INVESTIGATION OF SURFACE ROUGHNESS IN WIRE ELECTRICAL DISCHARGE MACHINING OF STAINLESS STEEL

BY

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ABSTRACT

In obtaining the best quality of engineering components, the quality of machined parts surface plays an important role. It is a fact that it improves fatigue strength, wear resistance, and corrosion of workpiece. Optimal machining parameters can only be determined by significant parameters that are affecting the properties of the machining performance. Theaim of this study is to investigate effects of wire electrical discharge machining (WEDM) parameters towards the surface roughness and kerf width of stainless steel. The parameters selected are voltage open (V_o), off time (OFF), wire speed (WS), wire tension (WT) and voltage gap (VG). This research uses stainless steel 304 as a workpiece, 0.2 mm brass wire as a tool, and for dielectric fluid distilled water is used. Taguchi's L_{16} orthogonal array has been used for experimental design and the optimum machining parameter was determined through signal-to-noise ratio analysis. Surface roughness and kerf width was determined by using Mitutoyo Surftest SV-514 and Jeol JSM-5600. The analysis of variance show that the off time had major influenced on the surface roughness and voltage gap on kerfs. The optimum machining parameter for the kerf and surface roughness was obtained at 12.65 V voltage open (Level 1), 4µs off time (level 4), 12 m/min wire speed (level 4), 6 N wire tension (level 1), 51.21 voltage gap (level 3). The average of kerf width and surface roughness from the three experiments was 0.273 mm and 2.23 µm respectively and from that, the error margin for kerf width was 8.79% and surface roughness was 8.07%.

الملخص

إنَّ الحصول على أجود أنواع المكونات الهندسية، ووجودة أنواع أجزاء الآلات السطحية تلعب دوراً في غاية الأهمية. وتشير الحقائق إلى أنَّ تحسين قوة الجهد، واحتواء المقاومة، وتآكل قطع التشغيل. لا يمكن بحال من الأحوال تحديد تلك العوامل بشكل قطعي.حيث يصعب تحديد المعايير الأساسية التي تؤثر على خصائص الأداء الميكني. ويتمثل الهدف من هذه الدراسة في دراسة الآثار الناتجة عن تفريغ الشحنات الكهربائية على تلك الآلات (WEDM) ، وتتمثل العوامل المتغيرة لهذه التجربة في معدل خشونة الأسطح الميكانيكيةومنحنى القطع في الفولاذ غير القابل للصدأ. ويمثل العامل المتغير هنا في الفولت الكهربائي غير المحدود (Vo)، والوقت المغلق (OFF)، وسرعة التيار الكهربائي (WS)، وجهد التيار (WT)، والفجوة الفولتية(VG).ويعتمد هذا البحث على استخدام الفولاذ غير القابل للصدأ 304 باعتباره مناطاًلبيئة العمل، والأسلاك النحاسية بقطر 0.2 ميللي متر باعتبارها أداة للتوصيل، ويتم استخدام الماء المقطر باعتباره الوسبة العازلة. وقد تمَّ استخدام مجموعة تقنيات تاجوشىL16 في بناء التصميم تجريبي، وتمَّ تحديد العامل المتغير الميكني الأمثل من خلال تحليل نسبة الإشارة إلى الضوضاء، كما تمَّ تحديد نسبة خشونة السطح ومنحنى القطع باستخدام تقنيتي ميتوتويو سارفيست SV-514 وجيول JSM-5600. وأظهرت نتائج التحليل أنَّ التباين في الوقت المغلق قد أثر يشكل كبير على درجة خشونة السطح والفجوة الفولتية على وعلى منحنى العامل المتغير بالقطع الأمثل وعلى خشونة السطح، ووجد أنه عند التعرض للجهد المفتوح بمقدار 12.65 V في المستوى الأول. في وقت مقداره 4 مايكروثانية في المستوى الرابع، وبسرعة تيار قطره 12 ميللي متر في المستوى الرابع، و توتر تيار مقداره 6N في المستوى الأول، وبفجوة فولتية مقدارها 51.21 فيالمستوى الثالث، وبلغ متوسط منحنى القطع وخشونة السطح في التجارب الثلاثة 0.273 ميللي متر، و 2.23 مايكرو ثانية على التوالي، وتمَّ التحقق من ثبات تلك النتائج بهامش خطأ في منحنى القطع مقداره 8.79٪، وفي خشونة السطح بمقدار 8.07٪

APPROVAL PAGE

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

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Mohammad Yeakub Ali
Supervisor

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

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Dean, Kulliyyah of Engineering

DECLARATION

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

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This dissertation is dedicated to my beloved parents

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LIST OF SYMBOLS

R_a	Average Surface Roughness
N	Newton
OFF	Off time
S/N	Signal to Noise
V	Volt
VG	Voltage Gap
V_o	Voltage Open
WS	Wire Speed
WT	Wire Tension

LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
DOE	Design of Experiment
et al.	(*et alia*): and others
EDM	Electrical discharge Machining
HB	Higher is Better
IIUM	International Islamic University Malaysia
LB	Lower is Better
MRR	Material Removal Rate
µm	Micro meter
µs	Micro second
mm	Millimeter
mm/min	Millimeter per minute
SEM	Scanning Electron Microscope
WEDM	Wire Electrical Discharge Machining

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

Wire electrical discharge machining (WEDM) is a specific thermal machining process. It has the capability to machine sharp edges, varies material hardness, and complex shapes precisely. Nowadays, WEDM become more popular in industry that produces high precision products. Materials either conductive or non-conductive can be manipulated by WEDM whereas a conventional machine limits the materials type and shape. From day to day, WEDM will develop constantly with the demand of various sector in manufacturing industry such as extrusion dies and stamping dies. Apart from that, WEDM is widely used in the area of production of aerospace parts, micro gas turbine blades and electronic components (Kumar & Ravikumar, 2013).

WEDM is an electro-erosion machining process. Metal is removed from the workpiece by the breakdown voltage of dielectric fluid. Due to this, high power sparks may increase the temperature up to 10000º C. A metal wire has been used as an electrode in WEDM. The wire is guided through the immersed work piece in a tank of dielectric fluid. Normal diameter of the wire is in the range of 0.1 mm to 0.25 mm, and typically distilled water is used as dielectric fluid. The types of wire during machining via WEDM depends on the steel product, cutting purpose, and types of the machine. It is either to choose a standard, special or coated wire. WEDM can be used to cut up to 400 mm thick of work piece with various type of material, has no cutting force, and low residual stress. However, some changes in material in terms of mechanical properties may happen because of these stresses.

In WEDM the quality of the machined part, with respect to its precision and surface integrity, is not only related to the machining parameters of current, gap voltage, discharge duration, wire tension, wire speed, dielectric fluid, and polarity but also depends on machining techniques (dry or wet)(Abdulkareem, Khan, & Zain, 2011). Kerf variation and corner errors in machined parts normally due to deflection of wire tools and discharge gap vibration. These factors influenced in machining accuracy of material. In conventional WEDM 25 µm -75 µm discharge gap can be achieved whereas 4 µm discharge gap in micro WEDM. Other than that open voltage and wire tension can affect the kerf variation (Huang, Chen, & Liao, 2004).

Thus it is important to study the variation of surface roughness and kerf comprehensively in an attempt to improve the accuracy in machined parts in WEDM. This research is purposely carried out to investigate the kerf width and surface roughness when stainless steel is machined through WEDM process.

1.2 PROBLEM STATEMENT

Reliability of surface in machined parts is important to define the quality of component. Dimensional accuracy is more crucial especially in micro-parts industry due to fast growth of micro-electromechanical system. However, electrical spark after WEDM may cause craters to the surface of machined parts. Crack and rippled surfaces due to high energy cause a malformed surface structure. A smooth surface has better reliability than a rough surface in terms of wear resistance and friction coefficients.

To lower the discharge energy can slow down the production process and to increase it can affect the surface finish. Thus, failure to achieve this may lead to failure of some product that needs a high reliability of surface roughness. Therefore during WEDM process, achieving a better surface reliability is a must.

1.3 RESEARCH OBJECTIVES

The purpose of this research is to exhibits the WEDM process parameters which are voltage open (V_o), wire speed (WS), wire tension (WT), voltage gap (VG), off time (OFF) that can be manipulated in order to get a better surface integrity . In this research, the objectives are as follows:

1. to investigate the influence of WEDM process parameters towards surface roughness
2. to study the influence of WEDM process parameters towards kerf width
3. to optimize the process parameters to get the minimum kerf and surface roughness

1.4 SCOPE OF THE RESEARCH

Parameters to be evaluated are voltage open (8-16V), wire speed (1-4 m/min), wire tension (6-9N), voltage gap (40-55V), off time (1-4 µs) and responses to be evaluated are kerf width and surface roughness. Other machining parameters remain constant. Work piece material for this study is stainless steel (S304), brass wire as an electrode with diameter of 0.2 mm, and dielectric fluid of distilled water to conduct the experiments. The fractional factorial design that is adopted is L_{16} orthogonal array using Taguchi Method.

CHAPTER TWO

LITERATURE REVIEW

2.1 ELECTRICAL DISCHARGE MACHINING (EDM)

EDM process is a non-traditional machining technique in manufacturing field. It is used to manufacture engineering components and parts from standard work piece materials. Normally, EDM is used to machine a tough, super-tough, hard, electrically conductive materials, and alloys to close tolerances. EDM in the presence of die electric fluid removes the metal through high current density and electrical discharge between the work piece and the tool.

