UNIVERSITI TEKNIKAL MALAYSIA MELAKA

An Analysis of Micro-Hole EDM Machining On Ti-6Al-4V

This report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering (Manufacturing Process) with Honours.

By

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2009

DECLARATION

I hereby, declared this reported entitled "An Analysis of Micro-Hole EDM Machining on Ti-6Al-4V" is the results of my own research expect as cited in references.

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APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (Manufacturing Process) with Honours. The member of supervisory committee is as follow:

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JUDUL: AN ANALYSIS OF MICRO-HOLE EDM MACHINING ON Ti-6AL-4V

SESI PENGAJIAN: 2009/2010

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ABSTRACT

Electrical discharge machining (EDM) is a process where the material removal of the workpiece is achieved through high frequency sparks between the tool (electrode) and the workpiece immersed into the dielectric. It is commonly used to produce moulds and dies, to drill small, burrfree holes and to make prototype quantities of contacts for the aerospace and electronics markets. In this study, micro-hole were fabricated on titanium alloys type of Ti-6AL-4V by using EDM Sodick High Speed EDM Die Sinking AQ55L type. The output responses investigated were material removal rate (MRR), electrode wear rate (EWR) and accuracy of micro hole shape. Full factorial of Design of Experiment (DOE) module in Minitab was used as a principal methodology to examine the effects of voltage, peak current, pulse on duration and pulse off time over output responses. The significant effect of various parameter for each output response was also identified and established. Experimental results indicate that the MRR was mainly affected by interaction between peak current with pulse off time, interaction between voltage with pulse on time and pulse off duration. For the EWR, significant effects were interaction between peak current with pulse on time and interaction between voltages with pulse on time. Finally, for the accuracy micro of hole shape were divided to two result that is result for entrance hole and result for exits hole.

ABSTRAK

Masin Nyahcas Elektrik (EDM) merupakan proses pembuangan bahan dari benda kerja melalui percikan berfrekuensi tinggi di antara benda kerja dan mata alat (electrode) direndam kedalam dielektrik (cecair elektrik). Ia umumnya digunakan untuk menghasilkan acuan, untuk gerudi kecil, membuat lubang tiada tatal dan membuat prototaip terhadap pengenalan untuk aeroangkasa dan elektronik pasaran. Dalam kajian ini, lubang mikro dibuat pada bahan titanium alloys jenis Ti-6AL-4V dengan menggunakan EDM dari jenis High Speed Sodick EDM Die Sinking AQ55L, diselidik kerana sifat bahan yang memiliki kekerasan dan kekuatan pada suhu tinggi. Tindak balas keluaran disiasat adalah kadar pembuangan bahan (MRR), kadar kehausan elektrod (EWR) dan ketepatan bentuk lubang mikro. Full factorial terhadap Design of Experiment (DOE) modul dalam Minitab software digunakan sebagai pengendalian utama untuk mengetahui pengaruh terhadap voltan, arus puncak, denyutan waktu hidup dan denyutan waktu mati keatas tindak balas keluaran. Pengaruh yang signifikan terhadap berbagai parameter untuk setiap tindak balas keluaran juga dikenalpasti dan ditetapkan. Keputusan kajian menunjukkan bahawa MRR sangat dipengaruhi oleh interaksi antara arus puncak dengan denyutan waktu mati, interaksi antara voltan dengan denyutan waktu hidup dan denyutan waktu mati. Untuk EWR, pengaruh yang signifikan adalah interaksi antara arus puncak dengan denyutan waktu hidup dan interaksi antara voltan dengan denyutan waktu hidup. Akhir sekali, untuk ketepatan bentuk lubang mikro adalah dibahagikan kepada dua keputusan iaitu keputusan untuk lubang masuk dan keputusan untuk lubang keluar.

DEDICATION

To my beloved father, Md Janis Bin Abd Manan and mother, Sayah Bte Mohammad
for all support that you given to me.
For my supervisor, Dr. Bagas Wardono, technician and all my fellow friends whom
never give up in supporting and encouraging me.

