



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

STATISTICAL APPROACH IN RESPONSE PREDICTION

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

RISHWARAJ A/L GENGARAJOO

FACULTY OF MANUFACTURING ENGINEERING

2010



BORANG PENGESAHAN STATUS TESIS*

TAJUK: STATISTICAL APPROACH IN RESPONSE PREDICTION

SESI PENGAJIAN: 2009/2010

Saya: RISHWARAJ A/L GENGARAJOO

mengaku membenarkan tesis (PSM/Sarjana/Doktor Falsafah) ini disimpan di Perpustakaan Universiti Teknikal Malaysia Melaka (UTeM) dengan syarat-syarat kegunaan seperti berikut:

1. Tesis adalah hak milik Universiti Teknikal Malaysia Melaka.
2. Perpustakaan Universiti Teknikal Malaysia Melaka dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. **Sila tandakan (√)

- SULIT (Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia yang termaktub di dalam AKTA RAHSIA RASMI 1972)
- TERHAD (Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)
- TIDAK TERHAD

Disahkan oleh:

(TANDATANGAN PENULIS)

(TANDATANGAN PENYELIA)

Alamat Tetap:
No 138, LORONG PJS 10/9A,
TAMAN DATO HORMAT,
46000 PETALING JAYA, SELANGOR.

Cop Rasmi:

Tarikh: _____

Tarikh: _____

* Tesis dimaksudkan sebagai tesis bagi Ijazah Doktor Falsafah dan Sarjana secara penyelidikan, atau disertai bagi pengajian secara kerja kursus dan penyelidikan, atau Laporan Projek Sarjana Muda (PSM).
** Jika tesis ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali sebab dan tempoh tesis ini perlu dikelaskan sebagai SULIT atau TERHAD.

DECLARATION

I hereby, declare this report entitled “Statistical Approach in Response Prediction” is the results of my own research except as cited in the references.

Signature :

Author's Name :

Date :

APPROVAL

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

.....

ABSTRACT

Statistics is a branch of mathematics used extensively in natural science and also in the engineering field as well as in social science, physics and computing. The title of this study is „Statistical Approach in Response Prediction“. The machining process selected for this study is the laser cutting process. In this study, an empirical model is developed through design of experiment and the effect of selected parameters i.e. cutting speed, frequency and duty cycle on the responses i.e. surface roughness and kerf width are investigated. This work shows that for the surface roughness, cutting speed and duty cycle is of a major concern whilst the frequency has no visible effect. The duty cycle and frequency are directly proportional in their effect on kerf width while high cutting speed value is always preferred for a good kerf width. The model developed shows good error upon validation suggesting a good predictability.

ABSTRAK

Statistik adalah salah satu daripada cawangan matematik yang digunakan secara meluas di bidang sains tulen. Selain itu, statistik juga digunakan secara mendalam dalam bidang kejuruteraan, sains social, fizik dan juga komputeran. Tajuk kajian ini ialah “Statistic Approach in Response Prediction”. Proses memesisan yang dipilih untuk dikaji ialah proses laser. Dalam projek ini, satu model matematik telah dijana melalui “Design of Experiment” dan cara ini juga telah digunakan untuk mengunkai kaitan di antara parameter eskperimen (halaju potong, frekuensi dan “duty cycle”) dengan response (kekasaran permukaan dan “kerf width”). Ujikaji ini menunjukkan bahawa halaju potong dan “duty cycle” amat penting untuk mendapatkan kekasaran permukaan yang baik manakala frekuensi tidak memnunjukkan pengaruh yang berkesan. Untuk “kerf width” pula halaju potong adalah tetap di mana halaju yang tinggi selalu member kesan yang baik manakala “duty cycle” dan frekuensi saling berkait bagi mendapatkan nilai “kerf width” yang bagus. Modal matematik yang telah dianalisa juga memberi ralat yang bagus mencadangkan bahawa modal ini boleh digunakan untuk meneliti “response” bagi suatu proses memesisan laser.

DEDICATION

To my mum and dad. You are my everything.

ACKNOWLEDGEMENT

My deepest abiding gratitude to my supervising lecturer Ir. Sivarao, whose guidance, support and encouragement had been outmost imperative in completing this project on course and on time. Without his guidance, this project would have not been possible. A special thanks to Mr. Nizam who helped me understand better the concept of response surface methodology. I would like to also thank my fellow friends whom helped me throughout the project duration by providing vital information and assistance. Last but not least, my heartfelt thanks to my family members and everyone who had helped me with this project directly or indirectly.

