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PAHANG

INVESTIGATION OF MICROMACHINING OF SILICON USING MICRO EDM

(PENYELIDIKAN DALAM PEMESINAN MIKRO BAGI SILICON MENGGUNAKAN EDM MIKRO)

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ABSTRACT

Investigation of Micromachining of Silicon using Micro EDM

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

This project aims in revealing the optimum results for micromachining of silicon and copper using Micro electric discharge machining (EDM) process with new advanced technology achieved which is implemented piezoactuator as the tool feed mechanism. Although Micro EDM usage is essential in manufacturing sector but the important parameters 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, material removal rate 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.

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ABSTRAK

Penyelidikan dalam Pemesinan Mikro bagi Silicom menggunakan EDM Mikro

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

Projek ini bertujuan untuk mendapatkan keputusan yang optima bagi pemesinan mikro yang diuji menggunakan bahan silicon dan copper dalam mesin Mikro Electric Discharge Machining atau EDM dengan penggunaan sistem Piezoelectric Transducer atau PZT dan menggunakan 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 secara automatik.

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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

NTRODUCTION

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

Micro machining has been renowned to produce high aspect ratio micro products and there is a uge 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 nergy between the workpiece and electrode. The working principles of EDM is based on the onversion if electrical discharge energy into thermal energy through a series of discrete electrical lischarges 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.

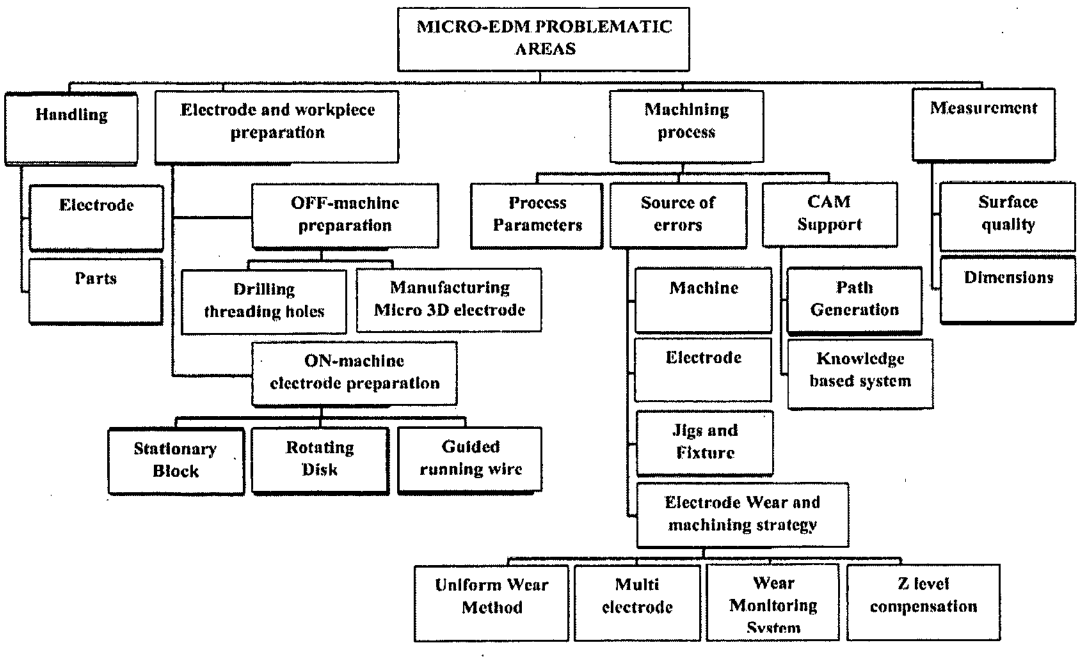

Figure 1: Problematic areas of Micro EDM

OBJECTIVES OF THE RESEARCH

To investigate the Micro-EDM potential in micromachining of silicon and high aspect ratio 3D channels (Copper)

Investigate the effect of different process parameters (Gap Voltage, Sparking Frequency, Tool and Workpiece polarity, MRR, TWR, Surface Roughness, etc.) and type of tool (Copper and Steel) on micromachining in Micro-EDM.

