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DEVELOPMENT OF MICRO-EDM WITH MICROACTUATOR FEED CONTROL SYSTEM

(MEMBANGUNKAN EDM MIKRO MENGGUNAKAN AKTUATOR MIKRO SEBAGAI SISTEM PENYUAPAN PEMOTONGAN)

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ABSTRACT

Development of Micro-EDM with Microactuator Feed Control System

(Keywords: EDM, Micro Machining, Micro EDM, Advance Machining Process)

This project aims in revealing varieties of methods in tool feed control for Micro electric discharge machining (EDM) process with new advanced technology achieved. Although Micro EDM usage is essential in manufacturing sector but the gap phenomena still remains complicated and unstable. Recent research improves the gap control problem with latest technology such as servomechanism, fuzzy logic, Piezoelectric transducer (PZT), ultrasonic vibration and many more. PZT tool feed control system is used in this project as the main system to prevent any adhesion and to reduce tool wear. This project also aims in discussing factors influencing tool wear and new tool materials in Micro EDM. Tool wear prevention in EDM is essential because quality and precision of the product machined by EDM depends on the tool wear. If the tool wear is high, the product machined depth will be inaccurate with low surface quality. In future prospect, Micro EDM should be equipped with self learning and user friendly utilities for mass production usage. Future Micro EDM will be a package of integrated self learning and fast production machine.

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ABSTRAK

Membangunkan EDM Mikro menggunakan Aktuator Mikro sebagai Sistem Penyuapan Pemotongan

(Keywords: EDM, Pemesinan Mikro, Mikro EDM, Sistem Pemotongan Termaju)

Projek ini bertujuan untuk membangunkan mesin Mikro Electric Discharge Machining atau EDM dengan penggunaan sistem Piezoelectric Transducer atau PZT dan mengungkan pelbagai kaedah yang berkaitan sistem kawalan alat mesin untuk proses EDM yang penting dalam sektor pembuatan yang maju. Walaupun Mikro EDM penting dalam pembuatan tetapi fenomena pengawalan celah antara alat mesin dan bahan masih merupakan masalah yang belum jelas dan tidak stabil. Kajian terbaru terbukti telah menolong dalam memperbaiki fenomena kawalan celahan antara alat mesin dan bahan seperti teknologi pengunaan motor servo, fuzzy Logic, PZT dan lain – lain. Sistem PZT dipilih dalam projek ini sebagai sistem yang menghalang kejadian penghakisan alat mesin. Projek ini juga bertujuan untuk membincangkan faktor – faktor yang mempengaruhi hakisan alat mesin Mikro EDM. Pencegahan hakisan adalah penting dalam EDM kerana kualiti bahan yang dimesin bergantung kepada keadaan alat mesin. Jika hakisan alat mesin adalah tinggi, lubang yang dimesin di permukaan bahan tidak akan tepat. Di masa hadapan, Mikro EDM haruslah disertakan dengan teknologi yang boleh menolong mesin tersebut dalam mengesan kesilapan dan memperbaikinya.

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LIST OF ABBREVIATIONS

CNC	Computer Numerical Machining
CVDD	chemical vapordeposition diamond
EDM	Electrical discharge machining
Et al	And Others
EDG	Electric Discharge Grinding
K10	cemented carbide
MOSFET	metal–oxide–semiconductor field-effect transistor
OpAmp	Operational Amplifier
PWM	Pulse Width Modulator
PCD	Graphite polycrystalline diamond

LIST OF ATTACHMENTS

CHAPTER 1

INTRODUCTION

In recent years the demand of micro parts has been increasing and the use of machining in micro scale became of outmost important. Recent studies have been conducted to optimize the full capacity of micro machining. In producing micro parts the use of Micro-EDM has been vastly used. Micro-EDM is produced micro parts for aerospace applications and small scale parts such as producing micro holes etc.

Micro machining has been renowned to produce high aspect ratio micro products and there is a huge demand in the production of micro-structures by this non-traditional method which is known as Micro-EDM (Electrical Discharge Machining). Micro-EDM concept is based on the thermoelectric energy between the workpiece and electrode. The working principles of EDM is based on the conversion if electrical discharge energy into thermal energy through a series of discrete electrical discharges occurring between the electrode and workpiece while immersed in the dielectric fluid (S. Kumar et. al. 2009). Micro-EDM is an efficient machining process for the fabrication of micro-metal hole with various advantages resulting from its characteristic of non-contact and thermal process. A pulse discharge occurs in a small gap between the workpiece and the electrode at the same time removes the unwanted material from the parent metal through the process of melting and vaporization.

Piezoelectric actuator is one of the most important mechanism in a Micro-EDM because a piezoelectric actuator controls the displacement of the Z-axis movement of the tool feed mechanism. Piezoelectric actuators are important in optics, space, aircraft, biomedical, and manufacturing field whereas in those field there is a strong need for a compact, robust, and efficient positioning mechanism that offer high precision, short response time, low power consumption, low electromagnetic interference and multiple degree of freedom (F. Claeyssen et. al. 2002).Piezoelectric is the best candidate to build a servo-feed mechanism since it has high precision and low power consumptions. In additional to that a piezoelectric actuator has fast response time where fast response is crucial in order to avoid short-circuit between the tool electrode and the workpiece when the erosion process takes place.

PROBLEM STATEMENT

Recent developments in Micro-EDM have made Micro machining a crucial process in manufacturing micro products. Micro-EDM is needed for a high precision machining where high precision machining is needed to produce microproducts that is essential in the future. In machining process there are countless problems that can reduce the quality of the product and that will affect the cost of the machining. In micro-EDM drilling, producing blind holes is stated as a problem because wear will constantly reduce the length of the electrode. Problems regarding the electrode wear will affect the erosion process where when eroding down to a fixed depth, the real depth of the hole will be significantly small. It becomes more complicated when machining complex 3D micro-cavities. High wear rate will cause more frequent wire breaks. This is because wear reduces the cross section of the micro-wire therefore the maximum tension the wire can take reduces as the cross section area of the micro-wire decreases. This will affect the spark gap where the spark gap area will change as the electrode moves down feeding in the Z-axis direction (Fig. 1). The absence of the dielectric flushing will result in low precision machining processes. The decomposition on the tool electrode and the workpiece will make the machining process hard to commence because the decomposed carbon particles will block the surface that is supposed to be machined. The machining process will become more complicated since the tool electrode is expensive to fabricate the machining process must be done accurately in order to lower the machining cost.

