



UNIVERSITI PUTRA MALAYSIA

**OPTIMIZATION OF MATERIAL REMOVAL RATE AND SURFACE
ROUGHNESS USING THE TAGUCHI METHOD**

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**OPTIMIZATION OF MATERIAL REMOVAL RATE AND SURFACE
ROUGHNESS USING THE TAGUCHI METHOD**

By

POORIA MATOORIAN

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,
in Partial Fulfillment of the Requirement for the Degree of Master of Science**

January 2008



DEDICATION

May this work commemorate my parents, who dedicated themselves to bringing me up. Through all life's sunny and rainy days, I feel you were there, which encouraged me to head up with smile. I would like to thank you in my heart, and I know you are listening.

To all my friends I thank you for the past 26 years. I cannot think of better people to be with through this dance we call life.



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment
of the requirement for the degree of Master of Science

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January 2008

Chairman : Shamsudin Sulaiman, PhD

Faculty : Engineering

A non-conventional hybrid machining method called electrical discharge turning (EDT) process is optimized in this research. The EDT process is a suitable method to produce small components with cylindrical geometries. This process is a type of hybrid electrical discharge machining (EDM), hence the material is removed by the action of electrical discharges between the tool electrode and the workpiece. It means materials of any hardness can be removed as long as the workpiece can conduct electricity. This makes the EDT process suitable for machining hard, difficult-to-machine materials. In this process linear geometry of a tool electrode reproducing the same geometry in the rotating workpiece cylindrically. In this study, a dressed copper block (8mm × 10mm × 50mm) serving as the forming tool electrode is fixed on the work table and rotary workpiece uses the rotational motion of 4th (C) axis of the machine. The Taguchi Robust Design method was used to determine the optimum machining performance namely the highest material removal rate (MRR) and the lowest surface roughness (SR) for EDT of High Speed Steel (HSS) 5%-Cobalt. Six control factors namely, Intensity, Pulse-on time, Pulse-off time, Voltage,



Servo, and Spindle speed were considered. Based on the analysis of variance (ANOVA) all six factors were influential for MRR but for SR rotational speed did not show any influence. Intensity was the most significant factor for both response of MRR and SR. Signal to Noise (S/N) analysis was performed and optimum levels of the mentioned factors for highest MRR and the lowest SR was achieved based on the S/N ratios. Results of confirmation tests shown the improvement of MRR and SR in optimum condition were 9.17 and 6.54 dB respectively. Finally general linear regression models were derived for 95% confidence interval to predict the output response. The p-value for the used α -level of 0.05 concluded that at least one of the regression coefficients is significantly different from zero and the linear predictors are not sufficient to explain the variation.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

**PENGOPTIMUM KADAR PENYINGKIRAN BAHAN DAN KEKASARAN
PERMUKAAN MENGGUNAKAN KAEDAH TAGUCHI**

Oleh

POORIA MATOORIAN

Januari 2008

Pengerusi : Shamsuddin Sulaiman, PhD

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Proses memesis hibrid bukan konvensional dipanggil mesin larik nyahcas elektrik (EDT) dioptimumkan dalam penyelidikan ini. Proses EDT adalah kaedah sesuai untuk menghasilkan komponen kecil bergeometri selinder. Oleh kerana proses ini adalah hibrid dari pemesis nyahcas elektrik (EDM), suatu bahan akan dikeluarkan melalui tindakan nyahcas elektrik antara elektrod dan bahankerja. Ini bermakna bahan dari setiap kekerasan boleh dibuang selama bahan boleh mendapat bekalan elektrik. Ini menjadikan proses EDT sangat sesuai untuk pemesisan yang sukar atau bahan yang sukar untuk dimesin. Dalam proses ini geometri lurus alat elektrod dihasilkan semula dengan geometri yang sama dalam bahan kerja berpusing tetapi berbentuk selinder. Dalam kajian ini, satu blok kuprum (8mm x 10mm x 50mm) bertugas sebagai alatan elektrod di pasang pada meja kerja dan bahan kerja berpusing menggunakan gerakan pusingan paksi ke 4 (C). Kaedah Taguchi Robust Design adalah digunakan sebagai satu pendekatan bagi mengenal pasti pengoptimum prestasi mesin untuk kadar pembuangan bahan (MRR) dan kekasaran permukaan (SR) terendah untuk EDT keluli halaju tinggi (HSS) 5%. Enam kawalan faktor iaitu,