To optimize the Micro-EDM process variables for silicon and copper micromachining.

SCOPE OF PROJECT

This study is to investigate the micromachining of silicon and copper using 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.

The development of new, advanced engineering materials and the need for precise flexible prototypes and low volume production have made Micro-EDM and important manufacturing process to meet such demands. The most important parameters in Micro-EDM are the removal rate, the electrode wear, accuracy and surface texture. The influence of peak current, gap voltage, pulse duration and process parameters are important parameters in material removal rate in EDM. These investigations are done to ensure the optimization of the MRR in the EDM processes. Dielectric flushing is important in EDM processes to ensure the removal of the unwanted waste metal particles on the machined surface and on the tool electrode. This is to ensure an accurate machining and high precision cutting in Micro EDM.

CHAPTER 2

Paper 1

MICROMACHINING OF COPPER - MATERIAL REMOVAL RATE AND DIELECTRIC FLUSHING IN MICRO-EDM

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MICROMACHINING OF COPPER - MATERIAL REMOVAL RATE AND DIELECTRIC FLUSHING IN MICRO-EDM

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ABSTRACT

The development of new, advanced engineering materials and the need for precise flexible prototypes and low volume production have made Micro-EDM and important manufacturing process to meet such demands. The most important parameters in Micro-EDM are the removal rate, the electrode wear, accuracy and surface texture. The influence of peak current, gap voltage, pulse duration and process parameters are important parameters in material removal rate in EDM. These investigations are done to ensure the optimization of the MRR in the EDM processes. Dielectric flushing is important in EDM processes to ensure the removal of the unwanted waste metal particles on the machined surface and on the tool electrode. This is to ensure an accurate machining and high precision cutting in EDM.

Keywords: Micro-EDM, MRR, Peak current, Gap voltage, pulse duration, dielectric flushing

INTRODUCTION

Electrical discharge machining, more commonly known as EDM or spark machining, removes electrically conductive material by means of rapid, repetitive discharges from electric pulse generators with the dielectric flowing between the tool and workpiece. No physical cutting forces exist between the workpiece and the tool. The non-contact machining process has been endlessly evolving from a mere tool from before to a micro-scale application machining today. Micro-EDM is the application if EDM in a microfield. The low energy range is becoming more important as the EDM process is used in a microfield. Micro-EDM has similar characteristics as EDM, except the size of the tool, the discharge energy and axes movements are in micron levels. In Micro-EDM, material removal is achieved by preferential erosion of the workpiece electrode as controlled discrete discharges are passed between the tool and the workpiece in a dielectric medium. Basic characteristic required of a dielectric used in EDM are high dielectric strength and quick recovery after breakdown, effective quenching and flushing ability. Tool wear and workpiece removal rates are affected by the media and hydrocarbon compounds and water.

Studies have been conducted and revealed a new method to improve EDM efficiency by supplying oxygen gas into gap (Kunieda et. al). They found that the stock removal rate is increased due to the enlarged volume of discharged crater and more frequent occurrence of discharge. Then in 1997 previous researcher discovered a 3D shape can be machined very precisely using a special NC tool path which can supply a uniform high velocity air flow over the working gap and MRR is improved as the concentration of oxygen in air is increased (Kunieda et. al).

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The mechanism for minute tool electrode wear in dry EDM was studied by Kunieda et. al. The tool electrode wear is almost negligible for any pulse duration because the attached molten workpiece material protects the tool electrode surface against wear. From observation of the cross-section of the tool electrode surface, it was found that the tool electrode wore by the depth of only 2mm during the early stage of successive pulse discharges since the initial surface of the tool electrode was not covered with the steel layer. The feasibility of 3D surface machining by dry EDM to investigate the influence of depth of cut and gas pressure, pulse duration and pulse interval and the rotational speed of the tool electrode (ZhanBo et al.). The results shows that the optimum combination between depth of cut and gas pressure and when pulse duration 25 mm it us leads to maximum MRR and minimum tool wear. As the rotational speed increases the tool wear increases moderately.