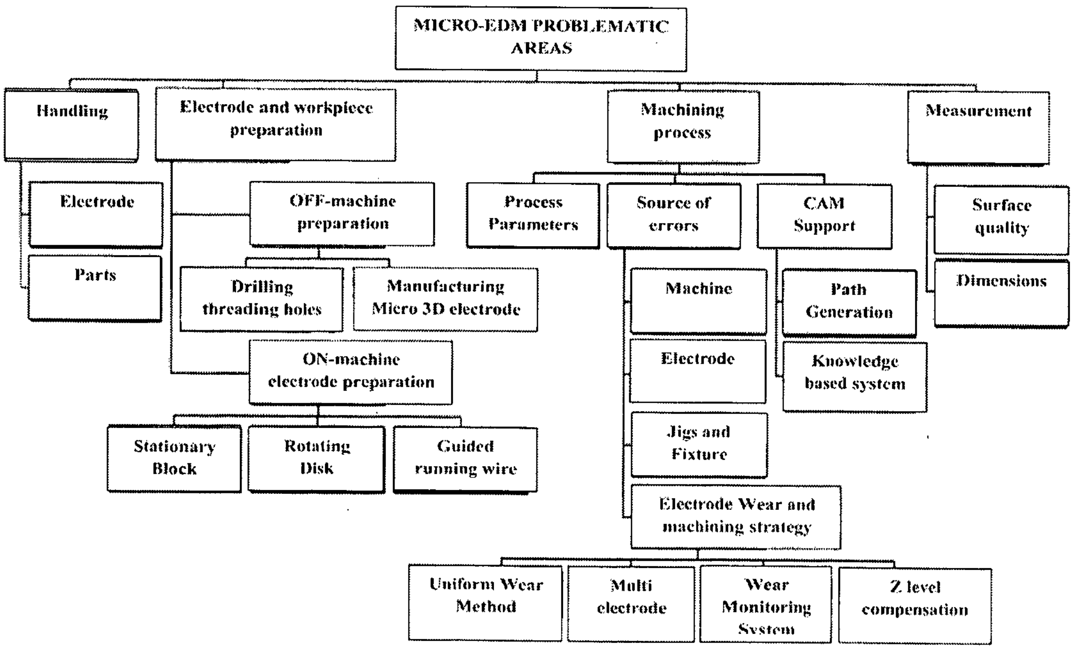

Figure 1: Problematic areas of Micro EDM

OBJECTIVES OF THE RESEARCH

The main objective of this research work is to model the micro EDM process with the microactuated tool feed mechanism to control the tool feed rate and to achieve the required depth of micromachining. This involves

- Modeling the microactuator as an electromechanical model considering the physical properties of various components.
- Modeling the Micro EDM Process for accurate estimation of tool and workpiece material removal rates
- Develop a Micro EDM with microactuated tool feed mechanism.

SCOPE OF PROJECT

This study is to develop a Micro-EDM with micro actuator tool feed system by using a piezoelectric actuator. The piezoelectric is a sensor that has high positioning precision, high resolution, quick response to feedback and it can also acts as both actuator and sensor. The required model of the piezoelectric actuator is analyzed from Cedrat Technologies and the preferred model for the experiments will be purchased. Previous design uses a servo motor as the tool feed control system where the servo motor is not accurate because the maximum displacement is not as small as the piezoelectric actuator where the piezoelectric actuator scale is in micro-scale.

Based on previous research circuitry on micro-EDM the circuit will be evaluated and produced based on the needs of our project. The study and interpretation of a rectifier circuit of Micro-EDM will be conducted in this project. Dielectric flushing is essential in Micro-machining because dielectric flushing will remove the waste metal particle that decomposes on the tool electrode. A dielectric circulation system will be proposed in this study and based on the design of the reservoir tank (dielectric tank).The circulation system is chosen based on the most suitable flushing system that can flush the dielectric fluid and cast away the unwanted waste metal particle after the machining processes. The circulation system in the tank is to ensure the dielectric fluid can flush the waste metal particles and cool the electrode.

CHAPTER 2

Paper 1

A Review of Micro-EDM

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A Review of Micro-EDM

S. Mahendran, R. Devarajan, T. Nagarajan, and A. Majdi

Abstract-There is a huge demand in the production of microstructures by a non-traditional method which is known as Micro-EDM. 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 which in the range of 50 µm -100 µm. Micro-EDM is an efficient machining process for the fabrication of a micro-metal hole with various advantages resulting from its characteristics of non-contact and thermal process. A pulse discharges occur in a small gap between the work piece and the electrode and at the same time removes the unwanted material from the parent metal through the process of melting and vaporization. In this paper describes the characteristics, parameters material removal rate and the tool wear rate that are essential in the Micro-EDM process.

Index Term: Micro-EDM, EDM, Micromachining, Non-Conventional Machining Process

1. INTRODUCTION

Micro Electrical Discharge machining is quite similar with the principals of Electrical Discharge Machining. According to Z. Katz and C.J Tibbles from the article "Analysis of micro-scale EDM process" states that Electro discharge machining (EDM) 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 (H. Zarepur, A. Fadaei Tehrani, D. Karimi, S. Amini, 2007) 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 work piece and tool electrode. EDM is a process that provides an alternative method to produce microstructures. It is also states that the micro EDM is similar to the principal of macro EDM where the process mechanism is based on an electro-thermal process that relies on a discharge through a dielectric in order to supply heat to the surface of the work piece. The current causes the heating of the dielectric, the work piece, and the electrode. The dielectric forms a channel of partially ionized gas. The discharge power is dissipated in the plasma channel with amount between 2% and 10%. The channel acts as a heat source on the surface of the work piece. Then the work piece is locally heated beyond its melting point and removed after the material ejected solidifies within the cooler dielectric medium. The significant difference between micro and macro EDM is the plasma channel radius (Diameter). In macro EDM the plasma size is larger by several orders of magnitude than the plasma channel radius. The size of the plasma can be changed by the pulse duration because the channel radius increases as the time increases. If the pulse duration time allows the channel to expand until it is larger than the electrode diameter, the rate of its expansion will change.

