



**STUDY OF PLASMA CUTTING EFFICIENCY WITH
DIFFERENT OPERATING PARAMETERS**

By

**MASITA BINTI RAJA MOHAMMAD
(0830510241)**

A thesis submitted
In fulfillment of the requirements for the degree of
Master of Science (Manufacturing Engineering)

**School of Manufacturing Engineering
UNIVERSITI MALAYSIA PERLIS
MALAYSIA**

2010

GRADUATE SCHOOL
UNIVERSITI MALAYSIA PERLIS

PERMISSION TO USE

In presenting this thesis in fulfillment of a post graduate degree from the Universiti Malaysia Perlis, I agree that permission for copying of this thesis in any manner, in whole or in part, for scholarly purposes may be granted by my supervisor(s) or, in their absence, by the Dean of the Graduate School. It is understood that any copying or publication or use of this thesis or parts thereof for financial gain shall not be allowed without my written permission. It is also understood that due recognition shall be given to me and to Universiti Malaysia Perlis for any scholarly use which may be made of any material from my thesis. Requests for permission to copy or to make other use of material in this thesis in whole or in part should be addressed to:

Dean of Graduate School
Universiti Malaysia Perlis (UniMAP)
Jalan Meranti Paya Off Jalan Bukit Lagi
01000 Kangar
Perlis

APPROVAL AND DECLARATION SHEET

This thesis titled Study of Plasma Cutting Efficiency with Different Operating Parameters was prepared and submitted by Masita Binti Raja Mohammad (Matrix Number: 0830510241) and has been found satisfactory in terms of scope, quality and presentation as partial fulfillment of the requirement for the award of degree of Master of Science (Manufacturing Engineering) in Universiti Malaysia Perlis (UniMAP). The members of the Supervisory committee are as follows:

PROF. MADYA DR. BHUVENESH RAJAMONY

Associate Professor
School of Manufacturing Engineering
Universiti Malaysia Perlis
(Head Supervisor)

DR. MUHAMMAD SAIFULDIN ABDUL MANAN

Deputy Dean (Research & Academic)
School of Manufacturing Engineering
Universiti Malaysia Perlis
(Co-Supervisor)

Checked and Approved by

.....
(ASSOCIATE PROFESSOR DR. BHUVENESH RAJAMONY)

Head Supervisor
School of Manufacturing Engineering
Universiti Malaysia Perlis

(Date :.....)

School of Manufacturing Engineering
Universiti Malaysia Perlis

ACKNOWLEDGEMENTS

First and foremost, I would like to convey my deepest thanks to the Almighty Allah (S.W.T), for the Omnipotent, the Merciful and the Compassionate, for giving me the strength, patience, courage and determination in compiling this research. Alhamdulillah. The journey towards the completion of this thesis was full of unexpected challenges and it is almost impossible to complete this thesis single-handedly without the help and support of others. I would like to give my heartfelt thanks to everyone who has provided me with such support.

I would like to extend my infinite gratitude to my supervisors Associate Professor Dr. Bhuvanesh Rajamony and Dr. Muhamad Saifuldin Abdul Manan for their extraordinary support and understanding in guiding me through this thesis successfully.

I would like to thank my parents and my dear one, who have given me utmost encouragement and support throughout this research. Thank you.

Last but not least, I would like to express my greatest appreciation to all of the people who have helped me in doing this research project, may ALLAH bless you all.

Thanks to Almighty ALLAH.

TABLE OF CONTENTS

	Page
DECLARATION OF THESIS	i
PERMISSION TO USE	ii
APPROVAL AND DECLARATION SHEET	iii
ACKNOWLEDGEMENT	iv
TABLE OF CONTENTS	v-ix
LIST OF FIGURES	x-xii
LIST OF TABLE	xiii-xiv
LIST OF EQUATIONS	xv
LIST OF SYMBOLS, ABBREVIATIONS AND NOMENCLATURE	xvi-xviii
ABSTRAK (BM)	xix
ABSTRACT (ENGLISH)	xx
CHAPTER 1 INTRODUCTION	