2.2 WIRE ELECTRICAL DISCHARGE MACHINING (WEDM)

Nowadays, WEDM is extensively conserved non-conventional material removal process. In the late 1960s, WEDM was initiated to manufacturing sector due to the needs of replacement of electrode in EDM. In 1970s after computer numerical control was introduced a major machining process evolution begun. WEDM process became more popular as it is used tremendously because of it significant capability.

Nihat et al. (2004) conducted experimental studies on material removal rate and cutting width using Taguchi experimental design method. Open circuit voltage, wire speed, pulse duration, and dielectric flushing pressure are the parameters chosen for the study.

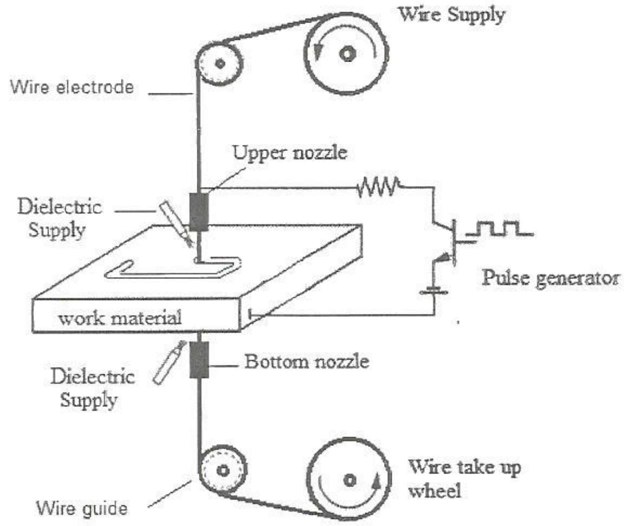

Figure 2.1 : Schematic Representation of WEDM Process (Shinde & Anand, 2014)

Mahapatra et al. (2007) used a non-linear regression analysis to study the relationships between various parameters with surface roughness, kerf, and material removal rate. WEDM process with multiple objectives optimized by genetic algorithm.Hewidy et al. (2005) used mathematical models to study response surface methodology between material removal rates, surface roughness, and wearratio with wire tension, duty factor, peak current, and water pressure. The research demonstrates that a better material removal rate, kerf and surface roughness can be achieved through manipulation of WEDM process parameters.

2.2.1 Wire Electrical Discharge Machining Process

WEDM is an electro thermal process. The machining process is controlled by a program using a computer numerical control programming. A desired product is cut by using a wire as an electrode. Ali et al. (2010) stated that WEDM process is economical and able to cut difficult shapes and materials. The diameter of wire that frequently being usedis in the range of 0.1 mm to 0.3 mm and normally the wire is made of stratified copper or brass. Groover (2007) confirmed that the commonly used WEDM wires are from copper, tungsten, brass coated, brass, molybdenum, multi coated and zinc. The size of wire depends on the machining process. For example, 0.30 mm multi coated wires with the diameter of 0.30 are used for roughing purposes and for skimming purposes 0.2 mm wires are used.

Machining process depends on the surface integrity and accuracy. It is either will be roughed and skimmed or just one cut. Throughout the roughing process, high pressure water is forced into the cut to give a fast cooling. Throughout the skimming process, low pressure water is used with the intention of avoiding the wire deflection. The tolerances that can be achieved in WEDM is up to +/- 0.0001 which is very accurate. That is why WEDM is preferable in micro parts manufacturing field.

In most of WEDM machining, the important performance measurements are surface roughness, kerf, and material removal rate. There are many WEDM machining parameters that can influence these performance measurements such as pulse duration, discharge capacitance, wire tension, dielectric flushing pressure, pulse frequency, and discharge current(Rizauddin, Roazam, & Jaharah, 2012).