2. Principals of Micro EDM

Based on the journal Rapid Biocompatible Micro Device Fabrication by Micro Electro-Discharge Machining by M. Murali & S. H. Yeo. Micro EDM is based on a simple theory, when two electrodes is separated by a dielectric medium, come closer to each other, the dielectric medium that is initially non conductive breaks down and becomes conductive. During this period sparks will be generated between the electrodes. The thermal energy released will be used for the material removal by melting and evaporation. By precisely controlling the amount energy released, it is possible to machine micro features on any electrically conductive material.

Based on "Advancing EDM through Fundamental Insight into the Process" journal by M. Kunieda(Tokyo University of Agriculture and Technology, Japan), B. Lauwers (Katholieke Universiteit Leuven, Belgium), K.P. Rajukar (University of Nebraska-Lincoln, USA), B.M Schumacher (University of Applied Science St Gallen, Switzerland) explains the basic principle of EDM. In the gap filled of insulating medium most preferable a dielectric liquid such as hydrocarbon oil or de-ionized water between the tool and electrode occurs the discharging of the pulsed arc. The insulating medium is to avoid the electrolysis effects on the electrodes during the EDM process. The electrode shape is copied with an offset equal to the gap size and the liquid will be selected to minimize the gap in order to obtain precise machining. To make sure it is safe, a certain gap width is needed to avoid short circuiting especially for electrodes that are sensitive to vibration or deformation is used. Initially, a high voltage current is needed to discharge in order to overcome the dielectric breakdown strength of the small gap. Formed between the electrodes is a channel of plasma (ionized and electrically conductive gas with high temperature) and it will develops further depends on the discharge durations.

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Discharge occurs at high frequencies between 10^3 and 10^6 hertz since the metal removal per discharge is very small. For every pulse, discharge occurs at a particular location where the electrode materials are evaporated or ejected in the molten phase then a small crater is generated both on the tool electrode and workpiece surfaces. The removed material are then cooled and re-solidified in the dielectric liquid forming several hundreds of spherical debris particles which will be flushed away from the gap by the dielectric flow.

At the end of the discharge duration, the temperature of the plasma and the electrode surfaces that is in contact of the plasma rapidly drops, resulting in the recombination of ions and electrons also the recovery of the dielectric breakdown strength. To obtain stable condition in EDM, it is important for the next pulse discharge occur at a spot distanced sufficiently far from the previous discharge location. This is because the previous location will result in having a small gap and it is contaminated with debris particles which may weaken the dielectric breakdown strength of the liquid. The time interval for the next discharge pulse should be long so that the plasma that is generated by the previous discharge can be fully de-ionized and the dielectric breakdown strength around the previous discharge location can be recovered by the time the next voltage charge is applied. If happens that the discharges occurs at the same location, resulting in thermal overheating and non-uniform erosion of the workpiece.

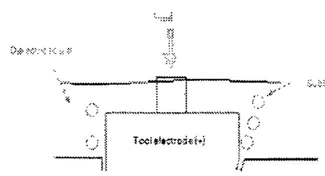

Figure 1: Concept of EDM

3. Types

3.1 Sin king EDM

Adapted from the article "Advancing EDM through Fundamental Insight into the Process" by M. Kunieda(Tokyo University of Agriculture and Technology, Japan), B. Lauwers (Katholieke Universiteit Leuven, Belgium), K.P. Rajukar (University of Nebraska-Lincoln, USA), B.M Schumacher (University of Applied Science St Gallen, Switzerland). The sinking electrical discharge machining is as shown in Figure 2. The workpiece can be formed either by replication of a shaped tool electrode or by 3-Dimensional movement of a simple electrode similar to milling or we can use the combination of both the methods. Normally we use copper or graphite as the electrode material. The numerical control monitors the gap conditions and synchronously controls the different axes and the pulse generator. The dielectric liquid is filtrated to remove debris particles and decomposition products. Hydrocarbons dielectric is normally used since the surface roughness is better and tool electrode wear is lower compared to the de-ionized water.

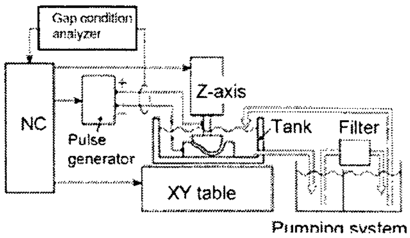

Figure 2: Sinking Electrical Discharge Machining

3.2 Wire EDM

In the figure below outlines the wire electrical discharge machining (WEDM method) which is taken from the article "Advancing EDM through Fundamental Insight into the Process" by M. Kunieda(Tokyo University of Agriculture and Technology, Japan), B. Lauwers (Katholieke Universiteit Leuven, Belgium), K.P. Rajukar (University of . Nebraska-Lincoln, USA), B.M Schumacher (University of Applied Science St Gallen, Switzerland). Wire electrode methods can cut complicated shapes like a wire sawing machine. Normally the wire electrode is brass wire or coated steel wires but in case of thin wires tungsten or molybdenum wires are used. Since we can change the orientation of the wire by controlling the horizontal position of the upper wire guide relative to the lower guide all types of surfaces can be cut. Discharge current with a high-peak value over a short duration of time are used, both the upper and lower feeding brush are supplied with current to obtain a quick rise in the discharge current by reducing the inductance in order to avoid breakage due to Joule heating. To reduce vibration and deflection tension is applied to the wire resulting in deteriorated cutting accuracies. Water is the most often used as the dielectric liquid but its specific electrical conductivity should be decreased using de-ionizing resins to avoid electrolysis and to keep high open voltage.