1.1 Overview	1
1.2 Problem Statement	2
1.3 Motivation	3
1.4 Objectives	5
1.5 Scopes	6

1.6 Thesis Outline	6
--------------------	---

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction	10
2.2 Copper Alloy	14
2.3 Mild Steel	15
2.4 Aluminium	16
2.5 Plasma Arc Cutting	17
2.5.1 System	18
2.5.1.1 Plasma Torch	19
2.5.1.2 Power Supply	20
2.5.1.3 Arc Starting Circuit	21
2.5.2 Process	22
2.5.3 Design Factors	22
2.5.3.1 Air Pressure	23
2.5.3.2 Current Flow Rate	24
2.5.3.3 Cutting Speed	24
2.5.3.4 Arc Gap	25
2.6 Material Removal	25
2.7 Surface Roughness	27
2.8 Taguchi Approach Designs of Experiments (DOE)	27
2.8.1 Introduction	28

2.8.2 Factors and Levels	30
2.8.3 Order of Running Experiments	31
2.8.4 Orthogonal Arrays	31
2.8.5 MSD and S/N Analysis	33
2.8.6 ANOVA (Analysis of Variance)	36
2.8.7 Experimental Procedure	37

CHAPTER 3 METHODOLOGY

3.1 Introduction to the Problem	40
3.2 Overview of the Methodology	41
3.3 Equipments	42
3.3.1 Plasma Arc Cutting System	42
3.3.2 Digital Weight Balancer	43
3.3.3 Mitutoyo CS-3100 (Surface Finish Analysis)	45
3.4 Experimental Planning	46
3.4.1 Clarify Project Objectives	46
3.4.2 Clarify All Designs Factors	46
3.4.3 Determine the Number of Levels	47
3.5 Material Test Sample Work piece	50
3.6 Conduct the Experiment	50

CHAPTER 4 RESULTS, ANALYSIS AND DISCUSSION

4.1 Introduction	53
4.2 Experimental Results	54
4.2.1 Result Analysis	57
4.2.2 Average Factor Effects	57
4.2.3 Analysis of Variance (ANOVA) Table	60
4.2.4 Predicted Optimum Condition & Confirmation Test	62
4.2.5 Material Removal Rate	64
4.2.5.1 Model Term Graph for MRR Factors	64
4.2.5.2 Model Term Graph for Mild Steel	65
4.2.5.3 Model Term Graph for Copper Alloy	68
4.2.5.4 Model Term Graph for Aluminium	71
4.2.6 Surface Roughness	74
4.2.6.1 Model Term Graph for Surface Roughness	74
4.2.6.2 Model Term Graph for Mild Steel	75
4.2.6.3 Model Term Graph for Copper Alloy	78
4.2.6.4 Model Term Graph for Aluminium	81
4.3 Confirmation Test for MRR & Ra	
4.4 Discussion	85
4.4.1 Effects of Design Factor over Material Removal Rate	85

4.4.2 Effects of Design Factor over Surface Roughness	86
4.4.3 Optimum Condition	87

CHAPTER 5 CONCLUSION

5.1 Contribution to This Work	89
5.2 Future Work Recommendation	90
5.3 Commercialize Potential	91
5.4 Conclusion	91

REFERENCES	93
-------------------	----

APPENDICES	96
-------------------	----

© This item is protected by original copyright

LIST OF FIGURES

Figure No.		Page
1.1	Selco Genesis 90 Plasma Arc Cutter	4
2.1	Plasma State	10
2.2	Plasma Arc Cutting in Industry	13
2.3	Plasma Arc Cutting	13
2.4	Plasma Arc Cutter System	18
2.5	The Internal Component of Cutting Torch	20
2.6	Plasma Arc Torch	20
2.7	DC Power Supply	21
2.8	Arc Starting Circuit	21
2.9	Plasma Arc Cutting Process	22
3.1	Methodology Overview	41
3.2	Alfa Mirage MD-300S	44
3.3	MITUTOYO CS-31000	45
3.4	Material Sample	50
3.5	Weight Measured Before and After Cutting Process	51
3.6	Cutting Experiment Process	51
3.7	Surface Roughness Experiment	52
4.1	Pressure (A) Factor Graph for MRR	65