CHARACTERISTIC OF EDM

Influence of peak current on Material Removal Rate (MRR)

Fig. 1 indicates the influence of different dielectrics on surface roughness $R_a$and the material removal rate at the peak current ranging from 0.5 to 6A. It is observed that almost the same appears between the two surface roughness data of workpieces after EDM. But when the peak current is higher than 1.5A, the material removal rate of the dielectric with span 20 (30 g/L) is higher that of pure kerosene dielectric. An improvement of material removal rate of the dielectric with Span 20 (30 g/L) by 84% is apparent at the peak current of 4A.

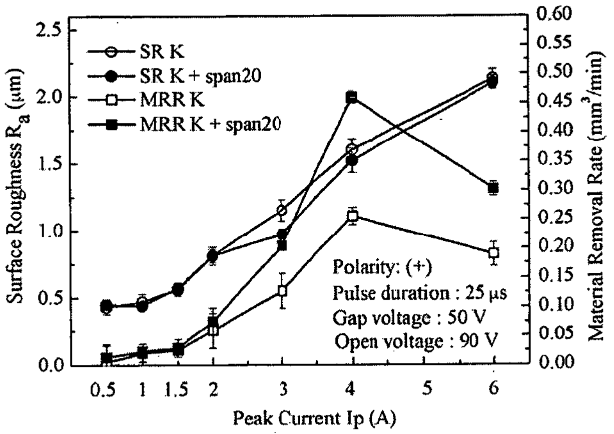

Figure 1: Influence of peak current on surface roughness and material removal rate: (SR) Surface roughness, (MRR) Material Removal Rate, and (K) kerosene

Source: B. B. Pradhan

It is important to point out that although the material removal rate is effectively increased, the surface roughness is not deteriorated (B. B. Pradhan). However, when peak current reaches 6A, the material rate is lower. It is argued that the debris and tars in larger diameter exist due to their higher electrical discharge energy, when peak current increases to 6A. Under the same sediment discharge space, the concentration of debris is higher due to inadequate sediment discharge between electrode and workpiece. As a result, there are higher discharge concentration and surface temperature of electrode and workpiece. Some of the debris particles are stuck on the surface of the workpiece by positive and negative ions. When temperature is reduced, particles

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are adhered to workpiece surface and machining efficiency is decreased due to the abnormal discharge.

The influence of gap voltage on MRR

In Fig. 2, there is no difference in gap voltage is found from the surface roughness data of workpieces using different dielectrics. However the material removal rate decreases when gap voltage is getting higher (K.L. Wu et. al.). It is observed that the space between electrode and workpiece becomes larger when a longer bridging time of neutral particles and ions is caused by the increase of gap voltage. The electrical discharge period also becomes longer, reducing the efficiency of the EDM. We can see that when the gap voltage is 35V, the average material removal rate of Span 20 surfactant is $0.217 mm^3/min$, which is 47% higher than that of pure kerosene.

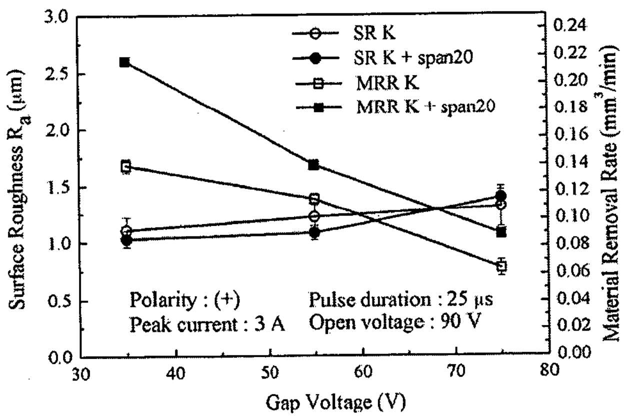

Figure 2: Influence of gap voltage on surface roughness and material removal rate: (SR) Surface roughness, (MRR) Material Removal Rate, and (K) kerosene