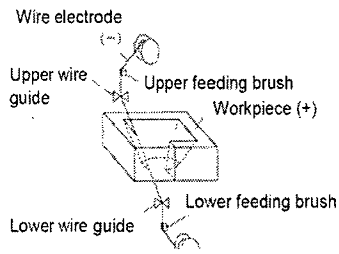

Figure 3: Wire Electrical Discharge Machining

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4. Dielectric Fluids

In micro electrical discharge (MEDM) machining the most important thing to ensure the efficiency of the feed is the dielectric fluids. In MEDM the dielectric fluid acts as a cutting medium to improve surface roughness, corrosion resistance and wear resistance. In most die-sinking process use kerosene as the dielectric fluid (Han-Min Chow, Lieh-Dai Yang, Chin-Tien Lin, Yuan Feng Chen, 2007). However there are a lot of dielectric fluids that can be replace to replace kerosene such as pure water (distilled water) because pure water has a high thermal conductivity, a low viscosity coefficient, and a high flowing rate. Pure water temperature is not affected by long working time, and this will improve the material removal rate (MRR).

Recent researches indicated that adding powder in EDM process will enhance MRR, therefore improving the surface roughness, corrosion resistance and wear resistance. Previous researchers (Yan, 1994, Chen, 1993) used kerosene added with aluminum powder as an EDM dielectric fluid and obtained a high material removal rate and improved surface roughness. Additives can improve the surface quality of workpiece quite effectively by increasing the material removal rate (MRR) and decreasing the tool wear rate especially in mid-finish machining and finish machining (Ming, He, 1995). But the addition of the powder will have an issue on the relative high cost of the powder addition. Other than that, we can also use oil as the dielectric fluids which will affect the tool electrode wear where it depends on the significance of the pulse duration (Masonori Kunieda, Teruki Kobayashi, 2004)

Recently green manufacturing has become very important to all manufacturing industries because using kerosene will give out pollution that pollutes the air. The use of kerosene has a low ignition temperature with possible conflagration if improper operations are undertaken (Han-Min Chow, Lieh-Dai Yang, Chin-Tien Lin, Yuan Feng Chen, 2007). The use of pure water has more good effect on the workpiece since water has a high thermal conductivity, a low viscosity coefficient, and a high flowing rate and pure water will not be affected by a long working time. Thus a constant high material removal rate will be obtained.

5. Minimum Machinable Size

Recently the demands for microscopic parts have increased and the research on Micro EDM is becoming more and more important. The minimum machinable diameter of micro rods obtained by EDM is about 5 μm at best. Thus more effort is needed to extend the limits of miniaturization in micro EDM. The factors that affect the limits is maybe because the electric discharge energy of each pulse discharge, this is a result of the discharge crater increases with increasing electric discharge energy(T. Kawakimi, M. Kunieda). However the limits of minimum machinable size are not decided only by the electric discharge energy. Residual stress that is caused by EDM results in distortion of micro workpieces (Spur, G., Uhlmann, Kruth).

6. Types of Power Supply

In conventional EDM, the current level is high as well as the voltage required. As a result of high currents, the electrode gets locally melted and there is welding of the workpiece and electrode. There are also problems of stray arcing. Moreover, uncontrolled discharge cannot be allowed in micro-machining. Thus a different power supply is required for micro EDM. Pulsed DC power supply is a critical component for achieving the required parameters of accuracy, finish and size of micro holes by using EDM process. The purpose if the power supply is to convert the alternating current into a pulsed unidirectional direct current required to produce the spark and also the effectiveness of the EDM is determined by the type of power supply used.

7.1 Rotary I mpulse Generator

This is the rotary impulse generator power supply where the voltage waveform is generated based on the DC motor principle, which it creates a sinusoidal wave pattern that is similar to rectification.

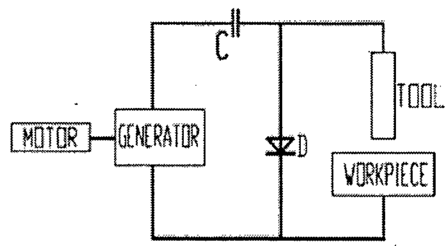

Figure 5: Rotary Impulse Generator (Aditya Shah, V. Prajapati, P. Patel, A. Pandey)

7.2 Relaxation Generator

Figure 6 is called the relaxation generator where the principal is based on the charging and discharging of the capacitor that is connected to the power supply. The type of wave that is generated by these arrangements is the saw tooth wave. In creating the spark, the capacitor is allowed to charge and then it is brought to contact with the workpiece and discharges.

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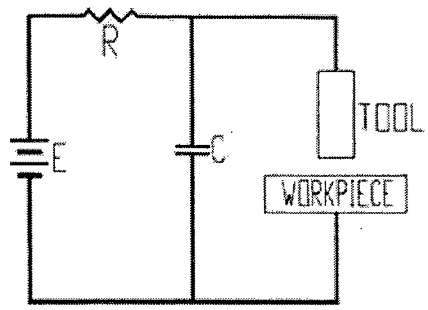

Figure 6: Relaxation Generator (A. Shah, V. Prajapati, P. Patel, A. Pandey)

Solid state devices are used instead of capacitor and resistors in pulse generator. Replacing the capacitor a solid-state devices such as the transistor are used. They are toggled between of state and saturation state to generate rectangular pulse which swing between zero and supply voltage. The idea is to increase the production efficiency which it have higher production efficiency than the relaxation circuits.