Intensity, Pulse-on time, Pulse-off time, Voltage, Servo, dan Spindle speed; diambil kira bagi tujuan penyelidikan ini. Daripada analisis varian (ANOVA) kesemua enam faktor telah dikenalpasti mempengaruhi MRR tetapi untuk SR kelajuan pusingan tidak menunjukkan pengaruhnya. *Intensity* telah kelihatan sebagai faktor yang paling ketara dalam MRR dan SR. Analisis petanda kebisingan (S/N) telah dilaksanakan dan paras optimum faktor berkenaan untuk MRR tertinggi dan SR terendah telah dicapai berdasarkan nisbah S/N. Ujian pengesahan menunjukkan pembaikan MRR dan SR paras optimum adalah 9.17 dB dan 6.54 dB. Akhirnya model regresi am dihasilkan untuk 95% jurang keyakinan untuk menjangkan tindakbalas output. Disimpulkan bahawa nilai-p untuk paras- α 0.05 memberi perbezaan pekali regresi yang ketara daripada sifar dan jangkakan lurus tidak mencukupi untuk menerangkan perbezaanya.

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I certify that an Examination Committee has met on 14 January 2008 to conduct the final examination of Pooria Matorian on his Master of Science entitled “Optimization of Material Removal Rate and Surface Roughness Using The Taguchi Method” in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the student be awarded the relevant degree. Members of the Examination Committee were as follows:

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotation and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

Pooria

POORIA MATOORIAN

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TABLE OF CONTENTS

	Page
DEDICATION	ii
ABSTRACT	iii
ABSTRAK	v
ACKNOWLEDGEMENTS	vii
APPROVAL	viii
DECLARATION	x
LIST OF TABLES	xiv
LIST OF FIGURES	xvi
LIST OF ABBREVIATIONS	xviii

CHAPTER

1	INTRODUCTION	
	1.1 Background of Electrical Discharge Machining (EDM)	1
	1.1.1 Nontraditional Machining	1
	1.1.2 Thermal Removal Process	2
	1.1.3 Electrical Discharge Machining	3
	1.1.4 EDM of Cylindrical Parts	4
	1.2 Problem Statement	5
	1.3 Research Objectives	6
	1.4 Scope of Study	6
	1.5 Thesis Outline	7
2	LITERATURE REVIEW	
	2.1 Introduction	9
	2.1.1 History of EDM	9
	2.2 EDM Process	11
	2.2.1 Analysis of Pulses and Gap Conditions in EDM	13
	2.2.2 Illustration of Spark and Theories	15
	2.3 EDM of Cylindrical Parts	19
	2.3.1 Electrical Discharge Turning (EDT)	19
	2.3.2 Electrical Discharge Grinding (EDG)	20
	2.3.3 Wire Electrical Discharge Grinding (WEDG)	20
	2.4 EDM Applications	21
	2.4.1 Heat Treated Materials	21
	2.4.2 Ceramic	22
	2.4.3 Modern Composite Materials	23
	2.5 Major Areas of EDM Research	24
	2.5.1 EDM Performance Measures	24
	2.5.2 Process Monitoring and Control	28
	2.5.3 Parametric Optimization	31
	2.6 Statistical Design of Experiments	36
	2.7 Role of Statistics in Experimentation	37
	2.8 Project Planning Phase	38



