNC machine. All components of this unit are fabricated out of aluminum. Then the product is ready to characterization of the device using system identification method. Thereafter the fixture mount on the EDM tank to test the performance of the vibration assisted μ-EDM and pure μ-EDM. Finally, a classification model has been done from the experimental results. To achieve the stated objectives of this proposal the following steps will be taken. The summarization of the methodology is shown in the flowchart in Figure 1.1

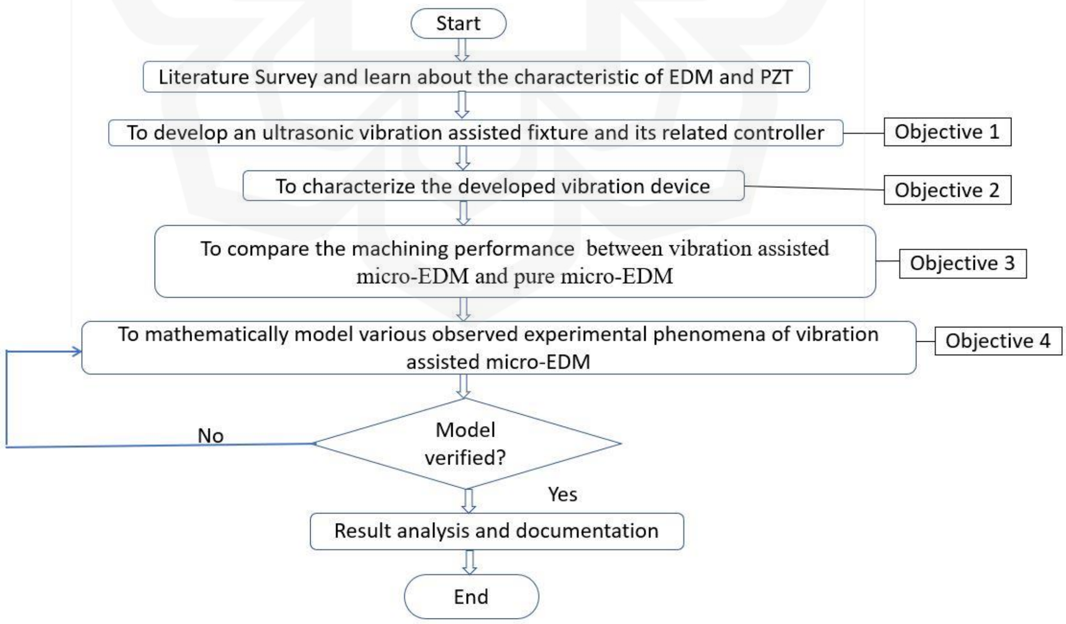

Figure 1.1 Research Methodology Flowchart

1.5 RESEARCH SCOPE

The research focuses on developing of an Ultrasonic vibration assisted device for μ-EDM operation. The range of vibration frequency from 1 kHz to 50 kHz. We have used the vibrator for resonance frequency to have the maximum displacement. So, the resonance frequency was 29.4KHz. The length of the workpiece holder are 65 mm and width are 49 mm. The workpiece should be of an exact dimension of 25 mm by 29 mm. We will characterize the device to understand the dynamic behaviour using system identification method and how it will improve the performance of the μ-EDM. We have compared the machining performance between vibration assisted μ-EDM and pure μ-EDM and done a mathematical model various observed experimental phenomena of vibration assisted μ-EDM.

1.6 THESIS ORGANIZATION

This thesis is organized into six chapters. Chapter One outlines the background of the study, problem statement, research objectives, Research Scope and Research Methodology.

Chapter Two provides the literature review of history of Electrical discharge machine (EDM), micro-EDM, principle of EDM and micro-EDM, ultrasonic vibration assisted EDM, ultrasonic vibration applied to the tool electrode, workpiece, and dielectric liquid. Also discussed about the EDM applications on micro EDM hole, ceramic, modern composite material.

Chapter Three describes the methodology of this research. Where developed an ultrasonic vibration assisted fixture and characterized the device and compare the machining performance between vibration assisted micro EDM and pure micro EDM.

Chapter Four describe the design, fabrication and performance analysis of an ultrasonic vibration-assisted fixture that has been approached. A system identification and validation model has been described.

Chapter Five represents the result and discussion about the micro EDM performance and investigation the study of material removal rate, Tool wear, short circuit occurrence, overcut and taperness.

Chapter Six summarizes the research work and further recommendation of ultrasonic vibration assisted micro-EDM research related work.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

Electro discharge machining (EDM) is a well-known and commonly utilized non-conventional machining method for hard-to-cut materials due to its independence from the workpiece's hardness, brittleness, or toughness. Micro and precision machining, such as in the mold-making sector, have successfully used low-energy lasers. Accuracy demands a very steady process in smaller and more complicated structures. Thus, flushing procedures must be improved. Electrical discharge machining can be utilized on a wide range of materials due to the non-contact between the workpiece and the tool, which means that the hardness of the material is irrelevant. Electrical discharge machining (EDM) is one of the most widely utilized non-conventional machining methods in the current industrial context. EDM's major benefit is its ability to machine any electrically conductive material, independent of its mechanical characteristics, such as strength and hardness, in complicated geometries and with great dimensional precision. Die and mold production, aerospace, the automobile industry, microelectronics, and biomedical engineering are just a few of the areas where electro-discharge machining (EDM) is used. In EDM, the material erosion mechanism is a sequence of discrete electrical discharges, which makes it a thermoelectric process.

