UNIVERSITI TEKNIKAL MALAYSIA MELAKA

OPTIMIZATION OF MACHINING PARAMETERS IN WIRE EDM

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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2010

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA MUDA

TAJUK: **Optimization of Machining Parameters in Wire EDM**

SESI PENGAJIAN: 2009/2010

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APPROVAL

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ABSTRACT

The objective of this project is to optimize the machining parameters in wire electrical discharge machining (WEDM) in order to machine an electrode with the desirable quality and accuracy. The intended purpose of the electrode is for the application of miniature machining in EDM die-sinking. The machining of small and precision part is problematic due to the presence of high mechanical force in most of the manufacturing processes that might damage or deform the part. The application of electrical discharge to remove material in WEDM is a potential solution to the problem due to the non-contact nature between the electrode and the workpiece during the machining process. Throughout the study, the variable machining parameters such as open circuit voltage, discharge current and voltage gap were investigated. Response surface methodology (RSM) has been used to design the experiment and analyze the results. The quality and accuracy of the electrode were measured on the surface roughness and kerf width, respectively. The significant machining parameters on the surface roughness are open circuit voltage and voltage gap while the significant machining parameter on the kerf width is discharge current. A fine surface roughness of 1.68 μm and a small kerf width of 0.271 mm were achieved. The confirmation runs have shown the acceptable percentage of variation between the predicted value and actual value on the surface roughness with 6.52% and kerf width with 2.01%.

ABSTRAK

Objektif projek ini adalah untuk mengoptimumkan parameter pemesinan dalam teknologi *wire electrical discharge machining* (WEDM) untuk menghasilkan elektrod yang berkualiti dan berketepatan. Tujuan elektrod ini adalah untuk digunakan dalam aplikasi pemesinan telus dalam teknologi EDM *die-sinking*. Pemesinan bahagian yang kecil dan jitu adalah rumit kerana kewujudan daya mekanikal yang tinggi yang dikenakan dalam kebanyakan process pemesinan yang boleh merosakkan atau mengubah bentuk bahagian. Aplikasi pembuangan bahan dengan penyahcasan elektrik di dalam teknologi WEDM adalah berpotensi untuk mengatasi masalah tersebut disebabkan keadaan elektrod yang tidak bersentuh dengan bahan kerja dalam process pemesinannya. Dalam projek ini, parameter pemesinan yang telah digunakan dalam kajian ialah *open circuit voltage, discharge current* dan *voltage gap. Response surface methodology* (RSM) telah digunakan untuk mereka eksperimen dan menganalisa keputusan eksperimen. Kualiti dan ketepatan elektrod telah dikaji ke atas kekasaran permukaan dan lebar pemotongan. Parameter pemesinan yang berpengaruh ke atas kekasaran permukaan ialah *open circuit voltage* dan *voltage gap*, manakala parameter pemesinan yang berpengaruh ke atas lebar pemotongan ialah *discharge current.* Kekasaran permukaan yang rendah sebanyak 1.68 μm dan lebar pemotongan yang kecil sebanyak 0.271 mm telah tercapai. Ujian ketentuan telah menunjukkan sesaran keputusan yang boleh diterima iaitu 6.52% pada kekasaran permukaan dan 2.01% pada kelebaran pemotongan.

DEDICATION

To my beloved family and friends

ACKNOWLEDGEMENT

First of all, I would like to express my gratitude to Universiti Teknikal Malaysia Melaka (UTeM) for the opportunity to pursue study in Bachelor of Manufacturing Engineering (Manufacturing Process) and to conduct and complete this "Projek Sarjana Muda". UTeM has provided many facilities such as machines and equipments to aid the success of this project.

A very special thanks to my supervisor Miss Liew Pay Jun for her guidance, encouragement and contribution in this project. She has given me useful advices and motivation when I encountered problems and willingly shares the knowledge regarding this project.

Besides that, I would like to thank ADTECH for providing the WEDM machine to conduct my study and experimental runs. Not forgetting, thanks to Mr. Zamree who is a lecturer in ADTECH that has guided me throughout the entire handling and running of the WEDM machine.