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LIST OF ABBREVIATIONS, SYMBOLS, SPECIALIZED NOMENCLATURE

EDM	-	Electrical discharge machining
MRR	-	Material removal rate
EWR	-	Electrode wear rate
DOE	-	Design of experiment
Cu	-	Copper
CW	-	Copper tungsten
SW	-	Silver tungsten
ECM	-	Electrical chemical machining
Micro-EDM	-	Micro-electro discharge machining
IC	-	Integrated circuit
T_{on}	-	Pulse on duration
T_{off}	-	Pulse off duration
MEMS	-	Micro-electro mechanical systems
DNA	-	Deoxyribonucleic acid
Sn	-	Stanum
Zr	-	Zirconium
Al	-	Aluminium
O	-	Oxygen
N	-	Nitrogen
C	-	Carbon
Mo	-	Molybdenum
V	-	Vanadium
Ta	-	Tantalum
Nb	-	Niobium
DC	-	Direct current
AC	-	Alternating current
EBM	-	Electron beam machining

MUSM	-	Micro-ultrasonic machining
SEM	-	Scanning electron microscope
SiC	-	Silicon carbide
V	-	Voltage
A	-	Ampere
µsec	-	Micro-second
g/sec	-	Gram per second
mm	-	Millimeter
MPa	-	Mega Pascal
UTHM	-	Universiti Tun Hussein Onn Malaysia
FKP	-	Fakulti Kejuruteraan Pembuatan
Δl	-	Different length
ΔW	-	Different workpiece weight
ΔE	-	Different electrode weight

CHAPTER 1

INTRODUCTION

1.1 Background

Electrical discharge machining EDM is a non-traditional machining process to metal removal by a series of rapidly reoccurring electrical discharge (spark) through a small gap filled with dielectric fluid between an electrode and a conductive workpiece. This discharge occurs in a voltage gap between the electrode and workpiece by eroding the material in the path of electrical discharges that form an arc between an electrode and the workpiece. Heat from the discharge vaporizes minute particles of workpiece material, which are then washed from the gap by the continuously flushing dielectric fluid. EDM is considered as one of the most accurate manufacturing processes available for creating complex or simple shapes and geometries within parts and assemblies. Therefore this technique is used in the industry especially that produces products with high accuracy, for example to make spray holes on diesel engine fuel injector where the hole spray must be exactly round shape and the dimension round must be very accurate.

In EDM, a potential difference is applied between the electrode and workpiece where both electrode and workpiece are to be conductors of electricity. The electrode and the workpiece are immersed in a dielectric medium and generally kerosene or deionised water is used as the dielectric medium. The material remove shapes that produce on workpiece is following the electrode shape. The gap maintained between the electrode and workpiece depends upon the applied potential difference where gap between the electrode and workpiece will become an electric field. Generally, the electrode is connected to the negative terminal of the generator and the workpiece is connected to positive terminal. When the electric field established between the electrode and workpiece, the free electrons on the electrode are subjected to electrostatic forces. If the work function or the bonding energy of the electrons is less, electrons would be emitted from the electrode (assuming it is connected to the negative terminal). Such emission of electrons are called or termed as cold emission.

The “cold emitted” electrons are then accelerated towards the workpiece through the dielectric medium. As they gain velocity and energy, and start moving towards the workpiece, there would be collisions between the electrons and dielectric molecules. Such collision may result in ionization of the dielectric molecule depending upon the work function or ionization energy of the dielectric molecule and the energy of the electron. Thus, as the electrons get accelerated, more positive ions and electrons would be generated due to collisions. This cyclic process would increase the concentration of electrons and ions in the dielectric medium between the electrode and workpiece at the spark gap. The concentration would be so high that the matter existing in that channel could be characterized as “plasma”. The electrical resistance of such plasma channel would be very less. Thus all of a sudden, a large number of electrons will flow from the electrode to workpiece and ions from the workpiece to electrode. This is called avalanche motion of electrons. Such movement of electrons and ions can be visually seen as a spark. Thus the electrical energy is dissipated as the thermal energy of the spark.

EDM is a machining method primarily for all type of conductive material and for the machining of hard metals or those that would be very difficult to machine with traditional techniques. For example conductive material is a metal or metal alloy such as titanium, hastelloy, kovar, inconel and of whatsoever that have high hardness property. Titanium is a chemical element with combination of iron, aluminium, vanadium, molybdenum and among other elements. The usage of titanium is increasing in many industrial and commercial applications because of these materials have excellent properties such as a high strength–weight ratio, high temperature strength and exceptional corrosion resistance. These properties make it considered in any application include aircraft turbine, engine components, aircraft structural component, aerospace fasteners, high performance automotive parts, marine applications, medical devices and sports equipment. Although this material have combination of high strength at low to moderate temperatures and lightweight but it is difficult to machine by using traditional machining techniques. Generally, titanium can be classified into three main categories that are alpha alloys, alpha + beta alloys and beta alloys in which each category have different combination properties. (Thedra Wagner and Mitchell Allenspach, 2000)

1.2 Problem Statement

Micro-holes are small holes with diameter less than 0.5 mm and have a wide range of applications, including ink-jet printer nozzles, orifices for bio-medical devices, cooling vents for gas turbine blade and diesel fuel injector spray holes. Micro-holes can be fabricated by electrical discharge machining (EDM). Besides utilizing EDM, the drilling machine also can be used to making micro-hole but only for material that have lower hardness property such as aluminum, plastic and etc.