Source: B. B. Pradhan

Influence of pulse duration on MRR

Pulse duration and discharge pulse-off time were of the same value. Discharge pulse duratior refers to the time of continuous pulse discharge during electrical discharge process. It is the period from the current flow of discharge to the ending discharge when the insulation betweer two electrodes is broken. Discharge pulse-off time refers to the duration of the ending of the discharge to the commencement of the next discharge. If the pulse-off time is too short, insulatior recovery will not be enough that unstable discharge arc can be easily induced. Then discharge efficiency will be decreased, and electrode wear will be increased. Fig. 3 shows the influence o pulse duration on the surface roughness and material removal rate of the dielectric with anc without Span 20 (30 g/L) surfactant.

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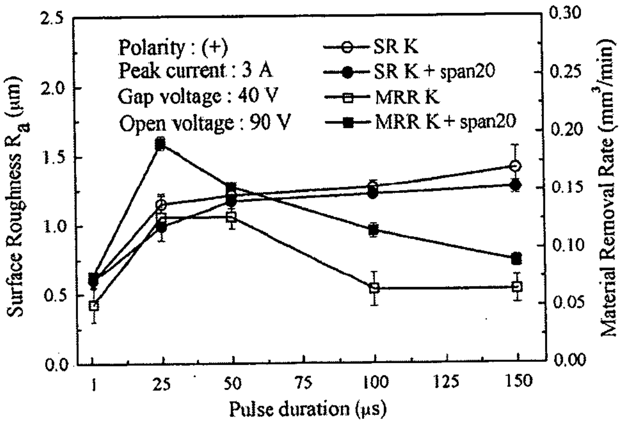

Figure 3: Influence of pulse duration on surface roughness and material removal rate: (SR) Surface roughness, (MRR) Material Removal Rate, and (K) kerosene

Source: B. B. Pradhan

The figure shows the surface roughness curve representing the dielectric of the two machining fluids rises with the lengthening of the pulse duration. In the aspect of the material removal rate, when the provided pulse duration is as short as 1s, the discharge current is still at a rising stage that discharge energy has not reach the maximum value. The heating time of workpiece is so short that only a small part if material is melted, indicating that the material removal rate is reduced. When pulse duration is lengthened, sufficient discharge energy can be achieved, and better peak current density is obtained. After the melted material is completely removed, a better material removal rate is acquired, and highly efficient impulsive force is achieved. If pulse duration is too long, the plasma channel will be so much expanded that the density of the electrical discharge energy of a unit area may be reduce. As a result, the material removal rate will be reduces, and the surface roughness will be deteriorated.

Influence of process parameters on MRR

Fig. 4 and 5 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 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.

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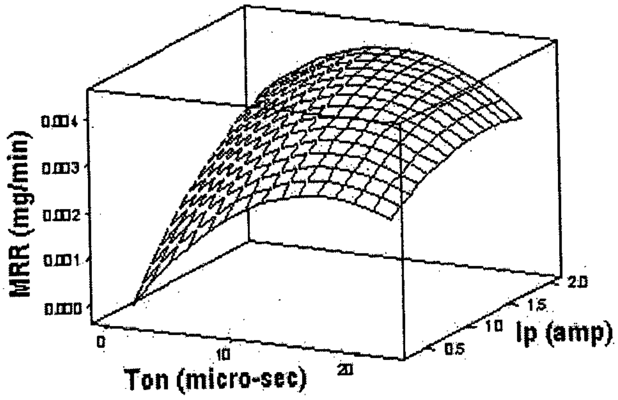

Figure 4: Response surface of material removal rate versus pulse-on-time and peak current

Source: B. B. Pradhan

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.