4.2	Current Flow Rate (B) Factor graph for MRR	66
4.3	Cutting Speed (C) Factor Graph for MRR	66
4.4	Arc Gap (D) Factor Graph for MRR	67
4.5	Factor Influence Percentages for MRR	68
4.6	Pressure (A) Factor Graph for MRR	68
4.7	Current Flow Rate (B) Factor graph for MRR	69
4.8	Cutting Speed (C) Factor Graph for MRR	70
4.9	Arc Gap (D) Factor Graph for MRR	70
4.10	Factor Influence Percentages for MRR	71
4.11	Pressure (A) Factor Graph for MRR	71
4.12	Current Flow Rate (B) Factor graph for MRR	72
4.13	Cutting Speed (C) Factor Graph for MRR	73
4.14	Arc Gap (D) Factor Graph for MRR	73
4.15	Factor Influence Percentage for MRR	74
4.16	Pressure (A) Factor Graph for Surface Roughness	75
4.17	Current Flow Rate (B) Factor Graph for Surface Roughness	76
4.18	Cutting Speed (C) Factor Graph for Surface Roughness	76
4.19	Arc Gap (D) Factor Graph for Surface Roughness	77
4.20	Factor Influence Percentage for Surface Roughness	78
4.21	Pressure (A) Factor Graph for Surface Roughness	78

4.22	Current Flow Rate (B) Factor Graph for Surface Roughness	79
4.23	Cutting Speed (C) Factor Graph for Surface Roughness	80
4.24	Arc Gap (D) Factor Graph for Surface Roughness	80
4.25	Factor Influence Percentage for Surface Roughness	81
4.26	Pressure (A) Factor Graph for Surface Roughness	81
4.27	Current Flow Rate (B) Factor Graph for Surface Roughness	82
4.28	Cutting Speed (C) Factor Graph for Surface Roughness	83
4.29	Arc Gap (D) Factor Graph for Surface Roughness	83
4.30	Factor Influence Percentage for Surface Roughness	84

© This item is protected by original copyright

LIST OF TABLES

Tables No.		Page
3.1	Technical Features for Selco Genesis 90	43
3.2	Technical Features of Digital Weight Balancer	44
3.3	Level of Design Factors for Mild Steel	48
3.4	Level of Design Factors for Copper Alloy	48
3.5	Level of Design Factors for Aluminium	49
3.6	Experiment Layout	49
4.1	Experiment Result for MRR – Mild Steel	54
4.2	Experiment Layout for MRR – Copper Alloy	55
4.3	Experiment Layout for MRR – Aluminium	55
4.4	Experiment Result for Surface Roughness – Mild Steel	56
4.5	Experiment Result for Surface Roughness – Copper Alloy	56
4.6	Experiment Result for Surface Roughness – Aluminium	57
4.7	Average Effects of Factors (S/N Ratio of MRR) – Mild Steel	58
4.8	Average Effects of Factors (S/N Ratio of MRR) – Copper Alloy	58
4.9	Average Effects of Factors (S/N Ratio of MRR) – Aluminium	59
4.10	Average Effects of Factors (S/N Ratio of Ra) – Mild Steel	59
4.11	Average Effects of Factors (S/N Ratio of Ra) – Copper Alloy	59

4.12	Average Effects of Factors (S/N Ratio of Ra) – Aluminium	59
4.13	Analysis of Variance for MRR – Mild Steel	60
4.14	Analysis of Variance for MRR – Copper Alloy	60
4.15	Analysis of Variance for MRR – Aluminium	61
4.16	Analysis of Variance for Ra – Mild Steel	61
4.17	Analysis of Variance for Ra – Copper Alloy	61
4.18	Analysis of Variance for Ra – Aluminium	62
4.19	Optimum Condition and Value for MRR – Mild Steel	62
4.20	Optimum Condition and Value for MRR – Copper Alloy	63
4.21	Optimum Condition and Value for MRR – Aluminium	63
4.22	Optimum Condition and Value for Ra – Mild Steel	63
4.23	Optimum Condition and Value for Ra – Copper Alloy	64
4.24	Optimum Condition and Value for Ra – Aluminium	64

© This item is protected by original copyright

LIST OF EQUATIONS

Equations No.