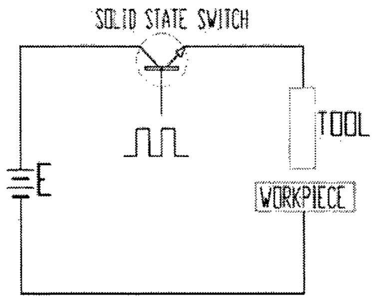

Figure 7: Pulse Generator (A. Shah, V. Prajapati, P. Patel, A. Pandey)

7. EDM process parameters

In theory, we can say that the process parameters of EDM and the process parameters of Micro-EDM are quite similar. This is because the working principal is the same which that both of the machining uses Electric Discharge Machining where electrodes discharges pulses and cut away the metal with help of dielectric fluid for better machining accuracy. The dielectric fluid also acts as a lubricant to ensure the machining is accurate and running smooth. We can assume that the process parameters needed in EDM and micro-EDM is similar due to the similarity explained above. It is also states that the micro EDM is similar to the principal of macro EDM where the process mechanism is based on an electro-thermal process that relies on a discharge through a dielectric in order to supply heat to the surface of the work piece (H. Zarepur, A. Fadaei Tehrani, D. Karimi, S. Amini, 2007).

8.1 Discharge Voltage

The spark gap and the breakdown strength of the dielectric is related to the discharge voltage in EDM processes. Current will flow into the system and before it happen the open gap voltage increases until it has created a path that will go through the dielectric. The path that is mentioned before is called the ionization path. When the current is flowing, voltage drops and stabilizes at the working gap level. The preset voltage determines the width of the spark gap between the leading edge of the electrode and the workpiece (Sanjeev Kumar, Rupinder Singh). If we set the voltage to a high value then the gap will increase, increasing the gap will improve the flushing conditions and helps to stabilize the cut. The open circuit voltage also have an impact to the system, as we increase the open circuit voltage tool wear rate (TWR) and surface roughness increases because the field strength increases.

8.2 Peak Curre nt

Peak current is known as the amount of power used in discharge machining which this parameter is measured in amperage and above all this is the most important parameter in EDM machining. During each on-time pulse, the current increases until it reaches a preset level which is express as the peak current. In roughing operations or cavities in large surface areas higher amperage is used. Using higher currents will definitely improve material removal rate (MRR) but it will give an impact on the surface finish and tool wear. Despite the machine cavity is a replica of tool electrode and excessive wear will hamper the accuracy of machining and as a result, all of the above statements is important in EDM. New improved electrode materials, especially graphite, can work on high currents without much damage (Ho and Newman, 2003).

8.3 Pulse duration and Pul se interval

Expressed in units of microseconds the cycle has an on-time and off –time. On the on-time all the work is produced and as a result the duration of these pulses and the number of cycles per second are important. Metal removal is directly proportional to the amount of energy applied during the on-time (Singh et. al., 2005). The energy applied during the on-time controls the peak amperage and the length of the on-time. Pulse duration and pulse off-time is called pulse interval. If the pulse duration is longer, then more workpiece material will be melted away. Then, it will have a broader and deeper hole than using shorter pulse duration. Even though the hole has rough surface finish, the extended pulse duration will allow more heat sink into the workpiece and in the mean time it will spread which means the recast layer will be larger and the heat affected zone will be deeper.

However, exceeding the pulse duration will also have its benefits. Whereas, when the optimum

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pulse duration for each electrode and work material combination is exceeded, the material removal rate will start to decrease. The longer the duration will have effect on the wear of the work material where when the duration of the pulse is longer, then there will be a no-wear situation. But there are a certain limits for that point to be reached. But if that point is reached, increasing the duration will cause the electrode to grow from plating build-up. To complete the cycle sufficient pulse interval is needed before the next cycle can be started. Other than that, the pulse interval also affects the speed and the stability of the cut. From theory, the shorter the interval the faster the machining operation will be. But this will affect the workpiece material where it will not be swept away by the flow of the dielectric and as a result the fluid will not be de-ionized. As a result the next pulse will be unstable and hard to control. This unstable condition will cause erratic cycling and retraction of the advancing servo and this will slow down the cutting rate. At the same time, pulse interval must be greater than the de-ionization time to prevent continued sparking at one point (Fuller, 1996). In ideal conditions, each pulse creates a spark. However, it has been observed practically that many pulses fail if duration and interval are not properly set, causing loss of the machining accuracy and those pulses are called open pulses (Sanjeev Kumar, Rupinder Singh).

8.4 Pulse Wavefor m

The normal pulse waveform that we always see is rectangle, but now new shapes have been developed. Pulse wave is a non-sinusoidal waveform that is similar to square wave. By using trapezoidal wave generators the relative tool wear can be reduced to a very low value. Other types of generators introduce an initial pulse of high voltage but low current and a few microseconds duration, before the main pulse, which facilitates ignition (Sanjeev Kumar, Rupinder Singh).

8.5 Polarity

Polarity can be either positive or negative. The current will pass through the gap and create high temperature that will cause the material to evaporate at both the electrode spots. The plasma channel is made of ion and electron flows. Electrons have mass smaller than anions and as the electrons processes it shows quicker reaction, the anode material is worn out predominantly. As a result it causes minimum effect to the tool electrode and becomes important for finishing operations with a shorter on-time. While running long discharges the early electron process predominance changes to positron process which will result in high tool wear rate. Polarity is determined by experiments and is a matter if tool material, work material, current density and pulse length combinations. Modern power supplies insert an opposite polarity "swing pulse" at fixed intervals to prevent arcing (Sanjeev Kumar, Rupinder Singh). A typical ratio is 1 swing for every 15 standard pulses (Ho and Newman, 2003).

8.6 Electrode Gap

The tool servo-mechanism is one of the most important in the efficient working of EDM process, and the servo-mechanism function is to control the working gap to the set value. An electro-mechanical and hydraulic systems are used and normally designed to respond to average gap voltage. In order to obtain good performance, gap stability and the reaction speed of the system needs to be account for where the presence of backlash is particularly undesirable. For the reaction speed, it must obtain a high speed so that it can respond to short circuits or even open gap circuits. Gap width is not measured directly, but can be inferred from the average gap voltage (Crookall and Heuvelman, 1971).