TABLE OF CONTENTS

Abstract.....	i
Abstrak.....	ii
Dedication.....	iii
Acknowledgement.....	iv
Table of Contents.....	v
List of Tables.....	vii
List of Figures.....	viii
List of Abbreviations, Symbols and Nomenclature.....	xi
List of Appendices.....	xiii

1.0 INTRODUCTION

1.1 Project Background.....	1
1.2 Problem Statement.....	2
1.3 Objectives.....	2
1.4 Scope.....	3
1.5 Theory	
1.5.1 Statistical model.....	4
1.5.2 Empirical model.....	4
1.5.3 Mathematical model.....	5

2.0 LITERATURE REVIEW

2.1 Introduction.....	6
2.2 Response Surface Methodology.....	7
2.3 Taguchi's Method.....	14
2.4 Artificial Neural Network.....	17
2.5 Factorial Analysis.....	19

3.0	METHODOLOGY	
3.1	Introduction.....	20
3.2	Pre – experiment	
3.2.1	Machine study.....	21
3.2.2	Laser processing.....	26
3.2.3	Process parameter identification.....	27
3.2.4	Design parameter identification.....	34
3.2.5	Design Matrix.....	36
3.2.6	Preparation of DOE matrix.....	39
3.3	Experiment.....	41
3.3.1	Material preparation.....	42
3.3.2	Machine start up and material loading.....	43
3.3.3	Cutting process.....	45
3.3.4	Results observation.....	46
3.4	Modeling.....	50
3.5	Validation.....	51
4.0	RESULTS AND DISCUSSIONS	
4.1	Response surface methodology.....	53
4.1.1	Analysis of surface roughness.....	55
4.1.2	Analysis of kerf width.....	58
4.2	Responses optimization.....	60
4.3	Model validation.....	63
4.4	Optimization validation.....	67
5.0	CONCLUSION AND RECOMMENDATION	
5.1	Conclusion.....	70
5.2	Recommendation.....	71
	REFERENCES.....	72
	APPENDICES.....	78

LIST OF TABLES

3.1	Detail of the laser machine.....	22
3.2	Gas that is suitable to be used based on the material selected.....	31
3.3	Detail of the design parameters.....	34
3.4	High and low values of the design parameters.....	36
3.5	Experimental Layout for Response Surface Model.....	40
3.6	Parameter settings for constant parameters.....	43
4.1	Parameters and responses from the experiment.....	53
4.2	Optimization results.....	62
4.3	Responses values obtained through calculation.....	63
4.4	Experimental observation.....	63
4.5	Error between calculated and observed surface roughness values.....	64
4.6	Error between calculated and observed kerf width values.....	64
4.7	The Desired Output with the Suggested Parameter Setting.....	67
4.8	Validation Results for surface roughness.....	67
4.9	Validation Results for kerf width.....	68

LIST OF FIGURES

2.1	The percentage of contribution of each parameter on the responses (Avanish K. D. & Vinod Y., 2007).....	8
2.2	Data obtained from the Box – Behnken analysis and factorial analysis (Beal V. E. <i>et al.</i> , 2005).....	10
2.3	Results obtained from analysis. GA predicted results closely resemble the experimental results (D. Dhupal <i>et al.</i> , 2009).....	11
2.4	Data comparing the initial value and the optimal value (Jenn T. H. <i>et al.</i> , 2008).....	13
2.5	The ANOVA analysis (D. I. Lalwani <i>et al.</i> , 2007).....	13
2.6	Results obtained from grey analysis (Raghavendra R. & Vinod Y., 2009).....	14
2.7	ANOVA analysis of the data that shows the fraction of contribution by the parameters (Chen H. L. <i>et al.</i> , 2006).....	15
2.8	Effect of peak current and gap voltage on surface roughness (Sameh S. H., 2009).....	15
2.9	Suggest optimal setting, the predicted results, experimental results and the percentage of error (Yung-Kuang <i>et al.</i> , 2008).....	16
2.10	Optimization results obtained. Data no. 7 agrees with the experimental results (Seung H. Y. <i>et al.</i> , 2008).....	17
2.11	Neural network for dimensional calculation (A. G. Olabi <i>et al.</i> , 2006)...	18
3.1	Steps involved during the study.....	21
3.2	Steps involved during pre- experiment.....	22
3.3	Helius Hybrid 2513 Laser Cutting Machine.....	23
3.4	Power supply.....	23
3.5	Laser source on the right. On the left is the assist gas cylinder. From right oxygen cylinders, gas regulators and nitrogen cylinders.....	24
3.6	Chiller on the left and the cooling unit on the right.....	24
3.7	The bridge.....	25