This chapter introduces the relevant literature review on Electrical discharge machine (EDM). The Principles of EDM/μ-EDM and different types of EDM and the effectiveness of ultrasonic vibration assisted EDM/μ–EDM are discussed in this chapter.

2.2 HISTORY OF ELECTRICAL DISCHARGE MACHINE (EDM)

English scientist Joseph Preistly invented Electro-discharge machining (EDM) in the 1770s (Meshram, Puri, & Engineering, 2017). Most researchers did not use it because of its poor accuracy and running issues. Russian scientists' continued engagement improved the machining and sparked an expansion of study. It was commercially developed in the middle of the 1970s and used wire-cut EDM to reshape the metalworking industries. The transfer of EDM technology in the middle of the 1980s led to the usage of machine tools and their enhanced utility for various applications. In the mid-1980s, EDM methods were adapted to a machine tool for the first time. As a result, EDM has become more commonly available and desirable as a machining technique (Modi, Agarwal, & Management, 2019). As research progressed in the twentieth century, it became increasingly focused on new applications that substantially benefited society. Complex shape fabrication in the die and mold sectors has seen significant advancements in EDM technology. (Meshram et al., 2017).

2.3 BASIC PRINCIPLE OF EDM/µ -EDM

It is possible to remove small amounts of electrically conductive material from workpieces using EDM, which involves utilizing a tool electrode in conjunction with the workpiece in order to produce precisely timed sparks while the workpiece is in the presence of a dielectric fluid (M. P. Jahan, Ali Asad, Rahman, Wong, & Masaki, 2011). Although the micro-EDM mechanism is essentially similar to that of the traditional electrode discharge machine (EDM) (T. J. C. A. Masuzawa, 2000). Each spark removes a tiny quantity (in the range of milligrams) of material by leaving a crater in the workpiece. This process is called arcing, and it is used to remove material from workpieces. It's possible that the sparking process can continue for a specific amount of time before pausing for another length of time, which is called the pulse duration [μs]. Each discharge cycle is defined by the length of the pulses and the interval between the pulses. The discharge frequency may be adjusted by adjusting the number of cycles that can be conducted in a second. The pulse generator may adjust the discharge energy for a single pulse dependent on the machining circumstances, such as roughing, semi-finishing, or finishing. A servo control system ensures that the electrode moves at the right speed toward and maintains a spark gap and removes it if there is a short circuit. As part of the EDM/μ-EDM system, a dielectric circulation system is incorporated with a pump, filter, and dielectric reservoir to maintain the spark gap's dielectric freshness and efficiently flush machined zone detritus. The fundamental EDM/Micro-EDM system is shown in Figure 2.1.

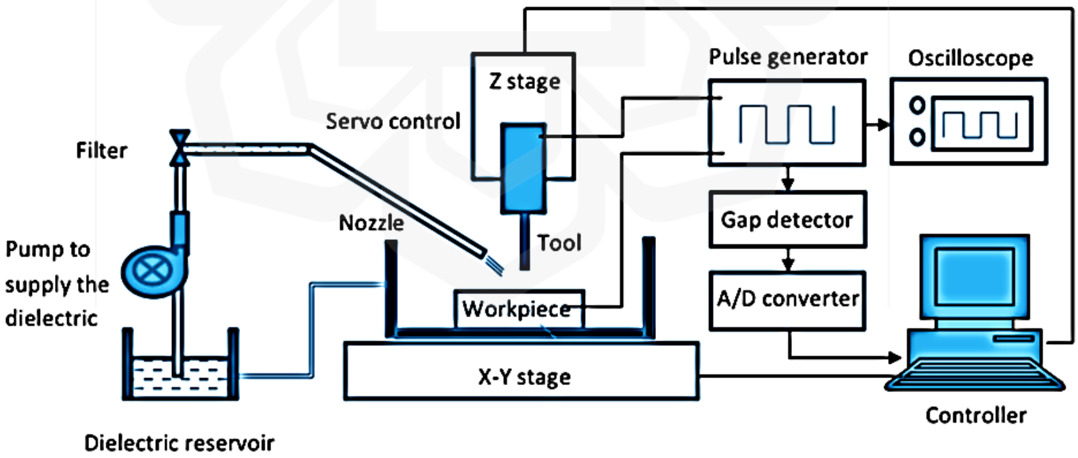

Figure 2.1 Schematic diagram of the EDM system
(Davim, 2013).

Two consecutive sparking phases are separated by an interval phase, which occurs in EDM and micro-EDM and prepares the part for the next step of the sparking process

(Schumacher, 2004). When the machining process begins, a voltage is placed across the spark gap, creating an electric field with an energy column around it. The energy column grows in size as the sparking process proceeds. Higher spark gaps make the energy column stronger. When the dielectric breaks down, electricity can travel across the spark gap and ignite the plasma. The energy column collapses as voltage decreases due to the current flowing through it. When the spark hits the electrode or workpiece, it melts and evaporates the materials, leaving behind a crater on both. The size of holes is determined by the electrode and the workpiece's polarity and may be adjusted to meet specific needs. The energy required for material removal is estimated at 3% of the machine tool's overall energy consumption, with EDM process efficiency at less than 0.01% (Tristo, Bissacco, Lebar, & Valentinčič, 2015). After removing the substance, the sparking process ends, and the pulse interval is defined. For a short period of time, the flushing mechanism works to remove debris from the spark gap, which allows fresh dielectric to enter the gap and prepares the system for new bursts of sparking. The sparking (Rajurkar et al., 2006) and gap (Kunieda, Lauwers, Rajurkar, & Schumacher, 2005) phenomena during the EDM/micro-EDM process are shown schematically in Figure 2.2.