2.2.2 Wire Electrical Discharge Machining Process Parameter

Process parameters are variable that influence machining process. Several parameters affects the performance measures. The performance measures of WEDM are kerf, surface roughness, and material removal rate. All of these performance measures can be affected by process parameters such as dielectric pressure, pulse on-time, wire feed, servo voltage, wire tension, open voltage, and etc. where these parameters can be controlled to reduce surface cracks and damage. Nihat et al.(2004) found that wire speed, discharge capacitance, wire tension, pulse duration, pulse frequency, dielectric flushing conditions, discharge current, average working voltage are the machining parameters that influence the performance measures. Adeel et al. (2013) concluded that wire tension, open voltage, and pulse on-time, are the major parameters for kerf width. Vishal et al. (2010) observed that SS 304L machined by WEDM process, the machining parameters like pulse off-time, gap voltage, dielectric flushing pressure, wire feed, and pulse on-time are the important controllable machining parameters in WEDM process. Rizauddin et al. (2012) decided WEDM machining parameters like wire tension, dielectric flushing pressure, pulse frequency, discharge capacitance, pulse duration, and discharge current are machining parameters that can influence the performance measurements. Abdulkareem et al. (2011) studied the effect of voltage gap (20-40V) on surface roughness and found that increase in gap voltage contribute to poor surface integrity. Nihat et al. (2003) studied the effect of wire speed (5-12.5 m/min) on wire wear in WEDM and found that it is insignificant. Sulastri et al. (2012) studied the multi-cutting passes for fine-cut WEDM of stainless steel under a condition of voltage gap (44-56 V), wire speed (12 m/min), off time (1-8 µs), wire tension (8-10 N) and voltage open (2-16 V) found that the surface roughness is decreased with the increment of cutting passes can produces.

Kanlayasiri et al. (2007) used multiple regresion method to establish a mathematical model found that wire-EDMed DC53 die steel's roughness affected by the pulse on-time and pulse peak-current while wire tension and pulse off-time are insignificant. Machining condition selection via WEDM is based on the analysis relating the various process parameters to different performance measures. Ho Newman et al. (2004) stated that inconsistent machining performance happened because of machining parts greatly rely on WEDM manufacturer's data and the operator's experience.Esme et al. (2009) obtained surface roughness was increased when wire speed, open circuit voltage, and pulse duration were increased while surface roughness decreased with the increased of flushing pressure.Ikram et al. (2013) suggested that open voltage is less significant than pulse on-time. By keeping wire feed velocity, pulse on-time, and open voltage at level 1, wire tension, servo voltage, and material thickness at level 2 while dielectric pressure and pulse off-time at level 3 optimum machining performance can be achieved. The significant factors for kerf are open voltage, wire tension, and pulse on-time. To get the minimum kerf, pulse on-time, wire feed velocity, dielectric pressure, and the material thickness must be retained at level 1, servo voltage at level 2 while wire tension, pulse off-time, and open voltage at level 3

2.2.3 Wire Electrical Discharge Machining Performance Measures

Performance measures in WEDM is an indicator to observe or to assess the quality of finished products or parts. In WEDM the most significant performance measures are surface finish, kerf, and material removal rate. Kerf width is used to determine the accuracy of dimension whereas surface roughness is used to control the quality of the machined part and material removal rate for economic purposes. The minimum kerf width with a maximum material removal rate are the main target of the production. Huang et al. (2004) proved that surface roughness can be improved by decreasing the discharge current and pulse duration.

2.2.3.1 Kerf

In WEDM, one of the performance measures that is significant is kerf. Kerf is the quantity of material wasted throughout machining process. It controls the dimensional accuracy of the machined part. The Figure 2.2 and Figure 2.3 shown detailed section of kerf width.

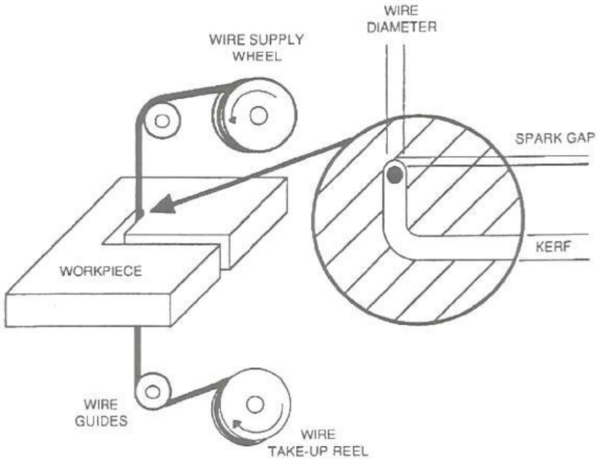

Figure 2.2 : WEDM Cutting Gap (D.Scott, Boyina, & K.P.Rajurkar, 1991)

Kerf limits the internal corner radius during machining the workpiece. The gap that can be obtained in the range of 0.025 mm to 1.075 mm if controlled by computer positioning system. The kerf width can be expressed as in Equation (1).

$$\text{Kerf width} = D + 2d_0 \qquad (1)$$

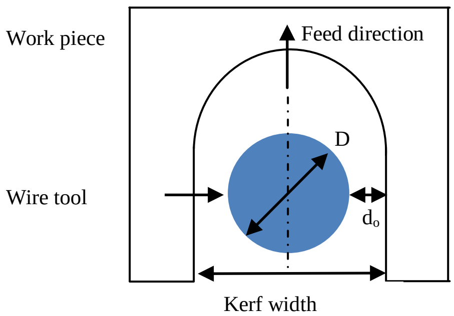

Figure 2.3 : Detail of WEDM Kerf Width