8.7 Type of dielectric flushi ng

A dielectric in EDM must have a basic characteristic of high dielectric strength and quick recoveries after breakdown also have an effective quenching and flushing ability. Tool wear rate and material removal rate is affected by the type of dielectric used and the method of its flushing. The use of hydrocarbon compounds and water are commonly used as dielectric fluids. But for de-ionized water is usually used for wire-EDM and high precision die-sinking because of its low viscosity and carbon free characteristics. The dielectric fluid is flushed through the spark gap to remove gaseous and solid debris during machining in order to maintain the temperature so that it is always below the flash point. A control feature that is commonly seen on many machines to facilitate chip removal is vibration or cyclic reciprocation of the servo tool electrode to create a hydraulic pumping action. Orbiting of the tool workpiece has also been found to assist flushing and improve machining conditions (Levy and Ferroni, 1975).

8. Material Removal Rate (MRR)

Based from the journal "Influence of pulsed power conditions on the machining properties in micro-EDM" shows that the source energy of electro discharge between the tool electrode and the workpiece is an electric one which power can be determined by the supplied voltage and current. Thus, the electro discharge energy can be expressed as shown in Eq. (1).

$$E = VIT$$

In the pulse current, if time T is substituted to an intermittent one with frequency, Eq. (1) is expressed to the following

$$E_p = V_p I_p t_{on} \frac{1}{t_{on} + t_{off}}$$

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Where;
V_p: Voltage of a single pulse, I_p: Current of a single pulse, t_{on}: pulse on-time, t_{off}: pulse off-time.

The equation for material removal rate can be produce by multiplication of machining property. Hence the expression can be written as Eq. (3):

$$MRR = \alpha V_p I_p t_{on} \frac{1}{t_{on} + t_{off}}$$

Where α is the removal constant of a material. This constant is the removal volume of a material per unit electric power.

From Eq. (3) the parameters of voltage, current and pulse On-time are proportional to the material removal rate. At the same time the frequency of the pulse is also proportional to the material removal rate, but the parameter is not perfectly independent of the pulse On-time. This is because the pulse Off-time is needed sufficiently, depending on the power of a single pulse.

The equation also indicates that a shorter duration is more advantageous than a longer one to make accurate machining under the same conditions. Since the removal rate is the same but the removal volume per pulse is smaller in the shorter pulse, if the ratio of pulse On-time to Off-time is the same.

10. Tool wear R ate (TWR)

The ratio of amount of electrode to the amount of workpiece removal is defined as the wear ratio (Yao Yang Tsai, Takahisa Masuzawa). There are four methods that are known to evaluate the electrode wear ratio by means of measuring weight, shape, length, and total volume respectively. A common one is by calculating the volumetric wear ratio (υ). Usually we will measure the weight differences and transfer them into the volumes by the density of materials. However this method is unsuitable for micro-EDM because the weight change is so small making it difficult to measure it accurately. Therefore, it is important to measure and analyze removed material directly.

In Fig. 8 the change of electrode length and corner rounding is illustrated. In the figure the worn electrode can be divided into two parts which is V_B and V_C. V_B is the wear volume on bottom portion and V_C is the wear volumes of corner portion and V_C are assumed to be the volume of a cylinder of a revolution body, respectively, because a rotating electrode is used during machining.

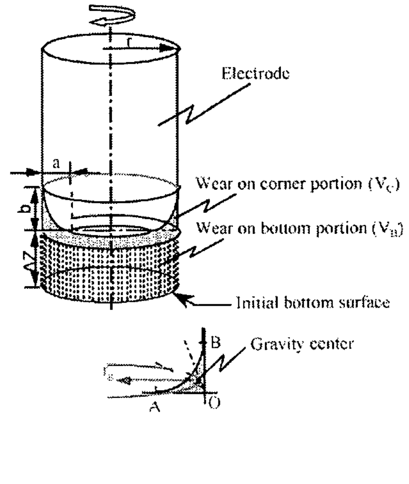

Figure 8: Wear volume of the electrode adapted from Y-Y. Tsai, T. Masuzawa Journal of Processing Engineering.

11. Piezo Actuators

Piezo Actuators offers a strong need for compact, robust and efficient positioning mechanism that also offer high precision, short response times, low power consumptions, low magnetic interference and multiple degree of freedom. They can easily be integrated in applications, for example a super amplified actuator for a MRI biomedical device, a chopper for X-ray diffraction, and a tip-tilt for mirrors.

Piezoelectric actuators have been widely used in recent technology applications. A large variety of actuators are commonly available for various applications. These actuators are based on multi-layer ceramics and it can produce large strains at low voltages (Meylan, 2000). They can expand almost proportionally to the applied voltage up to their electric field limit and can typically achieves strains of 0.1% at voltages of 200V (F. Claeyssen, R. Le Letty). Amplified piezoelectric actuators display deformation larger than 1% and strokes of more than 500µm. The linear and rotating piezoelectric motors uses a friction drive mechanism in producing linear displacements up to 100mm and infinite rotation. Actuators offer special advantages to electromagnetic technology in such a way that it gives out high precision machining, a fast response time, and low power consumptions. There are two types of piezo actuators that are discussed which are amplified piezo actuators and super amplified piezo actuators.

11.1Amplified Piezo Actuators

The concept of Amplified Piezoelectric Actuators (APA) according to Cedrat Recherde relies on the flexural-extensional principles. The concept is where elastic bends under elongation of the piezoelectric actuation. Flexural hinges is not included in the actuator because of its weak characteristics which will be an advantage on low cost. The shell can be used to directly prestress the Ceramic Multilayer Actuator (CMA) and prevent ceramics from working in tensile stress which will lead to an important mass saving. Amplified Piezoelectric Actuators was initially built to help the improvements for micro-positioning optics. This application has generated the largest types of ML and L series as shown in the figure 4.