3.8	The cutting table.....	25
3.9	The control panel.....	26
3.10	Surface roughness vs. Feed rate (Cutting speed) with CO2 laser cutting of 1.27mm steel sheet (Avanish K. D., 2008).....	28
3.11	Cutting speed vs. material thickness with 4 kW laser output (Theeban, N., 2007).....	30
3.12	Stand-off Distance (SOD) between the nozzle and the work piece (Theeban, N., 2007).....	30
3.13	Graph of power against time for continuous wave (Theeban, N., 2007).....	32
3.14	Graph of power against time for gated pulse (Theeban, N., 2007).....	32
3.15	Type of nozzle from left; standard nozzle, laval nozzle and autonomous nozzle (Theeban, N., 2007).....	33
3.16	The design parameters that were identified.....	34
3.17	A schematic sketch of the laser machine and work piece (Caristan C. L., 2004).....	34
3.18	Duty cycle of laser (Caristan C. L., 2004).....	35
3.19	The left shows the CCD for three factors while the right shows the Box – Behnken for three factors (Myers R. H., 2009)	38
3.20	Second stage details.....	41
3.21	The steps involved in the experimenting (Theeban, N., 2007).....	41
3.22	The final dimension of mild steel used for cutting process (1000 mm x 150 mm x 6 mm).....	42
3.23	The drawing for cutting process.....	42
3.24	Work piece loaded onto the work table.....	44
3.25	Three Clamps at Y-Axis to Clamp the Work Piece.....	44
3.26	Cutting of the work piece.....	45
3.27	Materials sorted and labeled.....	46
3.28	Kerf Width.....	47
3.29	Thickness gauge to measure the surface roughness.....	47
3.30	Measuring the Kerf Width.....	48
3.31	Surface roughness pattern on a thick – plate’s laser cut edge.....	48
3.32	Materials labeling for surface roughness measurement.....	49

3.33	The techniques used for the third stage.....	50
3.34	The final stage.....	51
4.1	Chart of the surface roughness observation from the experimentation...	54
4.2	Chart of the kerf width observation from the experimentation.....	54
4.3	Analysis of variance for surface roughness.....	55
4.4	2D contour plot for surface roughness at 1000 Hz.....	56
4.5	2D contour plot for surface roughness at 1800 Hz.....	57
4.6	Regression analysis for surface roughness.....	57
4.7	Analysis of variance for kerf width.....	58
4.8	2D contour plot for kerf width at 1000 Hz.....	59
4.9	2D contour plot for kerf width at 1800 Hz.....	59
4.10	Regression analysis for kerf width.....	60
4.11	Suggested Input Variables.....	61
4.12	Response Optimization for Ra = 6.6373 μm and Kerf = 0.6354 mm.....	61
4.13	Response Optimization for Ra = 3.7943 μm and Kerf = 0.4301 mm.....	61
4.14	Response Optimization for Ra = 8.328 μm and Kerf = 0.4267 mm.....	62
4.15	Response Optimization for Ra = 7.5657 μm and Kerf = 0.7772 mm.....	62
4.16	Comparison of Regression Model values to the Validation values of Surface Roughness.....	65
4.17	Comparison of Regression Model to the Validation of Kerf Width.....	66
4.18	Comparison of optimization values to the validation values of Surface Roughness.....	68
4.19	Comparison of optimization values with validation values of Kerf Width.....	69