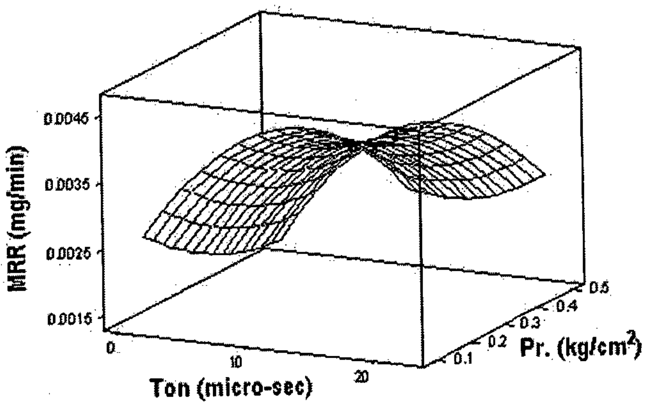

Figure 5: Response surface of material removal rate versus pulse-on-time and flushing pressure

Source: B. B. Pradhan

FLUSHING AND DIELECTRIC FLUIDS

In EDM flushing, the dielectric fluid is distributed through the spark gap to remove gaseou and solid debris generated during EDM and to maintain the dielectric temperature well below i flash point. Flushing method can be divided into four main categories; normal flow, reverse flov jet flushing and immersion flushing. In normal flow, the dielectric fluids is fed through the to and workpiece and exits through the gap; and as the name implies, as the case of reverse flow, th

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flow is reversed by drawing the dielectric away from the gap. Flow conditions must be properly regulated in these two methods of flushing; otherwise machining conditions may be unstable with reduced removal rate and uneven tool wear. The flow velocity can be monitored by measuring the differential pressure or of volume throughput. Jet flushing, in which a jet of dielectric is directed at the gap, is often used in Wire-EDM or machining of narrow slots and cavities. For jet flushing of an array of shallow cavities, important considerations are distribution of the nozzles, flow rates, angles at which the nozzle are directed at the gap, and layout of the cavities. For shallow cut and perforation of thin sections, simple immersion of tool and workpiece in a tank of circulating dielectric may be adequate.

Other means of improving flushing conditions involve some form of relative motion between tool and workpiece. A control feature that is available on many machines to facilitate chip removal is vibration or cyclic reciprocation of the servo-controlled tool-electrode to create a hydraulics pumping action, perhaps with synchronized pulse flushing during the lifting of the electrode. Other than that, orbiting of the tool and workpiece has also been found to assist flushing and improve machining conditions. An Orbiting EDM permits machining to proceed from roughing to finishing using only a single electrode, with suitable control of the orbit and machining conditions.

Improper flushing can result in uneven and significant tool wear affecting the accuracy and surface finish; it can also reduce material removal rates due to the unstable machining conditions and arcing around regions with high concentration of debris. Whereas there is much literature on the influence of flushing on machining rate, tool wear and accuracy of the profile produced, also known as the influence on the surface integrity of the electro-discharged machined components.

EXPERIMENTAL SETUP

The experiments are conducted on a copper material workpiece. The copper workpiece has a low melting point so that the material will be easy to be machined and penetrated by the spark discharge from the micro-EDM. In this experiment, the tool feed control is controlled by the piezoelectric actuator (APA 400MML). The control circuit has been developed based on the previous studies and optimized in the new developed design. The tool holder design is based on the piezoelectric actuator (PZT) so that the PZT can be easily being placed on the tool holder. A mild steel material is test run on the machine before placing the copper workpiece for the experiment. The experiment parameters are stated in table 1. The gap voltage varies from 45 to 49 volts.