Last but no least, I would like to thank my family for their continuous support and courage throughout the study and the project. Not forgettable, thanks to my friends that have been working side by side in completing this project.

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LIST OF ABBREVIATIONS

2FI	-	2-Factor Interactions
AISI	-	American Iron and Steel Institute
ANN	-	Artificial Neural Network
ANOVA	-	Analysis of Variance
C.V.	-	Coefficient of Variation
Cr	-	Chromium
DC53	-	Tool steel
DOE	-	Design of Experiment
EDM	-	Electrical Discharge Machining
FEA	-	Finite Element Analysis
IACS	-	International Association Cryospheric Sciences
MRR	-	Material Removal Rate
NSGA	-	Non-dominated Sorting Genetic Algorithm
PRESS	-	Predicted Residual Sum of Squares
R_a	-	Arithmetic Average Height
RSM	-	Response Surface Methodology
SA	-	Simulated Algorithm
SKD11	-	Hardened steel
SUS-304	-	Stainless steel
WEDM	-	Wire Electrical Discharge Machining

CHAPTER 1
INTRODUCTION

This chapter includes the overview of wire electrical discharge machining (WEDM). The problem statement and objective of the study are also included. Then, it is followed by the scope, importance of study and expected result of the project.

1.1 Introduction

According to Ho *et al.* (2004), WEDM is a specialized thermal machining process capable of accurately machining parts with varying hardness or complex shapes, which have sharp edges that are very difficult to be machined by the main stream machining process. Since the introduction of the process, WEDM has evolved from a simple means of making tools and dies to the best alternative of producing micro-scale parts with the highest degree of accuracy and surface finish quality.

Sanchez and Ortega (2009) stated that WEDM is unique that the machining process does not involve mechanical force exerted on the workpiece whereby material is removed by a series of discrete electrical discharge (spark) generated between a workpiece and wire electrode under the localized stream of dielectric fluid. Throughout the cutting process, the wire electrode is continuously fed and collected by spools or nozzles at certain speed and the movement of the wire electrode is controlled numerically to cut the desired path and dimension of the workpiece.

Prasad and Krishna (2008) explained that generally, the selection of optimal parameters in WEDM is difficult as it is a complex process and involves a large number of variables. The selection of optimal parameters in WEDM is primarily dependent on the operator's experience and machining parameter tables provided by the machine-tool manufacturers. However, researches have been carried out widely by various researchers in optimizing the machining parameters on various materials and conditions to obtain the desired machining result in WEDM.

Kohkonen (2009) intorduced that WEDM process found extensive use in producing parts, especially small parts with low wall thickness. The wire electrode and workpiece never make contact where there is virtually no cutting force on the part. This allows for small parts with thin wall sections to be cut without deformation. Furthermore, Hewidy *et al.* clarified that the high degree of the obtainable accuracy and the fine surface quality make WEDM valuable in miniature application. This has made WEDM process to surpass most of the conventional machining process.

1.2 Problem Statement

Besides than WEDM, electrical discharge machining is also applied in the means of die-sinking where the same electrical discharge concept is used but having a shaped electrode tool being directed towards the surface of the workpiece. The electrode in EDM die-sinking needs to be machined to the desire shape and size, where some would have intricate shape and low cross-section. The electrode is hardly producible by the conventional machining method. It is more crucial when the electrode is used for miniature machining in EDM die-sinking where the electrode is of high length to cross-section ratio. It is easily subjected to deformation by only little forces.

According to Kohkonen (2009), the manufacturing of small precision parts has always been a challenge because most manufacturing processes require mechanical cutting force. In conventional machining methods such as turning and milling, high cutting force is used for material removal. The large mechanical force is not desirable in small parts as it will damage or deform the parts. The WEDM process has excellent capability for manufacturing delicate small parts because there are no mechanical shearing forces to resist. Therefore, by using WEDM, the delicate and weak section of the EDM die-sinking electrode can be machined without any distortion.