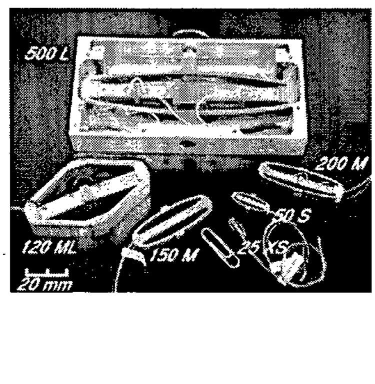

Figure 4: View of different APA series (F. Claeyssen, R. Le Letty)

The existence of a range of off-the-shelf actuators is important for developing piezoelectric mechanism because the development time for the actuator usually not included. Industrial applications also requires passing sever lifetime tests. The APA200M in the figure has passed 10^{10} fast cycles which undergo 200µs rise and fall times of full strokes of 240µm without failure.

11.2Super Amplified Piezo Actuators

Amplified Piezoelectric Actuators can be stacked in series to get a larger stroke because it is compact and centered. This stacking method has been used in a mechanism for a Magnetic Resonance Imaging (MRI). For example three APA200M-NM's is stacked to deliver more than 600µm displacement. In order to increase the actuator stroke to 3mm at 180V with a sub-micron resolution a lever arm is added. The APA is nonmagnetic in order to comply with the MRI environment requirements. The APA shells and the lever arm can be manufactured in a single block to reduce mass and cost because of the planar design.

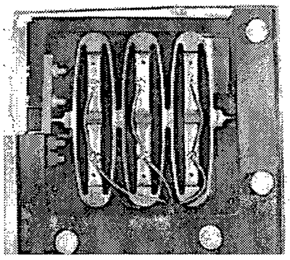

Figure 5: MRI compliant 3mm-stroke mechanism based on three APA200M-NM's. The actuator is actuated at 180V DC and displaying its maximum stroke.

In this paper, an overview of the process parameters, material removal rate, types of generators, dielectric fluids and the minimum machinable size of the diameter are being discussed. Other than that, the piezoelectric actuators are discussed because based on our project which is to fabricate a Micro-EDM machine we propose the use of a piezoelectric actuators. This review is done based on previous and recent research on Micro-EDM. The paper focuses on the principal of micro-EDM, the types of EDM processes, dielectric fluid, piezoelectric actuators, and types of generators, EDM process parameters, and the material removal rate (MRR) and the tool wear ratio (TWR). This paper is essential for the development in the research to fabricate the micro-EDM machine.

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CHAPTER 3

Paper 2

DEVELOPMENT OF MICRO-EDM WITH PIEZOACTUATED TOOL FEED MECHANISM

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DEVELOPMENT OF MICRO-EDM WITH PIEZOACTUATED TOOL FEED MECHANISM

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ABSTRACT

The development of Micro-EDM is a recent upgrade in the technology world. Micro-EDM concept is similar to the EDM process where the process is based on the thermoelectric energy between the workpiece and an electrode. Due to the high precision and good surface quality that it can give, Micro-EDM is potentially an important process for the fabrication of micro-tools, micro-components, and parts with micro-features. Piezoelectric actuator is used as the tool feed control system which the maximum displacement is up to 400 microns. This paper describes the development of the Micro-EDM based on the tool wear rate and material removal rate of the system using a piezoelectric actuator as the tool feed control system.

***Keywords**:* Micro-EDM, EDM, Piezoelectric actuators, EDM, Micromachining

INTRODUCTION

Electrical Discharge Machining or EDM is a manufacturing process in cutting complicated designs and shapes by using electrical discharge. Industries, now days, requires fast, precision and reliable fabricating machine such as EDM. Since the EDM is a thermal process, hard materials such as quenched steel, cemented carbide and electrically conductive ceramics can be machined. Since the tool electrode does not need to rotate for material removal like milling or grinding, holes with sharp corners and irregular contours can be machined without difficulty. EDM can be divided into two types that are sinker EDM and wire EDM (Kalpakjianet. al.).

PRINCIPAL OF MICRO – EDM

Micro EDM's principal of operating is just the same of the conventional EDM but the usage of small electrode size and micro scale MRR are the only differences between conventional and micro EDM. The tool feed for Micro EDM is sometimes different from the convectional EDM. A few of the Micro EDM machine uses fuzzy logic or PZT control system whereas the others still use stepper motor control tool feed system.

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MACHINING PARAMETERS IN MICRO EDM

Discharge Voltage

The spark gap and the breakdown strength of the dielectric is related to the discharge voltage in EDM processes. Current will flow into the system and before it happen the open gap voltage increases until it has created a path that will go through the dielectric. The path that is mentioned before is called the ionization path. When the current is flowing, voltage drops and stabilizes at the working gap level. The preset voltage determines the width of the spark gap between the leading edge of the electrode and the workpiece (S.Kumar et al). If the voltage is set to a high value then the gap will increase, increasing the gap will improve the flushing conditions and helps to stabilize the cut. The open circuit voltage also have an impact to the system, as we increase the open circuit voltage tool wear rate (TWR) and surface roughness increases because the field strength increases.

Peak Current

Peak current is known as the amount of power used in discharge machining which this parameter is measured in amperage and above all this is the most important parameter in EDM machining. During each on-time pulse, the current increases until it reaches a preset level which is express as the peak current. In roughing operations or cavities in large surface areas higher amperage is used. Using higher currents will definitely improve material removal rate (MRR) but it will give an impact on the surface finish and tool wear. Despite the machine cavity is a replica of tool electrode and excessive wear will hamper the accuracy of machining and as a result, all of the above statements is important in EDM. New improved electrode materials, especially graphite, can work on high currents without much damage (Ho et al).

Tool Wear Rate (TWR)

There a few main factors that influence the tool wear in Micro EDM. The tool material, dielectric fluid suitability, tool feed control; polarity and workpiece material are the most important aspect in tool wear. Tool wear can occur in form as in figure 1.0 shows the typical types of wear that have been simulated. There is another tool wear influence that has been studied that is the tool design. Tool design actually plays a vital part in tool wear because design can change thermal distribution and carbon deposition will be thicker if the tool has bigger surface area

Material Removal Rate (MRR)

Fig. 1 and 2 show the influence of pulse-on time, peak current and flushing pressure on material removal rate (MRR). From these figures, it can be observed that MRR increases with the increase in pulse-on time initially but seen to decrease after 10μs. However, MRR is observed to increase with the increase in peak current and flushing pressure. At low T_{on} for example 1μs, effective machining time is very short and this results in lower MRR. However as the T_{on} increase the MRR also increases. The

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discharge energy changes with the change in pulse-on time even when the duty cycle is constant due to the change in frequency of the cycle.