LIST OF ABBREVIATIONS, SYMBOLS AND NOMENCLATURES

LBM	-	Laser Beam Machining
EDM	-	Electric Discharge Machining
WEDM	-	Wire Electric Discharge Machining
RSM	-	Response Surface Methodology
CCD	-	Central Composite Design
ANN	-	Artificial Neural Network
MRSN	-	Multi-Response Signal-to-Noise
CPNN	-	Counter Propagation Neural Network model
FEA	-	Finite Element Analysis
RBFN	-	Radian Basis Function Network
SAO	-	Sequential Approximation Optimization
ANOVA	-	Analysis Of Variance
MRR	-	Material Removal Rate
QFN	-	Quad Flat No – lead
HAZ	-	Heat Affected Zone
PP	-	Polypropylene
PC	-	Polycarbonate
PMMA	-	Polymethyl Methacrylate
CD	-	Compact Disk
CO ₂	-	Carbon Dioxide
Nd:YAG	-	Neodymium-doped Yttrium Aluminium Garnet
Nd:Glass	-	Neodymium-doped Glass
He	-	Helium
Ne	-	Neon
N ₂	-	Nitrogen
kg/cm ²	-	Kilogram per Centimeter squared
ms	-	Milliseconds
μs	-	Microseconds
Hz	-	Hertz

kHz	-	KiloHertz
mm/min	-	Millimeter per Minute
mm/rev	-	Millimeter per Revolution
mm	-	Millimeter
A	-	Ampere
Rpm	-	Rotations per Minutes
N/mm ²	-	Newton per millimeter squared
kW	-	Kilowatt
mJ	-	Mill Joule
J/mm ²	-	Joule per millimeter squared
mm/s	-	Millimeter per Second
J	-	Joule
%	-	Percentage
°	-	Degree
ε	-	Error

LIST OF APPENDICES

- A Gantt Chart for PSM I
- B Gantt Chart for PSM II

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

The quality of the manufacturing industry has become a critical criterion where a slightest error in manufacturing and processing can cause tremendous lost in terms of financial value of the industry or company or worse still, lost of customers' trust on the product all together. Once the customers do not trust the quality of a company's products, it will be very hard to convince them other vice.

When it comes to product manufacturing and processing, the quality of the parts produced is directly related to the quality of the process outputs. In other words here, process outputs are also referred to as the process responses. The title of this research is "*Statistical Approach in Response Prediction*". As such, the primary focus of this study will be on predicting the responses of a process by statistical means. Statistical approach here refers to an empirical method of describing the relationship between the input factors (parameters) as to how far their influence ranges on the output (responses). It is a mathematical evaluation of signifying the relationship of the parameters to the responses.

Primarily, there are two concepts need to be understood; parameters and responses. Process parameters refers to the input factors of a machining process such as cutting speed, power and type of material. Responses refer to the quality of the machining process such as surface roughness, accuracy of cut and micro-hardness.

1.2 PROBLEM STATEMENT

Just as for other machining processes, laser beam machining also causes defects on the machined surface. These defects can either be a macro defect or micro defect. Defects such as rough surface cut, deviation in kerf width, HAZ and other can be avoided through research by correlating the effect of the parameters to the outcome of the cut.

In laser machining, various studies have been conducted in associating the responses to the parameters. Such studies were on average conducted with only one responses being studied by using mathematical modeling. However, the problem arises when one request the effect that the parameters have on two or more responses.

With the cost for machining being high and the stringent availability of time and technician services, trial and error method to obtain the best parametric settings for a good cut is unacceptable. Therefore, it is best if an empirical model is developed to investigate the relationship between the selected parameters and the responses.

1.3 OBJECTIVES

The objectives of this project are to:

- I. Develop an empirical model for kerf width and surface roughness by adjusting the design parameters.
- II. To be able to predict the output of the responses based on the parametric values.
- III. Validate the empirical model prediction with experimentation.

1.4 SCOPE

In a typical machining process, the input parameters are significant in determining the quality of the output and on the process performance. Among the output that will be affected by the setting of the input parameters are material removal rate, machined geometry, surface roughness, kerf conditions and mechanical properties. Here, laser machining is used as a primary machining process under investigation.

In this experimental study, mathematical modeling and prediction is done for process observation. The study focuses primarily on developing an empirical model and run validation for the predicted results. The relationship between the kerf width and surface roughness with the controlled parameters will also be analyzed.

1.5 THEORY

In a book by Arce R. G. (2005) part of statistical branch revolves around deriving information about the properties of random processes from sets of observed samples. A general objective for a statistical study is to investigate causality especially to correlate the effect of changes in the parametric values to the responses. As mentioned by Chatfield C. (1995), it is most helpful to construct a model which provides a mathematical representation of the given situation for most of the statistical based investigation. The model should provide an adequate description of the given data in order to enable prediction and other inferences to be made.