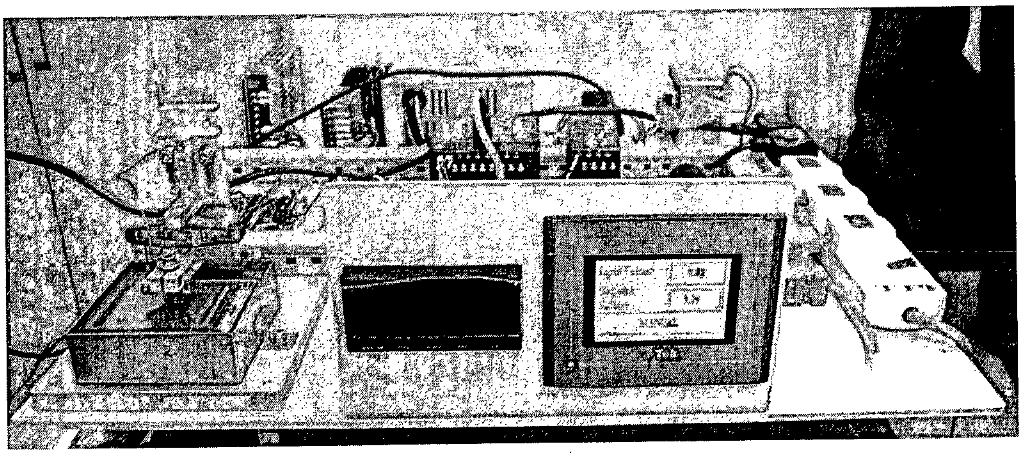

Figure 6: Micro-EDM

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Table 1: Experiment parameters

Supplied Voltage	110 V
Gap Voltage	45-49 V
Current	1.28A
Workpiece	Copper (thickness = 5mm)
Electrode	Copper: Rectangular shape(10mm(w)x0.1mm(t)x1mm(h))
Tool Feed Control	Piezoelectric Actuator (APA 400MML)

RESULTS AND DISCUSSION

Three experiments have been conducted by using the copper workpiece and the experiment values are stated in table 2. The machining time varies because to monitor the too condition considering that the Micro-EDM dielectric flushing is not available. Dielectric flushing is an important process for the Micro-EDM machining whereas the flushing will wash away al the unwanted metal particles that is trapped on the machined surface and on the tool electrode The machine is not equipped with flushing and these results in the carbon decomposition on th tool electrode and workpiece.

Table 2: Data of experiments on Material Removal Rate (MRR)

No. of exp.	Removed Depth from W/piece (micron)	Removed Length from W/piece(mm)	Removed width from W/piece(mm)	Machining Time (Min)	Gap Voltage(V)	MRR (mm^3/min)
1	18	0.984	0.1582	13	36.24	2.1554×10^{-4}
2	15	0.871	0.06397	6	46.13	1.393×10^{-4}
3	28	0.882	0.06470	10	42.82	1.598×10^{-4}

The table shows removed depth, removal length from the workpiece and the machining tin of the Micro-EDM. From the calculation of the MRR we can induce that as the machining tir increase the material removal rate will gradually increases.

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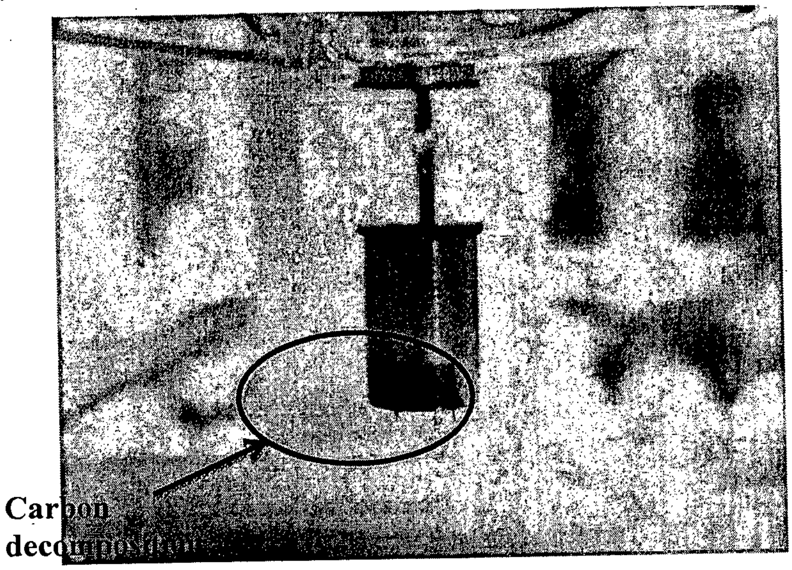