2.8.1	Step 1: State the Problem(s)	38
2.8.2	Step 2: Selecting Response Variable(s) and Measurement System	39
2.8.3	Step 3: Selecting Factors that may Influence Response(s)	39
2.8.4	Step 4: Identify Control and Noise Factors	40
2.8.5	Step 5: Select Levels for the Factors	40
2.9	Step 6: Choice of Experimental Layout	40
2.10	Step 7: Conducting Tests	41
2.10.1	Randomization Strategy	41
2.11	Step 8: Analysis and Interpretation of Results	42
2.11.1	Analysis of Variance (ANOVA)	42
2.11.2	S/N Ratio (signal to noise analysis)	46
2.11.3	Regression Analysis	48
2.12	Confirmation Tests (Verification of study)	50
2.13	Discussion	50
3	MATERIAL AND METHODS	
3.1	Introduction	53
3.2	Process Planning	55
3.2.1	Variable Parameters	56
3.2.2	Constant Parameters	60
3.3	Response	63
3.4	Design of Experiments	63
3.5	Experimental Setup and Tests	65
3.5.1	Tool Material	66
3.5.2	Workpiece Material	67
3.6	Measuring of MRR	69
3.7	Measuring of SR	70
3.8	Analysis	71
3.9	Confirmation Tests	71
4	RESULTS AND DISCUSSION	
4.1	Introduction	72
4.2	Analysis of Data for MRR	72
4.2.1	Discussion of MRR Results	80
4.3	Analysis of Data for Surface Roughness	85
4.3.1	Discussion of Surface Roughness Results	91
5	CONCLUSIONS AND RECOMMENDATIONS	
5.1	Conclusions	96
5.2	Recommendation for Further Studies	97
	REFERENCES	99
	APPENDICES	105
	BIODATA OF THE AUTHER	142
	LIST OF PUBLICATIONS	143



LIST OF TABLES

Table		Page
2.1	Summary of the literature on EDM optimizations	51
3.1	Table of variable factors	57
3.2	Table of constant parameters	60
3.3	Experimental layout of the test runs	64
3.4	Chemical composition and material properties of workpiece material	68
4.1	Experimental MRR data	73
4.2	Table of ANOVA for material removal rate	75
4.3	Significance level of variation parameters	75
4.4	ANOVA for verification of regression significance	77
4.5	Table of coefficients for regression analysis	77
4.6	S/N ratios for MRR	78
4.7	Optimum factor levels for MRR	78
4.8	Table of ANOVA for S/N ratio	79
4.9	Results of confirmation tests for MRR	79
4.10	Experimental SR data	85
4.11	Table of ANOVA for surface roughness	87
4.12	Significance level of variation parameters	87
4.13	ANOVA for verification of regression significance	88
4.14	Table of coefficients for regression analysis	89
4.15	S/N ratios for SR	89
4.16	Optimum factor levels for R_a	90
4.17	Table of ANOVA for S/N ratio	90



4.18	Results of confirmation tests for R_a	91
B.1	Experimental design terminology	113
B.2	Standard orthogonal arrays	121
B.3	L_8 orthogonal array and it's interaction Table	126
C.1	Two-level Orthogonal array Selection	130
C.2	Tree-level Orthogonal array Selection	130
C.3	Two-level Orthogonal Array Factor Assignment	131
C.4	Three-level Orthogonal Array Factor Assignment	131



LIST OF FIGURES

Figure		Page
1.1	Summery of Nontraditional Machining Methods	2
1.2	Microcracks Appear in the Recast Layer	3
2.1	The Basic RC Relaxation Circuit	9
2.2	Schematic Illustration of Electrical Discharge Machining	11
2.3	Four Types of Gap Conditions in EDM	13
2.4	Evolution of a Single Spark in the EDM Process	17
2.5	EDM Process Variants for Cylindrical Parts	19
2.6	Electrode Shape Recovery During One Layer Machining	26
2.7	Visual illustration of R_a	27
2.8	General Model of a Process or System	36
3.1	Methodology Flowchart of This Research	54
3.2	Components of Under Study System	56
3.3	ONA H300 EDM Machine	65
3.4	Schematic Illustration of Experimental Setup	66
3.5	Tool Electrode Made From Copper	67
3.6	Illustration of Conducted Tests	68
3.7	Sartoriuse LA230S, Used to Measure MRR	69
3.8	Mahr Perthometer M2 Used to Measure R_a	70
4.1	Plot of Residuals Versus the Fitted Values	73
4.2	Normal Probability Plot of Residuals	74
4.3	Plot of Residuals Versus the Fitted Values	86
4.4	Normal Probability Plot of Residuals	86