Besides that, in order to get a good quality of miniature machining in EDM die-sinking, the electrode must be of good quality and accuracy. According to Mahapatra and Amar (2007), the quality of the electrode is determined by the low surface roughness of the machined surface while the accuracy of the electrode is determined by the small kerf width of the WEDM process. Ho *et al.* (2004) stated that the settings for various process parameters required in the WEDM process play a crucial role in producing an optimal machining performance.

1.3 Objective

1. To optimize the machining parameters in WEDM in fabricating a quality electrode with good surface finish and accuracy for the application of miniature machining in EDM die sinking.
2. To determine the significant machining parameters and study the interaction between the machining parameters and responses involved.

1.4 Scope

This project included the study on the few variable machining parameters in WEDM which are open circuit voltage, discharge current and voltage gap. The other machining parameters such as pulse-off time, wire speed, wire tension, dielectric flow rate and dielectric flow rate are set constant. The performance measures of the study are evaluated on the surface roughness of the electrode and the kerf width of the WEDM process. Response surface methodology (RSM) method is used to study, analyze and relate the variables and responses involved. The significant machining parameters in WEDM are obtained. Finally, mathematical model is developed to represent the study and verification is conducted to determine the consistency of the mathematical model.

1.5 Importance of study

The primary concerns in this study are the surface finish of the electrode and the kerf width of the WEDM process, where both are of high importance in small precision parts. The surface roughness determines the surface quality of the electrode, while the kerf width determines the accuracy of the electrode. The quality of the electrode machined for the application of miniature machining in EDM die-sinking is important because it reflects the resulting machining surface and accuracy. The optimized machining parameters of the study can also be used as a reference to fabricate other intricate shapes such as tools and dies, fixtures and gauges, prototypes and medical parts with the identical workpiece feature and machining condition.

1.6 Expected result

At the end of this project, the study and experiment is expected to successfully fabricate an electrode with the desire surface roughness and kerf width by using the optimized machining parameters in WEDM. The mathematical model developed to represent the resulting surface roughness and kerf width under certain predetermined factors value are also expected to meet the result of the actual electrode fabricated with minimum error.

CHAPTER 2

LITERATURE REVIEW

This chapter includes the theory of the fundamentals involved in the study. Besides that, the related findings by past researchers are also included. At the end of this chapter, a summary of the study is included.

2.1 Wire Electrical Discharge Machining (WEDM)

Spedding and Wang (1997) stated WEDM has grown tremendously in conductive material machining recently because of its advantages of being unaffected by material hardness, no cutting force, high accuracy, and the ability to achieve complex workpiece shape as well as unmanned machining. Performance of the WEDM process, however, is affected by many factors (workpiece material, wire, dielectric medium, adjustable parameters, etc.) and a single parameter change will influence the process in a complex way.

Tosun *et al.* (2004) conducted the survey of literature review and indicates that there are published works on the effect of machining parameters on material removal rate (MRR), surface roughness, cutting speed, wire rupture and wire craters. Unfortunately, little research related to the kerf width variation has been done. Di *et al.* (2009) presented that it is significant to investigate the kerf variations in detail to improve the machining accuracy in WEDM.