Figure 7: Carbon decomposition on the tool electrode after machining

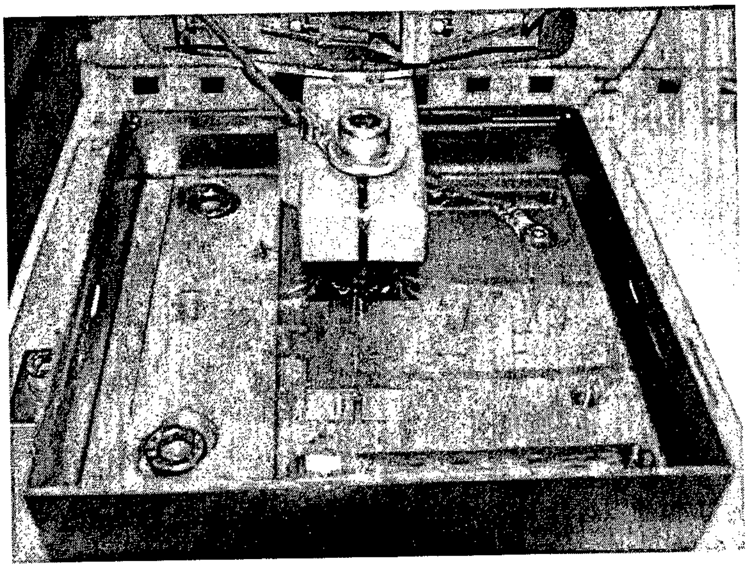

Figure 8: Copper workpiece machining processes

Observations are made on the tool electrode and the workpiece and there is a lot of carbor decomposition trapped on the surface of the tool and workpiece as you can see in Fig.7 and Fig 8. This is because there is no dielectric flushing flow in the system and that results in carbor decomposition in the tool and workpiece. Carbon decomposition will disrupted the accuracy o the machining of the workpiece. The spark produces bubbles that indicate the machining proces: is still commencing.

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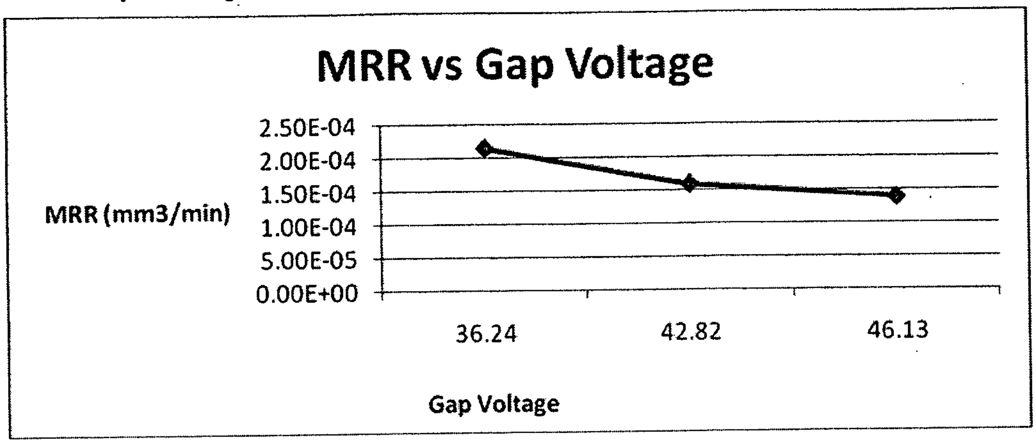

Figure 9: Material Removal Rate versus Gap Voltage

The data for the MRR is compared with the gap voltage obtained during the machining process and the MRR decreases as the gap voltage increases. The material removal rate decreases when gap voltage is getting higher. The space between electrode and workpiece becomes larger when a longer bridging time of neutral particles and ions is caused by the increase of gap voltage. The electrical discharge period also becomes longer, reducing the efficiency of the EDM (K.L.Wu. et.al.).