A.1	Discrete and Continuous Probability Distributions	106
A.2	Normal Probability Distribution	108
A.3	Several Chi-square Distributions	109
B.1	Taguchi Quadratic Loss Function	118
B.2	Typical Interaction Plot	124
B.3	Two Standard Linear Graphs of L_8	127
D.1	Plot of Main Factor-effects on MRR	132
D.2	Two-Factor Effects Versus MRR	136
D.3	Plot of Main Factor-effects on R_a	137
D.4	Two-factor Effects Versus R_a	141



LIST OF ABBREVIATIONS / GLOSSARY OF TERMS

ANOVA	Analysis of Variance
AWG	Abrasive Water Jet
CBN	Cubic Boron Nitride
CNC	Computer Numerical Control
DOE	Design of Experiment
DOF	Degree of Freedom
EDG	Electrical Discharge Grinding
EDM	Electrical Discharge Machining
EDT	Electrical Discharge Turning
EWR	Electrode Wear Ratio
FFEs	Fractional Factorial Experiments
GA	Genetic Algorithm
HAZ	Heat Affected Zone
HB	Higher is Better
HF	High Frequency
HMP	Hybrid Machining Process
HRC	Hardness Rockwell C
HSS	High Speed Steel
LB	Lower is Better
MMC	Metal Matrix Composite
MRM	Material Removal Mechanism
MRR	Material Removal Rate
NB	Nominal is Best



OA	Orthogonal Array
QC	Quality Control
RC	Resistor Capacitor circuit
RF	Radio Frequency
S/N	Signal to Noise ratio
SF	Surface Finish
SQ	Surface Quality
SR	Surface Roughness
SS	Sum of Squares
TWP	Tool Wear Process
TWR	Tool Wear Ratio
WEDG	Wire Electrical Discharge Grinding
WEDM	Wire Electrical Discharge Machining
WEDT	Wire Electrical Discharge Turning



CHAPTER 1

INTRODUCTION

1.1 Background of Electrical Discharge Machining (EDM)

1.1.1 Nontraditional Machining

The term nontraditional machining refers to a variety of thermal, chemical, electrical and mechanical material removal processes. The impetus for development of nontraditional machining methods has come from the revolution in materials, the demand for new standards of product performance and durability, the complex shapes of products engineered for specific purposes, and consideration of tool wear and economic return. It have also been developed to satisfy the trend toward increased precision and to create improved surface conditions (Walker, 1996). The requirements, and the resulting commercial and technological importance of the nontraditional processes, include:

1. The need to machine recently developed metals and nonmetals. These new materials often have special properties (high strength, high hardness, and high toughness) which make term difficult or impossible to machine by conventional methods.
2. The needs for unusual and/or complex part geometries that cannot easily be accomplished and in some cases are impossible to achieve by conventional machining.



3. The need to avoid surface damage that often accompanies the stresses raised by conventional machining (Groover, 2002).

Many of these requirements are associated with the aerospace and electronics industries, which have grown significantly in recent decades. Nontraditional machining methods are divided into three classifications: Thermal removal – Dissolution and Mechanical abrasion (Illustrated by Figure 1.1).