$$(1) \text{ MRR} = \frac{\text{WRW}}{T} \quad [\text{g}]$$

$$(2) \text{ MRR} = \frac{\text{WRV}}{T} \quad [\text{mm}^3]$$

$$(3) \text{ WRV} = \frac{\text{WRW}}{\rho}$$

$$(4) \text{ MSD} = \frac{(\quad) (\quad) \dots (\quad)}{\quad}, \text{QC} = \text{N}$$

$$(5) \text{ S/N} = 10 \text{Log}10 \quad , \text{QC} = \text{N}$$

$$(6) \text{ MSD} = \frac{(\quad) (\quad) \dots (\quad)}{\quad}, \text{QC} = \text{S}$$

$$(7) \text{ S/N} = -10 \text{Log}10 \quad , \text{QC} = \text{S}$$

$$(8) \text{ MSD} = \frac{\text{---} \quad \text{---} \quad \dots \quad \text{---}}{\text{---}}, \text{QC} = \text{B}$$

$$(9) \text{ S/N} = -10 \log_{10} \text{---}, \text{QC} = \text{B}$$

© This item is protected by original copyright

LIST OF SYMBOLS ABBREVIATIONS OR NOMENCLATURE

ANOVA	Analysis of Variance
DOE	Design of Experiment
OA	Orthogonal Array
g	gram
QC	Quality Characteristic
MSD	Mean Standard Deviation
CF	Correction Factors
S'	Factor sum of squares
P	Percentage
S/N	Single to Noise Ratio
ST	Total sum of square
SA	Sum of square of Factor A
PA	Percentage Deviation of Factor A
SB	Sum of square of Factor B

PB Percentage Deviation of Factor B

SC Sum of square of Factor C

PC Percentage Deviation of Factor C

SD Sum of square of Factor D

PD Percentage Deviation of Factor D

T Sum of all observations

$\sum Y_i^2$ Sum of square Deviation

© This item is protected by original copyright

KAJIAN KECEKAPAN PEMOTONGAN ARKA PLASMA DENGAN FAKTOR-FAKTOR YANG BERBEZA

ABSTRAK

Plasma, fasa keempat bahan yang membezakan pepejal atau cecair atau gas dan hadir dalam bintang-bintang kombinasi reaktor-reaktor; sesuatu gas menjadi plasma apabila gas tersebut dipanaskan sehingga atom-atomnya kehilangan elektron-elektronnya, dan meninggalkan sekumpulan nuklei dan elektron-elektron bebas yang tinggi pegecasan elektriknya. Penggunaan mesin temaju seperti Mesin Pemotong Arka Plasma adalah amat jarang di dalam industry untuk kegunaan pemotongan bahan-bahan seperti Mild Steel, Copper Aloji dan Aluminium. Mesin Pemotong Arka Plasma model Selco Genesis 90 telah digunakan dalam kajian ini untuk memotong Copper Aloji, Aluminium dan Mild Steel. Penggunaan kaedah Taguchi Design of Experiments bermula dari langkah perancangan sehingga ke peringkat penganalisan dapatan kajian telah digunakan. Dalam kajian ini, Lay-out L-9(34) telah digunakan. Faktor-faktor yang diambil kira dalam kajian ini adalah tekanan udara [bar], aliran arus elektrik [A], halaju pemotongan [mm/min] dan jarak arka [mm]. Faktor-faktor ini digunakan untuk penganalisan tentang pelarasan untuk mengoptimumkan pembolehubah Mesin Pemotongan Arka Plasma untuk mendapatkan kombinasi yang terbaik. Kesan faktor-faktor ini ke atas pencapaian Mesin Pemotongan Arka Plasma adalah Kadar Pembuangan Bahan (MRR) dan Kelicinan Permukaan (Ra). Ujian pengesahan perlulah dijalankan untuk mengesahkan nilai yang dianggarkan melalui perisian. Ujian pengesahan yang telah dijalankan menggunakan pelarasan yang diperolehi daripada perisian. Nilai optimum yang dijangkakan dan nilai sebenar yang diperolehi daripada ujian pengesahan yang dibenarkan mestilah di dalam ralat 10%.