According to P.F. Zhang (2008), producing micro-holes on titanium by using drilling machine is difficult because these materials have high strength properties and continuously give the effect on quality of micro-hole that produced. Usually, the quality of micro-hole that produced by drilling machine can evaluated in terms of hole diameter and cylindricity, surface roughness, and burr. However, Ahmet Hascalık said that the drilling machine is not suitable to make the micro-hole on titanium because the vibration from the tool during machining operation can causes the tool damage. Beside that, drills tool also easy to wear and broken because the tip of drill will occur higher stress during operate. Therefore, the machining titanium material usually encounters problem namely high tool wear rate, high machining cost, and low productivity. Thus, EDM is a best method to replace the drilling machine especially in producing a micro-hole. This is because, EDM can produce the product with complex shaped on material that has high hardness property that can not be produced by traditional machine.

In this study, the research is focused on the investigation of the effect of various EDM parameters on titanium by using copper electrode in the context of material removal rate (MRR), electrode wear rate (EWR) and accuracy of micro hole shape. The parameters considered in this research are voltage, peck current, pulse on time and pulse off time. To determine the significance of the parameter, a statistical tool namely two level full factorial design of experiment (DOE) was utilized. Beside that, this project also emerged based on the need of finding optimum parameter that affects the micro-hole machining by using copper electrodes.

1.3 Objective

The objective of this study can be described as the following:

1) To study the effect of various parameter values toward the material remove rate (MRR), electrode wear rate (EWR) and accuracy micro hole shape.
2) To implement the statistical analysis of value MRR, EWR and accuracy micro hole shape by using DOE method.
3) To develop a mathematical model from result analysis.

1.4 Scope

The scopes of work of the study consist of the following:

1) The parameters in this analysis are voltage, peak current, pulse on time and pulse off time.
2) The EDM Die-Sinking type of AQ55L SODICK will be used to make micro-hole.
3) The material used in this analysis is titanium (Ti-6Al-4V) and the thickness is 2.5mm.
4) The electrode that used is copper and the dimension of the electrode is 0.5mm
5) The data value will be analyzed using 2 level full factorial DOE.

CHAPTER 2

LITERATURE REVIEW

2.1 Principle of Electrical Discharge Machining

Electrical discharge machining (EDM) is a non-traditional manufacturing process based on removing material from a part by means of a series of repeated electrical discharges (created by electric pulse generators at short intervals) between a tool, called the electrode, and the part being machined in the presence of a dielectric fluid. (Puertas, 2003)

EDM was developed during World War II to remove broken taps from holes and today it was wider application to process only work on conductors of electricity (metal) and cannot be used to machine polymer or ceramics. EDM also is something called spark machining and this name comes from the fact that the metal removal is actually done by an electrical spark. During the process the spark can produce rapidly repeating between the electrode (tool) and the work that produces very high temperatures (about 10,000 ^{0}C) and high pressures. This spark can cause melting and vaporizing of the workpiece and finally the metal become particles or "chips" which are flushed away from the gap between the work and the electrode by non-conducting liquid. (R. Thomas Wright, 1999)

According to Biekert R. (1993), when operating EDM, there are two designs for the tool feed that is ram and quill. The ram-feed machines are more heavy duty and less expensive than the quill-feed. The ram-feed uses a hydraulic cylinder for the movement of the head, whereas the quill-feed uses a hydraulic motor to drive a lead screw. Both are controlled by “advancing and retracting the tool”. Not only are the designs different, but there are also a large number of factors to consider within the EDM process, such as the level of generator intensity, the pulse time, and the duty cycle. (Puertas, 2003)

The level of generator intensity represents the maximum value of the discharge current intensity. The pulse time is the duration of time that the current is allowed to flow per cycle and the duty cycle is the percentage of the pulse time relative to the total cycle time. In addition, none of these processes within EDM require force, because the anode never touches the cathode.