This is the reason why MRR varies with the change in T_{on}. At shorter T_{on} the size of the machined particles may be small but due to the high frequency of sparking the off-time is also small and when this couples with the low flushing pressure, the removal of these particles from the machining zone is not easy and this results in low MRR.

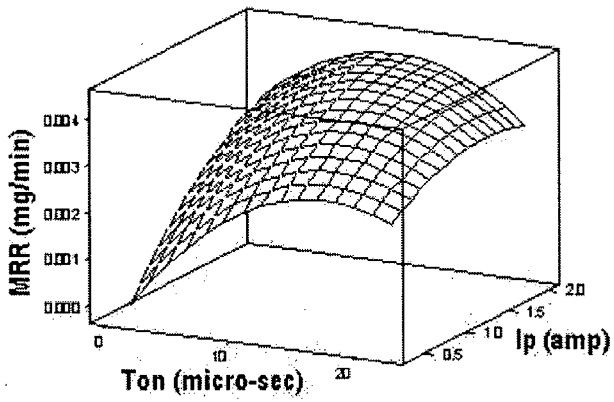

Figure 1: Response surface of material removal rate versus pulse-on-time and peak current

Furthermore, at low peak current (0.5A) the discharge energy is also low which has resulted in low MRR. But as the I_p increases, the discharge energy proportionately increases resulting in higher MRR. The low flushing pressure cannot remove the debris particles effectively from the machining zone as such the work surface for machining is not exposed to the discharge sparks and this will results in low MRR. As the flushing pressure increases from 0.1 to 0.5 $kg.cm^{-2}$the flushing becomes more effective and removes the debris particles efficiently which results in higher MRR.

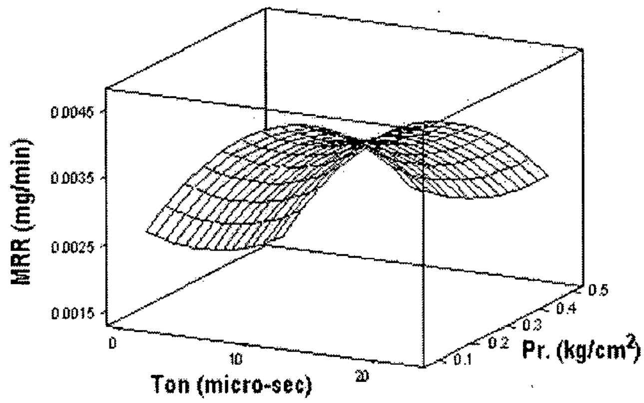

Figure 2: Response surface of material removal rate versus pulse-on-time and flushing pressure

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DEVELOPMENT OF MICRO EDM WITH PZT TOOL FEED SYSTEM

Developing of Micro EDM consist of a few stages. Stage 1 is about developing the control circuit and power circuit, stage 2 is about the machine design itself and after assembly, the final stage done that is analysis of TWR and MRR.

Stage 1: Control Circuit Development

The control circuit consists of 3 main components usage that is a rectifier, multiplexer and a Pulse Width Modulator (PWM). Based on figure 3, the purpose of the rectifier is to change signal received from sensor from AC to DC signals. The negative voltage signal is only input that processed by the rectifier and the positive input processed by the Operational Amplifier (OpAmp) with the aid of multiplexer. These signals are controlled by Metal–Oxide–Semiconductor Field-Effect Transistor (MOSFET) and these transistor gates only allowunfamiliar or unidentified signals to be processed by the rectifier. After converting the signal to DC, the signal will be send to the summing type OpAmp. At the same time positive signal from the electrode will be compared with a comparative type OpAmp by setting a reference voltage as the limit to prevent the tool from getting to near to workpiece causing high tool wear. If the signal voltage is higher than the reference voltage then the multiplexer will send a signal to the summing OpAmp to retract the PZT that is directly connected to the tool. These signals are observed by the PWD that converts the signals to the display.

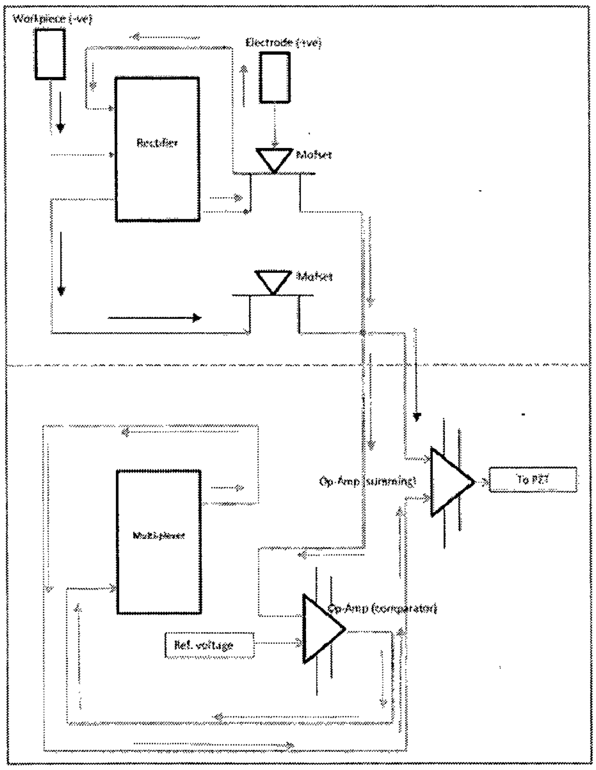

Figure 3: Simplification of control circuit

The control circuit and power circuit are then simulated in ORCAD v9.1 software to observe of any error. Figure 4 shows the simulation in the software.