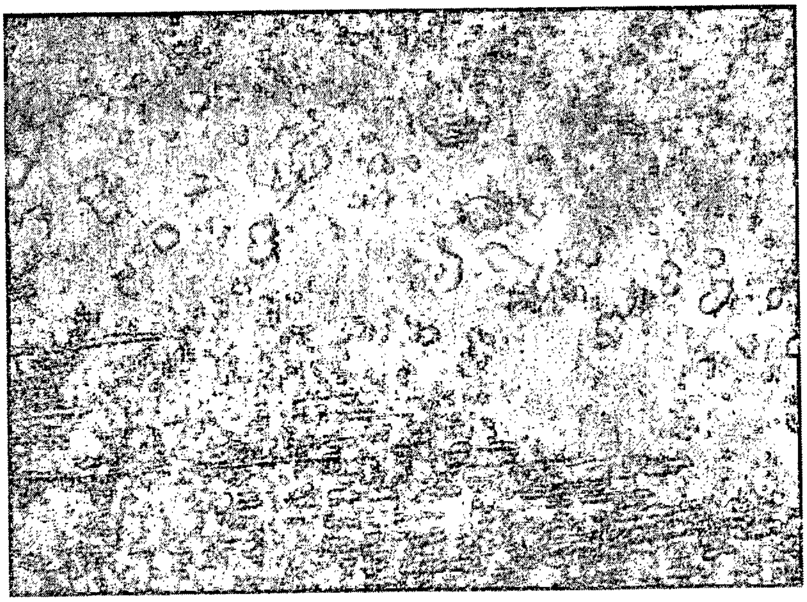

Figure 10: Machined groove of Micro-EDM

CONCLUSION

Material removal rate is an important parameters on EDM and this paper discussed about the influence on peak current, discharge gap, pulse duration and the process parameters on material removal rate of the material machined. Other than that, EDM flushing is also one of the outmost important parameters where the dielectric flushing will wash off unwanted waste metal particles that will be ionized on the tool electrode making the tool electrode less accurate than the initial condition. Thus, the dielectric flushing and material removal rate is essential in getting an accurate machined profile of the workpiece.

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CHAPTER 3

Paper 2

Development of Micro EDM with Directly Mounted APA 400MML Actuator as Tool Feed Mechanism

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Development of Micro EDM with Directly Mounted APA 400MML Actuator as Tool Feed Mechanism

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Keywords: Micro EDM, Micromachining, Non-Conventional Machining, Electro Discharge Machining, Advanced Machining Process.

Abstract. The development of new, advanced engineering materials and the need for precise flexible prototypes and low volume production have made Micro-EDM and important manufacturing process to meet such demands. The most important parameters in Micro-EDM are the material removal rate (MRR), the tool wear rate (TWR), accuracy and surface texture. The influence of peak current, gap voltage, pulse duration and process parameters plays important role in determining the material removal rate and tool wear rate on Micro EDM. Thus, this paper describes the development of the Micro-EDM based on the tool wear rate and material removal rate of the system using directly mounted APA 400MML actuator as the tool feed control system.

Introduction

Electrical discharge machining, more commonly known as EDM or spark machining, removes electrically conductive material by means of rapid, repetitive discharges from electric pulse generators with the dielectric flowing between the tool and workpiece. No physical cutting forces exist between the workpiece and the tool. The non-contact machining process has been endlessly evolving from a mere tool from before to a micro-scale application machining today. Micro-EDM is the application if EDM in a microfield. The low energy range is becoming more important as the EDM process is used in a microfield. Micro-EDM has similar characteristics as EDM, except the size of the tool, the discharge energy and axes movements are in micron levels. In Micro-EDM, material removal is achieved by preferential erosion of the workpiece electrode as controlled discrete discharges are passed between the tool and the workpiece in a dielectric medium. Basic characteristic required of a dielectric used in EDM are high dielectric strength and quick recovery after breakdown, effective quenching and flushing ability. Tool wear and workpiece removal rates are affected by the media and hydrocarbon compounds and water.

Tool Feed Control System and Machining Parameters

There a few methods studied to slow the rate of the tool wear. Work piece ultrasonic vibration method do increase the Material Removal Rate or MRR but tool wear increase rapidly as shown in Fig. 1 [2].