Another factor to consider in the EDM process is the speed of material removal. The speed of the material removal process as in most cases is measured by cubic inches per hour. The EDM process does not require force. There are several factors that control the material removal rate. The most important of these is the melting temperature of the workpiece material and lower the melting temperature wills faster the removal rate. The rate of which the electrode is eroded and also considered as “erosion rates", are not affected by the material hardness but by the melting temperature of the material being used. (Fellers, W. D., 2001)

The melting point and the latent heat of melting are important physical properties that determine the volume of metal removed per discharge. As these quantities increase, the rate of material removed decreases. The volume of material removed per discharge is typically in range of 10^{-6} to 10^{-4} mm (10^{-10} to 10^{-8} in). Because the process doesn’t involve mechanical energy, the hardness, strength and toughness of the workpiece do not necessarily influence the removal rate. The frequency of discharge or the energy per discharge is usually varied to control the removal rate, as are the voltage and current. The removal rate and surface roughness increase with increasing current density and decreasing frequency of sparks. (Serope Kalpakjian, 2000)

According to Helmi A. Youssef and Hassan El-Hafy (2008), the tool and workpiece are separated by a small gap of 10–500 μm. Both are submerged or flooded with electrically non-conducting dielectric fluid. When a potential difference between the tool and workpiece is sufficiently high, the dielectric in the gap is partially ionized, so, that a transient spark discharge ignites through the fluid, at the closest points between the electrodes. Each spark of thermal power concentration, typically 108 W/mm^2, is capable of melting or vaporizing very small amounts of metal from the workpiece and the tool (Figure 2.1).

To summarize the EDM process for example in electric arc welding the arc melts the metal. If that metal could be removed continuously from that particular spot where the electrode is located this would be EDM and any shape that can be made into an electrode can be reproduced in the work.

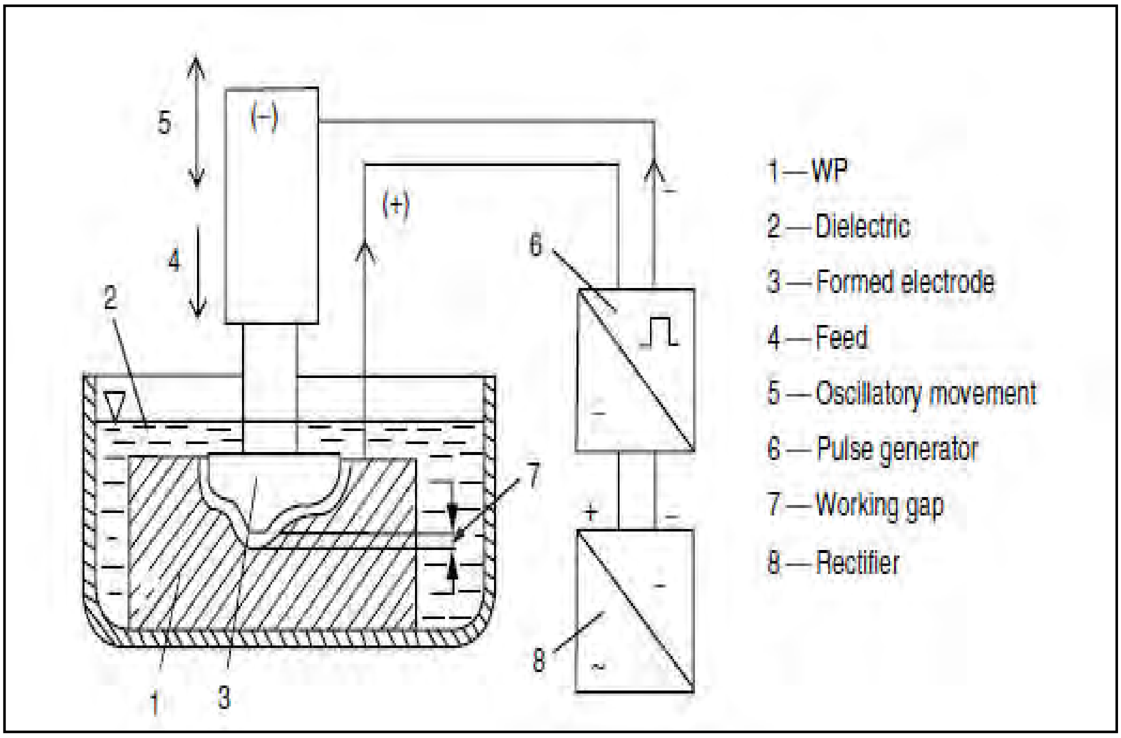

Figure 2.1: Concept of EDM. (Helmi A. Youssef and Hassan El-Hafy, 2008)