ABSTRACT

Plasma, a fourth state of matter distinct from solid or liquid or gas and present in stars and fusion reactors; a gas becomes plasma when it is heated until atoms lose all their electrons, leaving a highly electrified collection of nuclei and free electrons. The usage of advanced machining, such as Plasma Arc Cutting machine to cut Mild Steel, Copper Alloy and Aluminium was very limited in the industry. Selco Genesis 90 Plasma Arc Cutting machine was used to cut Copper Alloy, Aluminium and Mild Steel in this study. The usage of Taguchi approach Design of Experiments from the designing steps until the analyzing phase from the experiment was used. In this study, Design of Experiment L-9 (34) layout is used. In this study, the parameters determined were the air pressure [bar], current flow rate [A], cutting speed [mm/min] and arc gap [mm]. These parameters used to analyze the setting required for optimizing the process variables for Plasma Arc Cutting machine to gain the best combination. The effect of these factors was the calculation of Material Removal Rate (MRR) and Surface Roughness (Ra). Confirmation test must be done to confirm the value estimated through the software. The confirmation run was done by using the setting gain from the software. The estimated optimum value and the actual value obtained from the confirmation test that is allowed are in range 10%.

CHAPTER 1

INTRODUCTION

1.1 Overview

The topic for the thesis writing is to study of the efficiency of plasma cutting with different operating parameters. The focus on this project is to obtain the best combination of those parameters in order to achieve optimum performance measures.

Nowadays, a lot of industries in the government sector and private sector are advances in the field of plasma cutting and have permitted the application of this technology in their company. The function of this plasma cutting is an arc cutting process that cuts metal by melting a localized area with the heat of a constricted arc. The various shapes of electric arc are emergent properties of nonlinear pattern of current and electric field. The arc occurs in the gas-filled space between two conductive electrodes and its results in a very high temperature, capable of melting or vaporizing virtually anything. The high temperature plasma arc cuts through a wide variety of metals at high speeds.

Advanced machining such as plasma arc cutting also grows fast in Malaysia. Currently it is used in the industry. So advanced material such as nickel alloy can be used as the work piece of this machine.

Plasma cutters are used in place of traditional sawing, drilling, machining, punching, and cutting. The high-temperature plasma arc cuts through a wide variety of metals at high speeds. Although plasma arc cutting can cut most metals at thicknesses of up to 4 to 6 inches, it provides the greatest economical advantages, speed, and quality on carbon steels under 1 inch thick, and on aluminum and stainless steels under 3 inches thick.

Plasma Arc cutting has been widely used in the industry but the fundamental of the usage is still limited. The feasibility and effectiveness of the usage need to be approving by using the Fractional Factorial from the Design of Experiment.

1.2 Problem Statement

Cutting process is the most important process to produce a product. It takes a lot of time to cut the material. So this study has been developed to find the solution about the problem of the cutting process, so the process will improve. Below is the problem of the cutting process:

- i) Traditional way of cutting process takes a lot of time.
- ii) What are the most factors that influence the cutting process?

- iii) What are the optimum conditions to achieve optimum performances?
- iv) The effective way to conduct the cutting process for Aluminium, Copper Alloy and Mild Steel.

1.3 Motivation

The focus on this research is to study, runs and to analyze plasma arc cutting efficiency based on several parameters. The machine used in this study is Selco Genesis 90. The new portable plasma cut generator in the genesis range by Selco features a modern innovative design. Exploiting the inverter resonant, this system is even more compact and lightweight and offers excellent quality.

The generator is the most powerful one in its weight category and is provided with ergonomic handle for easy transport. If used beyond the rated parameters a thermal device and mains voltage protection, protect the internal components from malfunctioning. Figure 1.1 below shows the Selco Genesis 90 Plasma Arc Cutter. Further information about this machine is discusses in part 3.3.1



Figure 1.1
Selco Genesis 90 Plasma Arc Cutter

Optimization of process parameters is the key step in Taguchi method to achieve high quality without increasing cost such as time and money. This is because optimization of process parameters can improve quality characteristic and the optimal process parameters obtained from the Taguchi method are insensitive to the variation of environmental conditions and other noise factors. C. Montgomery says basically, classical process parameter design is complex and not easy to use especially when a large number of experiments have to be carried out when the number of the process parameters increases. The Taguchi method uses a special design of orthogonal arrays to study the entire process parameter space with a small number of experiments only (Roy, 2001).

There are three categories of the quality characteristic in the analysis of the S/N ratio, i.e. the smaller is better, bigger is better and nominal is the best. The S/N ratio for each level of process parameters is computed based on the S/N analysis. Regardless of the category of the quality characteristic, a larger S/N ratio corresponds to a better quality