In other words, for statistical approach of response prediction, statistical analysis is used, where a model is developed and relates the parameters to the response in mathematical terms and thus giving us the advantages of predicting the possible output for a set of parametric values.

In general, the statistical approach can be divided into three categories:

- a) Statistical model
- b) Empirical model
- c) Mathematical model

1.5.1 STATISTICAL MODEL

Chatfield C. (1995) described that a statistical model normally contains one or more systematic components as well as a random (or stochastic) element. The random element is sometimes referred to as noise. This element arises for various reasons and it is sometimes helpful to differentiate between:

- a) Measurement error
- b) Natural random variability

The natural random variability occurs due to the difference between experimental units and from changes in experimental circumstances that cannot be controlled. As for the systematic components, it is sometimes refers to as signal. In the engineering point of view, statistical analysis can be regarded as extracting information about the signal in the presence of noise.

1.5.2 EMPIRICAL MODEL

An empirical model can also be referred to as a regression or ANOVA model. In Chatfield C. (1995) book, the mentioned this model aims to capture some sort of smooth average behavior in the long run. The advantage of this model (or in some cases seen as the disadvantage) is that it is not based on highly specific subject-matter consideration.

In general, empirical model can be summarized as building a model then using experimentation data to test the model. Thompson J.R. (1989) stated that a scientist's empirical model is simply his current best guest as the underlying mechanism at hand. In other, an empirical model is developed to understand the factors that contribute to a process and how they affect each other as well as the output.

An empirical model can be built to explain the existing situation by using the existing data related to it. The empirical model consists of a function that fits the data. A matter to note here is that empirical model cannot be used to explain the

system. It can only be used to predict and estimate behavior where data does not exist.

1.5.3 MATHEMATICAL MODEL

A mathematical model can be described as a theoretical model that uses mathematical language to explain the behavior of a system. Among the forms of a mathematical model are game theory model, differential equation and dynamic system. However, mathematical model are not just limited these alone.

Mathematical model is able to overlap with other models involving an array of abstract structure. In a mathematical model, there are six basic groups of variables:

- a) Decision variables
- b) Input variables
- c) State variables
- d) Exogenous variables
- e) Random variables
- f) Output variables

A mathematical model can be categorized into a black-box model and a white box model. A black-box model is a system where there is no prior information of the system is available. A system with prior information is called a white-box system.

(Retrieved from http://www.sciencedaily.com/articles/m/mathematical_model.htm at 9.30pm)

CHAPTER 2

LITERATURE REVIEW

This chapter primary revolves around the literature review done in order to assist the course of the experimental study. The literature review here generally discusses and summarizes previously done experiments that were published in renowned journals with regards to the title undertaken. Therefore, this chapter dwells in the findings, results and data gathered from previous experimentation in the field of laser machining and response surface methodology.

2.1 INTRODUCTION

The main theme of this research is to use statistical approach to predict and also optimize the responses in laser beam machining process. Before we blindly rush into the experiment, it is most vital that we understand the concept of response surface methodology, RSM. According to R. H. Myers *et al* RSM refers to the utilization of statistical and mathematical technique for developing, improving and optimizing a process. It also includes in design, development and formulation of new products as well as improvement of existing products.

RSM is most advantageous in a situation to analyze the relationship of several input parameters to the output responses. The output responses can also be categorized as process performances or quality characteristics of the process. The input parameters are sometimes referred to as independent variable where it is manipulated and controlled by the engineers either according to the process performance or the process setting. The most commonly used RSM techniques are central composite design (CCD), Box – Behnken and Taguchi method. MINITAB and Design Expert are the few examples of software where RSM modeling can be done.

Asides from the mentioned RSM methods above, there are also other techniques and methods that can be used for optimizing a machining process. Among these methods are ANN, MRSN, CPNN and FEA. Although they each differ in the techniques used, the findings from the experiments can be used to attain the optimum parametric value settings.

2.2 RESPONSE SURFACE METHODOLOGY

According to Avanish Kumar Dubey and Vinod Yadava (2007), the CCD technique is the most commonly used experimental design technique in mathematical modeling for laser machining process optimization. In addition, they also stated that the most common research done in laser machining is experimental studies, modeling and optimization studies. In this case, the latter is used where statistical design experiment is used to show the relationship between input parameters and responses