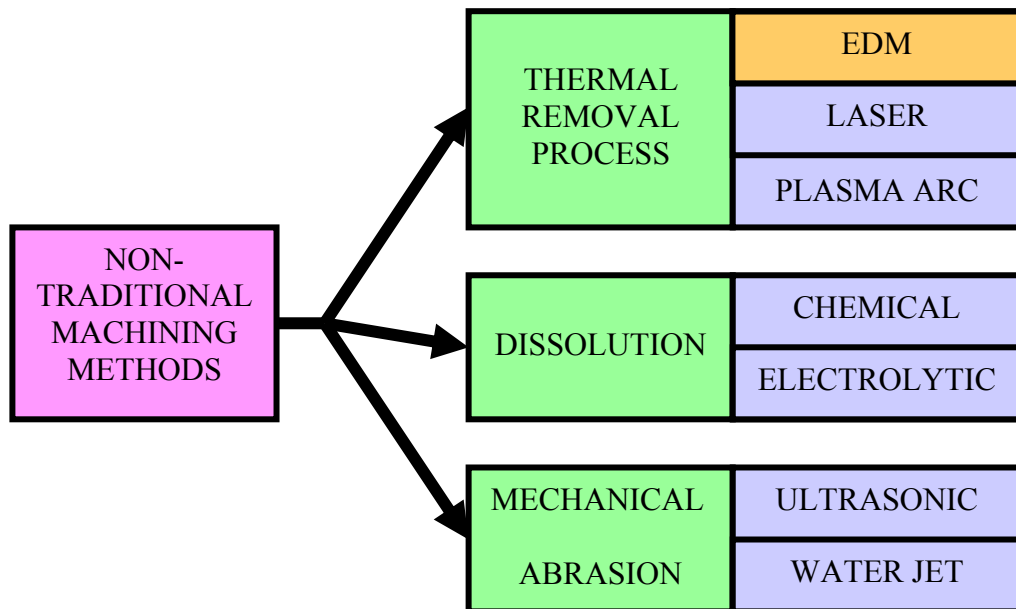


Figure 1.1: Nontraditional Machining Methods (Walker, 1996)

1.1.2 Thermal Removal Process

In thermal removal processes high-intensity heat is focused on a small area of the workpiece, causing it to be melted and vaporized. In all of the thermal removal processes not all of the material removed is vaporized but much of that is melted. Most of the melted material is expelled from the cut by the turbulence of the adjacent vaporization or by the flow of an “assist fluid” used in the process. Some material

remains and resolidifies on the surface and cooling rapidly as heat is transferred to the subsurface material. The remaining “recast layer” is likely to have microcracks and residual tensile surface stresses, encouraging those cracks to widen when the material is fatigued. Beneath the recast layer, there is typically a “heat-affected zone” where the material’s grain structure may have been altered (see Figure 1.2). One kind of thermal removal process is electrical discharge machining (EDM). In EDM, sparks between the electrode and the workpiece perform the material removal process (Walker, 1996).

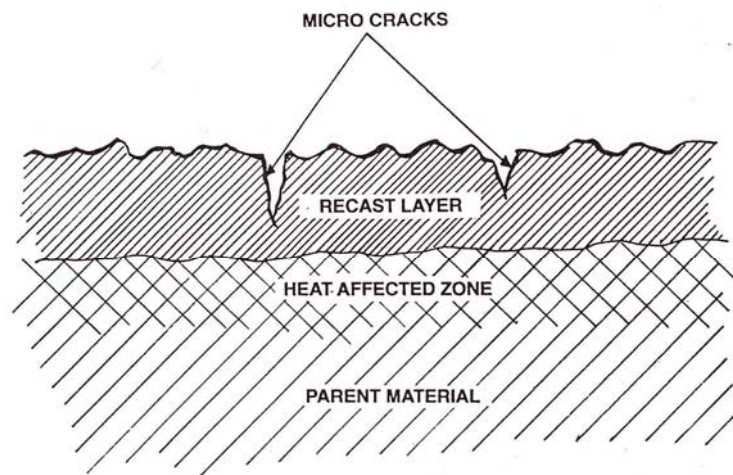


Figure 1.2: Microcracks Appear in the Recast Layer (Walker, 1996)

1.1.3 Electrical Discharge Machining

The principle of electrical discharge machining (EDM), also called electrodischarge or spark-erosion machining, is a non-traditional manufacturing process based on removing material from a part by means of a series of recurring electrical discharges (created by electric pulse generators at short intervals) between a tool called electrode and the workpiece in the presence of a dielectric fluid. This fluid makes it

possible to flush eroded particles (mainly in the form of hollow spheres) from the gap, and it is really important to maintain this flushing continuously (Kalpajian and Schmid, 2003).