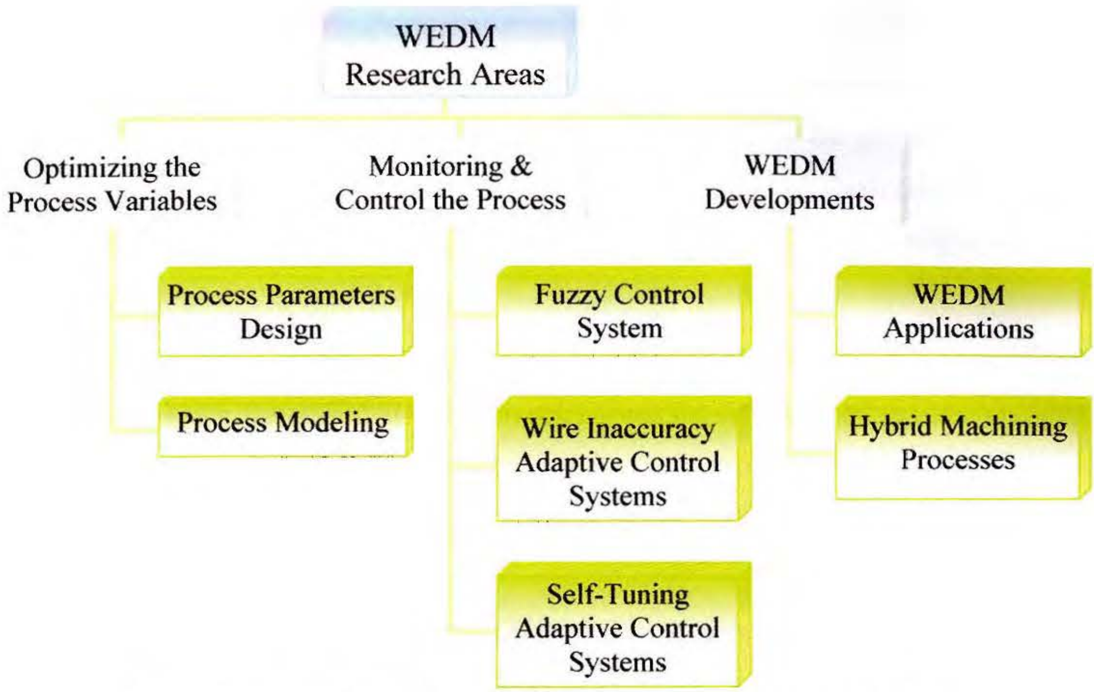

Figure 2.1: Classification of major WEDM research areas (Ho *et al.*, 2004).

2.1.1 WEDM Process

In WEDM process, a thin wire is used as an electrode tool to cut the workpiece. The workpiece is set at a fixed position while the wire travels along the desire cutting path. The cutting result is a narrow line when directly cut into the workpiece or can be layer by layer material removal from the surface of the workpiece.

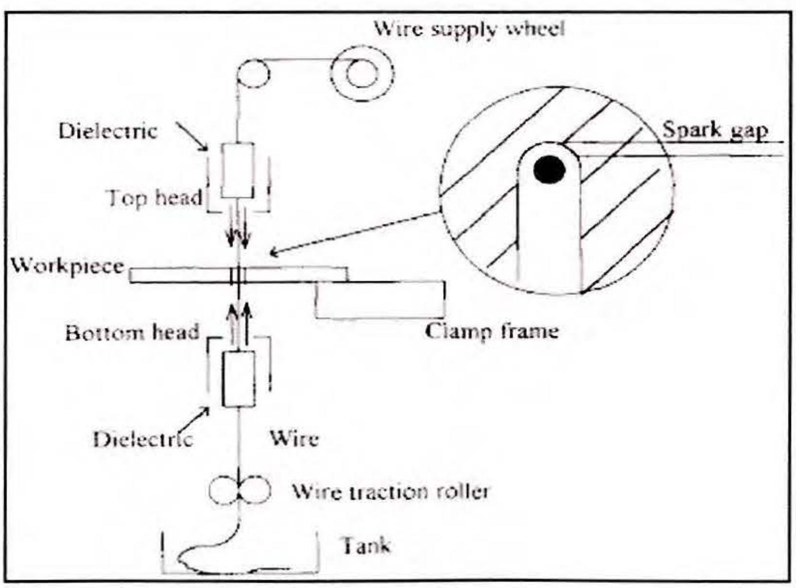

Figure 2.2: Schematic of WEDM (Spedding and Wang, 1997).

Sanchez and Ortega (2009) demonstrated that during cutting, electrical discharges occur within the continuous flushing of dielectric fluid. The dielectric fluid used in most WEDM machines is deionized water. During the application of each discharge, local temperature rises by several thousand degrees (ranging between 10,000°C-20,000°C). Consequently, part of the material melts and vaporizes generating craters on the surface of the workpiece, which is removed in the form of debris by dielectric flushing. As the gap between the workpiece and wire is very small (ranges from 0.025 to 0.05 mm), it is difficult to sufficiently flush the cutting zone especially when the part thickness is high. For that reason, most machining work is done in a completely filled tank and the workpiece is submerged fully in the dielectric fluid.

By referring to Prasad and Gopala (2008), the relative movement between the workpiece and wire is controlled numerically to get the required shape and accuracy of workpiece. The gap between the workpiece and the wire is maintained at an effective distance by servo control system. As it cuts, the wire is continuously fed and pulled by an automatic take-up mechanism. Sanchez and Ortega (2009) also explained that as the wire is constantly renewed, it provides a constant-diameter wire to the cutting and the wire wear is not a primary concern.

2.2 Machining Parameters in WEDM

Ho *et al.* stated that WEDM process is a complex process involving a wide range of machining parameters. Generally, the machining parameter settings can be obtained from the manufacturer guide but the machining settings provided might not be optimal due to the machining diversity. Levy and Maggi (1990) demonstrated that the parameter settings given by the manufacturers are only applicable for common steel grades.

Scot *et al.* (1991) found that discharge current, pulse duration and pulse frequency were the main significant control factors for both MRR and surface finish, while wire speed, wire tension and dielectric flow rate were relatively significant. Tarng *et al.* (1995) found that the machining parameters such as the pulse on/off time duration, discharge current, open circuit voltage, servo reference voltage, electrical capacitance and table speed are the critical parameters for the estimation of the cutting rate and surface roughness.

Mahapatra and Amar (2007) presented that based on the analysis of variance, it was found that the discharge current, pulse duration and pulse frequency are significant control factors for both the MRR and surface roughness. Tosun *et al.* investigated that the most effective parameters with respect to kerf width are open circuit voltage and pulse duration whereas the effect of wire speed and dielectric flushing pressure on the kerf was insignificant.

From the literature review in machining parameters, the surface roughness is mostly affected by discharge current, pulse duration, pulse-off time and open circuit voltage, while the kerf width is mostly affected by open circuit voltage and pulse duration. The variable machining parameters selected through the literature review and with accordance to the restraint of the machine used were open circuit voltage, discharge current and voltage gap.

2.2.1 Open Circuit Voltage

Open circuit voltage is the interpole voltage when no load is applied. According to Elman (2001), the open circuit voltage is the voltage between the electrodes when the dielectric is not yet broken. Under these conditions there is no external electric current between the terminals, even though there may be current internally. Voltage must be larger for thicker plates. Di *et al.* stated that the open circuit voltage not only determines the breakdown distance but also affects the wire vibration in the process, and it is demonstrated to be a key factor to influence the kerf width. In addition, the discharge energy increases with not only the peak current value but also the open circuit voltage which is proven by Tarng *et al.* (1994).

2.2.2 Discharge current

Discharge current refers to the peak current between poles. Hewidy *et al.* (2005) presented that the increase in peak current causes an increase in discharge energy at the point where the discharge takes place. Discharge current must be set to commensurate with workpiece materials and wire electrode. Hewidy *et al.* (2005) also stated that successive discharges that have random nature will result in the formation of overlapped crater, pockmarks and chimneys. The diameter and the depth of the crater depend on the discharge energy or in other words, on the peak current value. Sanchez and Ortega (2009) found that accuracy can be greatly improved by using low energy system.

2.2.3 Voltage Gap

Voltage gap is an average machining voltage used as a guideline value to machine with optimum feed. Elman (2001) stated that this voltage gap value fell from the open circuit voltage when the machining starts to generate spark. Sanchez and Ortega (2009) presented that the voltage gap, which is governed by the servo of gap, plays a determining role in the evacuation of debris. Liao *et al.* (2004) stated that smaller voltage gap ensure the occurrence of discharging spark but the electrostatic force between the anode and cathode will increase. Therefore, wire deflection increase and make it difficult to operate finishing process. This reflects on the surface finish and the accuracy of the resulting machining.

2.3 Response Variables

According to Mahapatra and Amar (2007), the most important measures in WEDM are MRR, surface roughness and kerf width. Among other performance measures, the kerf width, which determines the dimensional accuracy of the finishing part, is of extreme importance. In WEDM operations, MRR determines the economics of machining and rate of production. Besides that, the surface roughness is important because it determines the quality of the WEDM operation.