There were a number of problems faced when mathematical modeling of the EDM process was done. The gap pollution, the hydrodynamic and thermodynamic behavior of the working fluid was hard to model. Getting a model in all with practical technological results was difficult. This inability along with the high demand from the market lead to a more pragmatic and application oriented research into the EDM process.

1.1.4 EDM of Cylindrical Parts

Today's industries especially electrical and aerospace need to produce rotary components, with high precision and high surface hardness, associated with critical application of them. To achieve these requirements, using traditional turning (mechanical material removal) process, to form the workpiece which is hardened in terms to high dimensional precision is not easy and sometimes impossible. Further more, high temperature of mechanical material removal will cause surface structure to be changed; it means workpiece has lost its surface texture (Boothroyd and Knight, 1989). Also a reverse implementation, hardening workpiece next to the machining process will cause failure on dimensional precision as it has been expected (Chanter, 1998). Since, producing small-cylindrical components through the conventional processes, applies a large amount of forces against the workpiece, therefore a probably deformation might be occurred, or sometimes approaching

satisfactory dimensional precision will be impossible. Spark-Erosion Machining is one of the convenience methods which can cover mentioned problems in both normal and micro dimensions (Qu, 2002 and Pham et al., 2007).

1.2 Problem Statement

Electrical discharge machining is one of the most useful non-conventional machining methods in industry. As mentioned in section 1.1.3 this process is mostly used in die and mold industry but there are some hybrid machining processes based on EDM such as wire EDM, ultra sonic EDM, powder mixed EDM and so on which individually are kind of processes used for specific applications. As mentioned in section 1.1.4 electrical discharge turning process is a new approach in EDM process for shaping rotary, complex shaped and high-precision products suitable for hard to machine materials (Uhlmann, 2005) suitable for aerospace and engine industry such as servo actuators of helicopter, diesel injector plunger, engine valve, turbo-charger shaft and hydraulic pump actuator. High speed steel (since is a high resistant material) is one of the functional materials for these application and among usual tool materials pure copper is the most suitable electrode for erosion of any kind of steel (ONA H300, 2003). Two quality characteristics namely material removal rate (MRR) and surface roughness (SR) are the most important performance measures for all EDM processes (Qu, 2002). After material properties of tool and work piece these quality characteristics greatly depends on the machining parameters (McGeough, 1988). Usually the desired machining parameters are determined based on experiences or handbook values. However, this does not ensure that the selected machining parameters, results in optimal or near optimal machining performance

measures for that particular electrical discharge machine and environment (Lin et al., 2000; Tzeng and Chen, 2007) . Therefore in this study the optimization of electrical discharge turning process includes machining parameters for optimum quality characteristics such as MRR and SR will be carried out in EDM environment of ONA technology. According to literature survey summarized in table 2.1 Taguchi Robust design method is proposed to solve this task.

1.3 Research Objectives

To accomplish this goal in the specific range of parameters of interest, the following objectives will be considered:

1. To consider the significance of Intensity, Pulse durations (on-off), Ionization voltage, Servo and Rotational speed on material removal rate of EDT process and surface roughness of the EDT products.
2. To explore possible way of parameter adjustment to achieve the lowest surface roughness and the highest material removal rate.

1.4 Scope of Study

This study involves optimizing electrical discharge turning parameters and ranges namely: intensity (3 to 5A), pulse-on time (50 to 300 μ s), pulse-off time (20 to 180 μ s), voltage (80 to 160 V), servo (30 to 60 V) and spindle speed (15 to 40 RPM) in terms to highest MRR and lowest SR. The developed machining setup is innovated for applying on 4-axis EDM machine. Note that for this study surface roughness less